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Analysis of spatial-temporal evolution of agricultural drought based on regional agricultural drought index

Fuqiang Wang[a,b,c], Meiqi Sun[a], Subing Lü[a,b,*], Zuhao Zhou[d]

[a]*North China University of Water Resources and Electric Power, Henan Province, 450046, China, email: lvsubing2006@126.com (S. Lü)*
[b]*Collaborative Innovation Center of Water Resources Efficient Utilization and Support Engineering, Henan Province, 450046, China*
[c]*Henan Key Laboratory of Water Environment Simulation and Treatment, Henan Province, 450046, China*
[d]*China Institute of Water Resources and Hydropower Research, Beijing 100038, China*

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ABSTRACT

In recent years, the frequency and intensity of drought in China are on the rise, and most of the major grain producing provinces are situated in the drought-prone areas, so agricultural drought has become one of the main factors restricting the agricultural production in China. In this paper, with Henan province being taken as the research area, the change trend of agricultural drought area of Henan province was analyzed, and the spatial-temporal evolution characteristics of Henan province were evaluated based on the regional agricultural drought index. The research showed that the inter-annual change of agricultural drought index showed a decreasing trend year by year (tendency rate was –0.12/10*a*), indicating that the drought degree decreased year by year. The east and south of North Henan, east and north of Eastern Henan, and north and east of Central Henan were mild drought-prone areas; the east of Western Henan, west and north of North Henan, and west of Central Henan were moderate drought-prone areas; the west of North Henan, west of Western Henan, and north of South Henan were severe drought-prone areas.

Keywords: Agricultural drought; Regional agricultural drought index; Evolution characteristics; Spatial and temporal distribution; Henan province

1. Introduction

Agricultural drought mainly refers to crop losses due to the water supply cannot meet the normal water demand of crops in the process of crop growth and development [1–4]. In recent years, the frequency and intensity of drought in China are on the rise under the influence of climate, human activities and underlying surface, besides, most of the major grain producing provinces are situated in the drought-prone areas, so agricultural drought has become one of the main factors restricting the agricultural production in China [5,6].

Agricultural drought indexes reflect the drought degree and determine the drought grade by studying whether the water content of crops affect the growth and development of crops [7–11]. In the late 20th century, American scholars used the precipitation effectiveness index as a standard to evaluate drought [12,13]. In the early 21st century, comprehensive mechanism drought indexes relating to soil, runoff and vegetation have been widely used by scholars, such as Palmer and SMI [14]. In terms of the evaluation of agricultural drought, the agricultural drought indexes were calculated mainly using the measured or simulated soil water content, evapotranspiration and so on, and the agricultural drought intensity at different spatial and temporal scale was evaluated [15–18]. At the same time, the duration and frequency of agricultural drought were analyzed using the statistical method [19].

Henan province is a major agricultural province of China, with the highest total grain output in China for years. However, Henan province is located in the transitional

* Corresponding author.

zone of North-South Climate. Affected by the monsoon climate, it is characterized by great inter-annual change of precipitation, uneven seasonal distribution, big difference in regional distribution of precipitation, and high frequency of drought [20]. Therefore, in this paper, taken Henan province as the research area, the inter-annual and intra-annual distribution characteristics of agricultural drought areas were analyzed using the agricultural drought area during 1990–2013, and the spatial-temporal evolution of agricultural drought were evaluated based on the regional agricultural drought index.

2. Materials and methods

2.1. Regional agricultural drought index

The evaluation of drought degree involves both duration and scope of drought, and the regional agricultural drought index can be used to evaluate the agricultural drought in a region. The agricultural drought extent can be quantified by the drought level standard, and the evaluation of regional agricultural drought adopted the method of regional agricultural drought index. The calculation formula was:

$$I_a = \sum_{i=1}^{4} A_i B_i \quad (1)$$

where I_a was regional agricultural drought index (index interval was 0–4); i was the drought grade of crops (i = 1, 2, 3, 4 represented mild, moderate, severe and extra-severe drought, respectively); A_i was the ratio of area of crops to area of cultivated land under a drought grade, %; B_i was the weight coefficient of different drought grade (B_1 = 1, B_2 = 1, B_3 = 3, B_4 = 4 represented mild, moderate, severe and extra-severe drought, respectively).

