Postprint of Drought Hazard Assessment in Inner Mongolia Based on the SPEIbase v.2.6 Dataset

Authors: Jin Ling

Date: 2022-06-07T00:00:00+00:00

Abstract

To clarify the distribution characteristics of drought disaster risk at different temporal scales in Inner Mongolia, the SPEIbase v.2.6 dataset for Inner Mongolia from 1949 to 2018 was selected, Theil-Sen trend analysis and Mann-Kendall test were employed to analyze the spatiotemporal evolution characteristics of meteorological drought, and based on the multi-year average drought intensity and a weighted comprehensive evaluation model, drought disaster risk at annual and seasonal scales in the study area was evaluated. The results indicate that: both in terms of interannual variation and spatial distribution, the climate of Inner Mongolia at the annual scale and the three seasonal scales of spring, summer, and autumn exhibits a significant drying trend; the study area is dominated by medium and above levels of annual-scale drought disaster risk, accounting for 71% of the total area. Specifically, high and very high risk areas are mainly located in Hulunbuir City and eastern Xilingol League; during spring and summer, the spatial distribution of drought disaster risk in Inner Mongolia shows a "high in the north, low in the south" pattern, with high-level risk primarily located in the Xilingol Grassland and Alxa League, which is situated in an arid region; high-risk areas are significantly reduced in autumn and winter, especially in winter, which is characterized by low and very low risk in the northeastern region, consistent with the characteristics of drought trend changes. The research results can provide a reference basis for drought disaster risk management in Inner Mongolia.

Full Text

Evaluation of Drought Hazards in Inner Mongolia Based on SPEIbase v.2.6 Dataset

JIN Ling[1], WANG Yongfang[1,2,3], GUO Enliang[1,2], LIU Guixiang[3], BAO Yulong[1,2]

[1]College of Geographical Science, Inner Mongolia Normal University, Hohhot 010022, Inner Mongolia, China
[2]Inner Mongolia Key Laboratory of Disaster and Ecological Security on the Mongolian Plateau, Hohhot 010022, Inner Mongolia, China
[3]Grassland Research Institute, Chinese Academy of Agricultural Sciences, Hohhot 010010, Inner Mongolia, China

Abstract

To clarify the distribution characteristics of drought hazards across different timescales in Inner Mongolia, this study utilized the SPEIbase v.2.6 dataset for the region. Theil-Sen trend analysis and Mann-Kendall test methods were employed to analyze spatiotemporal evolution characteristics of meteorological drought. Based on the multi-year average intensity of drought and a weighted comprehensive evaluation model, drought hazards were assessed at annual and seasonal scales. The results demonstrate that both interannually and spatially, the climate of Inner Mongolia shows a significant drying trend at annual and seasonal (spring, summer, autumn) scales. The study area is dominated by medium and above-grade annual-scale drought hazards, accounting for 71% of the total area. High and extremely high hazard areas are primarily located in Hulunbuir City and eastern Xilingol League. During spring and summer, the spatial distribution of drought hazard exhibits a "north-high, south-low" pattern, with high-grade hazards concentrated in the Xilingol grasslands and Alxa League in the arid zone. In autumn and winter, high-grade hazard areas decrease significantly, particularly in winter, which is characterized by low and extremely low hazards in the northeastern region—consistent with the characteristics of drought trend changes. These findings provide a scientific reference for drought disaster risk management in Inner Mongolia.

Keywords: Inner Mongolia; Standardized Precipitation Evapotranspiration Index (SPEI); drought; spatiotemporal characteristics; hazard assessment

---

Introduction

Global climate warming represents the most significant and severe environmental challenge humanity has faced to date, attracting widespread attention from governments and the public worldwide as one of the most complex challenges confronting human society. The Intergovernmental Panel on Climate Change (IPCC) reports that global surface temperatures have risen approximately 1.5°C above pre-industrial levels, with projections indicating this increase will reach or exceed 2°C. China is among the countries most severely affected by drought disasters globally, with high frequency, long duration, and extensive impact areas that have become critical constraints on economic development and social progress. Annual drought-related losses in China reach 9.10$\times10^{9}$ yuan, seriously threatening sustainable socioeconomic development and ecological civilization construction.

