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Evolution Characteristics of Seasonal Drought in Hunan Based on the Standardized Precipitation Index (SPI)

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Abstract: Seasonal drought frequently occurred in Hunan, which had a profound impact on agricultural production. Analysis of the characteristics and laws of the evolution of drought in Hunan can provide a theoretical basis for the formulation of regional drought resistance and disaster reduction countermeasures responding to global climate change. The study of Hunan Province 14 cities (prefectures) of meteorological stations' precipitation data, selects the standardized precipitation index (SPI) as the drought index to calculate the area of Hunan Province in the last 20 years (1989-2008) each month's drought index. Based on the precipitation data of 14 meteorological stations in Hunan Province, each month's Standard Precipitation Index (SPI) in recent 20 years (1989-2008) was calculated. Based on the above analysis, the station proportion of seasonal drought frequency of annual and season and inter-annual variation of drought intensity were analyzed. The results show that the degree of drought increases with different degrees of the timescale; the seasonal characteristics of summer drought and autumn drought are aggravating trend, and the spring drought is the second; the drought is more severe in the central-southern Hunan Province, and is relatively light in the northeastern.

1. Introduction

In recent years, under the background of global climate change, extreme weather and climate events frequently occurred. Simultaneously, the frequency and intensity of drought increased significantly, especially in southern China. The severe seasonal drought in Southern China had a severe impact on agricultural production, which resulted in a significant reduction in grain crops and a threat to national food security. Statistics show that the average drought-stricken area of Hunan Province is 701000 hm^2/year, and 324000 hm^2 are disastrous. Drought caused 694,000 tons of grains reduction, more than twice that produced by floods. The average annual investment in drought relief is 137 million Yuan. In 1978, Drought relief funds even reached 214 million Yuan [1]. The drought has become an essential factor which affects the economic development and the social

stability of Hunan province and restricted the agricultural construction. Therefore, the study on the distribution and evolution characteristics of drought in Hunan is very significant to assist the government decision-making.

Many people have studied the drought index [2, 3]. Because of the complex causes and too many influencing factors, the applicability of drought index has obvious regional characteristics, and the time scale will limit it. Meteorological drought indices are mainly single drought index and integrated meteorological drought index, such as a percentage of precipitation anomaly, relative moisture index, standardized precipitation index, soil relative moisture index, Palmer drought severity index, etc. Due to the entirely different spatial precipitation variation and the greater temporal precipitation variation, it is difficult to directly use the precipitation as a drought index to compare with each other on different spatial and temporal scales [4]. Standardized Precipitation Index (SPI) uses the standardized precipitation cumulative frequency distribution of Γ function to describe the precipitation variation and characterize the occurrence probability of precipitation on a specified period. SPI index makes the occurrence of drought in different regions or different periods are comparable. SPI calculation is simple and easy to operate, because the calculation only needs to enter the precipitation data, and the data is easy to obtain. So, this paper selects the standardized precipitation index (SPI) recommended by the China Meteorological Administration as the meteorological drought analysis index [5]. On the timescale of a month, the paper analyzed the spatial and temporal evolution law of the occurrence frequency and intensity of seasonal drought in Hunan from meteorological drought. This study will provide a theoretical basis for making the crop distribution of drought resistant and disaster reduction and technical measures under the background of the global climate change.

2. Materials and methods

2.1 Background of the study area

In this paper, the area includes 14 cities (prefectures) under the jurisdiction of Hunan Province, including Changsha, Zhuzhou, Xiangtan, Hengyang, Shaoyang, Yueyang, Changde, Zhangjiajie, Yiyang, Loudi, Chenzhou, Yongzhou, Huaihua, and Jishou. The climate of Hunan Province belongs to a subtropical monsoon humid weather with a 1200~1700mm average precipitation. Although the hydrothermal resources are abundant, the seasonal distribution of rainfall is uneven. The dry and wet seasons exist in most areas, and sometimes severe seasonal drought occurs, which has become one of the limiting factors of grain production in Hunan. The drought has severely restricted the agriculture development in Hunan because of its frequent occurrence and its enormous impact degree [1, 6].