2.2. Standard for drought grade

Based on the calculated results of regional agricultural drought index, the drought was evaluated according to the standard for drought grade, and the standard for drought grade is shown in Table 1.

3. Results

3.1. Changes in agricultural drought area

3.1.1. Annual change

Henan province, located in the mid-eastern China, is between 31°23′N–36°22′N and 110°21′E–116°39′E. Fig. 1 showed the location and administrative regions of Henan Province. Affected by warm and humid air from Pacific and Indian Oceans and cold air from Siberia in winter, it enjoys a climate featuring dry and windy spring, hot and rainy summer, mild autumn with abundant sunshine, and cold winter with little rain and snow.

The change of drought area under different grade during the current year is shown in Fig. 2. The proportion of mild drought areas during the current year increased obviously; and the proportion of moderate and above drought areas decreased year by year, of which, the proportion of extra-severe drought area was about 3%–10% during 1990–2002 and dropped to 1%–5% during 2003–2013.

3.1.2. Inter-annual change

From 1990 to 2013, the change in agricultural drought area of Henan province tended to be stable (Fig. 3). During 1990–2001 and 2009–2013, it showed obvious fluctuation. From 2002 to 2008, it showed a stable change. In 1999 and 2011, the agricultural drought area was relatively large; in 1990, 2005 and 2010, the agricultural drought area was relatively small.

3.2. Spatial-temporal evolution of agricultural drought

3.2.1. Temporal distribution

The I_a of typical cities including Zhengzhou (Central Henan), Luoyang (Western Henan), Anyang (North Henan), Shangqiu (Eastern Henan) and Xinyang (South Henan) was calculated (Table 2), and the temporal distribution of drought in the whole province and five typical cities was analyzed. As can be seen from Fig. 4, the temporal change of I_a showed a decreasing trend year by year (tendency rate was –0.12/10*a*), which indicating that the drought degree decreased year by year; I_a index was greater than 0.5 in 1991, 1992, 1994, 1997, 1999, 2000, 2001 and 2011, indicating that the drought degree was a little severe in those years. During 1990–2002, the temporal fluctuation of I_a was obvious, during 2003–2008 it tended to be stable, and during 2009–2013 it showed an increasing trend. According to the classification standard for drought grade, the results showed: during 1990–2013 Henan province was affected by agricultural drought every year, thus suffering a certain degree of drought losses, of which, moderate drought occurred in 1991, 1992, 1994, 1997, 1999, 2000, 2001 and 2011, and mild drought occurred in the rest of the years.

Zhengzhou: During 1990–2010 the inter-annual fluctuation of I_a was obvious, and during 2011–2013 it tended to be stable, showing a slow decreasing trend overall (tendency rate was –0.09/10*a*), of which, moderate drought occurred in

Table 1
Drought grade standard

Region	Regional agricultural drought index I_a			
	Mild drought	Moderate drought	Severe drought	Extra-severe drought
Nationwide	$0.05 \le I_a < 0.1$	$0.1 \le I_a < 0.2$	$0.2 \le I_a < 0.3$	$0.3 \le I_a < 4$
Province	$0.1 \le I_a < 0.5$	$0.5 \le I_a < 0.9$	$0.9 \le I_a < 1.5$	$1.5 \le I_a < 4$
City	$0.1 \le I_a < 0.6$	$0.6 \le I_a < 1.2$	$1.2 \le I_a < 2.1$	$2.1 \le I_a < 4$