The role of disaster risk management in disaster prevention and mitigation has become increasingly prominent, with drought hazard assessment as its core component, providing comprehensive characterization of drought disaster intensity. Current drought hazard assessment methods primarily construct probability distribution functions based on drought frequency, intensity, and coefficient of variation to estimate exceedance probabilities of different disaster levels. For example, Zhang et al. analyzed spatiotemporal distribution patterns of drought disasters during different developmental stages of winter wheat in North China using phenological, meteorological, and yield data. Fei et al. employed precipitation anomaly percentage as a meteorological drought indicator to identify drought processes through monthly precipitation data, analyzing spatiotemporal distribution characteristics of drought hazards in China over the past 50 years. Tan et al. utilized the Standardized Precipitation Evapotranspiration Index (SPEI) to analyze meteorological drought characteristics in Ningxia, constructing a weighted comprehensive evaluation model based on five drought severity levels to assess drought-causing hazards.

However, existing drought hazard research has primarily focused on agricultural drought, with relatively few studies on grassland drought hazards. As one of China' s four major grassland regions, Inner Mongolia serves as an important base for agricultural and livestock product processing, a major grain production area, and a crucial ecological barrier in northern China. Nevertheless, as a typical arid and semi-arid region highly sensitive to global climate change, Inner Mongolia has experienced fluctuating precipitation decline and temperature increases of 0.52°C per decade, with frequent drought disasters, increasingly acute contradictions between forage and livestock, and increasingly severe grassland degradation, desertification, and salinization, causing significant impacts on the ecological environment and the production and livelihood of farmers and herders. The drought situation in Inner Mongolia is extremely severe, making disaster prevention work particularly urgent. However, current research on Inner Mongolia has predominantly focused on drought monitoring and its impact assessment on vegetation, with few studies conducting large-scale grassland drought hazard assessments from a disaster risk science perspective. Therefore, this study comprehensively considers precipitation and evapotranspiration, selecting grid-scale SPEI as a drought monitoring indicator to analyze spatiotemporal evolution characteristics of drought in Inner Mongolia. Combined with multi-year average intensity of different drought grades and using a weighted comprehensive evaluation model, this study provides a comprehensive assessment of drought hazards in Inner Mongolia to offer theoretical support for regional drought risk management.

1.1 Study Area Overview

Inner Mongolia Autonomous Region is located in the mid-latitude inland area of East Asia, geographically positioned between 97°12 –126°04 E and 37°24 – 53°23 N, spanning northwestern, northern, and northeastern China. The terrain transitions from plains and mountains in the northeast to plateaus in the southwest, alternating in arrangement and influencing atmospheric circulation and redistribution of surface water and heat conditions, thereby affecting vegetation development and distribution and ultimately forming unique natural conditions and resources. The region extends approximately 1,700 km from east to west and 2,400 km from north to south, bordering eight provinces and regions. Except for the northern section of the Greater Khingan Mountains, which has a cold temperate continental monsoon climate, the remaining areas have a temperate continental monsoon climate. The entire region is controlled by the Mongolian high-pressure system, with long, cold winters and short, hot summers influenced by the southeastern oceanic warm air mass. Spring temperatures rise rapidly, while autumn temperatures drop sharply. Annual sunshine hours range from 2,500 to 3,400 hours; annual precipitation ranges from 100–500 mm and is concentrated in summer, decreasing gradually from east to west; the annual average temperature ranges from 0–8°C, increasing gradually from east to west. Evapotranspiration in Inner Mongolia is equivalent to 2–8 times the precipitation, reaching up to 20 times in some areas of Alxa League.

