Evolution of Spatiotemporal Patterns of Land Desertification Sensitivity in the Hulunbuir Grassland, 2001–2020: A Postprint

Authors: Do not Jisguleng, Narisu, Lina, Silver Mountain, Wuyundalai, Mingxing Li, Lai Shaojie

Date: 2025-05-14T13:23:24+00:00

Abstract

Desertification is one of the most severe environmental problems impacting human society. Investigating the spatiotemporal dynamics of desertification sensitivity and identifying its driving factors are critical for effective desertification prevention and control. Based on the Mediterranean Desertification and Land Use (MEDALUS) model, this study employs GIS spatial analysis, Geodetector, and other methods to construct a desertification sensitivity assessment model integrating multiple natural and anthropogenic factors, thereby revealing the spatiotemporal evolution patterns and driving mechanisms of desertification sensitivity in the Hulunbuir Grassland. The results indicate that: (1) During 2001–2020, the desertification sensitivity level in the Hulunbuir Grassland exhibited a decreasing-increasing-decreasing trend, specifically declining from 2001 to 2010, rising from 2010 to 2015, and declining again from 2015 to 2020. (2) Spatially, desertification sensitivity decreased from west to east, with sequential distributions of extremely high, high, moderate, low, and non-sensitive zones. (3) Climate, vegetation, and soil factors exerted the strongest influence on desertification sensitivity, followed by human disturbance factors, while topographic factors had the weakest effect; moreover, interactions between any two factors were stronger than individual factor effects. These findings can inform desertification prevention and control strategies in the Hulunbuir Grassland.

Full Text

Spatiotemporal Pattern Evolution of Land Desertification Sensitivity in Hulun Buir Grassland from 2001 to 2020

Wujisiguleng[1], Narisu[1], Li Na[2], Yin Shan[1], Wuyundalai[1], Li Mingxing[1], Lai Shaojie[1]

[1]College of Geographical Sciences, Inner Mongolia Normal University, Hohhot 010022, Inner Mongolia, China
[2]College of Economic and Trading Management, Inner Mongolia Normal University, Hohhot 010022, Inner Mongolia, China

Abstract: Desertification is one of the most severe environmental problems affecting human society. Investigating the spatiotemporal changes in desertification sensitivity and revealing its driving factors are critical for effective desertification prevention and control. Based on the MEDALUS (Mediterranean Desertification and Land Use) model, this study employs GIS spatial analysis, geographic detectors, and other methods to construct a desertification sensitivity assessment model by integrating multiple natural and human activity factors. The model reveals the spatiotemporal evolution patterns and driving mechanisms of desertification sensitivity in the Hulun Buir grassland. The results indicate that: (1) From 2001 to 2020, the degree of desertification sensitivity in the Hulun Buir grassland showed a declining trend, with a decrease from 2001 to 2010, followed by another decline after 2015. (2) Spatially, the degree of desertification sensitivity decreased from west to east across the Hulun Buir grassland, with distributions of extreme, high, moderate, mild, and insensitive zones in sequence. (3) Climate, vegetation, and soil factors exert the greatest influence on desertification sensitivity, followed by human disturbance factors, while topographic factors have the lowest impact. Moreover, the interaction between any two factors is greater than that of single factors. These findings can provide valuable references for desertification prevention and strategy formulation in the Hulun Buir grassland.

Keywords: desertification sensitivity; MEDALUS model; geographic detector; Hulun Buir grassland

---

1. Introduction

Under the influence of climate change and human activities, land desertification has become increasingly severe, emerging as a globally significant ecological and environmental issue. Currently, over 20% of the global population is affected by desertification, with more than 100 countries and regions experiencing varying degrees of desertification. China is one of the countries most severely impacted by desertification worldwide. According to the sixth national survey on desertification and sandification, China's desertified land area reached 2.6113 million km^2 in 2019, accounting for 27.2% of its total land area.

Desertification (sandy desertification) represents a typical characteristic of land degradation processes in extremely arid, arid, semi-arid, and partially semi-humid regions. Land desertification sensitivity refers to the degree of land degradation vulnerability in arid, semi-arid, and sub-humid regions caused by multiple factors including climate change and human activities. Domestic research on desertification sensitivity originated from ecological environmental sensitivity evaluation, with current studies predominantly adopting the "Pressure-State-Response" analytical framework and employing methods such as the Analytic Hierarchy Process (AHP) and the MEDALUS model to select different types of indicators for research across various temporal and spatial scales.

The MEDALUS model serves as an important tool for assessing land degradation and desertification processes. By integrating basic data related to soil, climate, vegetation, and management quality factors, the model analyzes desertification sensitivity levels. Its flexible framework and parameters can be revised according to the natural and human environmental characteristics of the study area, making it applicable across broad spatial environments. Desertification sensitivity is a crucial component of desertification monitoring, representing the outcome of interactions among a series of comprehensive factors. Therefore, this study constructs a desertification sensitivity index based on the MEDALUS model using geomorphology, soil, climate, vegetation, and human factors as indicators. The research aims to investigate the spatiotemporal evolution patterns and internal driving mechanisms of desertification sensitivity in the Hulun Buir grassland, providing theoretical foundations for desertification prevention and environmental improvement.

