Drought Assessment Based on Drought Index and Principal Component Analysis: A Case Study of the Xilin River Basin (Postprint)

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Abstract

Using monthly meteorological data from the Xilin River Basin, this study analyzed interannual extreme variations in precipitation and temperature; calculated the Standardized Precipitation Index (SPI) and Comprehensive Meteorological Drought Index (CI) to characterize drought conditions in the study area; and employed principal component analysis to evaluate drought conditions in the Xilin River Basin. The results indicate that from 1981 to 2016, maximum temperature exhibited a weak increasing trend while minimum temperature remained essentially stable. Maximum precipitation showed a decreasing trend, and monthly minimum precipitation essentially approached zero. The CI index revealed that only light drought events occurred during the 36-year period, with the highest frequency in spring, followed by autumn, and the lowest in summer. The SPI index indicated that events of severe flood, moderate flood, light flood, severe drought, moderate drought, and light drought occurred during the 36-year period, with higher hazard levels associated with lower probabilities of occurrence; drought and flood events in winter mostly had relatively high hazard levels. Principal component analysis results showed that the first principal component of meteorological factors primarily reflected the impact of water stress on drought, the second principal component primarily reflected the impact of sunshine on drought, and the third principal component primarily reflected the impact of temperature on drought. Comprehensive score results indicated that the ranking of drought conditions across locations was: Zhalute Banner > Balin Left Banner > Wengniute Banner > Duolun County > Huade County > West Ujimqin Banner > Xilinhot City > Linxi County > East Ujimqin Banner > Zhurihe > Abaga Banner > Erenhot City > Sonid Left Banner.

Full Text

Drought Characteristics of the Xilin River Basin Based on Meteorological Drought Indices

Abstract: Monthly meteorological data from the Xilin River Basin were used to analyze annual variations in precipitation and temperature within the study area. The Standardized Precipitation Index (SPI) and Comprehensive Meteorological Drought Index (CI) were calculated to characterize drought conditions. Principal component analysis was applied to evaluate drought conditions in the Xilin River Basin. Results showed that maximum temperature increased slightly over the 36-year period, while minimum temperature showed no substantial change. The maximum precipitation trend decreased, and the monthly minimum precipitation trend was basically zero. The CI index indicated that only light drought events occurred during the 36 years, with the highest frequency in spring, followed by fall, and the lowest in summer. The SPI index revealed varying drought and flood levels across the years, with higher disaster degrees corresponding to lower occurrence probabilities. In winter, the disaster level of drought and flood events was relatively high. Principal component analysis results showed that the first principal component of meteorological factors in the study area mainly reflected the impact of water stress on drought conditions, the second principal component mainly reflected the effect of sunshine on drought conditions, and the third principal component mainly reflected the effect of temperature on drought conditions. Comprehensive scores indicated that drought severity across various locations followed the order: Zaruq > Bahrain Left Banner > Wengniute Banner > Duolun County > Huade > West Wuzhumuqin > Xilinhot > Linxi County > East Wuzhumuqin > Zhurihe > Abaga Banner > Erlianhaote > Sunit Left Banner.

1.2.2 Comprehensive Meteorological Drought Index (CI)

The Comprehensive Meteorological Drought Index (CI) was calculated using 30-day and 90-day precipitation scales. The 30-day scale reflects short-term water conditions, while the 90-day scale reflects longer-term water availability. The index is computed as:

$$A = 6.75 \times 10^{-7} H^3 - 7.71 \times 10^{-5} H^2 + 1.792 \times 10^{-2} H + 0.49$$

where H represents altitude. The CI values were calculated for each meteorological station, with negative values indicating drought conditions.

1.2.3 Standardized Precipitation Index (SPI)

The Standardized Precipitation Index (SPI) was calculated using the Pearson Type III distribution to fit precipitation data. The calculation involves transforming the precipitation time series into a normal distribution. SPI values were computed for multiple timescales (1, 3, 6, and 12 months) to capture different drought characteristics. The index classification follows standard categories where negative values indicate drought and positive values indicate wet conditions.

2.1.1 Temperature and Precipitation Correlation

Tab. 4 Correlation between temperature and precipitation

The correlation analysis revealed significant negative correlations between temperature and precipitation at several stations. The strongest correlations were observed at Station 7 ($r = -0.669^{**}$) and Station 3 ($r = -0.582^{**}$), indicating that higher temperatures were associated with lower precipitation. The analysis covered the period 1981-2016, with particular attention to extreme years such as 1984, 1991, 1992, and 1998, which exhibited notable drought characteristics.

2.1.2 Drought Characteristics

During 1981-2016, drought events showed distinct temporal patterns. The CI index identified drought periods primarily in 1983-1992 and 1999-2011. The SPI index revealed that extreme drought events occurred in 2002 and 2016, with moderate events in 1984 and 1998. Seasonal analysis indicated that spring droughts were most severe, affecting 45.5% of the region, followed by autumn droughts at 33.3%. Summer showed the lowest drought frequency at 25%.

2.2 Principal Component Analysis

Tab. 5 Characteristic roots and cumulative contribution rates

Principal component analysis extracted three main components explaining 98.585% of the variance. The first component accounted for 43.482% of variance, the second for 31.523%, and the third for 23.579%. The eigenvalues were 2.609, 1.891, and 1.415 respectively, all exceeding 1.0, confirming their significance.

Tab. 6 Factor load matrix

The factor loadings revealed that: - The first principal component loaded heavily on precipitation variables (0.718-0.866), representing water stress effects - The second component loaded on sunshine duration (0.916), representing radiation effects - The third component loaded on temperature variables (0.508-0.768), representing thermal effects

[Figure 3: see original paper]

Fig. 3 Seasonal change of the CI index

[Figure 4: see original paper]

Fig. 4 Seasonal variation of the SPI index

[Figure 5: see original paper]

Fig. 5 Characteristic roots and cumulative contribution rates

[Figure 6: see original paper]

Fig. 6 Factor load matrix

[Figure 7: see original paper]

Fig. 7 Comprehensive drought assessment

The comprehensive assessment integrating CI and SPI indices showed that the most severe drought conditions occurred in Zaruq and Bahrain Left Banner, while Sunit Left Banner and Erlianhaote experienced relatively milder conditions. The spatial pattern reflected the gradient from arid western regions to slightly more humid eastern areas.

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