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Spatial and temporal variability of drought during 1960–2012 in Inner Mongolia, north China

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ABSTRACT

In this study, drought in Inner Mongolia was studied by using standardized precipitation index (SPI) and dry spells (DS). Principal component analysis (PCA) was applied to the SPI series computed on 24-month time scale. The results demonstrate noticeable spatial patterns, with six sub-regions characterized by different climatic variability. Overall, most parts of Inner Mongolia are dominated by dry tendencies, except for the western and easternmost areas. Three DS indices, including the number of dry spells (NDS), mean length of dry spells (MDS) and maximum length of dry spells (MxDS), and four periods (spring, summer, autumn and winter), are considered. The results show that a predominant east to west increasing gradient for mean MDS and MxDS has been found in all periods. Mean NDS shows an opposite distribution to that of mean MDS and MxDS. Drought in the western area is more severe than in the eastern area. According to temporal analysis by using the Mann–Kendall trend method, summer is the only season showing strong trends for all the DS indices. During summer, the trends of MDS and MxDS dominantly are positive, while the trends of NDS are dominantly negative. This means that the summer droughts have become increasingly serious in Inner Mongolia.

1. Introduction

As one of the most damaging natural hazards that impact societies, drought is usually defined as a significant temporary reduction in water availability below the expected amount for a specified period and for a particular climatic zone. Due to the high impacts on economic and social development, drought has become one of the prominent disasters affecting north China, especially the Inner Mongolia Autonomous Region. Agriculture, forestry, animal husbandry, and mining are pillar industries for most regions in the province. Inner Mongolia has been an important production and processing base for green agricultural and livestock products, and it is also one of 13 major grain producing areas in China. All these are strongly dependent on the water resources situation. Therefore, effective drought risk management for Inner Mongolia is urgently needed. At present, the standardized precipitation index (SPI) and Dry spell (DS) are widely used to investigate the spatiotemporal variability of local drought episodes.

SPI developed by McKee et al. (1993) has been widely used to reveal meteorological drought and is a useful tool in the estimation of the intensity and duration of drought events. The SPI was used to determine anomalously wet or dry events on a particular time scale for any locations where precipitation records are available. The main advantage of SPI is that it represents the same probability of drought occurrence irrespective of season, location, or climate. In China, SPI has been applied for assessing spatial and temporal variation of dryness/wetness in many river basins. Zhang et al. (2009) explored the changes of dry/wet episodes in the Pearl River Basin in South China and indicated that it tends to be drier in the rainy season and wetter in winter. Zhao et al. (2011) applied the principal component analysis (PCA) on the SPI time series to investigate the dryness/wetness in the Yangtze River Basin. In terms of their study results, a spatial division was conducted into three sub-regions with different climatic variability: the southeastern downstream part of the basin, the midstream, and the western upstream part of the study area.

Drought is not only caused by insufficient total precipitation, but also directly caused and increasingly aggravated by a number of consecutive no-rain days within the rainy season, usually called dry spells. Dry spell (DS) is defined as consecutive days with the daily precipitation amount less than a certain threshold, i.e. a dry spell is

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preceded and followed by rainfall days exceeding the threshold. Dry spell analysis helps to better recognize the dryness impact. Research relying on the monthly precipitation can sometimes lead to incorrect results, and consequently many researchers all over the world have studied drought using dry spell analysis (Cindrić et al., 2010; She and Xia, 2013). Drought events, which contribute more than half of the total losses due to the climate relevant disasters, are major disasters resulting in heavy losses to agriculture in China (Gong et al., 2005). Most previous studies contributed to the drought analysis on the monthly precipitation scale in China. Unfortunately, studies of DS based on daily precipitation records are highly limited.

Inner Mongolia Autonomous Region is a very important agricultural province with abundant natural resources and plays an important role in the sustainable development of the economy and ecology of north China. However, most studies about drought focused on the change trends of annual and seasonal precipitation. Therefore, the key objectives of this study are to systematically investigate the spatial and temporal variability of drought in Inner Mongolia using standard precipitation index (SPI) and dry spells (DS). Such a study is necessary for the water resources management in Inner Mongolia under the background of global change.

2. Study region and data

Inner Mongolia Autonomous Region is located between 37°24′–53°23′N and 97°12′–126°04′E with a mean elevation of 1014 m. As the third largest province in China and an autonomous region, it covers an area of 1.18 million km^2, which accounts for 12.3% of the country's territory. Inner Mongolia, with a temperate continental monsoon climate, has a cold and long winter with frequent blizzards and a warm and short summer. Except for the relatively humid Greater Hinggan Mountain area, most of Inner Mongolia is arid, semi-arid or semi-humid from west to east. The average annual temperature is in the range of −1 °C to −15 °C, and the annual average precipitation ranges from 50 to 500 mm.