1.1 Study Area Overview

The Hulun Buir grassland (47°25 –49°33 N, 115°31 –121°09 E) is located in Hulun Buir City, Inner Mongolia Autonomous Region, administratively including Manzhouli City, Hailar District, Ewenki Autonomous Banner, Chen Barag Banner, New Barag Right Banner, and New Barag Left Banner, with elevations ranging from 451 to 1582 m. The region features a temperate semi-humid continental monsoon climate with cold, dry winters and hot, rainy summers. The annual average temperature ranges from -1.5°C to -0.2°C, with maximum temperatures reaching 35–38°C. Annual precipitation decreases from east to west, averaging 295.25 mm, concentrated in summer and autumn. The area enjoys abundant sunshine, concurrent heat and rainfall, and average wind speeds exceeding 4 $\mathrm{m \cdot s^{-1}}$.

The dominant plant species in the eastern Hulun Buir grassland include Stipa baicalensis, Leymus chinensis, Filifolium sibiricum, and Cleistogenes squarrosa, while the western region is dominated by rhizomatous and tufted grasses, particularly Leymus chinensis, Stipa grandis, and Stipa krylovii. Soil types are primarily composed of chernozem, dark brown forest soil, and dark meadow soil.

1.2 Data Sources and Processing

All data sources and spatial resolutions for this study are listed in Table 1. All data were processed using ArcGIS 10.8, including clipping, resampling to 1 km resolution, projection, and reclassification. Among these, slope aspect, drought resistance, and land use types were reclassified based on relevant literature and the natural conditions of the study area, while other factors were reclassified using the natural breaks method.

Table 1 Data sources of land desertification sensitivity assessment in Hulun Buir grassland

Data Type	Source	Spatial Resolution
Digital Elevation Model (DEM)	Geospatial Data Cloud Platform (https://www.gscloud.cn)	30 m
Soil erosion data	Chinese Academy of Sciences Resource and Environmental Science Data Center (https://www.resdc.cn)	1 km
Soil texture spatial distribution data	Chinese Academy of Sciences Resource and Environmental Science Data Center (https://www.resdc.cn)	1 km
1:1 million vegetation type spatial distribution data	Chinese Academy of Sciences Resource and Environmental Science Data Center (https://www.resdc.cn)	1 km
NDVI factor data	Chinese Academy of Sciences Resource and Environmental Science Data Center (https://www.resdc.cn)	1 km

Data Type	Source	Spatial Resolution
Soil dataset	National Tibetan Plateau Scientific Data Center (https://data.tpdc.ac.cn)	1 km
Surface soil moisture data	Spatiotemporal Three Poles Environment Big Data Platform (https://poles.tpdc.ac.cn/)	0.1°$×$0.1°
Net Primary Productivity (NPP) data	European Centre for Medium-Range Weather Forecasts (https://cds.climate.copernicus.eu/)	1 km
Land cover type product data	NASA (http://ladsweb.nascom.nasa.gov/)	1 km
Population density data	WorldPop (https://hub.worldpop.org)	1 km

1.3 Methods

1.3.1 Background Element Quality Index This study includes five single background elements: Terrain Quality Index (GQI), Soil Quality Index (SQI), Climate Quality Index (CQI), Vegetation Quality Index (VQI), and Anthropogenic Disturbance Quality Index (AQI).

- **Terrain Quality Index** uses slope and aspect factors, where slope represents the inclination degree of the surface, and aspect indicates the direction of inclination from high to low.
- **Soil Quality Index** incorporates soil erosion, sand content, organic matter content, and soil moisture factors. Soil erosion is the process of destruction, detachment, transport, and deposition under external forces. Higher sand content results in coarser particles, faster infiltration, and poorer water retention. Soil organic matter includes all carbon-containing organic materials in various forms, including plant and animal residues, microorganisms, and their decomposition and synthesis products. Soil moisture is the primary source of water for plants.
- **Climate Quality Index** includes annual average temperature and annual precipitation factors, where temperature reflects overall heat conditions,

and precipitation represents the sum of monthly rainfall.

- **Vegetation Quality Index** uses NDVI, Net Primary Productivity (NPP), and drought resistance factors. NDVI is an important indicator of vegetation growth, while NPP is a key factor in terrestrial ecosystem response to global change and can measure ecosystem stability and sustainability.
- **Anthropogenic Disturbance Quality Index** includes population density and land use type factors. Population density is an important indicator measuring population distribution status, while land use type reflects land purpose and property characteristics.