2.2 SPI value calculation

Standardized precipitation index is an index of characterizing the occurrence probability of the precipitation in a certain period. The index is appropriate for drought monitoring and assessment of the local climate conditions at the scale of a month and above [5]. SPI uses Γ distribution probability to describe the change of precipitation. SPI deals the skewed probability distribution of the rainfall with the normal standard treatment and finally divides the grades of drought by the standard precipitation cumulative frequency distribution. SPI can be obtained by the formula (1):

$$SPI = S\frac{t-(c_2t+c_1)t+c_0}{((d_3t+d_2)t+d_1)t+1.0} \quad (1)$$

In the equation (1), $t = \sqrt{\ln \frac{1}{G(x)^2}}$; $G(x)$ is the precipitation distribution probability which associated with Γ function; x indicates the sample value of precipitation; S indicates the positive and negative coefficients of the probability density.

If $G(x) > 0.5$, $G(x) = 1.0 - G(x)$, S=1; if $G(x) \leq 0.5$, S=-1. $G(x)$ can be obtained by the integral formula of Γ distribution probability density function:

$$G(x) = \frac{1}{\beta^{\gamma}\Gamma(\gamma)_0}\int_0^x x^{\gamma-1}e^{-x/\beta}dx \qquad x>0 \tag{2}$$

In the formula (2), γ and β are the shape and scale parameters of Γ distribution function; c_0, c_1, c_2, d_1, d_2 and d_3 are the calculation parameters of the simplified approximate formula of cumulative frequency converted by the Γ distribution function. Their values are c_0=2.515517, c_1=0.802853, c_2=0.010328, d_1=1.432788, d_2=0.189269, and d_3=0.001308 [3].

The seasonal SPI and annual SPI values can be calculated by the formula (1) and (2) through inputting the monthly (seasonal and annual) precipitation of each weather station. Here, the season of a year is divided into spring (from March to May), summer (from June to August), autumn (from September to November) and winter (from December to February of the next year). According to the value of SPI, the drought is divided into four grades, such as the Slight Drought (-1.0<SPI≤-0.5), the Middle Drought (-1.5<SPI≤-1.0), the Severe Drought (-2.0<SPI≤-1.5), and extreme drought (SPI≤-2.0) [3].

2.3 Assessment Indices of the Drought

To better reflect the regional drought degree in a wide range, the frequency of drought is introduced, and the station proportion of drought frequency and the intensity of drought are further defined.

1) The frequency of drought (P_i). Pi is used to evaluate the frequency of drought occurrence in a station. The calculation formula is as follows:

$$P_i = (n/N) \times 100\% \tag{3}$$

In equation (3), N is the total year of meteorological data for a station; n is the whole year of drought occurrence of the station; i stands for different weather stations.

2) Station proportion of drought frequency (P_i). Pi represents the percentage of the total number of weather stations, which occurred drought events accounting for the whole number of weather stations in an area. P_i can reflect the severity of the drought influence scope indirectly. The calculation formula is as follows:

$$P_j = (m/M) \times 100\% \tag{4}$$

In equation (4), M is the total number of meteorological stations within an area; m is the total number of meteorological stations, which had occurred drought events. j stands for different years. Table 1 shows the severity level of drought.

Table 1 Classification of severity of drought-affected areas

Grade	Scope of influence	Station proportion of drought frequency
1	Global Drought	$P_j \geq 50\%$
2	Regional Drought	$50\% > P_j \geq 33\%$
3	Partial Regional Drought	$33\% > P_j \geq 25\%$
4	Local Drought	$25\% > P_j \geq 10\%$
5	No Obvious Drought	$P_j < 10\%$

3) The intensity of drought (S_{ij}). S_{ij} is used to evaluate the severity of drought. Generally, the drought intensity of a single station can be reflected by the SPI value in a certain period. The higher the absolute value of SPI is, the more serious the drought is. The degree of dryness in a particular area can be calculated by the formula (5).

$$S_{ij} = \frac{1}{m}\sum_{i=1}^{m}\left|SPI_i\right| \tag{5}$$

In the formula (5), $\left|SPI_i\right|$ indicates the absolute value of the SPI when the drought occurred. Therefore, if $1 > S_{ij} \geq 0.5$, it is a Slight Drought; if $1.5 > S_{ij} \geq 1$, it is a Middle Drought; if $S_{ij} \geq 1.5$, it is a Severe Drought.

