

APPLICABILITY EVALUATION ON THE INDEXES OF TYPICAL DROUGHT IN HENAN PROVINCE, CHINA

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Abstract. Drought index is the basic parameter for drought monitoring and evaluation, which is the foundation of drought management and decision-making. Based on the monthly precipitation data collected from 18 stations in Henan Province, China from 1953 to 2012, we select Pa, Z and M as three typical drought indexes to analyze the evolution rules of arid from drought variations and the characteristics of drought index sequence values, and evaluate the applicability of the three kinds of drought indexes in the arid region. The results show that high frequency and evident seasonal variations are the characteristics of drought areas in Henan Province. Meanwhile, the drought strength and duration have an evident interannual fluctuation and increase slowly as a whole. The evaluation result shows that the Pa (M) index has a lower (higher) reflection than the reality, but the Z index can provide a more realistic result. Pa index is much more dependent on the average value, and has a slow response to the drought and can't indicate extremely dry conditions. M index is more sensitive to the drought but may exaggerate the actual situations sometimes. Z index not only considers the reality that precipitation varies according to partial distribution (PD), but also uses the normalization method to avoid errors from different spatial and temporal scales. Therefore, the result is more consistent with the real situation. The results can provide references for evaluating the agricultural drought in Henan Province.

Keywords: *drought index; precipitation; applicability evaluation; China-Z Index*

Introduction

Drought is one of the most serious threats to human beings. The triggering factors for drought are sophisticated, ranging from multi-dimensional systems to climate change. The absence of precipitation is the superficial indicator of drought. With the influence of evaporation from soil surface, human activities and the maldistribution of water resources, the world is frequently stricken by serious droughts (Liu et al., 2012). Drought is a natural and multi-dimensional phenomenon that persists long enough to adversely affect different aspects of human life such as the environment, industry and economy (Zamani et al., 2015; Liu, 2012). Although there is not a universal definition of drought, in the most general sense, drought can be defined from different disciplinary perspectives, namely, meteorological drought, agricultural drought, hydrological drought and socioeconomic drought (Yang, 2010). It is often said that drought is the most complex of all natural hazards (Wilhite et al., 2007). In order to study the drought characteristics and evolution law effectively, selecting an appropriate drought index is very important (Vicenteserrano et al., 2010). The most widely applied drought indexes include precipitation anomaly percent index (Pa), standardization precipitation index

(SPI), soil moisture index and aridity index. In addition, there are also the Palmer drought index on the basis of soil water balance, the comprehensive index CI based on standardized precipitation index and moisture index. Moreira et al. (2008) developed the Standardized Precipitation Index (SPI) to predict the change of drought situation using log-linear model theory. Mirabbasi and his colleagues (2013) applied the JDI index to analyze the meteorological drought characteristics in the northwest of Iran; Ma et al. (2012) used the SPI index and relevant moisture indexes to analyze the changes of drought from May to September in the northeast of China. Akinremi et al. (1996) chose the Palmer index to assess the drought characteristics of Canadian prairies; Cao et al. (2012) and Zhang et al. (2012) used the Z and CI indexes respectively to analyze the drought distribution characteristics of Liaoning Province and Jilin Province.

However, restricted by geographical conditions, there are big differences in meteorological observation, data collection and other aspects, and the drought in different regions' sensitivity of precipitation, evaporation, runoff and other factors are also different. Among the existing drought evaluation indexes, there is not yet an index that is universally applicable to different regions and different time scales of the indicators (Keyantash and Dracup, 2002). In the meantime, in current drought assessment and research, there is a lack of applicability analysis of drought index. Therefore, how to select the evaluation index of drought has become the key of regional drought assessment (Mishra and Singh, 2010).

Against this backdrop, in this paper, we have tested three drought indexes, namely, Pa, Z and M in assessing the drought in Henan Province and analyzed the characteristics of drought index changes and drought index sequence. We have also studied the drought characteristics from 1953 to 2012 in Henan Province systematically, evaluated the applicability of the three indexes in drought assessment in the hope of providing reference for regional drought assessment (Deng et al., 2008).