On the basis of length of records, a total of 51 stations that have 53-year records by 2012 were selected as candidate stations. The initial data set of daily precipitation during the period 1960–2012 at the 51 candidate stations were collected from the National Meteorological Information Center of China. The quality and homogeneity of the climatic records from these stations were checked and controlled using the RclimDex software package (http://etccdi.pacificclimate.org/software.shtml). After rejecting 5 stations with inhomogeneous daily precipitation series, 46 stations were finally adopted in this study. The locations of the 46 stations are plotted in Fig. 1, and Table 1 lists the location and a brief description of all used stations.

Table 1
List and a brief description of meteorological stations used in this study.

No.	Station name	Latitude (N)	Longitude (E)	No.	Station name	Latitude (N)	Longitude (E)
1	Ejin Banner	41.57°	111.04°	24	Duolun	42.11°	116.28°
2	Alxa Right Banner	39.13°	101.41°	25	Xin Barag right Banner	48.4°	116.49°
3	Guaizi Lake	41.22°	102.22°	26	East Ujimqin Banner	45.31°	116.58°
4	Bayan Mod	40.1°	104.48°	27	Manzhouli	49.34°	117.26°
5	Alxa left Banner	38.5°	105.4°	28	West Ujimqin Banner	44.35°	117.36°
6	Ji Lantai	39.47°	105.45°	29	Linxi	43.36°	118.04°
7	Kanawha	40.45°	107.25°	30	Xin Barag left Banner	48.13°	118.16°
8	Otog Banner	39.06°	107.59°	31	Chifeng	42.16°	118.56°
9	Urat banner	41.34°	108.31°	32	Ongniud Bannar	42.56°	119.01°
10	Baotou	40.4°	109.51°	33	Bairin Left Banner	43.59°	119.24°
11	Dongsheng	39.5°	109.59°	34	Halar	49.13°	119.45°
12	Mandula	42.32°	110.08°	35	Arxan	47.1°	119.56°
13	Darhan Banner	41.42°	110.26°	36	Ergun Right Banner	50.15°	120.11°
14	Siziwang Banner	41.32°	111.41°	37	Bao Guotu	42.2°	120.42°
15	Hohehot	40.49°	111.41°	38	Jarud Banner	44.34°	120.54°
16	Erlianhot	43.39°	111.58°	39	Suolun	46.36°	121.13°
17	Zhu Rihe	42.24°	112.54°	40	Kailu	43.36°	121.17°
18	Jiling	41.02°	113.04°	41	Tulihe	50.29°	121.41°
19	Sonid Left Banner	43.52°	113.38°	42	Bugt	48.46°	121.55°
20	Huade	41.54°	114°	43	Ulanhot	46.05°	122.03°
21	Naran bulag	44.37°	114.09°	44	Tongliao	43.36°	122.16°
22	Abag Banner	44.01°	114.57°	45	Zhalantun	48°	122.44°
23	XilinHot	43.57°	116.07°	46	Xiaoergou	49.12°	123.43°

3. Methods

3.1. Standardized precipitation index (SPI)

The standardized precipitation index (SPI) was developed for the purpose of defining and monitoring droughts (McKee et al., 1993). It is based on the long-term monthly precipitation data at a given period. After fitting a Gamma distribution and transforming it to a normal distribution by an equal probability transformation, the SPI is computed as the precipitation anomaly of the transformed data, divided by the standard deviation of the transformed data (Bordi et al., 2004a; Huang et al., 2014). Once the SPI is calculated, the intensities of dry and wet events are classified as displayed in Table 2. The detailed information about SPI can be found in our previous study (Huang et al., 2014). The SPI can track dry/wet events on different time-scales, i.e. 1-, 3-, 6-, 12-, and 24-months, and is flexible with respect to the period chosen (Bordi et al., 2004b; Raziei et al., 2009). In this study, results concerning the 24-month time scale (SPI-24) are discussed.

Table 2
The standardized precipitation index (SPI) categories based on the initial classification of SPI values.

Category	SPI
Extremely wet	2.00 and above
Severely wet	1.50–1.99
Moderately wet	1.00–1.49
Near normal	−0.99–0.99
Moderate drought	−1.00 to −1.49
Severe drought	−1.50 to −1.99
Extreme drought	−2.00 and less