Based on the natural and human characteristics of the study area, the natural breaks method was used to reclassify these indicators into different categories (Table 2). Higher classification levels contribute more to desertification sensitivity. The classification results were used to calculate single background quality indices using geometric mean calculations:

$$GQI = \sqrt{Slope \times Aspect}$$

$$SQI = \sqrt{SE \times Sand \times SOM \times SM}$$

$$CQI = \sqrt{TEM \times PRE}$$

$$VQI = \sqrt{NDVI \times NPP \times DR}$$

$$AQI = PD \times LU$$

where SE is soil erosion, $Sand$ is soil sand content, SOM is soil organic matter content, SM is surface soil moisture content, TEM is annual average temperature, PRE is annual precipitation, $NDVI$ is normalized difference vegetation index, NPP is vegetation net primary productivity, DR is drought resistance, PD is population density (people $\cdot$ km^{-2}), and LU is land use type.

1.3.2 Land Desertification Sensitivity Index The MEDALUS model is a representative method for desertification sensitivity assessment. Based on this method, this study used the raster calculator in ArcGIS 10.8 to calculate the geometric mean of the five quality indices (terrain, soil, climate, vegetation, and anthropogenic disturbance) to derive the Land Desertification Sensitivity Index (DESI). The natural breaks method was then applied to reclassify DESI into five categories: extreme sensitivity, high sensitivity, moderate sensitivity, mild sensitivity, and insensitive, to represent the sensitivity degree of Hulun Buir grassland to desertification (Table 3).

$$DESI = \sqrt{GQI \times SQI \times CQI \times VQI \times AQI}$$

Table 2 Classification of index factors of land desertification sensitivity index

Factor	Classification				
Terrain Quality					
Aspect	N, NE, E	SE, S, SW	W, NW	Flat	
Slope (°)	<3	3–8	8–15	15–25	>25
Soil Quality					
Soil erosion ($t \cdot km^{-2} \cdot yr^{-1}$)	<0.619	0.619–1.497	1.497–2.844	2.844–3.913	>3.913
Soil organic matter (%)	>2.448	2.448–3.913	1.293–2.448	<1.293	
Soil sand content (%)	10–48	30–63	>206.10	175.10–206.10	83.15–175.10
Surface soil moisture content (%)	<83.15				
Climate Quality					
Annual average temperature (°C)	<0.007	0.007–1.350	>1.350		
Annual precipitation (mm)	>489.176	406.949–489.176	321.886–406.949	<321.886	
Vegetation Quality					
NDVI	>0.700	0.517–0.700	0.243–0.517	<0.243	
NPP ($g\ C \cdot m^{-2}$)	>16495.6	3919.7–16495.6	2658.9–3919.7	<2658.9	
Drought resistance	Coniferous forest, broadleaf forest, shrub, swamp	Perennial herbaceous plants	Cropland, annual plants, others		

Factor	Classification				
Anthropogenic Disturbance					
Population density (people · km^{-2})	<364.070	364.070–1395.603	1395.603–3337.311	3337.311–7038.692	>7038.692
Land use type	Forest, forested grassland, shrub, permanent wetland, urban and built-up, permanent snow, water	Savanna, cropland	Grassland, barren land		

Table 3 Classification of desertification sensitivity index in Hulun Buir grassland

Sensitivity Level	Index Range
Insensitive	<1.589
Mild	1.589–2.016
Moderate	2.016–2.383
High	2.383–2.732
Extreme	>2.732

1.3.3 Geographic Detector The desertification process exhibits significant spatial differentiation characteristics under the influence of various interacting factors. Identifying and analyzing these spatial differentiation patterns and driving factors forms the foundation for desertification control. Geographic detector is a statistical method widely applied in natural, social, and environmental fields to detect spatial heterogeneity and explore multi-factor driving mechanisms. This study employed the factor detector and interaction detector modules in geographic detector to investigate the desertification sensitivity in Hulun Buir grassland.

The factor detection results use q-values to represent explanatory power and P-values to represent significance. Larger q-values indicate more significant spatial differentiation. Interaction detection identifies interactions between different risk factors, assessing whether their combined effect increases or decreases the explanatory power for dependent variable Y, or whether these factors influence Y independently.

A 5 km × 5 km fishnet was created to generate uniformly distributed sample points. After removing null values, 2,500 effective samples were used. Data for dependent and independent variables were collected for different years to conduct factor detection and interaction detection analyses, revealing the specific influence degrees of single factors and their interactions on desertification sensitivity.

The geographic detector formula is:

$$q = 1 - \frac{SSW}{SST}$$

$$SSW = \sum_{h=1}^{L} N_h \sigma_h^2$$

$$SST = N\sigma^2$$

where $h = 1, 2, \ldots, L$ represents strata of dependent variable Y or independent variable X; N_h and N are the numbers of units in stratum h and the entire region, respectively; σ_h^2 and σ^2 are the variances of dependent variable Y in stratum h and the entire region, respectively. The q-value ranges from [0, 1], with larger values indicating greater influence of the factor on desertification sensitivity.

