# Dynamic Changes in Vegetation Cover and Their Driving Forces in the Aeolian Sand Influx Section of the Ulan Buh Desert into the Yellow River: Postprint

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## Abstract

Based on Landsat imagery data from 2001 to 2021, vegetation coverage was estimated using the Normalized Difference Vegetation Index (NDVI) and the pixel dichotomy model to investigate the spatiotemporal variation trends and driving forces of vegetation coverage in the wind-sand flow into the Yellow River section of the Ulan Buh Desert, aiming to provide a theoretical basis for vegetation restoration and the selection of key areas for future ecological construction in this region. The results indicate that: (1) The overall vegetation coverage in the study area exhibited a fluctuating upward trend, with favorable vegetation recovery conditions, as the average vegetation coverage increased from 0.294 to 0.526, with the most pronounced increase occurring between 2007 and 2017. (2) From 2001 to 2021, frequent transitions occurred among different vegetation coverage levels in the wind-sand flow into the Yellow River section of the Ulan Buh Desert, wherein large areas of low and relatively low vegetation coverage transitioned to medium and relatively high vegetation coverage, with transition areas of 102.00 $km^2$ and 128.82 $km^2$, respectively. Additionally, 42.1% of the study area demonstrated a significant increasing trend, while 4.90% showed a significant decreasing trend, predominantly distributed in the section near Wuhai, which should be designated as a priority area for future ecological restoration efforts. (3) The spatial heterogeneity of vegetation coverage in this region was primarily driven by the combined influence of human activities and climatic factors, with the interactions among driving factors predominantly characterized by two-factor enhancement, among which the most influential key interactive factor was land use type and annual average temperature. This study systematically and segmentally investigated the dynamic variation characteristics and driving forces of vegetation coverage in the wind-sand flow into the Yellow River section of the Ulan Buh Desert, providing theoretical and data support for de-

sertification control, rational land utilization, and high-quality development in the study area.

## Full Text

# Dynamic Change Characteristics and Driving Forces of Vegetation Cover in the Ulan Buhe Desert Along the Yellow River

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### Abstract

Based on Landsat imagery data from 2001 to 2021, this study employs the Normalized Difference Vegetation Index (NDVI) and pixel dichotomy model to estimate vegetation coverage and investigate its spatiotemporal variation trends and driving forces in the Ulan Buhe Desert section where wind-blown sand enters the Yellow River. The aim is to provide a theoretical basis for vegetation restoration and the selection of priority areas for future ecological construction in this region. The results show that: (1) The overall vegetation coverage in the study area exhibited a fluctuating upward trend, indicating good vegetation recovery status. The average vegetation coverage increased from 0.294 to 0.526, with the most significant improvement occurring between 2007 and 2017. (2) From 2001 to 2021, frequent transitions occurred between different vegetation coverage levels in the Ulan Buhe Desert's wind-sand entering Yellow River section. Specifically, large areas of low and lower vegetation coverage transitioned to medium and higher vegetation coverage, with transferred areas of 102.00 $km^2$ and 128.82 $km^2$, respectively. (3) The spatial differentiation of vegetation coverage in this area is primarily driven by the combined effects of human activities and climate factors. The interactions between driving factors are mainly characterized by dual-factor enhancement, with land use type and annual average temperature being the key interactive factors with the highest influence. This study systematically and sequentially investigates the dynamic change characteristics and driving forces of vegetation coverage in the Ulan Buhe Desert's wind-sand entering Yellow River section, providing theoretical and data support for desertification control, rational land use, and high-quality development in the study area.

**Keywords:** vegetation coverage; temporal and spatial variation; driving factors; Ulan Buhe Desert

## Introduction

Desert vegetation is an important component of arid and semi-arid ecosystems and serves as an indicator of the comprehensive effects of the ecological environment in desert regions. It plays a critical role in soil and water conservation, windbreak and sand fixation, and maintaining oasis stability in arid areas. Fractional Vegetation Coverage (FVC) is an important parameter for studying surface ecological environment changes and a key indicator reflecting land degradation and desertification degree.

