Applicability of Five Drought Indices for Drought Assessment in Ordos City (Postprint)

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Abstract

Taking five drought indices from 2002 to 2022—Precipitation Anomaly in Percentage (PA), Standardized Precipitation Index (SPI), Relative Moisture Index (MI), Meteorological Drought Composite Index (MCI), and Relative Soil Moisture (Rsm)—as the research objects, this study analyzes the applicability of these five drought indices in typical drought years and drought-prone areas of Ordos, integrated with historical drought records from the Meteorological Disaster Management System of the China Meteorological Administration. Furthermore, the Empirical Orthogonal Function (EOF) analysis method is employed to reveal the spatiotemporal evolution characteristics of drought in Ordos.

The results indicate that:

(1) The evaluation results of the five drought indices vary across typical drought years. For the spring and summer drought in 2017, MI is suitable for evaluating drought in May and June, while Rsm is applicable for evaluating drought in June and July; for the autumn drought in 2022, the evaluation results of PA and SPI are closer to the actual drought conditions.

(2) Regarding the applicability evaluation for drought-prone areas, spatial analysis shows that the Pearson correlation coefficients between MI, MCI, and NDVI in drought areas are relatively large. In regions with a high proportion of grassland, the proportions of grassland and cropland both passed the 0.05 significance level test with PA, SPI, MI, and MCI. Conversely, since the calculation of Rsm considers deep soil moisture, its correlation with shallow-rooted plants is not significant. From a temporal perspective, the drought conditions evaluated by MI and Rsm during the plant growing season from May to August are more consistent with actual conditions.

(3) The EOF1 spatial analysis results indicate that Rsm provides the optimal drought evaluation, with negative values in the southwest and parts of the east, while other indices show overall consistent positive values. EOF2 shows negative values in the central region and positive values in the surrounding areas, indicating strong spatiotemporal heterogeneity. Analysis of the temporal coefficient variations shows that in the southwest and parts of the east for EOF1, the period 2002–2009 was dry, 2010–2013 was wet, and 2014-2022 was dry, which coincides with the vegetation distribution in Ordos, while other regions exhibited inverse changes. EOF2 displays a distribution characteristic of alternating wet and dry conditions every 2-3 years between the central and surrounding areas.

The research findings provide a scientific basis for drought monitoring and early warning, optimal allocation of water resources, and drought risk prevention and control in Ordos City.

Full Text

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Abstract

In combination with historical drought disaster records from the Meteorological Disaster Management System of the China Meteorological Administration, this paper analyzes the applicability of five drought indices—Precipitation Anomaly in Percentage (PA), Standardized Precipitation Index (SPI), Relative Moisture Index (MI), Meteorological Drought Composite Index (MCI), and Relative Soil Moisture (R_{sm}) over the 2002 to 2022 period—to the typical drought years and drought-prone areas of Ordos City, Inner Mongolia, China. In addition, the spatiotemporal evolution characteristics of drought in Ordos are revealed through an empirical orthogonal function (EOF) analysis. It was found that: (1) The assessment results of the five drought indices differed among the typical drought years. For instance, the MI was suitable for assessing the drought conditions in May and June during the spring/summer drought of 2017, whereas the R_{sm} was more applicable to the drought conditions in June and July of that year. Meanwhile, the PA and SPI best assessed the actual drought situation during the autumn drought in 2022. (2) In the spatial analysis, the MI and MCI were relatively strongly correlated (moderately high Pearson correlation coefficients) with the normalized difference vegetation index (NDVI) in the drought-prone areas. In regions with a large proportion of grassland, the proportions of grassland and cultivated land were correlated with PA, SPI, MI, and MCI at the 0.05 significance level. However, as the R_{sm} calculation accounts for deep soil moisture, R_{sm} is not significantly correlated with the proportion of shallow-rooted plants. From a temporal perspective, the drought conditions assessed by MI and R_{sm} are more aligned with the actual drought situation during the plant-growth season from May to August. (3) In the EOF1 spatial analysis, the R_{sm} measure optimized the drought assessment performance; the other indices exhibited consistent variations overall, with negative values in parts of the southwest and east of Ordos and positive values in all other regions. In EOF2, the indices were negatively valued in the central part of Ordos and positively valued in the surrounding areas, presenting strong spatiotemporal heterogeneity. Analyzing the variation in time coefficients, it was observed that the southwest and partial eastern areas covered by EOF1 were drought-stricken in 2002–2009, humid in 2010–2013, and again drought-stricken in 2014–2022, consistent with the vegetation distribution in Ordos. Meanwhile, EOF2 was characterized by alternating dry and wet conditions between the central part and the surrounding areas of Ordos at 2–3 year periods. The results provide a scientific basis for monitoring and early warning of droughts, optimal allocation of water resources, and prevention and control of drought disaster risk in Ordos City.