3. Results and analysis

3.1 Occurrence regularities of the annual drought in Hunan

3.1.1 Drought variations in the scale of a year

From the view of the statistical results of the station-times of drought occurrence, the total years of above the Slight Drought is 17 years from 1989 to 2008 (Figure. 1), which 9 times of the drought occurred in the 1990s, 8 times of drought had happened since 2000, and most of them are the Partial Regional Drought. Global extreme drought is mainly in 1992, 2003, 2007 and 2008. Regional Droughts took place in 1991, 1996, 2000 and 2006; the Partial Regional Drought occurred in 1995, 2001, 1989 and 2005. From the temporal distribution of the drought occurrence, almost every decade will be a drought in Hunan. From drought severity, the frequency of Regional Drought occurrence has increased since 2000, especially in 2003, an extreme drought in the entire province occurred. Simultaneously, drought intensity also gradually becomes stronger. A specific interval of the drought before 1995, but in the next 15 years, every year had a drought.

3.1.2 Drought Intensity

In the past 20 years, the drought intensity over the drought years was in 0.5-1.9, and the average drought intensity was 0.7. In the 17 years of the drought occurrence, two years achieved the Severe Drought intensity, four years' drought intensities were in 1.0-1.5, and the other years' drought intensity was the Slight Drought. Based on the above results, the intensity of drought in Hunan is mainly the Middle Degree Drought and below. Before 2000, no extreme drought occurred. However, the number of droughts increased, and the drought intensity significantly strengthened since 2000. From the temporal distribution of the occurrence of drought intensity, the strongest drought intensity in the past 20 years appeared in 2003 and 2007, followed by 1992 and 2008 (Figure. 2).

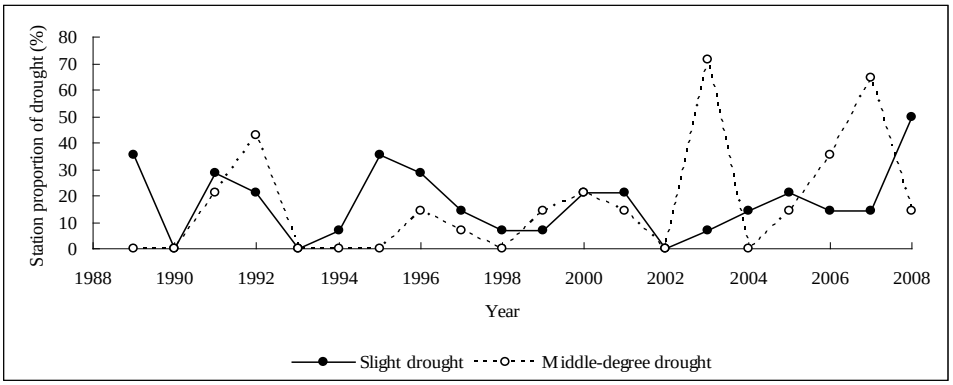


Figure. 1 Variation features of the station proportion of drought frequency from 1989 to 2008 in Hunan

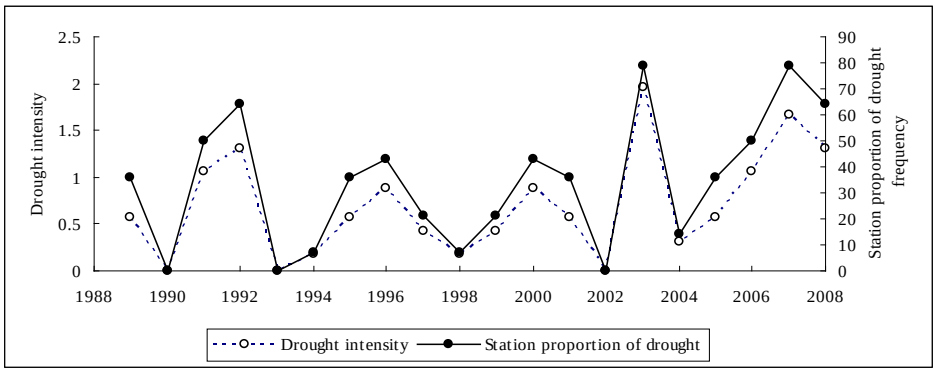


Figure. 2 Variation features of the drought intensity from 1989 to 2008 in Hunan

3.1.3 Station Proportion of Drought Frequency

In the 1990s, the station proportion of drought frequency of Hunan is not high, and mainly the Slight Drought, the Severe Drought only occurred in local regions. However, since 2000, the drought-stricken areas had expanded, and the drought degree had strengthened. The station proportion of Middle Drought reached 25% from 2001 to 2008, and the drought intensity also reached 1.0746 (Table 2).