Table 2
I_a of typical city

Year	Whole province	Zhengzhou	Luoyang	Anyang	Shangqiu	Xinyang
1990	0.24	0.16	0.69	0.19	0.15	0.00
1991	0.64	0.81	0.92	0.71	0.41	0.00
1992	0.58	0.77	0.82	0.66	0.21	0.00
1993	0.47	0.21	0.25	0.99	0.52	0.00
1994	0.85	0.35	1.52	1.43	0.80	1.72
1995	0.49	0.90	1.81	0.62	0.27	0.00
1996	0.29	0.47	0.53	0.28	0.10	0.20
1997	0.81	0.84	1.32	0.72	0.31	0.62
1998	0.46	0.88	0.21	0.15	0.19	0.00
1999	0.79	0.40	1.07	1.41	0.34	0.48
2000	0.77	0.59	1.13	1.48	0.22	1.46
2001	0.86	0.28	0.86	0.79	0.32	2.00
2002	0.37	0.50	0.65	0.53	0.22	0.00
2003	0.26	0.16	0.23	0.25	0.17	0.00
2004	0.25	0.12	0.37	0.29	0.13	0.00
2005	0.25	0.45	0.62	0.09	0.12	0.00
2006	0.30	0.43	0.43	0.07	0.13	0.42
2007	0.33	0.26	0.83	0.10	0.16	0.27
2008	0.25	0.06	0.46	0.12	0.20	0.10
2009	0.49	0.38	0.69	0.18	0.39	0.33
2010	0.19	0.32	0.02	0.26	0.09	0.20
2011	0.56	0.53	0.36	0.22	0.45	0.50
2012	0.32	0.55	0.17	0.19	0.30	0.77
2013	0.37	0.57	0.84	0.14	0.30	0.36

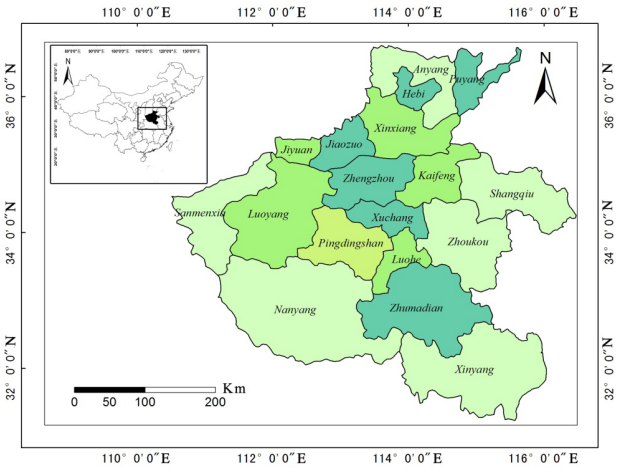

Fig. 1. Location of Henan Province in China.

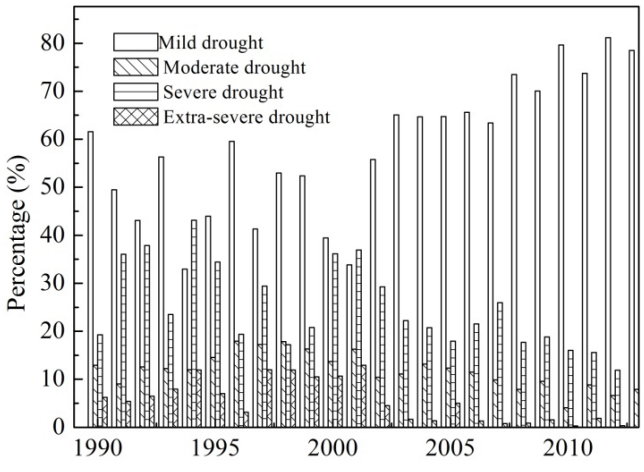

Fig. 2. Change of different grades drought area.

1991, 1992, 1995, 1997 and 1998, and mild drought occurred in the rest of the years.

Luoyang: The inter-annual fluctuation of I_a was obvious, showing a decreasing trend overall (tendency rate was –0.28/10*a*). Agricultural drought occurred in all the years except 2010, of which, moderate drought occurred in 1990, 1991, 1992, 1999, 2000, 2001, 2002, 2005, 2007, 2009 and 2013, and severe drought occurred in 1994, 1995 and 1997.

