Regional applicability analysis of four drought indices in Chongzuo of South China

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Abstract: Based on the precipitation anomaly percentage index (Pa), the relative moisture index (MI), the standardized precipitation index (SPI), and the standardized precipitation evapotranspiration index (SPEI), the regional applicability was examined in Chongzuo over the period 1961 to 2012. The results showed that: (1) The MI and Pa significantly underestimated severe drought and extreme drought at annual time scale. The monitoring result of annual SPEI and SPI was accurate and more close to the actual drought level. (2) The frequency range of different drought class is close to actual level for the SPI and SPEI at different time scale. The severe and extreme drought seldom occurred using Pa and MI monitoring results, the adaptability and reliability of MI were relatively lower in Chongzuo. (3) The annual MI and Pa showed smaller coverage with the severity of moderate and above drought than statistical results of SPI and SPEI in Chongzuo. (4) The SPI was found more sensitive to precipitation changes than the SPEI at 1-month scale in dry period. SPI and SPEI can be properly used for the monitoring as well.

Keywords: Chongzuo; drought monitoring; drought index; applicability.

1. Introduction

Drought is a natural phenomenon mainly caused by below normal precipitation over an extended period of time ranging from months to years [1-2]. Droughts have severe economic, environmental and social impacts. Timely determination of the current level of drought may aid the decision making process in reducing the impacts from drought. Drought indices have a wide range of applications, including drought monitoring, quantitative assessment and development of management strategies under current climate [3]. Drought indices, such as the precipitation anomaly percentage index (Pa), the relative moisture index (MI), standardized precipitation index (SPI)[4], standardized precipitation evapotranspiration index (SPEI)[5-6], which have relatively simple definitions and demands regarding variables, have also been used widely to quantify drought severity since the 1990s[7-9]. Generally, different drought indices focus on different aspects or physics of drought and they require different variables for their calculation. Therefore, for a specific drought event, different indices could yield different results[10-13]. No single index can be applicable in drought research in different regions. Few studies have addressed the regional applicability in China of the most commonly used drought indices.
Chongzuo, which is located in the upstream region of the Xijiang River Basin, the main sugarcane producing region in China, however, drought is an important factor to limit the sugarcane productivity. However, few comprehensive studies on the spatiotemporal patterns of drought at various time scales in Chongzuo. Therefore, the primary objectives of the present study is evaluated systematically the regional applicability of four drought indices and their ability to quantify, monitor and analyze drought severity.

2. Methods and data

2.1. Study area
The Chongzuo is located in the south of Guangxi province China, within the range of 21°36′-23°22′N and 106°33′-108°06′E. The total area of the Chongzuo is approximately 17,440km², of which more than 82% is the hills and mountains. The rivers in Chongzuo mainly belong to the Zuojiang River. Chongzuo is located in subtropical monsoon climate zone, with warm weather, abundant sunshine, rainfall, little frost and snowfall. Annual average air temperature are between 20.8-22.4°C. Average annual precipitation is approximately between1000mm and 12000 mm, most of which falls between April and September. Chongzuo is particularly prone to suffer from drought, which has a great influence on agricultural crop production, social-economic development, and people’s livelihood. Therefore, comprehensively investigating on the spatiotemporal patterns of drought at various time scales in Chongzuo is of great significance.

![Fig 1. Location of selected meteorological stations in Chongzuo of south China.](image)

2.2. Data description
In this study, Monthly precipitation and air temperature data during the period 1961–2016 at 12 meteorological stations in Chongzuo of Guangxi province China were provided by the Chinese Meteorological Data Sharing Service System, China Meteorological Administration. The detailed information and spatial distribution of the gauging stations are displayed in Fig 1.
2.3. Drought indices calculations

The standardized precipitation index (SPI) and the standardized precipitation evapotranspiration index (SPEI) were calculated for drought assessment at different time scales\[5,14\]. The simplicity and relatively less data demand make SPI and SPEI widely used for drought analysis. The calculation procedures of SPI and SPEI proposed by Vicente-Serrano et al. and Mckee et al. The calculation program of SPI and SPEI were proposed by the US National Drought Mitigation Center (http://www1.ncdc.noaa.gov/pub/data/cirs/) and Spanish National Research Council(http://digital.csic.es/handle/10261/10002)[15-16].

The relative moisture index (MI) was defined as follows:

\[ MI = \frac{P - ET_0}{ET_0} \] (1)

Where ETo was originally calculated with Thornthwaite’s (1948) equation. Similarly, to ETo calculated for SPEI. P is the monthly or annual total precipitation (mm).

The precipitation anomaly percentage index (Pa) was defined as follows:

\[ Pa = \frac{P - P}{P} \] (2)

Where P is the monthly or annual total precipitation (mm), \( \bar{P} \) is the monthly or annual average precipitation (mm).