In recent years, research on the dynamic change characteristics of vegetation coverage in sandy areas, with the combined effects of natural and human activities at the core, has become a focus for many scholars. Numerous studies have shown that among the many climatic factors affecting vegetation coverage change, precipitation is an important driving factor for vegetation cover change. In desert areas where vegetation growth is constrained by water conditions, the amount of precipitation directly affects changes in soil water content. Correlation analysis shows that vegetation coverage change in desert areas has varying degrees of positive and negative correlation with temperature. Appropriate temperature can accelerate plant physiological and biochemical reactions and promote plant growth, but when temperature exceeds the optimal temperature for photosynthesis, high temperature accelerates soil water evaporation and transpiration, creating arid conditions that negatively affect plant growth. Additionally, vegetation coverage change is closely related to wind speed and direction changes in different periods, which affect the speed of desert expansion or contraction. For example, on dry and loose sandy ground, strong winds can cause intense sand particle movement, leading to sand burial at oasis edges and vegetation degradation.

In addition to climatic factors, the impact of human factors on vegetation coverage change cannot be ignored. Land use type, population density, urban and rural construction, and ecological restoration all have corresponding impacts on vegetation coverage change. For example, ecological construction projects can improve vegetation coverage, while unreasonable utilization of ecological resources by humans can also cause vegetation degradation.

The Ulan Buhe Desert section where wind-blown sand enters the Yellow River has sparse precipitation, coarse soil, strong evaporation, and a fragile ecological environment, resulting in particularly frequent wind-sand activities along both banks of the Yellow River. Large amounts of sand material are transported to the Yellow River, making it one of the main sources of sediment. According to statistics, the section of this desert that directly harms the Yellow River exceeds 20 km, transporting approximately $7.72\times10^{6}$ tons of sand to the Yellow River annually, accounting for a significant portion of the Yellow River's sediment content. Large amounts of sand entering the Yellow River cause riverbed siltation and frequent flood disasters, seriously threatening the ecological security of the region and making it a key area for desertification control at both national and autonomous region levels.

In recent years, under the influence of natural factor changes and multiple major ecological projects, the surface vegetation in the Ulan Buhe Desert's wind-sand entering Yellow River section has fluctuated significantly. In particular, the dynamic change characteristics of vegetation coverage under different habitats and the main driving factors remain unclear. Studying the spatiotemporal dynamics of vegetation distribution and the environmental driving mechanisms at different spatial scales in this region is of important scientific significance for maintaining the ecological balance of the Ulan Buhe Desert's wind-sand entering Yellow River section. Based on this, this study utilizes remote sensing technology, with Landsat data as the source, combined with NDVI and pixel dichotomy model methods, to systematically and quantitatively study the spatiotemporal variation trends of vegetation coverage from 2001 to 2021 in the Ulan Buhe Desert's wind-sand entering Yellow River section, and uses geographical detectors to analyze the driving factors of vegetation coverage spatial differentiation, aiming to provide a theoretical basis for windbreak and sand fixation, vegetation restoration and reconstruction, and ecological restoration in this region.

## 1. Study Area Overview and Data Processing

### 1.1 Study Area Overview

The Ulan Buhe Desert section where wind-blown sand enters the Yellow River (39°35 -40°19 N, 106°46 -107°02 E) is located between Wuda District of Wuhai City and Dengkou County of Bayannur City in Inner Mongolia, adjacent to Alxa Left Banner in the west and bordering Hangjin Banner of Ordos City in the east. Based on the boundary of the Ulan Buhe Desert's wind-sand entering Yellow River section and vegetation coverage change conditions, this study delineated the research area with a total length of approximately 184.35 km and an area of about 364.13 $km^2$.

The region belongs to a mid-temperate continental arid monsoon climate, with dry climate and frequent winds. The annual average temperature is 7.8°C, annual average precipitation is 142.7 mm, and annual average sunshine hours are 2400-2900 mm. The annual average wind speed is 4.1 $m \cdot s^{-1}$, with southwest winds prevailing throughout the year, most frequent from April to June. The Ulan Buhe Desert's wind-sand entering Yellow River section is dominated by mobile dunes, followed by semi-fixed and fixed dunes. Common plants in the study area include *Agriophyllum squarrosum*, *Haloxylon ammodendron*, *Caragana korshinskii*, and *Suaeda salsa*.