Data and methods

Data sources

Our data is from China Meteorological Data Sharing Network (<http://www.cma.gov.cn/2011qx fw/2011qs jgx>) and Hydrology Handbook of Henan Province (Yang et al., 2009), including weather data collected from 18 typical weather stations from 1953 to 2012 in Henan Province (*Fig. 1*).

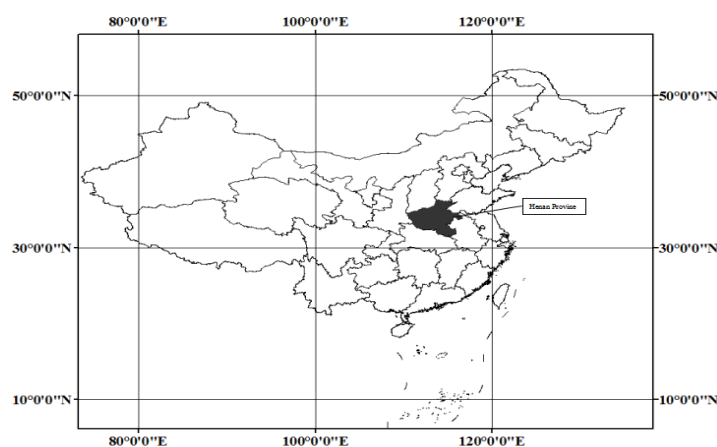


Figure 1. Location of the study region

The drought index

The precipitation anomaly percent

Precipitation anomaly percentage reflects the degree at which hydrological element values deviate from the average level over the same period for a number of years, which decide the drought degree based on the historical average level. The hierarchy standard is shown in *Table 1* according to Equations (1)-(4). The precipitation anomaly percentage is calculated as:

$$Pa = \frac{P - \bar{P}}{\bar{P}} \times 100\% \quad (\text{Eq.1})$$

where Pa is precipitation anomaly percentage, P is precipitation in the calculation period, and $\bar{P}$ is average precipitation of years over the same period.

The Z index

The Z index is related to the Wilson-Hilferty cube-root transformation. Assuming that precipitation obeys the Pearson Type III distribution. The hierarchy standard is showed in *Table 1*. The China Z-index (CZI) is calculated as :

$$Z = \frac{6}{C_s} \left(\frac{C_s}{2} \Phi + 1 \right)^{\frac{1}{3}} - \frac{6}{C_s} + \frac{C_s}{6} \quad (\text{Eq.2})$$

where C_s is coefficient of skewness, and Φ is standardized variable precipitation. The formula of C_s and Φ are shown as below:

$$\Phi = (R_i - R) / S \quad (\text{Eq.3})$$

$$C_s = \frac{\sum_{i=1}^n (R_i - R)^3}{(nS^3)} \quad (\text{Eq.4})$$

where R_i is precipitation, R is average precipitation; S is the sample's mean-variance, and n is the number of samples.

The soil moisture index

The soil moisture index is calculated as:

$$M = 100(x_i - \bar{x}) / \sigma \quad (\text{Eq.5})$$

where M is the soil moisture index; x_i is precipitation of a certain period of time, $\bar{x}$ is the average precipitation in the same period; and σ = standard deviation. The hierarchy standard is shown in *Table 1*.

Table 1. The drought grade standard

Level	Types	$P_a\%$			Z	M
		annual scale	seasonal scale	monthly scale		
0	normal	$-15 < P_a \leq 15$	$-25 < P_a \leq 25$	$-40 < P_a \leq 40$	$-0.524 \leq Z < 0.524$	$-30 \leq M < 30$
1	mild	$-30 < P_a \leq -15$	$-50 < P_a \leq -25$	$-60 < P_a \leq -40$	$-1.037 \leq Z < -0.524$	$-80 \leq M < -30$
2	moderate	$-40 < P_a \leq -30$	$-70 < P_a \leq -50$	$-80 < P_a \leq -60$	$-1.645 \leq Z < -1.037$	$-150 \leq M < -80$
3	severe	$P_a \leq -40$	$P_a \leq -70$	$P_a \leq -80$	$Z < -1.645$	$M < -150$