2. Results and Analysis

2.1 Spatial Distribution Characteristics of Single Background Elements of Land Desertification Sensitivity

The spatial distribution of single background elements in 2020 is shown in Figure 2. High-value areas of terrain quality index are concentrated in the eastern forest-steppe ecotone, while medium and low-value areas are distributed in the meadow and typical steppe regions in central and western areas. The proportions of extreme, high, medium, and low grades are 1.2%, 18.8%, 45.3%, and 34.7%, respectively.

High-value areas of soil quality index are concentrated in lowland meadows and sandy regions in central and southwestern parts of the study area, while medium and low-value areas are in the eastern forest-steppe ecotone. Medium and low-value areas also appear around Hulun Lake and westward regions. The proportions of extreme, high, medium, and low grades are 2.1%, 22.4%, 41.6%, and 33.9%, respectively.

High-value areas of climate quality index are concentrated in central and western typical steppe regions, particularly high in the western area centered on Hulun Lake, while medium and low-value areas are in eastern meadow and forest-steppe ecotones. The proportions of extreme, high, medium, and low grades are 3.2%, 26.5%, 38.7%, and 31.6%, respectively.

High-value areas of vegetation quality index are concentrated in central and western typical steppe regions, particularly high in lowland meadows and sandy areas, while medium and low-value areas are in eastern meadow and forest-steppe ecotones. The proportions of extreme, high, medium, and low grades are 2.8%, 24.3%, 40.9%, and 32.0%, respectively.

High-value areas of anthropogenic disturbance quality index are concentrated in Manzhouli City and Hailar District, while medium and low-value areas cover the entire study area. The proportions of extreme and high grades are 2.1% and 21.4%, respectively, while medium and low grades account for 41.3% and 35.2%, respectively.

Figure 2 [Figure 2: see original paper] Spatial distributions of single background elements of land desertification sensitivity in Hulun Buir grassland in 2020

2.2 Temporal and Spatial Distribution Characteristics of Land Desertification Sensitivity

The spatial distribution of desertification sensitivity in the Hulun Buir grassland from 2001 to 2020 is shown in Figure 3, exhibiting a clear trend of low sensitivity in the east and high sensitivity in the west. Sensitivity gradually weakens eastward of the moderate sensitivity zone and strengthens westward. Low sensitivity areas (including insensitive and mild sensitivity) are mainly distributed in eastern Chen Barag Banner, Hailar District, eastern Ewenki Autonomous Banner, and southeastern New Barag Left Banner. High sensitivity areas (including high and extreme sensitivity) are mainly distributed in western Chen Barag Banner, western Hailar District, northwestern Ewenki Autonomous Banner, Manzhouli City, north-central New Barag Left Banner, and the entire New Barag Right Banner.

Although the area proportions of different sensitivity types varied across years, the high sensitivity area proportion in the Hulun Buir grassland showed a declining trend from 2001 to 2020. The total proportions of low sensitivity areas from 2001 to 2020 were 83.4%, 81.2%, 82.7%, and 83.1%, respectively, remaining relatively stable overall.

The centroid distribution and migration trajectory of desertification sensitivity indices in the Hulun Buir grassland from 2001 to 2020 are shown in Figure 4. The centroids are distributed from northeast to southwest in the order of insensitive, mild, moderate, high, and extreme sensitivity. Notable migration trends include: extreme sensitivity centroid migrated 16.3% southwestward; high sensitivity centroid migrated 6.961 km southwestward; moderate sensitivity centroid migrated 16.666 km westward; mild sensitivity centroid migrated 10.081 km southwestward; and insensitive centroid migrated 19.091 km southwestward from 2001 to 2005.

From 2005 to 2010, the centroids migrated south, west, southeast, southeast, and southwest by distances of 6.144 km, 5.297 km, 2.487 km, 19.091 km, and 14.021 km, respectively. From 2010 to 2015, they migrated northeast, southeast, northwest, northwest, and northeast by distances of 10.435 km, 31.089 km, 35.436 km, 18.782 km, and 10.563 km, respectively. From 2015 to 2020, they migrated southwest, northwest, southwest, northeast, and southwest by distances of 8.095 km, 38.810 km, 17.607 km, 5.223 km, and 18.635 km, respectively.

Figure 3 [Figure 3: see original paper] Spatial distributions of desertification sensitivity in Hulun Buir grassland

Figure 4 [Figure 4: see original paper] Distribution and migrations of gravity center of land desertification sensitivity

2.3 Conversion Characteristics of Land Desertification Sensitivity Types

The desertification sensitivity index in the Hulun Buir grassland from 2001 to 2020 exhibited a trend of initial decline, followed by increase, and then decline again, with 2010 and 2015 as key nodes showing significant phased changes. The changing area of sensitivity from 2001 to 2010 was 66,401 km^2, while from 2010 to 2015 it was 66,674 km^2, showing little difference. However, the desertification sensitivity index decreased by 1,642 from 2001 to 2010 and increased by 2,435 from 2010 to 2015.

