Postprint of Drought Characteristics in Inner Mongolia Based on Precipitation Anomaly Percentage

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Abstract

Using monthly precipitation observation data from 52 meteorological stations in the Inner Mongolia region from 1971–2015 and adopting the precipitation anomaly percentage (Pa), this study analyzed the spatiotemporal distribution characteristics of drought in the study area over the recent 45 years from the perspectives of drought frequency and drought variation trend rate. The results show that: From a temporal perspective, annual precipitation exhibited a slight decreasing trend, with abrupt changes occurring in 1998 and 2012; precipitation in spring, autumn, and winter showed an increasing trend, while precipitation in summer showed a decreasing trend; annual-scale drought mainly occurred during 1999–2011; the frequency of seasonal-scale drought occurrence was in the order of winter drought > spring drought > autumn drought > summer drought. From a spatial perspective, multi-year average precipitation showed a stepwise decreasing trend from east to west, with distinct regional characteristics in precipitation distribution; areas east of the Greater Khingan Mountains and the western part of Bayannur City exhibited higher precipitation variation trend rates, while the northwestern part of Hulunbuir City, central-southern part of Tongliao City, central part of Chifeng City, and western part of Alxa League exhibited lower precipitation variation trend rates; the probability of different drought grades occurring was in the order of mild drought > extreme drought > moderate drought > severe drought, with areas prone to various drought grades concentrated in the western part of Hulunbuir City, central-northern part of Chifeng City, northern part of Tongliao City, central-western part of Xilingol League, and western part of Alxa League. The variation trend rate of Pa showed that the central-eastern part of Hulunbuir City, western part of Bayannur City, and eastern part of Alxa League exhibited an increasing trend, i.e., drought severity decreased; the area from southern Xing' an League to

Ordos City and the central-western part of Alxa League exhibited a decreasing trend, i.e., drought severity increased.

Full Text

Preamble

Drought Characteristics in Inner Mongolia Based on Precipitation Anomaly Percentage

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Abstract: Monthly precipitation data from 52 meteorological stations in Inner Mongolia from 1971 to 2015 were used. The methods of M-K test and precipitation anomaly percentage (Pa) were used to analyze the change trend and abrupt change of precipitation, and the spatiotemporal variation of drought at different time scales was also analyzed. The results showed that the inter-annual precipitation variation trend was basically maintained, and two abrupt changes took place in 1998 and 2012 in recent 45 years. Precipitation increased in spring, autumn and winter, but it was opposite in summer. Drought events occurred mainly in winter during the period from 1999 to 2011, and their frequency was the lowest in summer. Spatially, the annual precipitation decreased gradually from the east to the west. The change rate of precipitation was high in the area east of the Greater Khingan Mountains and west Bayan Nur, but it was low in Northwest Hulun Buir, central and southern parts of Tongliao, central part of Chifeng, and western Alxa. In addition, the probability of occurring drought at different levels was in an order of slight drought > extreme drought > moderate drought > severe drought. Drought events occurred generally in west Hulun Buir, Central-North Chifeng, North Tongliao, Central-West Xilin Gol League and West Alxa League. The Pa was in an increase trend in Central-East Hulun Buir, West Bayan Nur and East Alxa League, but it was in a decrease trend from South Hinggan League to Erdos and in Central-West Alxa.

Keywords: drought level; precipitation anomaly percentage (Pa); Inner Mongolia

1. Methods

1.1 Precipitation Anomaly Percentage and Drought Analysis

The precipitation anomaly percentage (Pa) is calculated as:

$$Pa = \frac{P - \bar{P}}{\bar{P}} \times 100\%$$

where P is the annual precipitation and $\bar{P}$ is the multi-year average precipitation.

Drought Classification: Drought levels were classified based on Pa values according to national standards .

TABLE 1 Drought level classification based on precipitation anomaly percentage

Drought Level	Pa (%)
1 (No drought)	$Pa > -40$
2 (Slight drought)	$-60 < Pa \leq -40$
3 (Moderate drought)	$-80 < Pa \leq -60$
4 (Severe drought)	$-95 < Pa \leq -80$
5 (Extreme drought)	$Pa \leq -95$

Drought Frequency Analysis: The frequency of drought at each station was calculated as:

$$Frequency = \frac{N_d}{N} \times 100\%$$

where N_d is the number of drought events and N is the total number of years.