[Figure 1: see original paper]

1.2 Data Sources and Processing

This study employed the global gridded dataset SPEIbase v.2.6, a standardized precipitation evapotranspiration index dataset obtained from the Spanish National Research Council institutional repository (http://hdl.handle.net/10261/202305). The dataset has a temporal scale of 1–48 months, spatial resolution of 0.5°, and was published in 2017. Precipitation and temperature data in the calculation were sourced from the CRU TS V3.24.01 dataset, with potential evapotranspiration calculated using the FAO-56 Penman-Monteith formula. Using the boundary of Inner Mongolia Autonomous Region, monthly datasets for SPEI-12 (12-month scale) and SPEI-3 (3-month scale) were extracted, creating grids with pixel sizes of approximately 57 km, with format conversion performed, totaling 2,244 grid points.

SPEI-12 reflects annual drought conditions, while SPEI-3 values corresponding to March, June, September, and December reflect spring, summer, autumn, and winter drought conditions, respectively. Based on this, the study established a 70-year dataset reflecting seasonal and annual drought conditions from 1949–2018. According to the "Meteorological Drought Grade" standard (GB/T20481-2017), drought grades were classified into five levels (Table 1).

1.3.1 Theil-Sen Trend Analysis and Mann-Kendall Test

Theil-Sen trend analysis is a robust non-parametric calculation method used to determine trends in long time series data. The calculation formula is:

β = median((x_j - x_i)/(j - i)) for all i < j

where β is the slope; x_i and x_j are sequence values at times i and j, respectively; n is the sequence length. If $\beta > 0$, it indicates an upward trend; if $\beta < 0$, a downward trend; if $\beta = 0$, stability.

The Mann-Kendall (M-K) test is a rank-based non-parametric statistical method effective for testing sequence trends and diagnosing abrupt changes, widely applied in meteorological and hydrological sequence analysis. The calculation formulas are:

For time series SPEI_i (i = 1, 2, ···, n), construct the rank sequence S_k = Σ_{i=1}^k r_i where r_i = +1 when SPEI_i > SPEI_j (j = 1, 2, ···, i), otherwise r_i = 0. Define the statistic UF_k = [S_k - E(S_k)]/√Var(S_k), where E(S_k) = k(k+1)/4 and Var(S_k) = k(k-1)(2k+5)/72. UF_k is the forward statistic sequence. Given significance level α, if |UF_k| > U_α, the sequence shows a significant trend. By inverting the original time series and repeating the calculation, UB_k = -UF_k + 1 is obtained as the backward statistic sequence. Plotting UF_k and UB_k curves, if they intersect within critical lines y = $±$1.96, the intersection point indicates an abrupt change time.

1.3.2 Drought Hazard Assessment Model

This study used extracted grid data to calculate multi-year averages of different drought grades and applied a weighted comprehensive model to compute annual and seasonal drought hazard indices for Inner Mongolia. Based on the drought grade classification criteria in Table 1, years with light, moderate, severe, and extreme droughts were identified, and their corresponding SPEI values were averaged to obtain the multi-year average intensity for each drought grade. Weights were assigned and summed to obtain the hazard index for each grid point for the entire year and four seasons. The calculation formula is:

H_{ij} = Σ_{j=1}^4 (M_{ij} × W_j)

where H_{ij} is the drought hazard index (smaller values indicate greater hazard); i is the grid point index; j is the drought grade index; M_{ij} is the multi-year average intensity of drought grade j at grid point i; W_j is the weight for drought grade j. If a certain drought grade did not occur in a particular year, it was not included in the weighted synthesis, so n values range between 1-4.

The natural breaks classification method identifies inherent natural groupings in data to appropriately group similar values and maximize differences between classes. Due to Inner Mongolia' s large east-west span and significant regional differences in hazard index distribution, the natural breaks method is well-suited for mapping non-uniformly distributed data values. Therefore, this study used ArcGIS' s natural breaks method to classify hazard indices into five levels: extremely low, low, medium, high, and extremely high (Table 2).