From 2001 to 2010, the land in the Hulun Buir grassland showed a continuous declining trend in desertification sensitivity. Although the net area of sensitive regions decreased by 1,228 km^2, the desertification sensitivity index decreased by 1,642 due to reductions in extreme and high sensitivity areas. Extreme sensitivity decreased by 6,793 km^2 (net reduction of 207 km^2), mainly converting to high and moderate sensitivity with conversion areas of 6,653 km^2 and 140 km^2, respectively. High sensitivity decreased by 8,883 km^2 (increase of 205 km^2, net reduction of 8,678 km^2), mainly converting to moderate sensitivity with a conversion area of 7,199 km^2. Both mild and moderate sensitivity showed increasing trends, with net increases of 4,213 km^2 and 5,699 km^2, respectively.

From 2010 to 2015, the land showed an increasing trend in desertification sensitivity. Although the net area of sensitive regions decreased by 1,684 km^2, the desertification sensitivity index increased by 2,435 due to increases in extreme and high sensitivity areas. Extreme sensitivity showed the largest net increase of 6,586 km^2, mainly from moderate and high sensitivity with conversion areas of 6,653 km^2 and 140 km^2, respectively. High sensitivity decreased by 8,678 km^2 (increase of 8,396 km^2, net reduction of 282 km^2), mainly converting to extreme sensitivity with a conversion area of 6,604 km^2. Both mild and moderate sensitivity showed increasing trends with net increases of 723 km^2 and 8726 km^2, respectively.

From 2015 to 2020, the land again showed a continuous declining trend in desertification sensitivity. Although the net area of sensitive regions decreased by 1,066 km^2, the desertification sensitivity index decreased by 1,066 due to reductions in extreme sensitivity. Extreme sensitivity decreased by 7,557 km^2 (increase of 718 km^2, net reduction of 6,839 km^2), mainly converting to high and moderate sensitivity with conversion areas of 7,086 km^2 and 471 km^2, respectively. Both mild and moderate sensitivity showed increasing trends with net increases of 2,312 km^2 and 5,816 km^2, respectively.

Figure 5 [Figure 5: see original paper] Changes in the area of different types of desertification sensitivity from 2001 to 2020

Figure 6 [Figure 6: see original paper] Transition characteristics of different types of desertification sensitivity from 2001 to 2020

2.4 Analysis of Internal Driving Factors of Land Desertification Sensitivity

According to geographic detector factor detection results (Figure 7), the influence of single background elements on desertification sensitivity in 2001, ranked by q-value, was: climate quality index > vegetation quality index > soil quality index > anthropogenic disturbance quality index > terrain quality index. Although q-values changed, the importance ranking remained unchanged, indicating that desertification sensitivity in the Hulun Buir grassland is mainly influenced by climate and vegetation factors, followed by soil and anthropogenic disturbance factors, with terrain factors having the least influence.

In 2010, the ranking was: climate quality index > soil quality index > vegetation quality index > anthropogenic disturbance quality index > terrain quality index, indicating that climate and soil factors were dominant, followed by vegetation and anthropogenic disturbance factors, with terrain factors having minimal influence.

In 2015, the ranking was: vegetation quality index > anthropogenic disturbance quality index > soil quality index > climate quality index > terrain quality index, indicating that vegetation and anthropogenic disturbance factors were dominant, followed by soil and climate factors, with terrain factors having minimal influence.

In 2020, the ranking was: vegetation quality index > climate quality index > soil quality index > anthropogenic disturbance quality index > terrain quality index, indicating that vegetation and climate factors were dominant, followed by soil and anthropogenic disturbance factors, with terrain factors having minimal influence.

Interaction detection results (Figure 8) show that the interaction between any two single background elements had a greater impact on desertification sensitivity than individual elements alone, indicating that the evolution of desertification sensitivity in the Hulun Buir grassland is the result of combined effects from multiple factors. Higher interaction q-values indicate greater influence of the corresponding two-element combination on desertification sensitivity index.

Figure 7 [Figure 7: see original paper] Factor detection results of geodetector

Figure 8 [Figure 8: see original paper] Interaction detection results of geodetector

3. Discussion

3.1 Spatial Distribution Pattern of Land Desertification Sensitivity

The spatial distribution of each single background element shows significant regional differences. For instance, poor soil quality in southwestern New Barag Right Banner and central and northern New Barag Left Banner reflects the unique characteristics of sandy environments. The central and western parts of the study area receive less precipitation and have higher temperatures, resulting in poorer climate conditions. Vegetation types transition from forest-steppe and meadow-steppe in the central-eastern region to typical steppe in the west, with significantly reduced vegetation coverage and diversity, leading to increased vegetation quality index. Urbanization development in Hailar District and Manzhouli City has increased population density and caused irrational land resource utilization, resulting in increased anthropogenic disturbance quality index in these areas.

The degree of land desertification sensitivity shows a clear east-low, west-high trend, indicating varying vulnerability of grassland ecosystems across different geographic locations. Eastern forest-steppe ecotones and riverine areas have better vegetation cover and abundant water resources, providing stronger resistance to desertification and thus lower sensitivity. In contrast, western regions face higher sensitivity due to arid climate and sparse vegetation, making them more vulnerable to desertification threats.