Anyang: During 1990–2003 the inter-annual fluctuation of I_a was obvious, and during 2004–2013 it maintained a stable change with small values, showing an obvious decreasing trend overall (tendency rate was –0.33/10*a*). Agricultural drought occurred in all the years except 2005, 2006 and 2007, of which, moderate drought occurred in 1991, 1992, 1993, 1995, 1997 and 2001, and severe drought occurred in 1994, 1999 and 2000.

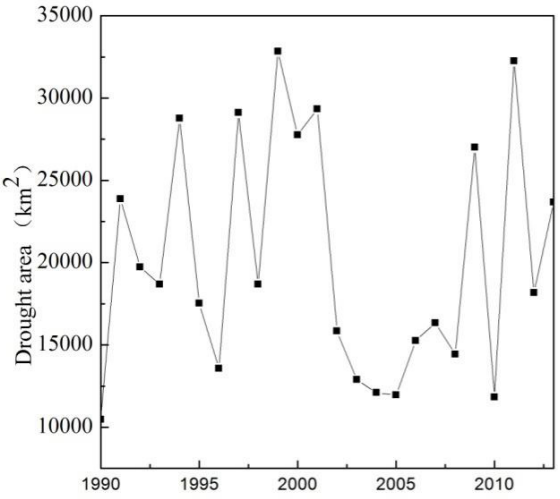

Fig. 3. Inter-annual change of drought area.

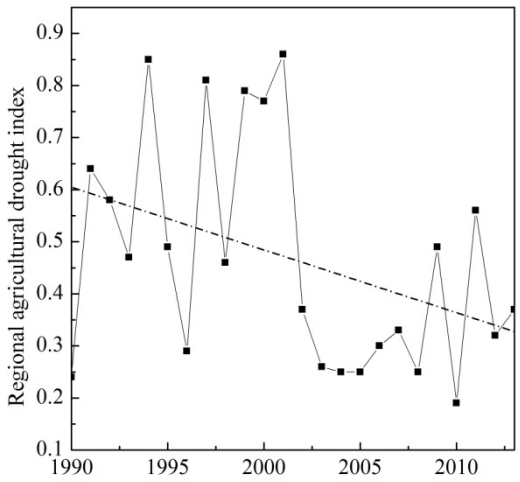

Fig. 4. Temporal change of regional agricultural drought index in Henan province.

Shangqiu: During 1990–1996 and 2008–2012 the inter-annual fluctuation of I_a was obvious, during 1997–2007 it maintained a stable change with small values, and tended to be stable overall, with no obvious variation trend. Agricultural drought occurred in all the years except 2010, of which, moderate drought occurred in 1994. On the whole, Shangqiu suffered mild drought.

Xinyang: During 1993–2002 and 2005–2013 the inter-annual fluctuation of I_a was obvious, and tended to be stable overall. Moderate drought occurred in 1997 and 2012, and severe drought occurred in 1994, 2000 and 2001. On the whole, Xinyang suffered drought less frequently compared with the other four typical cities.

3.2.2. *Spatial distribution*

The spatial distribution diagram of drought frequency was drawn using the ArcGIS 10.0 software (Fig. 5). In spatial distribution, Luohe, Nanyang, Zhumadian and Xinyang suffered drought less frequently compared with the other areas of

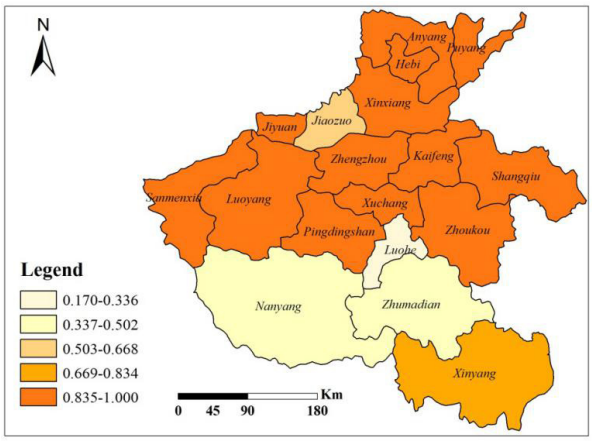

Fig. 5. Spatial distribution of agricultural drought frequency.