2.1 SPEIbase v.2.6 Applicability Analysis

Although SPEIbase is a global gridded product dataset that has undergone validation during production, its capability to represent regional drought remains uncertain, necessitating applicability analysis to ensure research accuracy. Previous studies using SPEIbase v.2.4 with meteorological station data from Inner Mongolia showed correlation coefficients with observation-based SPEI values as high as 0.89, indicating good applicability. The SPEIbase v.2.6 dataset used in this study is an updated version providing higher precision and longer time series drought information. Therefore, SPEIbase v.2.6 demonstrates good applicability in representing drought spatiotemporal distribution and hazards in Inner Mongolia.

2.2.1 Drought Interannual Variation Characteristics

The interannual variation characteristics of SPEI-12 from 1949–2018 show an overall significant downward trend (β = -0.0222 $\cdot$ a^{-1}, P < 0.05), indicating significant climate drying in the study area. SPEI-12 ranged from -1.99 to 1.49, with maximum values in 1950 and minimum values in 1965. The 1950s–1970s had more positive SPEI-12 values, indicating relatively humid periods, while the 1980s showed obvious alternating positive and negative values with mainly light droughts. The 1990s experienced moderate droughts, and since 2000, SPEI-12 has shown a declining trend with significantly increased drought frequency and intensity, dominated by moderate droughts. The year 2007 experienced severe drought, marking the driest period in nearly 60 years in Inner Mongolia.

Seasonal drought interannual variations show different degrees of drying trends across all four seasons (Figure 3). Spring SPEI-3 showed a significant declining rate (-0.0216 $\cdot$ a^{-1}, P < 0.05), indicating significant spring drying, with values ranging from -1.88 to 1.87 and no significant abrupt change points. Summer showed similar characteristics with a significant downward trend (-0.0138 $\cdot$ a^{-1}, P < 0.05). Autumn showed a non-significant declining trend (-0.0106 $\cdot$ a^{-1}, P > 0.05), with fewer drought events mainly occurring after the 1990s. Winter showed a non-significant declining trend (-0.0029 $\cdot$ a^{-1}, P > 0.05), with relatively humid periods at the beginning and end of the study period and droughts mainly occurring in the 1960s–2000s. The 1990s was the most humid period.

[Figure 2: see original paper]
[Figure 3: see original paper]

2.2.2 Drought Trend Change Characteristics

Based on the SPEIbase v.2.6 dataset, Theil-Sen trend analysis calculated slope values for the study area from 1949–2018, with Mann-Kendall test determining significance levels (Table 3). Results show alternating positive and negative β values. All β values for SPEI-12 are negative, with 99.6% of grids passing the 0.05 significance test, indicating overall drought trends across the study area, with slopes gradually decreasing from central Inner Mongolia toward the northeast and southwest.

Spring drought trend distribution resembles annual drought patterns, with 99.6% of 2,244 grids showing negative β values, 77.6% significantly decreasing. Drying rates in central and western regions reached -0.024 to -0.036 $\cdot a^{-1}$, indicating significant spring drying across Inner Mongolia. Summer drought trends were milder than spring but still showed overall drying, with high-value areas including Xilingol League, Ulanqab City, Baotou City, and Bayannur City, gradually decreasing eastward and westward. Hulunbuir City, Alxa League, and Ordos City showed slight drying trends but mostly non-significant. Autumn had 1,446 grids showing decreasing trends, with 32.4% significantly decreasing, mainly concentrated in Xilingol League, Chifeng City, and Tongliao City with slopes of -0.018 to -0.024 $\cdot a^{-1}$. Most other areas showed non-significant drying trends. Winter drought showed an obvious east-west pattern, with 1,798 grids decreasing but few passing significance tests, mainly distributed in central-eastern and northeastern regions showing non-significant humid trends due to proximity to coastal monsoon areas where enhanced subtropical high pressure in winter facilitates moisture transport inland.