### 1.2 Data Sources and Processing

The remote sensing images and DEM data used in this study were obtained from the Geospatial Data Cloud (http://www.gscloud.cn). Considering data availability, Landsat 4-5 TM images were selected as the data source for 2001-2011, and Landsat 8 OLI images for 2013-2021, with a resolution of 30 m$×$30 m. All scene images were selected during the plant growing season (June-September) each year, with cloud cover below 10%.

Preprocessing included radiometric calibration and atmospheric correction. Among them, Landsat 4-5 TM images were geometrically corrected using Landsat 8 OLI images as the standard. The preprocessed images were used to extract NDVI, estimate vegetation coverage, reclassify, and subsequently study the spatiotemporal variation trends and driving forces of vegetation coverage in the Ulan Buhe Desert's wind-sand entering Yellow River section.

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## 2. Research Methods

### 2.1 Estimating Vegetation Coverage

Based on the Normalized Difference Vegetation Index (NDVI) and pixel dichotomy model, vegetation coverage (FVC) was calculated using the formula:

$$FVC = \frac{NDVI - NDVI_{soil}}{NDVI_{veg} - NDVI_{soil}}$$

where NDVI_{soil} represents the NDVI value of pure soil pixels without vegetation cover, with its value approaching 0; NDVI_{veg} represents the NDVI value of pure vegetation pixels completely covered by vegetation, with its value approaching 1. Due to the influence of external environments, NDVI_{soil} and NDVI_{veg} values may vary, so they need to be assigned based on actual conditions. This study used the 5% and 95% confidence intervals of NDVI frequency accumulation as NDVI_{soil} and NDVI_{veg} values, respectively.

### 2.2 Vegetation Coverage Classification

To more clearly study the spatiotemporal variation characteristics of vegetation coverage in the Ulan Buhe Desert's wind-sand entering Yellow River section, vegetation coverage was classified based on relevant literature [19-20] and the actual conditions of the study area as follows: low vegetation coverage (0<FVC$ 0.2), lower vegetation coverage (0.2 < FVC 0.4), medium vegetation coverage (0.4 < FVC 0.6), higher vegetation coverage (0.6 < FVC 0.8), and high vegetation coverage (0.8 < FVC 1). The image pixels used in this study were all 30 m ×$30 m. Combined with the number of pixels under different vegetation coverage levels, the area occupied by each category in each period was calculated using GIS 10.6 software.

### 2.3 Vegetation Coverage Dynamic Degree

The vegetation coverage dynamic degree is used to quantitatively describe the intensity of vegetation coverage change within a specific time period and reflect the change speed of vegetation coverage. The formula is:

$$K = \frac{L_b - L_a}{L_a} \times \frac{1}{T} \times 100\%$$

where K represents the vegetation coverage change dynamic degree, with positive values indicating vegetation coverage increase and negative values indicating vegetation degradation; L_a represents the area of vegetation coverage in the initial study period ($km^2$); L_b represents the area of vegetation coverage in the final study period ($km^2$); and T represents the study period.

### 2.4 Vegetation Coverage Transfer Matrix

The vegetation coverage transfer matrix can more clearly describe the spatiotemporal variation characteristics of vegetation coverage in different periods, reveal the mutual transformation relationships between different vegetation coverage levels, and intuitively reflect the area changes of different vegetation coverage levels.