Henan province. Most parts of Henan province were affected by agricultural drought with differences in drought degree and area of affected crops, and the North Henan, Western Henan, Eastern Henan and most parts of Central Henan suffered more severe drought compared with some parts of South Henan.

Fig. 6 showed the spatial distribution of drought of different grade. In terms of mild drought, Xinxiang, Jiaozuo, Puyang, Kaifeng, Zhengzhou, Shangqiu and Xuchang were relatively large. As for moderate drought, Luoyang, Jiyuan, Hebi, Pingdingshan and Sanmenxia were relatively large. Jiyuan, Sanmenxia and Zhumadian were relatively vulnerable to severe drought.

Therefore, the east and south of North Henan, east and north of Eastern Henan, and north and east of Central Henan were mild drought-prone areas; the east of Western Henan, west and north of North Henan, and west of Central Henan were moderate drought-prone areas; the west of North Henan, west of Western Henan, and north of South Henan were severe drought-prone areas.

4. Discussion

Combined with the analysis results of spatial-temporal evolution characteristics of agricultural drought based on the regional agricultural drought index, the research showed that:

- First item. In the 1990s the drought frequency was high; during 2000–2013 the drought frequency decreased but the drought intensity increased.
- Second item. In the years with significantly little precipitation, such as 1992, 1995, 1997, 1999, 2001, 2012 and 2013, the drought was severe.
- Third item. In the absence of annual scale drought, such as 1990, 1991, 1993, 1996, 1998, 2000 and 2002–2010, a certain degree of drought losses occurred under the influence of factors such as uneven distribution of precipitation, and the drought was mostly mild.
- Fourth item. Most parts of Henan province were affected by agricultural drought with differences in drought degree and area of affected crops, and the North Henan, Western Henan, Eastern Henan and most parts of Central Henan suffered more severe drought compared with some parts of South Henan.

