Application of SPEI Index in Drought Evolution in Fujian Province

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Abstract: In recent years, global warming has significantly increased the number of extreme weather and climatic drought events. Therefore, based on the meteorological monitoring data of 19 stations in Fujian province from 1959 to 2011, the standardized precipitation evapotranspiration index (SPEI index) was obtained to analyse the spatio-temporal evolution characteristics of drought in Fujian province during the past 50 years. The results showed that the trend of climate warming in Fujian province in recent 50 years was obvious. Except for Xiamen, all the other stations showed an insignificant drying trend. The variation of SPEI index in recent 50 years shows that the dry and wet state of Fujian province did not change significantly before 2000, while the SPEI index was mostly negative after 2000, which showed a trend of drought. This study will provide an important scientific basis for scientific prediction of future surface moisture and water resources utilization and protection in Fujian province.

1. Introduction

The fifth PICC assessment report pointed out that sustained greenhouse gas emissions would further increase the global temperature after entering the middle of the 21st century, and global warming would continue to have an impact on climate system change [1]. In recent decades, various extreme weather and climate events have shown a significant increase trend, among which drought is characterized by its high frequency, large disaster area, long duration and "gradual change" [2]. Fujian is located at the southeast edge of China. The strength and appearance of monsoon will make the rainfall distribution uneven in time and space, leading to frequent drought and flood disasters [3].

At present, common analysis methods for drought evolution include standardized precipitation index (SPI), and relative humidity index (MI), and so on [4]. SPI is a dry and wet index based on precipitation, but it only considers the role of precipitation and cannot reflect the trend of drying caused by temperature increase, so it is questioned [5]. Standardized Precipitation Evapotranspiration Index (SPEI Index) considering the evaporation, transpiration and the role of Precipitation, which can fully reflect the effects of the drought degree of warming, but also on the multiple time scales assessing drought, it has become a new ideal index for scholars at home and abroad to study and analyze the trend of drought evolution [6]. Shehar et al. used SPEI index to analyze the width data of pine and cypress rings in the Gawa region, western Himalayas, revealing several high intensity drought events since the 17th century [7]. Therefore, this paper used SPEI index to analyze the drought evolution of Fujian province. This will play a very important role in promoting the development of agricultural economy and the utilization and management of water resources in the
Fujian province.

2. Materials and Methods

2.1. Overview of the study area

Fujian is located in the southeast of China, the water system in the province is densely covered with numerous mountain rivers, as shown in Figure 1. The annual average temperature and annual rainfall of the whole province are respectively between 17-21℃ and 1400-2000mm, and the accumulated temperature of ≥10℃ is between 5000 ℃ and 7600℃, accounting for 70% of the whole province. There are significant differences in climate regions in Fujian province. The southeast coast of Fujian province belongs to the south subtropical climate, while the rest of Fujian province belongs to the middle subtropical climate. The vertical variation of hydrothermal conditions in each climatic zone is also quite different.

![Figure 1. The distribution map of meteorological stations in Fujian province](image)

2.2. Data and Methods

In this study, meteorological observation data of 19 stations in Fujian province from 1959 to 2011 were collected from the meteorological data sharing website (http://data.cma.cn/) and the national climatic data center (www.ncdc.noaa.gov), including monthly mean temperature, precipitation, air pressure, wind speed and sunshine duration.

2.2.1 Research methods. According to the accumulation probability distribution function, the SPEI value is divided into 7 grades, and the year and degree of drought can be determined by this grade standard. As shown in Table 1:
Table 1. SPEI grade standard divided for drought

| Extreme drought | Moderate drought | Mild drought | Normal or wet years | Mild moist | Moderate moist | Extreme wet |
|-----------------|-----------------|-------------|---------------------|----------|---------------|------------|
| SPEI            | ≤-2.0           | -2.0~1.0    | -1.0~-0.5           | -0.5~0.5 | 0.5~1.0       | 1.0~2.0    | ≥2.0       |

SPEI index of Xiamen station at different scales is shown in Figure 2. In the figure, spei-1, spei-3, spei-6 and spei-12 represent SPEI sequence of 1, 3, 6 and 12 months’ time scales respectively. The sensitivity of SPEI values in different time scales with time variation is obviously different. The greater the time scale, the more gradual the alternating transition between dry and wet. Therefore, this paper analyzes the evolution of drought trend in Fujian province based on spei-12 index sequence.