Table 2 Station proportion of drought frequency, and drought intensity in the different period

Period		1989-1998	1999-2008
Station proportion of drought frequency	Slight Drought	18.6	45.8
	Middle degree drought	8.5	25
Drought intensity		0.52	1.07

3.2 Occurrence Regularities of Seasonal Drought in Hunan

3.2.1 Spring Drought

Spring drought in Hunan occurred five times from 1989 to 2008. The frequency of drought occurrence was mainly in 1995-1997 and after 2004. The spring drought was not evident and was

the Local Drought. Only in 2006 and 2008, there occurred a Partial Regional Drought. From the station proportion of drought frequency, it was higher and higher since 2000, and the maximum value appeared in 2007 and 2008. For the drought intensity, the drought intensity in the 1990s was low, but since 2000, the drought intensity began to increase, and the drought intensity reached the maximum in 2007 (Figure. 3).

3.2.2 Summer Drought

Based on the station proportion of summer drought, it was mainly the Local Drought in the early 1990s, and the station proportion of summer drought was less than 20% and no apparent drought from 1993 to 1999. The station proportion of summer drought showed an ever-growing trend from the late 1990s to 2008 and mainly was the Regional Drought. Especially in 2003, a global summer drought occurred and reached the highest. The drought intensity has been more prominent since 2000, but in the middle and later period of the 1990s, the drought intensity was relatively low to indicate no apparent drought. From the frequency of drought, nine times of summer drought occurred from 1989 to 2008 with a feature of greater intensity fluctuations. Overall, the station proportion of summer drought showed a rising tendency, and the drought intensity increased slightly. So, the drought degree generally showed an increasing trend (Figure. 3).

3.2.3 Autumn Drought

During the study period, the autumn drought in Hunan occurred five times and mainly emerged in late 2003. Although the number of years, which drought occurred was not much, the intensity of drought was great. The autumn drought in the 1990s fluctuated and showed a bound feature, without apparent regularity. At 2002, the station proportion of autumn drought and drought intensity all reached their maximum, 92.8% and 1.96 respectively. After 2000, the station proportion of autumn drought and drought intensity all increased, and regional autumn drought occurred continuously in 2003 and 2004 (Figure. 3).

3.2.4 Winter Drought

The occurrence frequency of winter drought in Hunan was relatively low. Only six times of winter drought had occurred throughout the study years. However, five times of drought are the Global Drought, including 1996, 1999, 2000, 2006, and 2008. The station proportion of winter drought was at 78.5% - 92.8% and the drought intensity belonged to the Severe Drought. Therefore, although the frequency of winter drought was not high, its impact was enormous. From the temporal distribution, the frequency of winter drought in the 1990s was very low, only a Local Drought in 1996.

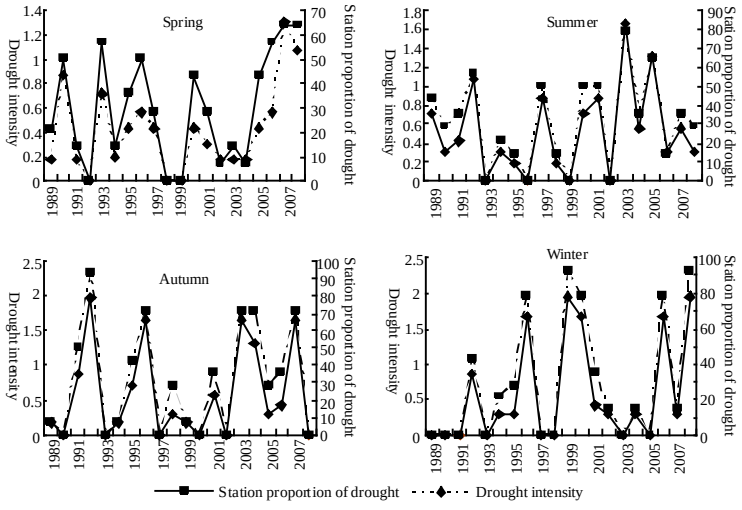


Figure. 3 Station proportion of drought frequency of different season and drought density from 1989 to 2008