### 2.5 Slope Trend Analysis

The Slope trend analysis method was used to test the spatial distribution of vegetation coverage change trends from 2001 to 2021 in the Ulan Buhe Desert's wind-sand entering Yellow River section. The calculation formula is:

$$Slope = \frac{n \times \sum_{i=1}^{n} i \times FVC_i - \sum_{i=1}^{n} i \times \sum_{i=1}^{n} FVC_i}{n \times \sum_{i=1}^{n} i^2 - (\sum_{i=1}^{n} i)^2}$$

where n is the number of monitoring years; FVC_i is the vegetation coverage in year i; and Slope is the linear fitting slope of multi-year vegetation coverage. When Slope $>$ 0, it indicates an increasing trend in vegetation coverage; when Slope $=$ 0, it indicates basically unchanged vegetation coverage; when Slope $<$ 0, it indicates a decreasing trend in vegetation coverage. Referring to relevant literature [27-28], vegetation coverage change trends were classified as: significant decrease (Slope $\leq$ -0.1), slight decrease (-0.1 $<$ Slope $\leq$ -0.003), basically unchanged (-0.003 $<$ Slope $\leq$ 0.003), slight increase (0.003 $<$ Slope $\leq$ 0.1), and significant increase (Slope $>$ 0.1).

### 2.6 Geographical Detector

The geographical detector is a statistical method for detecting the spatial differentiation of research subjects and revealing the driving forces causing their spatial changes. This study mainly used factor detection and interaction detection to analyze the spatial differentiation and driving forces of vegetation coverage in the Ulan Buhe Desert's wind-sand entering Yellow River section.

Factor detection is used to explore the spatial differentiation of research subjects and analyze the explanatory power of driving factors on spatial differentiation. Interaction detection can identify the interactive relationships between driving factors, explaining whether the influence on research subjects increases or decreases when multiple factors act together, or whether each factor independently affects the research subject.

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## 3. Results

### 3.1 Temporal Variation Characteristics of Vegetation Coverage

From 2001 to 2021, the average vegetation coverage in the Ulan Buhe Desert's wind-sand entering Yellow River section showed a continuous upward trend, increasing from 0.294 to 0.526, with the most significant increase occurring from 2007 to 2017. In terms of vegetation coverage area changes, the combined area of low and lower vegetation coverage decreased from 15.3% and 17.4% to 13.9% and 20.8%, respectively, while the combined area of medium, higher, and high vegetation coverage increased from 44.1% to 42.10% (note: this seems contradictory, but I'll keep the numbers as they appear in the original).

The vegetation coverage dynamic degree showed obvious differences [Figure 3: see original paper]. The low vegetation coverage area tended to decrease overall, with the largest reduction of -12.18% occurring in 2001-2007. The lower vegetation coverage area showed a phased increase after 2007, with dynamic degrees of 24.59% and -14.71%, respectively. The medium vegetation coverage area tended to increase overall, with the largest increase of 21.05% in 2007-2017. The higher vegetation coverage area tended to increase overall, with the largest increase of 13.07% in 2007-2017. The high vegetation coverage area showed little change, with the maximum dynamic degree of 6.53% in 2001-2007. This indicates that with the launch of key forestry projects and a series of desert ecological projects, vegetation coverage along the Yellow River section of the Ulan Buhe Desert has been correspondingly improved, and ecological restoration in the study area has achieved certain results.

### 3.2 Spatial Variation Characteristics of Vegetation Coverage

The spatial distribution of vegetation coverage in the Ulan Buhe Desert's wind-sand entering Yellow River section from 2001 to 2021 [Figure 4: see original paper] shows obvious distribution patterns: vegetation coverage gradually increased from the near-Wuhai section to the near-Dengkou section along the Yellow River flow direction, and due to water constraints, vegetation coverage showed varying degrees of decrease extending transversely from the bank to the desert hinterland.

Slope trend analysis [Figure 5: see original paper] shows that vegetation coverage in the study area overall developed in a sustained positive direction. Areas with significantly and slightly increasing trends accounted for approximately 42.10% and 37.10% of the total study area, respectively, mainly distributed in the western and central parts of the study area. Areas with basically unchanged vegetation coverage accounted for 15.60% of the total area. Due to wind-sand entering the Yellow River and sand accumulation in the river channel, vegetation coverage around the Yellow River showed a slight decreasing trend, accounting for about 14.90% of the total area. Areas showing a significant decreasing trend accounted for 4.90% of the study area, mainly distributed in the southeastern part of the Ulan Buhe Desert's wind-sand entering Yellow River section, i.e., the near-Wuhai section, where vegetation coverage showed significant degradation and should be a key focus area for future ecological restoration.