In Fig. 3, we can conclude that the drought intensity increased from 1952 to 2012, and the interannual fluctuation changed significantly. In particular, the seasonal drought all showed a trend of slow increase and the drought aggravating trend in spring was more evident than those in other seasons. In the past 60 years, the severe drought condition is evaluated by Z and M in 1966 and 1978 and 1997 and 2001 and 2012. All these years are evaluated as drought years by the three indexes, which are 1959, 1966, 1976, 1978, 1981, 1986, 1988, 1992, 1997, 1999, 2001, 2011, and 2012. The mild drought condition is evaluated by Pa and Z in 1959, 1976, 1988, 1992, 2011. However, the moderate drought condition is evaluated by M in the same years. The mild drought condition is evaluated by Pa in 1981, 1986, 1999, but the evaluation results via Z and M are moderate drought conditions.

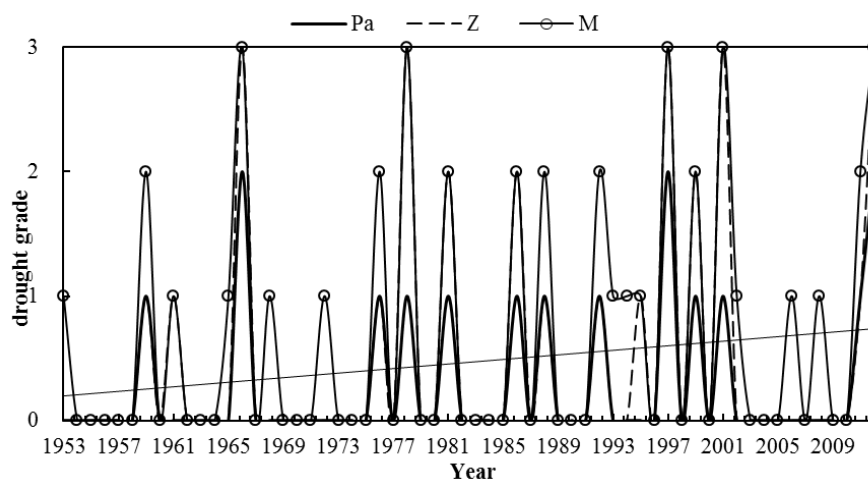
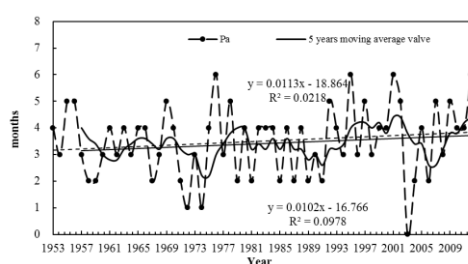


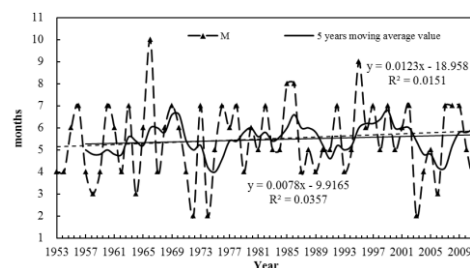
Figure 3. The drought intensity change

The drought duration

The drought duration analysis results by three indexes are showed in Fig. 4. According to the results, we can draw a conclusion that the drought duration increased year by year and the interannual fluctuations changed significantly. The linear trend change rates were 0.0113/a, 0.0123/a, and 0.0123/a. The sliding average for five years increased evidently, and the linear trend change rates were 0.0102/a, 0.0106/a, 0.0078/a. The results by Pa and Z showed a prominent uptrend and the two indexes were approved by significant testings whose correlation coefficient were 0.31 and 0.30, respectively. Thus it can be seen that the drought duration in Henan Province increased year by year, and the sliding average for five years slow increased evidently.