Figure 2. Comparison of SPEI series in the time scales of 1, 3, 6 and 12 months in Xiamen from 1959 to 2011

3. Results and Analysis

3.1. Spatiotemporal characteristics of climate change in Fujian province

(1) Temperature change. As shown in Table 2 and Figure 3, the annual temperature variation in Xiamen, Longyan, Changting, Pucheng and other places in Fujian province is relatively small, about 0.07℃/10a. Some studies believe that the average temperature in Xiamen has shown a slightly insignificant upward trend over the years, which can be regarded as a process of random variation [8]. But Zhangzhou, Yongan, Fuzhou and other places the amplitude is up to 0.27℃/10a. In general, the temperature in Fujian province shows an overall rising trend. Since 1990, the climate environment in Fujian province has been accelerating warming [9]. From 1960 to 2013, the average temperature in the southeast coastal area increased by about 0.92℃ at a rate of 0.17℃/10a, slightly lower than the national temperature increase (0.23 ℃/10a) [10].
Table 2. The temperature variation trend of major stations in Fujian province in recent 60 years (℃/a)

|       | Xiamen | Zhangzhou | Longyan | Changting | Pingnan | Nanping | Fuding | Fuzhou |
|-------|--------|-----------|---------|-----------|---------|---------|--------|--------|
| Spr   | 0.020  | 0.040     | 0.025   | 0.019     | 0.031   | 0.028   | 0.022  | 0.033  |
| Sum   | 0.006  | 0.026     | 0.004   | 0.010     | 0.016   | 0.020   | 0.019  | 0.026  |
| Fal   | -0.006 | 0.019     | 0.004   | 0.004     | 0.011   | 0.020   | 0.011  | 0.011  |
| Win   | 0.001  | 0.031     | 0.003   | 0.012     | 0.014   | 0.022   | 0.008  | 0.020  |
| Year  | 0.004  | 0.028     | 0.009   | 0.010     | 0.017   | 0.020   | 0.013  | 0.023  |

Note: Bold marking indicates a significant change trend (p<0.05)

(2) Precipitation change. As shown in Table 3 and Figure 4, except Xiamen station, precipitation in different seasons of major stations showed no significant change trend, while precipitation in summer showed a decline trend except Xiamen station. In terms of time, annual precipitation in Fujian province changes periodically under the influence of seasons, mostly in March to September, and there is a great difference in annual variation [11].

Table 3. The trend of precipitation change in recent 60 years in major stations in Fujian province (mm/a)

|       | Xiamen | Zhangzhou | Longyan | Changting | Pingnan | Nanping | Fuding | Fuzhou |
|-------|--------|-----------|---------|-----------|---------|---------|--------|--------|
| Spr   | 0.097  | -0.097    | 0.476   | 0.085     | 0.109   | 0.120   | 0.034  |
| Sum   | 0.140  | -0.509    | -0.767  | -1.077    | -0.463  | -0.219  | -0.597 |
| Fal   | 0.925  | 0.768     | 0.217   | 0.067     | -0.383  | 0.195   | -0.041 |
| Win   | 0.339  | 0.060     | 0.187   | -0.220    | 0.122   | 0.269   | 0.359  |
| Year  | 0.508  | 0.047     | 0.115   | -0.019    | -0.144  | 0.097   | 0.047  |

Note: Bold marking indicates a significant change trend (p<0.05)