To further study the spatial variation characteristics of vegetation coverage, a transfer matrix of different vegetation coverage levels from 2001 to 2021 was constructed based on ArcGIS 10.6. The results show that vegetation coverage transfer between different levels was not obvious but overall developed positively. From 2001 to 2007, low vegetation coverage mainly transferred to lower vegetation coverage, with a transfer area of 83.16 $km^2$. From 2007 to 2017, large areas of low and lower vegetation coverage transferred to medium and higher vegetation coverage, with transfer areas of 102.00 $km^2$ and 128.82 $km^2$, respectively. From 2017 to 2021, transfers between different vegetation coverage levels tended to stabilize, with transfer-in and transfer-out states basically balanced [Figure 6: see original paper].

### 3.3 Analysis of Driving Factors of Vegetation Coverage

The geographical detector was used to analyze the driving forces of vegetation coverage spatiotemporal changes in the Ulan Buhe Desert's wind-sand entering Yellow River section and the interactions between driving factors.

Single-factor detection results show that, except for the aspect factor, all driving factors had significant effects on vegetation coverage in the study area. Among them, land use type change was the primary factor affecting vegetation coverage change, followed by annual average sunshine hours and annual average temperature . In recent years, artificially planted vegetation through ecological restoration projects has become the main vegetation cover type in the study area, and land use types in the region have gradually diversified, making significant contributions to the spatiotemporal changes of vegetation coverage in the study area.

Interaction detection results [Figure 7: see original paper] show that all two-factor interactions in the Ulan Buhe Desert's wind-sand entering Yellow River section significantly strengthened the explanatory power for vegetation coverage spatial differentiation compared to single factors, mainly showing dual-factor enhancement. The key interactive factors with high influence include land use type and annual average temperature (q=0.847), land use type and population spatial distribution (q=0.831), land use type and annual precipitation (q=0.823), and land use type and annual average wind speed (q=0.816). The remaining factor interactions had relatively smaller explanatory power for vegetation coverage spatial differentiation, indicating that land use type change dominates the impact on vegetation coverage, while annual average temperature, annual precipitation, and annual average sunshine hours also have corresponding effects on the spatial heterogeneity of vegetation coverage in the study area.

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## 4. Discussion

Vegetation coverage, as one of the important parameters indicating ecological environmental quality, can characterize the spatiotemporal dynamic changes of vegetation cover. The research results are consistent with studies by Qi Zhao et al. and Zhang Zhiqiang et al. The study area is located in an arid and semi-arid region where vegetation responds highly sensitively to water conditions, and precipitation is a limiting factor for vegetation growth.

Since 2000, precipitation in the Ulan Buhe Desert's wind-sand entering Yellow River section has increased significantly, with annual average precipitation reaching 129.58 mm and evaporation decreasing during the period. Using trend analysis and transfer matrix models, the study found that affected by gradient differences in site conditions and ecological restoration projects, vegetation coverage in the Ulan Buhe Desert's wind-sand entering Yellow River section showed a spatial distribution pattern of low in the south and high in the north, extending transversely from the bank to the desert hinterland. Transfers between different vegetation coverage levels were frequent during the period, with lower and low vegetation coverage transferring to medium and higher vegetation coverage in large areas (47.13% from lower to medium coverage, 37.01% from medium to higher coverage). In recent years, the state and autonomous region have vigorously implemented the 'Three-North Shelterbelt System', sand closure for afforestation and grass cultivation, and Ulan Buhe Desert ecological construction projects. The comprehensive forest and grass vegetation coverage in the study area is relatively good, and wind-sand entering the Yellow River has been further controlled.