[Figure 4: see original paper]
[Figure 5: see original paper]

2.3 Drought Hazard Assessment in Inner Mongolia

Drought disaster occurrence involves both the variation of drought-causing factors themselves and their impact on socio-economic systems. Clarifying spatiotemporal evolution characteristics and systematically assessing drought hazards are crucial for effective drought prevention. Based on the hazard assessment model, spatial distribution maps of annual and seasonal drought hazard grades were obtained. Results show annual-scale drought hazards are dominated by medium grades, accounting for 71% of the study area. High and extremely high hazard areas (12.3% and 4.7% of total area, respectively) are distributed in Hulunbuir City and eastern Xilingol League due to high average intensities of severe and extreme droughts. Medium hazards are distributed across all leagues and cities, accounting for 54% of the total area. Low and extremely low hazards are mixed, accounting for 29% of the total area. The extremely low hazard area in the southwestern edge results from the absence of extreme drought events.

Due to high average intensities of severe and extreme droughts across regions in spring, medium and high hazard grades are widely distributed, accounting for 62.3% of the study area. Southern areas without extreme drought events belong to low and extremely low hazard categories. Notably, the Xilingol grasslands in central Inner Mongolia are high-hazard areas; since spring is the grass revival period when vegetation resistance is weakest, drought events significantly impact grass growth and development.

Summer hazard levels increase significantly, with high and extremely high hazard grades accounting for 16.3% of the area, concentrated in Xilingol grasslands and Alxa League. Low and extremely low hazard areas expand to 38.7% in northeastern and southeastern regions. Northeastern areas show east-west differences in hazard distribution, with higher indices in the east, including all hazard grades.

Autumn high and extremely high hazard areas decrease by 7.4% compared to summer, mainly concentrated in southern Tongliao City, Chifeng City, and western Alxa League. Central-western and northeastern regions consist of low and extremely low hazards, especially in the northern margin.

Winter low and extremely low hazard areas account for 78.1%, most significantly in eastern regions, consistent with humid trends in these areas. High and extremely high hazards decrease markedly, scattered sporadically at the region' s edges.

Overall, seasonal drought hazards are dominated by medium grades without obvious spatial patterns. Spring and summer show a "north-high, south-low" distribution pattern, while autumn and winter are characterized by expanded low and extremely low hazard areas in southern and northeastern regions.

[Figure 6: see original paper]
[Figure 7: see original paper]

3 Discussion

This study analyzed spatiotemporal variation characteristics of drought at different timescales in Inner Mongolia from 1949-2018. Results show a significant drying trend, consistent with Wu et al. but differing in seasonal interannual variations due to different indicators: Wu et al. used precipitation anomaly percentage while this study used SPEI, which incorporates potential evapotranspiration. Research indicates that increased evapotranspiration raises regional water demand, thereby intensifying drought. SPEI not only has multi-timescale advantages but also reveals drought formation mechanisms. This study also found significantly increased drought frequency and intensity in Inner Mongolia since the 21st century, consistent with Qin et al., though the latter used meteorological observation data while this study used spatial gridded product datasets, which are more efficient by eliminating complex calculation processes.

Using multi-year average intensity of different drought grades and a weighted comprehensive model, this study assessed drought hazards in Inner Mongolia. Results show high-hazard areas in central and western Inner Mongolia, with overall spatial patterns consistent with Zhao et al. and Zhang et al., who found "north-high, south-low" patterns in grassland pastoral areas. This model, using average intensities of different drought grades, is simple to calculate with easily obtainable data, enabling rapid post-disaster hazard assessment. However, its limitation lies in considering only drought intensity as a parameter. Future work will incorporate drought duration and other factors to optimize and improve the model' s comprehensive evaluation capability.

4 Conclusions

This study selected the SPEIbase v.2.6 dataset for Inner Mongolia Autonomous Region, analyzed spatiotemporal evolution characteristics of meteorological drought using Theil-Sen trend analysis and Mann-Kendall test, and comprehensively evaluated regional drought hazards through multi-year average intensity of different drought grades and a weighted comprehensive evaluation model. The main conclusions are:

1) **Interannual variation:** SPEI-12 shows a significant declining rate of -0.0222 $\cdot$ a^{-1} ($P < 0.05$), indicating significant climate drying, particularly after 2000 with gradually increasing drought frequency and intensity. Spring drought trends are most significant, followed by summer and autumn, while winter shows non-significant drying trends.