(A)



(B)

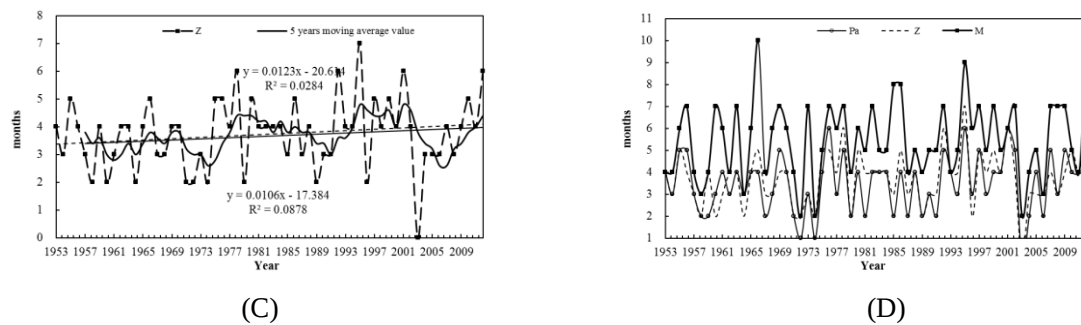


Figure 4. The drought duration change (A: Pa; B: M; C: Z; D: Total)

As we can see in *Fig. 4*, the drought intensity was related strongly to duration. Through correlation analysis, all three drought indexes have passed the relation significance test between drought intensity and drought duration. The results are showed in *Table 3*.

Table 3. The correlation analysis of drought duration and intensity from 1953 to 2012

Variable	Pearson correlation			Kendall coefficient of concordance			Spearman rank relational coefficient			Average
	Pa	Z	M	Pa	Z	M	Pa	Z	M	
D/I	0.371**	0.580**	0.379**	0.313**	0.517**	0.248*	0.356**	0.588**	0.298*	0.406

Note: * means significance level of 0.05; ** means significance level of 0.01.

The characteristics of statistical sequence value

From the evaluation results calculated with Pa, Z and M, we can get the statistical sequence value. The analysis of statistical sequence value are showed in *Table 4*. We can conclude that the average drought duration per year is 4.23 months, the maximum duration is 10 months, the average drought intensity level is 0.48 and the greatest level is 3.

Table 4. The drought characteristics index statistics

single variable	drought duration (month)				drought intensity (S)			
	average	Pa	Z	M	average	Pa	Z	M
average	4.23	3.5	3.7	5.5	0.48	0.27	0.47	0.7
standard deviation	1.45	1.33	1.27	1.75	0.83	0.55	0.93	1
maximum	-	6	7	10	-	2	3	3
minimum	-	0	0	2	-	0	0	0
variance coefficient	0.35	0.38	0.34	0.32	1.82	2.06	1.99	1.42
skewness coefficient	-0.11	-0.16	-0.04	0.13	1.7	1.99	1.94	1.18

According to each characteristic indexes standard deviation and variance coefficient, we can draw a conclusion that the distribution of discrete degree is smaller in drought intensity. Meanwhile, the distribution of discrete degree is larger in drought duration. From each index's coefficient of skewness, compared with normal distribution, the drought duration (intensity) present left deviation (right deviation), and the drought duration is close to normal distribution. From the above results, we come to the conclusion that the same level drought intensity has a small probability to occur for successive periods, and the years of drought duration with the same months are quite concentrated. Based on this characteristic, we can estimate frequencies of yearly which occur in a certain drought month interval.