Using geographical detectors to further analyze the influencing factors of vegetation coverage spatial changes in the wind-sand entering Yellow River section, the results show that land use type is an important driving factor affecting vegetation coverage distribution in the study area. Human activities mainly affect vegetation changes by altering land use types. The study area is a typical region for high-quality development and ecological construction in the Yellow River Basin, where reasonable vegetation allocation remains the main restoration measure. The near-Dengkou section has diverse land use types, including typical oases, forest land, grassland, farmland, and water areas. Since 2015, this section has built an efficient water-saving irrigation project using Yellow River water, with good water conditions that are beneficial for accelerating the decomposition and transformation of soil organic matter, thereby positively promoting plant growth and improving vegetation coverage trends.

The near-Wuhai section has a typical desert climate, with annual average wind speed of about 3.7 $m \cdot s^{-1}$, strong surface wind erosion, and vegetation degradation in some areas of this section. The area is still dominated by mobile sand and low vegetation coverage, with significant vegetation degradation, making it a key focus area for future ecological restoration.

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## 5. Conclusion

Using the dynamic degree index, vegetation coverage transfer matrix, Slope trend analysis, and factor detection methods, this study investigated the spatiotemporal variation characteristics and driving forces of vegetation coverage in the Ulan Buhe Desert's wind-sand entering Yellow River section from 2001 to 2021. The results are as follows:

(1) In terms of temporal variation, vegetation coverage in the Ulan Buhe Desert's wind-sand entering Yellow River section from 2001 to 2021 showed an overall fluctuating upward trend, with good vegetation recovery status. The average vegetation coverage increased from 0.294 to 0.526, with the greatest improvement from 2007 to 2017. In terms of vegetation coverage area changes, the area of lower and low vegetation coverage decreased from 15.3% and 17.4% to 13.9% and 20.8%, respectively, while the area of higher and high vegetation coverage increased from 20.8% to 44.1%.

(2) In terms of spatial variation, vegetation coverage in the Ulan Buhe Desert's wind-sand entering Yellow River section from 2001 to 2021 showed an overall increasing trend with local decreases. Transfers between different vegetation coverage levels were frequent, with large areas of low and lower vegetation coverage transferring to medium and higher vegetation coverage. In addition, 42.1% of the study area showed a significant increasing trend, mainly in the near-Dengkou section, while 4.90% of the area showed a significant decreasing trend, mainly distributed in the near-Wuhai section, which should be a key focus area for future ecological restoration.

(3) The spatial differentiation of vegetation coverage in the Ulan Buhe Desert's wind-sand entering Yellow River section is mainly related to climate factors and human activities. The interactions between driving factors are primarily characterized by dual-factor enhancement, with the most significant interactions occurring between land use type and annual average temperature, land use type and annual precipitation, and land

use type and annual average sunshine hours.

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## References

[1] Li Changlong, Wang Yan, Gao Zhihai, et al. Spatial and temporal characteristics of forest and grass cover in the potential range of desertification in China from 2000 to 2020[J]. Acta Geographica Sinica, 2022, 77(11): 2803-2816.

[2] Yan S G, Li H D, Fang Y, et al. Dynamics of vegetation in the Wuliangsuhai Basin under climate change during the years from 1999 to 2013[J]. Journal of Ecology and Rural Environment, 2016, 32(6): 958-963.

[3] Yuan J, Xu Y, Xiang J, et al. Spatiotemporal variation of vegetation coverage and its associated influence factor analysis in the Yangtze River Delta, eastern China[J]. Environmental Science and Pollution Research, 2019, 26(32): 32866-32879.

[4] Cao Yongxiang, Mao Donglei, Xue Jie, et al. Dynamic changes and driving factors of vegetation cover in the oasis-desert ecotone: A case study of Cele, Xinjiang[J]. Arid Zone Research, 2022, 39(2): 510-521.

[5] Liu Jing, Yin Shan, Zhang Guosheng, et al. Dynamic change of vegetation coverage of Mu Us Sandland over the 17 years by remote sensing monitor[J]. Journal of Arid Land Resources and Environment, 2009, 23(7): 162-167.

[6] Cheng Junfeng, Jia Baoquan, Zhao Xiuhai, et al. Dynamic change of desertification in semi arid and arid environment[J]. Journal of Arid Land Resources and Environment, 2009, 23(12): 172-176.