2) **Spatial patterns:** Annual and spring drought trend patterns are similar, dominated by significant decreasing trends gradually alleviating from central regions toward both sides. Summer drought slope high-value areas are mainly in central regions; autumn trends lean toward central-eastern areas; northeastern regions show non-significant humidification trends in winter.

3) **Hazard distribution:** The study area is dominated by medium hazard grades. Annual-scale high-hazard areas are located in Hulunbuir City and eastern Xilingol League. Spring and summer drought hazards show a "north-high, south-low" pattern, with summer high and extremely high hazard areas mainly in Xilingol grasslands and Alxa League. Autumn and winter are characterized by expanded low and extremely low hazard areas in southern and northeastern regions.

References

[1] IPCC. Climate change 2021: The physical science basis[M]. Cambridge: Cambridge University Press, 2021.

[2] Zhang Yujing, Wang Chunyi, Zhang Jiquan. Hazard analysis of drought disaster for winter wheat in north China[J]. Journal of Natural Disasters, 2014, 23(6): 183-192.

[3] Fei Zhenyu, Sun Hongwei, Jin Juliang, et al. Temporal and spatial patterns of meteorological drought hazard in China for recent 50 years[J]. Water Resources and Power, 2014, 32(12): 5-10.

[4] Tan Chunping, Yang Jianping, Yang Yuan, et al. Spatial temporal variation

of drought hazard in Ningxia Hui Autonomous Region, China[J]. Journal of Catastrophology, 2015, 30(2): 89-93.

[5] Wu Yingjie, Gui Yang. Drought characteristics in Inner Mongolia based on anomaly percentage[J]. Arid Zone Research, 2019, 36(4): 943-952.

[6] Yang Shuchang, Yang Hengshan. Drought evolution and vegetation response in Inner Mongolia from 1982 to 2013[J]. Journal of Natural Disasters, 2019, 28(1): 175-183.

[7] Zhang Cunhou, Zhang Li, Wu Yingjie, et al. Assessment on the integrated drought disaster risk in Inner Mongolia grassland[J]. Journal of Arid Land Resources and Environment, 2019, 33(7): 115-121.

[8] Wang Y F, Liu G X, Guo E L. Spatial distribution and temporal variation of drought in Inner Mongolia during 1901–2014 using standardized precipitation evapotranspiration index[J]. Science of the Total Environment, 2019, 654: 850-862.

[9] Vicente Serrano S M, Beguería S, López Moreno J I, et al. A new global 0.5° gridded dataset (1901–2006) of a multiscalar drought index: Comparison with current drought index datasets based on the Palmer drought severity index[J]. Journal of Hydrometeorology, 2010, 11(4): 1033-1043.

[10] GBT20481-2017. Meteorological drought grade[S]. Beijing: China Standard Press, 2006.

[11] Zhao Jiaqi, Zhang Qiang, Zhu Xiudi, et al. Quantitative assessment of drought risk in China[J]. Acta Ecologica Sinica, 2021, 41(3): 1021-1031.

[12] Tong Siqin. Spatio-temporal variations and prediction of meteorological drought in Inner Mongolia under climate change[D]. Changchun: Northeast Normal University, 2019.

[13] Si Wenyang, Zhang Mingjun, Liu Puxing. Spatial and temporal response differences to global warming hiatus of the thermophilic crops climate growth period in oases of China[J]. Arid Land Geography, 2020, 43(4): 899-908.

[14] Zhang Yin, Tuerxunbat Gulixian, Su Litan, et al. Spatial and temporal characteristics of climate change at different altitudes in Xinjiang in the past 60 years[J]. Arid Land Geography, 2019, 42(4): 822-829.

[15] Zhao Tiesong, Wang Lirong, Guo Enliang, et al. Hazard assessment of precipitation events based on Copula function: Take the typical area of Ziya River Basin as an example[J]. Journal of Natural Disasters, 2020, 29(6): 199-208.