Differences in migration directions of desertification sensitivity centroids across different years indicate that grassland ecosystem changes are influenced by multiple complex factors, including both natural and anthropogenic elements. During periods of decreasing sensitivity, extreme sensitivity centroids migrated southwestward, while during increasing sensitivity periods, centroids migrated northeastward. The total southwestward migration distance exceeded the northeastward distance, indicating a contraction trend of extreme sensitivity toward the southwest over the past 20 years. Although high sensitivity centroid migration showed multiple directions, the combined analysis of distance and direction still revealed a southwestward trend. Extreme migration phenomena occurred during specific periods, such as the large-distance migration of insensitive and extreme sensitivity centroids in 2005 and 2015, and the southwestward migration of extreme sensitivity centroids in 2010, all indicating local ecological environment changes.

3.2 Temporal Evolution Pattern of Land Desertification Sensitivity

From 2001 to 2020, the overall desertification sensitivity degree in the study area showed a declining trend, consistent with findings from other scholars. During this period, the desertification sensitivity index exhibited significant phased changes, with 2010 and 2015 as key nodes. From 2001 to 2010, the index experienced a declining phase, indicating grassland ecosystem recovery. However, under combined natural and anthropogenic factors, the index showed an upward trend from 2010 to 2015, indicating increased desertification pressure. After a period of fluctuation, the index decreased again from 2015 to 2020, suggesting gradual ecosystem recovery after challenges. Overall, the changing areas of desertification sensitivity from 2001 to 2010 (66,401 km^2) and 2010 to 2015 (66,674 km^2) were similar, indicating that despite local desertification intensification, the grassland ecosystem maintained certain balance and recovery capacity.

The desertification sensitivity index in 2020 (1.589) was lower than in 2001 (2.016), indicating enhanced resistance to desertification or effective containment of desertification trends. This improvement is associated with ecological protection policies implemented in recent years, such as grassland fencing, rational grazing, vegetation restoration projects, and climate change adaptation management strategies, which have improved the structure and function of grassland ecosystems and achieved certain success in desertification control.

3.3 Driving Mechanism of Land Desertification Sensitivity

Although q-values (quantified influence indicators) of various factors changed from 2001 to 2020, their importance ranking for desertification sensitivity in the Hulun Buir grassland remained relatively stable across most years. Climate factors were the most important influence in most years, as climate change (precipitation, temperature, etc.) directly affects vegetation growth and soil moisture, thereby influencing desertification processes. Vegetation factors were particularly important in 2015 and 2020, indicating that vegetation coverage and health are crucial for preventing desertification. Plant roots can fix soil and reduce erosion, representing key factors for maintaining grassland ecosystem stability. Soil factors also occupied important positions in multiple years, as soil quality directly affects vegetation growth and water retention capacity.

Anthropogenic disturbance and terrain factors had relatively smaller influence in most years but remain non-negligible. For example, overgrazing and excessive cultivation exacerbate desertification, while terrain factors indirectly affect desertification by influencing water distribution and soil erosion.

Interaction detection results show that the interaction between any two single background elements had a greater impact on desertification sensitivity than individual elements alone, highlighting the importance of multi-factor combined effects in changing desertification sensitivity degrees. Single-factor changes may be insufficient to significantly alter desertification sensitivity. Higher q-values indicate greater contributions from specific element combinations to land desertification sensitivity, helping identify which factor combinations have the highest impact.

4. Conclusions and Recommendations

4.1 Conclusions

1) The spatial distribution of single background elements in the Hulun Buir grassland shows significant differences, with desertification sensitivity exhibiting an east-low, west-high trend. Western regions are more vulnerable to desertification threats due to arid climate and sparse vegetation. The desertification sensitivity centroid is distributed from northeast to southwest with gradually increasing sensitivity degrees, and migration directions of centroids for equivalent sensitivity levels vary significantly across years.
2) From 2001 to 2020, although the area of sensitive regions showed no significant change, the overall desertification sensitivity index exhibited a decreasing trend, with 2010 and 2015 as key nodes showing significant phased changes.
3) Temporally, the importance ranking of single background elements for desertification sensitivity remained relatively stable. Climate was the dominant factor in most years, followed by vegetation and soil factors, then anthropogenic disturbance and terrain factors. Interactions among multiple factors had greater impact on desertification sensitivity than single factors.

4.2 Recommendations

Based on these findings, practical recommendations for desertification prevention and control include:

1) Implement regionally differentiated management strategies and dynamically adjust prevention strategies to adapt to changing ecological environments.
2) Strengthen long-term monitoring of desertification sensitivity, particularly focusing on areas with rising sensitivity indices, timely evaluate the effectiveness of ecological management measures, and adjust strategies based on evaluation results.
3) Adopt comprehensive management measures that consider multiple factors including vegetation, climate, soil, anthropogenic disturbance, and terrain.