Overall, the occurrence frequency and the station proportion of summer drought of spring drought, summer drought, and autumn drought had increased since 2000. However, the fluctuation of drought intensity was significant, and spring-summer droughts, summer-autumn droughts, even spring-summer-autumn droughts occurred many times [7]. From the monthly occurrence frequency of drought, the frequency of summer drought and autumn drought was high, followed by spring drought. Despite less winter drought, it is more intense.

3.3 Evolution Characteristics of Seasonal Drought in Different Regions of Hunan

According to the climatic and drought characteristics, Hunan can be divided into northeast, West and Central-South regions. Because the variation tendency of the drought intensity was the same as that of the station proportion of the drought, only the yearly variation of the station proportion of the drought was analyzed in the paper. The inter-annual variation of the annual drought and the seasonal drought of different areas and the average values of the station proportion of the drought of different years were counted [8]. The paper mainly analyzed the seasonal characteristics of drought, which mostly affected agricultural production.

3.3.1 Evolution Characteristics of Seasonal Drought in the Northeast of Hunan Province

1) Annual drought. Station proportion of annual drought appeared the fluctuation status. There would be a continuous drought in one or two years, although the drought intensity was not strong. However, since 2003, the intensity of drought has greatly improved. In 1998-2008, the annual Global Drought only occurred in 2003 and 2007. Station proportion of annual drought is a slight increase trend (Figure. 4(a)).

2) Spring drought. Station proportion of spring drought has an increasing trend and is similar to that of the annual drought. After 2000, the degree of drought increased. Moreover, a Severe Drought appeared in the whole region in 2007.

3) Summer drought. Station proportion of the summer drought was relatively smooth. The middle degree intensity of the global summer drought occurred in 1991, 2003, 2004, 2005 and 2007. From the inter-annual variation, the summer drought occurred fewer before 2000. However, since 2000, times of summer drought increased significantly.

4) Autumn drought. The autumn drought doesn't occur in many years and is not continuous. Nevertheless, most of the autumn drought was the Global Drought and belonged to the Middle Drought and above. Annual Global Drought occurred in 1992, 1996, 2003, 2004 and 2007, and had a significant impact upon the crop.

5) Winter drought. On the whole, the winter drought was similar to the autumn drought. The year of global winter drought was 1996, 1999, 2000, 2006 and 2008, and the other years had no winter drought.

3.3.2 Evolution Characteristics of Seasonal Drought in the West of Hunan Province

1) Annual drought. Overall, the station proportion of annual drought is at a relatively high level. From 1998 to 2008 (except for 1990, 1993, 1998, 1999, 2002, and 2004), no obvious drought occurred. However, the drought intensity was not large, mostly in the Middle Drought and below. Continuity of drought occurrence was strong (Figure. 4(b)).

2) Spring drought. The spring drought has obvious characteristics of continuous presence in the following year. Slight Drought occurred in five consecutive years from 2008 to 2005. And the global middle drought only occurred in 1996.

3) Summer drought. Overall, the number of summer drought occurrence is not much, and the summer drought is not strong. The occurrence frequency of summer drought began to increase since 2005.

4) Autumn drought. Although the autumn drought was less before 2000, the station proportion of

autumn drought reached 80% in 1992 and 1995. After 2000, the frequency of autumn drought increased significantly. The continuing drought has occurred within five years since 2003.

5) Winter drought. Winter drought showed an upside-down U shape distribution. No obvious drought appeared before 1993 and after 2000. However, between 1994 and 2001, winter drought occurred six times.