Table 1 shows the standard for using the Pa, SPI, SPEI and MI to classify drought. Both the SPEI and SPI standardized algorithms are very similar, so the SPEI is classified with reference to the classification standard of SPI drought category [5,14].

| Class       | Pa(%)      | 1-month timescale | 3-month timescale | 12-month timescale | SPI/SPEI | MI     |
|-------------|------------|------------------|-------------------|-------------------|----------|--------|
| Normal      | > -40      | > -25            | > -15             | > -0.5            | > -0.4   |
| Mild drought| (-60.-40)  | (-50.-25)        | (-40.-15)         | (-1.0.-0.5)       | (-0.65.-0.4) |
| Moderate drought| (-80.-60) | (-70.-50)        | (-40.-30)         | (-1.5.-1.0)       | (-0.8.-0.65) |
| Severe drought| (-80.-95) | (-80.-70)        | (-45.-40)         | (-2.0.-1.5)       | (-0.95.-0.8) |
| Extreme drought| < -95     | < -80            | < -45             | < -2.0            | < -0.95  |

3. Results

3.1. Comparisons of drought classes using four indices

Drought class evaluation of representative stations using drought indices SPI, SPEI, Pa and MI varied at annual time scale from 1961 to 2016(Fig 2). Overall, there were significant differences in annual drought class evaluation using for indices. The annual drought class is below mild drought by determined MI at four representative stations in most years. The severe drought and extreme drought were rarely detected by Pa index in past 56 years. The MI and Pa significantly underestimated severe drought and extreme drought at annul time scale for the four stations. The SPI was found more sensitive to precipitation changes than the SPEI in dry year. the SPEI is closer to actual drought. Above all, the analysis shows that SPEI and SPI were close to the characteristics of actual drought and suitable for drought monitoring in Chongzuo of south China.
3.2. Comparisons of drought frequency using four indices

The Fig 3 showed the drought frequency on different time scales using four indices in Chongzuo district from 1961 to 2016. The frequency range of mild, moderate, severe and extreme drought are about 15.3-18.1%, 7.8-10.8%, 3.9-6.5% and 1.5-2.7% using SPEI, and are about 14.1-17.4%, 9.1-9.6%, 4.3-5.1% and 1.9-2.5% using SPI at 1-month, 3-month and 12-month time scale. The frequency range of different drought class is close to actual level for the SPI and SPEI at different time scale. The frequency range of different drought classes are more reasonable at 1-month. The average frequency of severe and extreme drought is respectively 0.15% and 0 using Pa at 12-month scale, and are respectively 0.56% and 0, 0.29% and 0 using MI at 3-month and 12-month scale. The frequency of severe and extreme drought does not match with the actual level.
3.3. Comparisons the spatial extent of annual droughts

![Fig 3. Drought frequency on different time scales using four indices in Chongzuo district from 1961 to 2016.]

![Fig 4. Annual change of stations proportion with the severity of moderate and above drought in Chongzuo.]

The Fig 4 showed the annual change of spatial extent with the severity of moderate and above drought in Chongzuo. During 1961–2016, the annual SPI and SPEI indicated there are 13 years and 14 years over 30% coverage, 8 years and 6 years over 50% coverage, peaking at 91.7% coverage at 2009 drought (SPI consistent with SPEI), the coverage included the Chongzuo area experienced dry conditions (moderate and above drought classes). The annual MI and Pa showed there is no year with over 30% of the spatial extent of annual droughts (moderate and above drought classes) from 1961 to 2016, peaking only at 25% and 16.7% coverage for the annual MI and Pa. After 2000, the annual drought generally occurred most frequently and had a wider coverage.

3.4. Comparisons typical drought monitoring

![Fig. 5 Performance of SPI and SPEI drought indices for 1-month time scale at Longzhou station during typical drought years.](image)

According to the former history data, from September 2009 to March 2010 the most severe drought occurred over southwestern China since meteorological records began. There was persistent dryness, high temperature, and precipitation less than normal by 30%-80%. The Fig 5 illustrates performance of SPI and SPEI drought monitoring at 1-month time scale for Longzhou station from January 2009 to December 2010. SPI and SPEI monitoring in Fig 4 showed that the drought dominating the Longzhou from August through December 2009 was mainly moderate, the drought intensified to severe level for SPEI and extremely level for SPI in October 2009. Afterwards, it continued to aggravate, reaching extremely level for SPI and severe level for SPEI by January 2010, this was in good agreement with observations. However, SPI showed extremely drought over the SPEI monitoring results in October 2009 and January 2010. Therefore, the SPI is more sensitive to variability in precipitation than SPEI at 1-month scale. SPI and SPEI can be properly used for the monitoring as well.

4. Conclusion

Using monthly meteorological observation data at 12 sites in Chongzuo during 1961–2016, the regional applicability is analyzed in terms of the Pa, MI, SPI and SPEI. Major conclusions can be summarized as follows:

The drought severe indicated by the Pa and MI was obviously less than those by the SPEI and SPI. Annual SPEI and SPI were roughly consistent with actual drought records. The frequency of different drought class indicated by SPI is consistent with those detected by SPEI at different time scale. The
frequency of extreme and severe drought indicated by the Pa and MI at different time scales is very low, almost closing to zero, their adaptability and reliability of MI is relatively lower in Chongzuo. The SPI was found more sensitive to precipitation changes than the SPEI at 1-month scale in dry period. Therefore, the SPI and SPEI was the drought index suitable for mid and long-term drought monitoring.

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