References

[1] Gao Shangwu, Wang Baofang, Zhu Lingyi, et al. Monitoring and evaluation indicator system on sandy desertification of China[J]. Scientia Silvae Sinicae, 1998, 34(2): 1-10.

[2] Huan Qinzhi. Studying the scientific system of Xi Jinping's thought on ecological civilization: An analytical framework[J]. Journal of Fujian Normal University (Philosophy and Social Sciences Edition), 2022(6): 67-76, 169-170.

[3] Li Hua. Research on constructing my country's desertification control system guided by Xi Jinping's thoughts on ecological civilization[J]. Qinghai Environment, 2023, 33(3): 105-109.

[4] Zhang Tianqi, Yang Guang, Liu Feng, et al. Land use change and ecological service value of Hulun Buir Sandy Land from 2000 to 2020[J]. Bulletin of Soil and Water Conservation, 2021, 41(4): 331-349.

[5] Gao Yunsheng. A brief discussion on the impact of Hulun Buir Sandy Land management on the ecological environment[J]. Inner Mongolia Forestry Investigation and Design, 2013, 36(2): 41-42.

[6] Sun Shuanghong, Zhu Binbin, Chang Jincai, et al. Summary of comprehensive management in the sand area of Hulunbeir[J]. Journal of Grassland and Forage Science, 2021, 259(2): 79-82.

[7] Dai Ping, Ren Jingxia, Li Yanhui. Research on the countermeasures of grassland desertification in Inner Mongolia Autonomous Region[J]. Inner Mongolia Forestry Investigation and Design, 2016, 39(1): 135-137.

[8] Wang Tao, Zhu Zhenda. Study on sandy desertification in China: 1. Definition of sandy desertification and its connotation[J]. Journal of Desert Research, 2003, 23(3): 209-214.

[9] Zhang Sarilang, Wulantuya, Buhe, et al. Bibliometric analysis of land desertification research on the Mongolian Plateau in recent 40 years[J]. Arid Land Geography, 2023, 46(12): 1984-1994.

[10] Tong Liga, Ning Xiaoli, Zhang Jing, et al. Spatial-temporal variation and driving mechanism of desertification in Hunshandake (Otindag) Sandy Land in recent 30 years[J]. Arid Land Geography, 2021, 44(4): 992-1002.

[11] Chen Xieyang, Li Tongsheng, Zhu Xiaoqing, et al. Evaluation of land desertification sensitivity based on comparison and verification of actual investigation and observation interpretation: A case of Shaanxi Province[J]. Arid Land Geography, 2023, 46(11): 1813-1825.

[12] Ouyang Zhiyun, Wang Xiaoke, Miao Hong. China's eco-environmental sensitivity and its spatial heterogeneity[J]. Acta Ecologica Sinica, 2000, 20(1): 9-12.

[13] Tian Lu, Qiu Sijing, Peng Jian, et al. Desertification sensitivity evaluation in Inner Mongolia Autonomous Region based on PSR framework[J]. Progress in Geography, 2018, 37(12): 1682-1692.

[14] Narisu. Spatio-temporal variation characteristics of desertification in Hulunbeier Sandy Land[D]. Hohhot: Inner Mongolia Normal University, 2017.

[15] Li Chunli, Dong Jun, Wang Hongbin, et al. Profile distribution characteristics of humus components in chernozem soil under different land use types[J]. Journal of Northeast Forestry University, 2022, 50(8): 104-110.

[16] Jiang Xuhai, Han Ling, Bai Zongfan, et al. Analysis of the temporal and spatial evolution pattern and trend of desertification sensitivity in the Inner Mongolia Autonomous Region[J]. Acta Ecologica Sinica, 2023, 43(1): 364-378.

[17] Liu Yidan, Yao Xiaojun, Li Zongxing, et al. Impacts of climate change and land use/cover change on the net primary productivity of vegetation in Hexi Region, northwest China[J]. Arid Zone Research, 2024, 41(1): 169-180.

[18] Han Yiwen, Liu Jingyao, Zhang Fuguo, et al. Study on relationship between urban spatial expansion and living environment quality in Shanghai[J]. Environmental Protection Science, 2022, 48(5): 38-44, 68.

[19] Li Ke, Qi Zhong, Yu Xueqian, et al. Desertification monitoring and early warning in context of sandy land consolidation[J]. Transactions of the Chinese Society of Agricultural Engineering, 2017, 33(10): 271-277.

[20] Plaiklang S, Sutthivanich I, Sritarapipat T, et al. Desertification assessment using MEDALUS model in upper Lamchiengkrai Watershed, Thailand[J]. ISPRS International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 2020, XLIII-B3-2020: 1257-1262.

[21] Wu Yingying, Wang Zhenting. Desertification sensitivity assessment in the middle and lower reaches of the Shule River Basin[J]. Journal of Desert Research, 2022, 42(4): 163-171.

[22] Ren Yu, Zhang Bo, Chen Xidong. Desertification sensitivity assessment in Horqin Sandy Land[J]. Journal of Desert Research, 2023, 43(2): 159-169.