The applicability evaluation of the three kinds of drought index

Through the application of three kinds of drought indexes in Henan Province's drought characteristics analysis, we can see:

Drought frequency. In terms of heavy drought discrimination, the Pa index indicates no severe drought, but the Z and M indexes both indicate an 8.33% heavy drought frequency. In terms of medium drought identification, Pa and Z are less than M index, in terms of light drought identification, Pa index and M index are more consistent and Z index is lighter. In terms of the type of drought season, due to the fact that the effects of summer drought on agriculture in Henan Province is the largest, our focus is on summer drought: the drought frequency of Pa index in summer drought is 4 times less than that in spring drought, and the drought frequency of Z, M indexes are both more than those spring drought. The drought frequency of Z in summer drought is 4 times more than that in spring drought and the drought frequency of M index in summer drought is 1 time more than spring drought.

Compared with historical drought in Henan Province (Wang, 2013), the Z and M indexes are more consistent with the reality. In addition, through comparing the evaluation results of the three kinds of drought indexes with the results of literature, we can draw the objective evaluation of the calculated results and obtain the matching degree of the drought index. From the *Table 5*, we can see that the Z index has the highest degree of matching, and the evaluation conclusion is more consistent with the actual situation.

Table 5. *The comparison of the results of different drought indexes and historical date*

Year	The drought frequency			
	Historical reality	Pa	Z	M
1961-1970	1	1	1	4
1971-1980	5	2	4	4
1981-1990	6	3	4	2
1991-2000	3	3	3	6
2001-2010	1	1	1	4
total	15	10	13	20

Drought strength. Seasonal droughts showed a slow increasing trend, and the drought in spring was more evident compared with those in other seasons. The number of years

in which 3rd level of drought (severe drought) occurred, Pa index evaluation result was 0. Compared with Z, M indexes evaluation result, Pa was evidently partial light; and Z and M indexes had a high consistency, and was consistent with the reality.

Drought duration. Drought duration showed a slow increasing trend, and the average annual drought duration of the three kinds of index evaluation was from large to small: $M > Z > Pa$. The correlation analysis indicated that the drought intensity and the drought duration had a strong correlation.

As we can see, Pa index has the advantages of easy access to data, simple calculation and clear meaning, but the response to drought is slow, the sensitivity is low, the degree of drought reflection is weak, and the reliance on average is strong. In the practical application process, the data analysis is applied to the monthly, seasonal and annual data of the single station. Compared with the above two kinds of indexes, the response of M index to drought is faster and more sensitive, but sometimes it exaggerates the extent of the actual drought too much. Due to the rainfall in general obeys Pearson-III type distribution, the Z index considers the reality of precipitation and obeys skew distribution, the normal standardization treatment is carried out to avoid errors caused by the difference in the scale precipitation mean in different time and space. Therefore the Z index can reflect the drought situation in a certain period of time better (Han et al., 2009). Overall, Z index has a better applicability in the assessment of drought situation in Henan Province (Zhang et al., 2016).

Conclusions

(1) High frequency and evident seasonal variations are the characteristics of the draught of Henan Province for nearly 60 years. The drought strength and duration have an evident interannual fluctuation and increase slowly as a whole. In particular, the drought aggravating trend in spring is more evident than those in other seasons. The drought duration increased year by year and interannual fluctuation changed significantly. The average drought duration per year is 4.23 months, and the average drought intensity level is 0.48. The distribution of discrete degree is smaller in drought intensity. Meanwhile, the distribution of discrete degree is larger in drought duration. The drought duration is close to normal distribution compared with other indicators.

(2) Z is more applicable than the other two indexes in evaluating drought situation of Henan Province. In contrast to historical reality, the matching degree calculated by Z index is 86.7%, which is more consistent to actual condition and is easier to calculate (Wu H, 2001). However, the calculation principle of Z assumes that the precipitation data obeys the Pearson Type III distribution and neglects the function of temperature, evaporation and other factors. So the actual precipitation may have some differences from the fitting functions used for the Z index. Thus, the universality is to be further investigated.

(3) Drought occurrence is not only related to meteorological factors such as precipitation, temperature, evaporation, but is also affected by human being activities. Therefore, a single indicator may not fully evaluate drought characteristics, and using comprehensive multi-criterion estimation will be the hotspot of drought assessment in the future.

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