3.3.3 Evolution Characteristics of Seasonal Drought in the South-central of Hunan Province

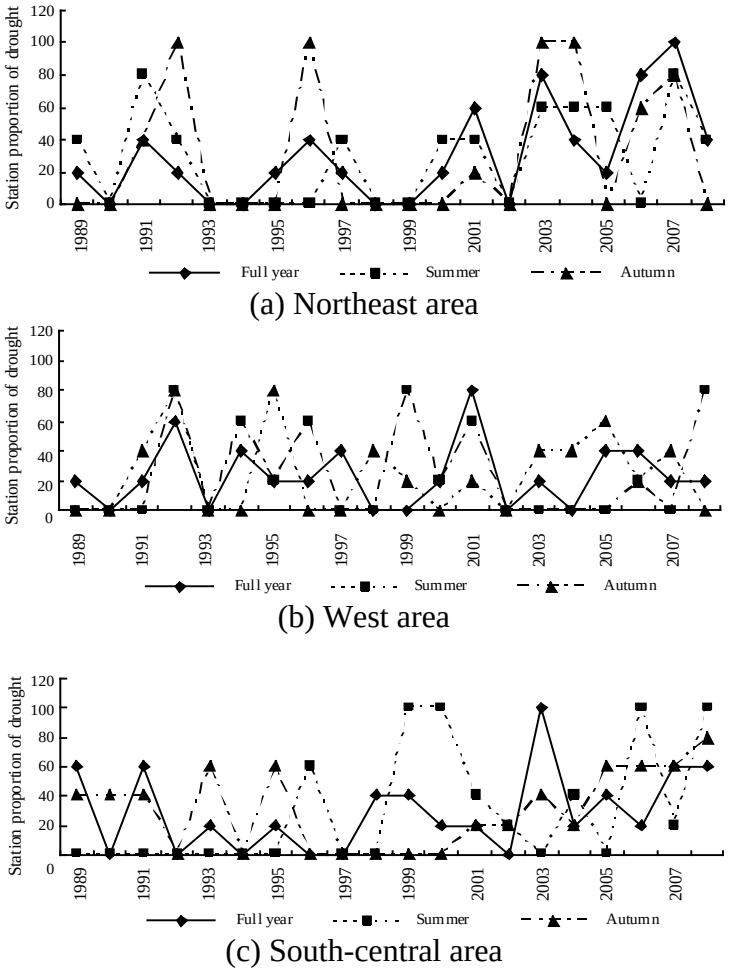
1) Annual drought. The drought in the region principally concentrated in 1998-2008. Ten times of droughts occurred among the 11 years (no drought only in 1992), and the drought intensities reached the middle degree drought and below (Figure. 4(c)).

2) Spring drought. Winter drought showed the characteristics of high at both ends and low in the middle. Especially since 2001, eight consecutive years of drought occurred, and the drought intensity was increasingly strong.

3) Summer drought. Global extreme summer drought occurred in 2003, and the drought intensity of the other year was not high. On the whole, the summer drought showed a trend of decrease.

4) Autumn drought. The occurrence of autumn drought has not shown any obvious regularity. Besides, no obvious autumn drought occurred or had a low degree of drought intensity.

5) Winter drought. No winter drought occurred before 1998, except for 1993. However, the winter drought occurred frequently after 1999 (except for 2003 and 2005). Especially in 1999, 2000, 2006, and 2008, the extreme Global Drought occurred.



(a) Northeast area

(b) West area

(c) South-central area

Figure. 4 Variations of station proportion of drought frequency and drought density in each area in Hunan from 1998 to 2008

4. Conclusions and Discussion

Research results of seasonal drought variation characteristics in Hunan and its different regions indicated: station proportion of annual drought and annual drought intensity of Hunan have visible stage distribution characteristics. Moreover, with the change of time, the drought has increased in different degree. For the season, it is primarily the summer drought and the autumn drought, followed by spring drought, and then the winter drought with low intensity. From the station proportion of drought frequency in each area, drought trends are the same as the trends of Hunan Province.

This paper analyzed almost 20 years situation of annual and seasonal drought occurrence frequency and drought intensity in Hunan and its different part by using the standardized precipitation index and the precipitation data of Hunan from 1989 to 2008. The analysis results are consistent with the actual situation. Therefore, the Standardized Precipitation Index (SPI) can well reflect the changes of drought in Hunan Province. Analysis results of SPI not only help to understand the spatial and temporal variations of drought in Hunan Province more comprehensively but also help to provide the basis for drought monitoring and prediction, disaster prevention and mitigation engineering construction.

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