Trend Analysis: Linear regression was used to analyze precipitation trends:

$$X = at + b, \quad (t = 1, 2, 3, \ldots, n)$$

where a is the slope (trend rate) and b is the intercept. A positive a indicates an increasing trend, while a negative a indicates a decreasing trend.

Mann-Kendall Test: The M-K test was used to detect significant trends in precipitation and drought indices. The test statistic Z is calculated as:

$$Z = \begin{cases} \frac{S-1}{\sqrt{var(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sqrt{var(S)}} & \text{if } S < 0 \end{cases}$$

where $S = \sum_{k=1}^{N-1} \sum_{j=k+1}^{N} \text{sign}(x_j - x_k)$ and $\text{sign}(x_j - x_k)$ is the sign function. When $|Z| > 1.96$ at significance level $\alpha = 0.05$, the trend is statistically significant.

Drought Probability: The probability of drought occurrence was calculated as:

$$P_j = \frac{M}{m} \times 100\%$$

where M is the number of drought events and m is the total number of observations. Drought probability was classified as: $P_j \geq 50\%$ (high probability), $35\% \leq P_j < 50\%$ (relatively high), $25\% \leq P_j < 35\%$ (moderate), $10\% \leq P_j < 25\%$ (relatively low), and $P_j < 10\%$ (low).

1.2 Data Sources

Monthly precipitation data from 52 meteorological stations in Inner Mongolia covering the period 1971–2015 were used [Figure 1: see original paper]. The data were obtained from the Inner Mongolia Meteorological Bureau and underwent quality control procedures.

FIGURE 1 Distribution of elevation and meteorological stations in Inner Mongolia

2. Results

2.1 Inter-Annual Variation of Precipitation

The inter-annual precipitation variation trend was basically maintained over the study period. Two abrupt changes occurred in 1998 and 2012. Precipitation increased in spring, autumn, and winter, but decreased in summer. Drought events occurred mainly in winter during 1999–2011, with the lowest frequency in summer.

During the 45-year period, drought occurred in 9 years (1972, 1980, 1982, 1999, 2000, 2001, 2005, 2007, 2009, and 2011), accounting for 20% of the total years. The most severe drought year was 2001 with $Pa = -26.56\%$. Extreme drought events ($Pa \leq -40\%$) occurred in 3 years (1986, 1993, and 1995).

2.2 Spatial Distribution of Drought

Spatially, annual precipitation decreased gradually from east to west. The precipitation change rate was high in areas east of the Greater Khingan Mountains and west of Bayan Nur, but low in northwestern Hulun Buir, central and southern Tongliao, central Chifeng, and western Alxa.

Drought events generally occurred in western Hulun Buir, central-northern Chifeng, northern Tongliao, central-western Xilin Gol League, and western Alxa League. The probability of drought at different levels followed the order: slight drought > extreme drought > moderate drought > severe drought.

The Pa showed an increasing trend in central-eastern Hulun Buir, western Bayan Nur, and eastern Alxa League, but a decreasing trend from southern Hinggan League to Erdos and in central-western Alxa.

3. Conclusion

Based on analysis of precipitation data from 52 meteorological stations in Inner Mongolia from 1971–2015 using M-K test and precipitation anomaly percentage (Pa), the main findings are:

1. The inter-annual precipitation variation trend was basically maintained, with two abrupt changes in 1998 and 2012. Precipitation increased in spring, autumn, and winter, but decreased in summer.
2. Drought events occurred mainly in winter during 1999–2011, with the lowest frequency in summer. Spatially, drought events were concentrated in western Hulun Buir, central-northern Chifeng, northern Tongliao, central-western Xilin Gol League, and western Alxa League.
3. Annual precipitation decreased gradually from east to west. The precipitation change rate was high in areas east of the Greater Khingan Mountains and west of Bayan Nur, but low in northwestern Hulun Buir, central and southern Tongliao, central Chifeng, and western Alxa.
4. The probability of drought at different levels followed the order: slight drought > extreme drought > moderate drought > severe drought.
5. The Pa showed an increasing trend in central-eastern Hulun Buir, western Bayan Nur, and eastern Alxa League, but a decreasing trend from southern Hinggan League to Erdos and in central-western Alxa.

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Note: Figure translations are in progress. See original paper for figures.