[7] Li Yixuan, Zhu Qingke, Shi Ruoying, et al. Spatial and temporal changes of vegetation cover and its influencing factors in the Loess Plateau from 2000 to 2018[J]. Science of Soil and Water Conservation, 2021, 19(4): 60-68.

[8] Yang Yi, Wu Shixin, Zhuang Qingwei, et al. Spatiotemporal change of EVI in the Gurbantunggut Desert from 2000 to 2018[J]. Arid Zone Research, 2019, 36(6): 1512-1520.

[9] Fu Shasha, Peng Wei, Shao Aimei, et al. Variations in the NDVI characteristics during the summer and the climatic factor responses in the Qinling Daba Mountains[J]. Arid Zone Research, 2023, 40(10): 1563-1574.

[10] Wang Tingting, Yin Gang, Xu Huajun, et al. GIS based analysis of Kumtag Desert and vegetation cover changes and their driving mechanisms over the past 50 years[J]. Journal of Fujian Normal University (Natural Science Edition), 2023, 39(4): 57-67.

[11] Yan Deren, Yuan Limin, Huang Haiguang, et al. Study on windproof effect of gauze sand barriers on mobile sand dunes in Ulan Buh Desert[J]. Research of Soil and Water Conservation, 2021, 28(2): 198-202.

[12] Wang Jing, Zhou Weiqi, Xu Kaipeng, et al. Spatiotemporal pattern of vegetation cover and its relationship with urbanization in Beijing Tianjin Hebei megaregion from 2000 to 2010[J]. Acta Ecologica Sinica, 2017, 37(21): 7019-7029.

[13] Zhao Jun, Yang Jianxia, Zhu Guofeng. Effect of ecological water conveyance on vegetation coverage in surrounding area of the Qingtu Lake[J]. Arid Zone Research, 2018, 35(6): 1251-1261.

[14] Li Yongshan, Peng Wenchang, Ren Liang, et al. Evolution of Ulan Buh Desert braided channel of the Yellow River in recent 50 years[J]. Journal of Desert Research, 2016, 36(6): 1689-1694.

[15] Yang Gensheng, Tuo Wanquan, Dai Fengnian, et al. Contribution of sand sources to the silting of riverbed in Inner Mongolia Section of Huanghe River[J]. Journal of Desert Research, 2003, 23(2): 54-61.

[16] Wang Jinfeng, Xu Chengdong. Geodetector: Principle and prospective[J]. Acta Geographica Sinica, 2017, 72(1): 116-134.

[17] Yang S, Dong B, Liu L, et al. Research on vegetation coverage change in Shengjin Lake wetland of Anhui Province[J]. Wetlands, 2016.

[18] Xiao X, Huang X, Jiang L, et al. Empirical study on comparative analysis of dynamic degree differences of land use based on the optimization model[J]. Geocarto International, 2022, 37(25): 1-18.

[19] Du X, Jin X, Yang X, et al. Spatial pattern of land use change and its driving force in Jiangsu Province[J]. International Journal of Environmental Research and Public Health, 2014, 11(3): 3215-3232.

[20] Wang Yinan, Kong Xiangbing, Zhao Chunjing, et al. Change of vegetation coverage in the Loess Plateau from 2000 to 2020 and its spatiotemporal pattern analysis[J]. Journal of Soil and Water Conservation, 2022, 36(3): 130-137.

[21] Li Qinghe, Bao Yaoxian, Wang Zhigang, et al. Study on aeolian sand movement law in Ulan Buh Desert[J]. Journal of Soil and Water Conservation, 2003, 17(4): 86-89.

[22] Song Qi, Shi Zhou, Feng Chunhui, et al. Analysis of landscape pattern from 1990 to 2019 based on multi-temporal imagery in arid oasis[J]. Arid Zone Research, 2022, 39(2): 594-604.

[23] Li Changbin, Yang Linshan, Yang Wenjin, et al. Land use and land cover change in Taohe River basin and its driving forces[J]. Scientia Geographica Sinica, 2014, 34(7): 848-855.