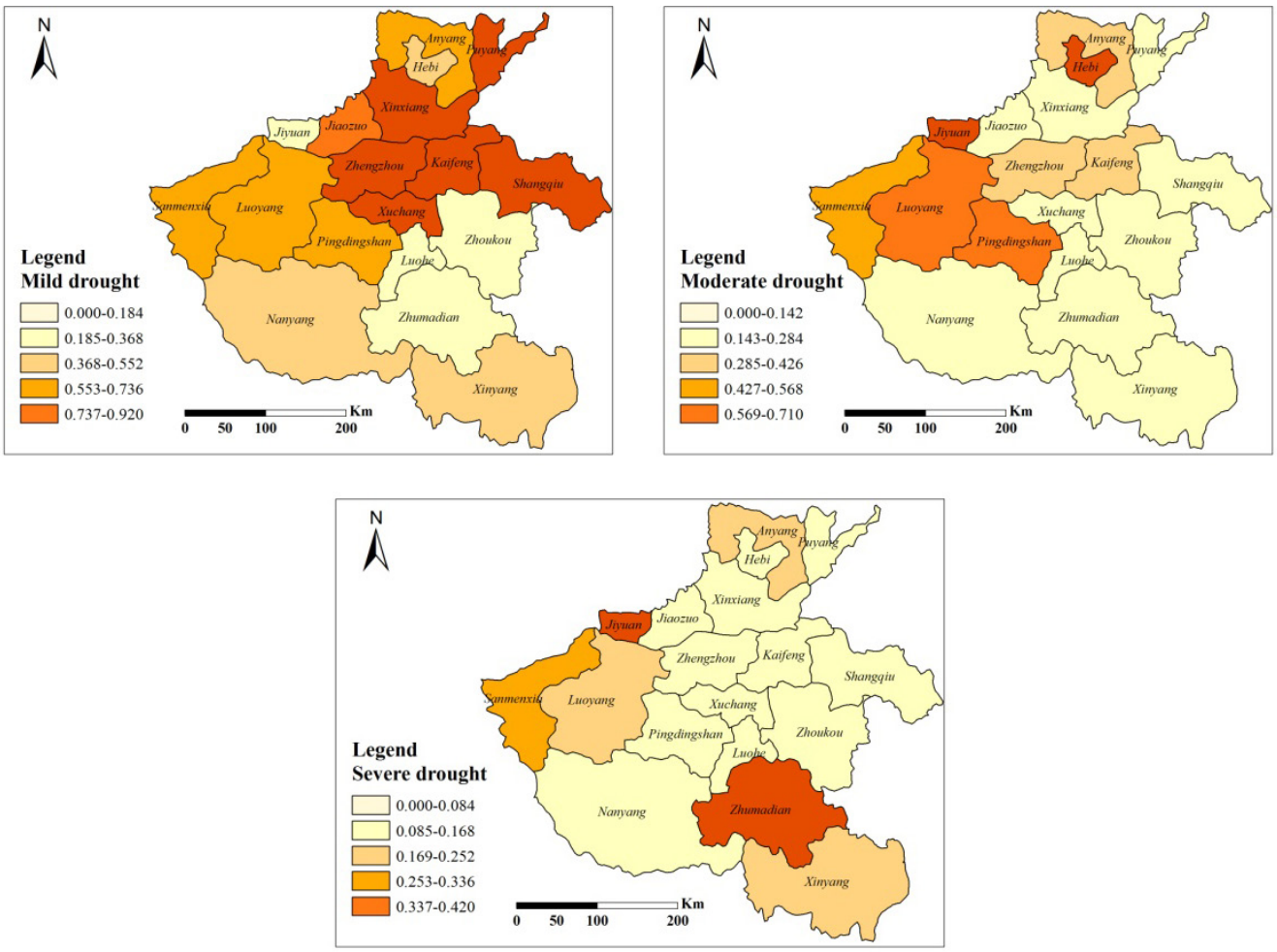

Fig. 6. Space distribution of different grades of agricultural drought.

5. Conclusions

The agricultural drought and spatial-temporal evolution characteristics of Henan province during 1990–2013 were analyzed by selecting the regional agricultural drought index using the data of agricultural drought area.

- First item. The change in agricultural drought area of Henan province tended to be stable from 1990 to 2013. In 1999 and 2011, the agricultural drought area was relatively large while in 1990, 2005 and 2010, the agricultural drought area was relatively small. The proportion of mild drought area during the current year increased obviously, and the proportion of moderate and above drought area decreased year by year. The proportion of extra-severe drought area was about 3%–10% during 1990–2002 and dropped to 1%–5% during 2003–2013.
- Second item. The inter-annual change of I_a showed a decreasing trend year by year (tendency rate was –0.12/10*a*), indicating that the drought degree. Moderate drought occurred in 1991, 1992, 1994, 1997, 1999, 2000, 2001 and 2011.
- Third item. The inter-annual fluctuation of I_a of Zhengzhou, Luoyang and Anyang was obvious, showing a decreasing trend, and their agricultural drought degrees were relatively severe. The inter-annual change of I_a of Shangqiu and Xinyang tended to be gentle overall. Xinyang suffered drought less frequently compared with the other four typical cities.
- Fourth item. Most parts of Henan province were affected by agricultural drought with different drought degree and area of affected crops, The North Henan, Western Henan, Eastern Henan and most parts of Central Henan suffered more severe drought compared with some parts of South Henan. The spatial distribution of agricultural drought of different grade showed: the east and south of North Henan, east and north of Eastern Henan, and north and east of Central Henan were mild drought-prone areas; the east of Western Henan, west and north of North Henan, and west of Central Henan were moderate drought-prone areas; the west of North Henan, west of Western Henan, and north of South Henan were severe drought-prone areas.

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