1. Introduction

Drought is one of the most complex and damaging natural disasters, characterized by a prolonged deficiency in precipitation that leads to significant water shortages. Unlike sudden-onset disasters such as floods or earthquakes, drought develops gradually, often referred to as a "creeping phenomenon." Its impacts are multifaceted, affecting agriculture, ecosystems, and socio-economic stability. In recent decades, the frequency and intensity of drought events have increased globally due to climate change, necessitating more accurate and timely monitoring systems.

Traditional drought monitoring relies heavily on ground-based meteorological stations. While these provide high-quality point data, their spatial representation is often limited, particularly in regions with complex topography or sparse station networks. To address these limitations, remote sensing technology has become an indispensable tool, offering continuous spatial coverage and multi-temporal observations. Indices such as the Precipitation Anomaly in Percentage (PA) and the Standardized Precipitation Index (SPI) are widely used to quantify meteorological drought. Meanwhile, indices derived from satellite imagery, such as the Vegetation Condition Index (VCI), allow researchers to monitor the biological response of the land surface to moisture stress.

Ordos City, located in the southwestern part of the Inner Mongolia Autonomous Region, serves as a critical ecological barrier in northern China. However, due to its arid and semi-arid climate, the region is highly sensitive to climate change, making drought a primary factor limiting local agricultural production and ecological stability. Accurate drought monitoring is essential for mitigating these impacts.

2. Data and Methods

2.1 Data Sources The primary datasets used in this study span the period from 2002 to 2022. Meteorological data, including daily precipitation and temperature records, were obtained from the National Meteorological Information Center. Satellite-derived vegetation data were sourced from the Moderate Resolution Imaging Spectroradiometer (MODIS) products, specifically the MOD13A3 monthly product with a 1 km spatial resolution. Historical drought disaster data were retrieved from the Meteorological Disaster Management System of the China Meteorological Administration.

2.2 Drought Indices This study evaluates five drought indices: - **Precipitation Anomaly in Percentage (PA):** Represents the degree to which precipitation deviates from the historical average.

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

- **Standardized Precipitation Index (SPI):** Characterizes the probability of precipitation using a normal distribution transformation. - **Relative Moisture Index (MI):** Represents the balance between precipitation and potential evapotranspiration (PET).

$$MI = \frac{P - PET}{PET}$$

- **Meteorological Drought Composite Index (MCI):** Integrates multiple factors including weighted precipitation and relative humidity over various timescales.

$$MCI = a \times SPIW60 + b \times MI30 + c \times SPI90 + d \times SPI150$$

- **Relative Soil Moisture (R_{sm}):** Characterizes soil water status, specifically for the 0–20 cm layer.

$$R_{sm} = \frac{W_{sim} - W_{wilt}}{W_{fc} - W_{wilt}} \times 100\%$$

3. Results and Analysis

3.1 Applicability in Typical Drought Years Records indicate that 2017 and 2022 were typical drought years for Ordos. In 2017, drought conditions emerged in the central and southern regions, characterized by significantly lower

Figure 1

Figure 1: Figure 1

Figure 2

Figure 2: Figure 2

precipitation. The MI proved suitable for assessing drought conditions in May and June, while R_{sm} was more applicable for June and July. For the 2022 autumn drought, the assessment results of PA and SPI were more consistent with actual conditions.

3.2 Spatial and Temporal Correlation Spatial analysis indicates that MI and MCI exhibit higher Pearson correlation coefficients with the Normalized Difference Vegetation Index (NDVI). In regions with high grassland proportions, the spatial distribution of grassland and cropland coverage shows a significant correlation with PA, SPI, MI, and MCI (passing the 0.05 significance level test). However, because R_{sm} accounts for deeper soil moisture, its correlation with shallow-rooted plants was not significant. Temporally, drought conditions evaluated by MI and R_{sm} during the plant growing season (May to August) were most consistent with actual conditions.

3.3 Spatiotemporal Evolution (EOF Analysis) The EOF1 spatial pattern indicates that R_{sm} provides the optimal drought assessment. The southwestern and localized eastern regions experienced drought from 2002 to 2009, a humid period from 2010 to 2013, and a return to drought from 2014 to 2022. This aligns with the actual vegetation distribution in Ordos. The EOF2 pattern reveals a spatial distribution where the central region and its surrounding areas undergo alternating wet and dry cycles approximately every 2 to 3 years.

4. Conclusion

The integration of multi-source data provides a comprehensive reflection of farmland conditions. While traditional indices like SPI offer multi-scalar advantages, the composite MCI and soil-based R_{sm} provide higher accuracy for agricultural monitoring in the arid and semi-arid transition zones of Ordos. These findings provide a scientific foundation for drought monitoring, early warning systems, and water resource management in the region.

Figures

Source: ChinaXiv —Machine translation. Verify with original.