[23] Ogbue C, Igboeli E, Ajaero C, et al. Remote sensing analysis of desert sensitive areas using MEDALUS model and GIS in the Niger River Basin[J]. Ecological Indicators, 2024, 158: 1-17.

[24] Lee E J, Piao D F, Song C H, et al. Assessing environmentally sensitive land to desertification using MEDALUS method in Mongolia[J]. Forest Science and Technology, 2019, 15(4): 210-220.

[25] Wang Yuehui, Zhang Linbo, Guo Yang, et al. Analysis of spatiotemporal pattern and tendency of land desertification sensitivity in six provinces of China[J]. Research of Soil and Water Conservation, 2014, 21(5): 132-143.

[26] Hamad K O, Surucu A. Land degradation sensitivity and desertification risk in Harrir region, northern Iraq[J]. Heliyon, 2024, 5: 1-14.

[27] Gou F, Liang W, Sun S B, et al. Analysis of the desertification dynamics of sandy lands in northern China over the period 2000-2017[J]. Geocarto International, 2019, 36(17): 1938-1959.

[28] Li J C, Han L Y, Liu Y, et al. Insights on historical expansions of desertification in the Hunlun Buir and Horqin Deserts of northeast China[J]. Ecological Indicators, 2018, 85: 944-950.

[29] Guo Zecheng, Wei Wei, Shi Peiji, et al. Spatiotemporal changes of land desertification sensitivity in the arid region of northwest China[J]. Acta Geographica Sinica, 2020, 75(9): 1948-1965.

[30] Zhang Qian, Ai Likun. Adaptive governance and climate change: Case analysis of Inner Mongolia grassland and counterplan study[J]. Climate Change Research, 2018, 14(4): 411-422.

[31] Hong Haiyue. Analysis of characteristics of climate change in Hulun Buir grassland during 1970-2020[J]. Journal of Agricultural Catastrophology, 2021, 11(12): 84-87.

[32] Li Jiao, Zhang Chunlai, Li Qing, et al. Development of sandy desertification and driving forces in Hulun Buir Sandy Land in the past 15 years[J]. Journal of Beijing Normal University (Natural Science Edition), 2017, 53(3): 323-328.

[33] Shan Dan, Zhu Yuanjun, Liu Yanshu, et al. Differentiation of vegetation types and biodiversity in the southern edge of Hulun Buir[J]. Chinese Journal of Ecology, 2019, 38(3): 619-626.

[34] Turan D, Dengiz O, Özkan B. Spatial assessment and mapping of soil quality index for desertification in the semi-arid terrestrial ecosystem using MCDM in interval type-2 fuzzy environment[J]. Computers and Electronics in Agriculture, 2019, 164: 1-12.

[35] Uzunera Ç, Dengizb O. Desertification risk assessment in Turkey based on environmentally sensitive areas[J]. Ecological Indicators, 2020, 114: 1-12.

[36] Gou F, Liang W, Sun S B, et al. Analysis of the desertification dynamics of sandy lands in northern China over the period 2000-2017[J]. Geocarto International, 2019, 36(17): 1938-1959.

[37] Wan Qinqin, Pu Qiheng, Ding Guodong, et al. Analysis on the reason of sandy desertification in Hulun Buir steppe[J]. Research of Soil and Water Conservation, 2007, 14(4): 263-266.

[38] Su Qianxin, Li Jing, Li Zhiqiang, et al. Analyzing the coastline changes and its influencing factors in the Greater Bay Area from 1980 to 2020[J]. Journal of Tropical Oceanography, 2022, 41(4): 116-125.

[39] Liu Junhao, Zhou Haisheng, Guo Qun. The effects of desertification control on the patterns of vegetation in arid and semi-arid regions of northern China[J]. Journal of Desert Research, 2023, 43(5): 204-213.

[40] Fan Kaikai, Li Shuzhen, Chen Jinqiang, et al. Spatial heterogeneity analysis of soil respiration in Hulun Buir grassland[J]. Acta Agrestia Sinica, 2022, 30(1): 205-211.

[41] Li Shanjie, Luo Gang. Ecological environment analysis of Hulunbuir Sandy Land and its key areas[J]. Inner Mongolia Forestry Investigation and Design, 2022, 45(6): 1-4.

[42] Wang Guoxia, Li Man. The spatial interaction between inter-provincial migration and manufacturing industry transfer[J]. Scientia Geographica Sinica, 2019, 39(2): 183-194.

[43] Zhao Xiaofeng, Li Yaya, Zhao Yuntai, et al. Spatio-temporal differences and driving factors of land development degree in China based on geographical detector[J]. Resources and Environment in the Yangtze Basin, 2018, 27(11): 2426-2433.

[44] Ma Yong, Tong Yun, Ren Jie, et al. Spatial-temporal pattern and driving factors of public participation in environmental regulation: Taking the Yangtze River Economic Belt as an example[J]. Scientia Geographica Sinica, 2018, 38(11): 1799-1808.

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

Source: ChinaXiv — Machine translation. Verify with original.