3.2. Spatiotemporal characteristics of drought and flood changes in Fujian province
As shown in Figure 5, in the 1960s, the SPEI index was mainly negative, but fluctuated around -0.5,
which was generally within the normal range. In the 1970s, the SPEI index showed that the period was wet. In the 1980s, the SPEI index was alternately positive and negative with small amplitude, indicating that the trend of drought change during this period was relatively stable. In the 1990s, the SPEI index was all above 0, indicating that the overall trend of the 1990s was toward wetness. In general, before the 2000s, the overall dry and wet change trend of Fujian province did not change much, and gradually tended to be wet, but the variation trend was not significant, which was consistent with the research results of Ma Zhiguo et al. [12]. However, since the 21st century, the SPEI index has been below -0.5 for several years, showing a significant trend of drought. This is related to the overall increase of temperature and no obvious change of precipitation in Fujian province, which leads to the rapid development trend of drought and deserves our attention.

Figure 5. Times series of SPEI from 1959 to 2011 in Fujian province

As shown in figure 6, SPEI values of all stations in Fujian from 1959 to 2011 were divided into drought grades according to the drought grade standards in Table 1. From 1959 to 1961, there was no dry station in the whole province. From 1959 to 1970, it was a relatively wet state, and the SPEI index was within the range of -0.5 and 0.5. Only 1966, 1967, and 1970 were in a slightly dry state. From 1971 to 1999, except that there was no drought in 1972, 1974, 1975, 1982, 1992, 1997 and 1999, droughts of different degrees in all the remaining years, no extreme drought and mild drought events. In addition, 1997 was the wettest year during the past 50 years. Four stations reached extreme wetter in this year, and most of the stations were in the range of moderate wetter. From 2000 to 2011, Fujian experienced the most severe drought, with an average of 10 sites reaching drought, accounting for 53% of the total stations. Especially in 2003, the whole province was in a state of drought, and 2 sites showed extreme drought. The number of sites experiencing drought events in successive years after 2000 accounted for more than 50%, indicating frequent drought events appeared in this period, especially the first extreme drought event in 50 years in Fujian province in 2003, and the occurrence probability of extreme drought events in 2011 was further deepened.

Figure 6. Number of stations that different grades of drought occurred from 1959 to 2011 in Fujian province

As shown in Figure 7, the eastern coastal areas show a trend of wetting, while the rest of the areas
show a trend of drying. Therefore, it can be concluded that the rapid decline of SPEI index in recent years, this is due to the obvious decrease of summer precipitation in this period. On the whole, Fujian showed an overall trend of drying and warming. Chen et al. [3] Used SPI index to analyze the spatial and temporal variation characteristics of drought and flood in Fujian from 1960 to 2006. This is contrary to the conclusion of us. The reason is that SPI index only considers precipitation factor, while SPEI index considers the relationship between precipitation and temperature, including the influence of evapotranspiration on drought and flood evaluation.

Figure 7. SPEI-12 index of ten years in Fujian Province

4. Conclusion
Based on the SPEI index, this paper analyzed the spatial distribution of drought and flood in Fujian during the past 50 years, and reached the following conclusions:

(1) The temperature of Fujian province has been rising, the precipitation has not changed significantly, and the climate warming trend is obvious.

(2) By SPEI index changes of nearly 50 years, 2000 years ago the Fujian in a normal wet state, only a few years in a mild drought, but after the 2000 SPEI rapid test index, making the overall rapid development towards the direction of the drought in Fujian province this with a significant reduction in nearly a decade of summer rainfall and temperature rise.

(3) Precipitation may be the main controlling factor for the correlation between dry and wet changes in Fujian province, but the observed data in this paper are limited. Further analysis is needed to verify this viewpoint. The SPEI index takes into account the effect of evaporation due to temperature on changes in drought, and the results are in line with the actual situation. Applying SPEI index to the analysis of drought trend in Fujian province will play an important role in the socio-economic development of Fujian province.

Acknowledgements
This study was funded by National natural science foundation of China (No.51809222).
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