[16] Zhi Xun, Lin Zhongguan, Sha Li, et al. Agricultural drought hazard characteristics in southern Sichuan during 1989–2019[J]. Journal of Agriculture, 2020, 10(8): 78-82.

[17] Huang Hao, Zhang Bo, Ma Shangqian, et al. Temporal and spatial variations of meteorological drought and drought risk analysis in Hedong area of Gansu Province[J]. Chinese Journal of Agrometeorology, 2020, 41(7): 459-469.

[18] Chen Jiajin, Huang Chuanrong, Sun Chaofeng, et al. Disaster causing hazard division and evaluation of meteorological disasters for tea in Fujian Province[J]. Journal of Natural Disasters, 2018, 27(1): 198-207.

[19] Xiao Yang, Zhou Xu, Luo Xue, et al. Spatiotemporal variation characteristics of potential evapotranspiration and identification of leading factors in central Guizhou in recent 60 years[J]. Research of Soil and Water Conservation, 2021, 28(6): 1-9.

[20] Ma Kai, Xu Yuxia, Fang Feng. Study on temperature and precipitation change characteristics of ant forest plantation in Ordos City from 1959 to 2018[J]. Journal of Water Resources and Water Engineering, 2019, 30(6): 109-115.

[21] Ning Zhongrui, Zhang Jianyun, Wang Guoqing. Variation and global pattern of major meteorological elements during 1948–2016[J]. China Environmental Science, 2021, 41(9): 4085-4095.

[22] Wang Jufeng, He Liang, Lu Shaojuan, et al. Photosynthetic vegetation cover response to precipitation on the Inner Mongolian steppe[J]. Acta Ecologica Sinica, 2020, 40(16): 5620-5629.

[23] Dai Haiyan, Li Dan, Na Risu, et al. Dry and wet environment evolution and climatic background analysis of regional ecological construction in Inner Mongolia[J]. Arid Land Geography, 2019, 42(4): 745-752.

[24] Zhang Siyuan, Nie Ying, Zhang Haiyan, et al. Spatiotemporal variation of vegetation NDVI and its driving forces in Inner Mongolia based on geodetector[J]. Acta Agrestia Sinica, 2020, 28(5): 1460-1472.

[25] Li Wenlong, Kuang Wenhui, Lü Jun, et al. Adaptive evolution mechanism of rural human-land system in farming-pastoral areas of northern China[J]. Acta Geographica Sinica, 2021, 76(2): 487-502.

[26] Guo Ting, Xue Biao, Zhou Yanming, et al. Current status and enlightenment of production and trade of forage production in China[J]. Acta Agrestia Sinica, 2019, 27(1): 8-14.

[27] Liu Xiaoyuan, Liu Xisheng. Variation characteristics and cause analysis of wetland area in Qinghai Province[J]. Yellow River, 2021, 43(8): 90-95.

[28] Li Naiqiang, Xu Liwei, Wang Wenjun, et al. Grid analysis of land use based on natural breaks (jenks) classification[J]. Bulletin of Surveying and Mapping, 2020(4): 106-110, 156.

[29] Lu Yu, Xiang Ping, Yu Liang. Agglomeration and spatial dependence of organic agriculture in China[J]. Chinese Journal of Eco-Agriculture, 2021, 29(3): 440-452.

[30] Thornthwaite C W. An approach toward a rational classification of climate[J]. Soil Science, 1948, 66(1): 77.

[31] Tan Yi. Comprehensive drought monitoring based on SPEI and TVDI in Inner Mongolia, China[D]. Chengdu: Chengdu University of Technology, 2020.

[32] Xie Huijun, Zhang Tingbin, Yi Guihua, et al. Dynamic characteristics of NDVI values and its response to climatic factors in western Sichuan Plateau[J]. Bulletin of Soil and Water Conservation, 2020, 40(4): 286-294.

[33] Zhi Xun, Sha Li, Li Shi, et al. Analysis on evolution characteristics of agricultural drought risk in Yibin City[J]. Modern Agricultural Science and Technology, 2019(19): 191-193, 195.

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