[24] Zhang Jiazheng, Li Chonggui, Wang Tao. Dynamic changes of vegetation coverage on the Loess Plateau and its factors[J]. Research of Soil and Water Conservation, 2022, 29(1): 224-230, 241.

[25] Zhang Zhiqiang, Liu Huan, Zuo Qiting, et al. Spatiotemporal change of fractional vegetation cover in the Yellow River Basin during 2000-2019[J]. Acta Geographica Sinica, 2022, 77(5): 1153-1168.

[26] Li Chongwei, Wang Zhihui, Tang Qiuhong, et al. Dynamics of surface water area in the Yellow River Basin and its influencing mechanism during 1986-2019 based on Google Earth Engine[J]. Resources Science, 2021, 43(4): 849-858.

[27] Wang Xin. The Spatial-temporal Change of Vegetation in Source Region of the Yangtze and Yellow River and Its Response to Climate Change from 1982 to 2013[D]. Lanzhou: Lanzhou University, 2016.

[28] Bi Shuoben, Ji Han, Cheng Changchun, et al. Application of geographical detector in human-environment relationship study of prehistoric settlements[J]. Progress in Geography, 2015, 34(1): 118-127.

[29] Wen Miaoxia, He Xuegao, Liu Huan, et al. Analysis of spatiotemporal variation characteristics and driving factors of grassland vegetation cover in Ningxia based on geographical detectors[J]. Arid Zone Research, 2023, 40(8): 1322-1332.

[30] Liu Yifeng, Guo Bing, Lu Miao, et al. Quantitative distinction of the relative actions of climate change and human activities on vegetation evolution in the Yellow River Basin of China during 1981-2019[J]. Journal of Arid Land, 2023, 15(1): 91-108.

[31] Lin M, Hou L Z, Qi Z M, et al. Impacts of climate change and human activities on vegetation NDVI in China's Mu Us Sandy Land during 2000-2019[J]. Ecological Indicators, 2022, 142: 109-164.

[32] Yang Xiaoxia. Impacts of Climate Change and Human Activities on the Terrestrial Vegetation Cover Changes in the Poyang Lake Basin[D]. Chongqing: Southwest University, 2023.

[33] Luo Hong, Yang Cunjian. Dynamic change and driving force analysis of vegetation coverage in the upper reaches of the Yangtze River in recent 19 years[J]. Ecological Science, 2023, 42(1): 234-241.

[34] Xu Xingkui, Lin Chaohui, Xue Feng, et al. Correlation analysis between meteorological factors and the ratio of vegetation cover[J]. Acta Ecologica Sinica, 2003, 23(2): 221-230.

[35] Qi Zhu, Tan Bingxiang, Cao Xiaoming, et al. Spatial-temporal dynamics of ecological carrying capacity of the northeastern margin of the Ulan Buh Desert[J]. Remote Sensing for Natural Resources, 2023, 35(1): 222-230.

[36] Ren Yu, Gao Yong, Yu Yi, et al. Analysis on relationship between lake change and climate change in the Ulan Buh Desert[J]. Arid Zone Research, 2011, 28(1): 168-174.

[37] Meng Yang, Yang Song, Yin Jun. Promoting high-quality development of ecological agriculture in the Yellow River Basin of Inner Mongolia: The case of

Ulan Buh Desert in Dengkou County[J]. Northern Economy, 2021(4): 26-28.

[38] Li Xinlei, Li Ruiping, Wang Xiuqing, et al. Spatiotemporal change and analysis of factors driving forest-grass vegetation coverage in Hetao Irrigation District based on geographical detector[J]. Arid Zone Research, 2023, 40(4): 623-635.

[39] Wu R, Zhang J, Bao Y, et al. Geographical detector model for influencing factors of industrial sector carbon dioxide emissions in Inner Mongolia[J]. Sustainability, 2016, 8(2): 149.

[40] Li Jinrong, Guo Jianying, Dong Zhi, et al. Sand moving characteristics and the protective effect of governance measures along bank of Yellow River in Ulan Buh Desert[J]. Journal of Arid Land Resources and Environment, 2016, 30(8): 113-119.

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