

Spatiotemporal Variation of Vegetation and Its Driving Forces in the Ebinur Lake Basin (Post-print)

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Abstract

Vegetation is one of the sensitive factors reflecting changes in terrestrial ecosystems and plays a crucial role in maintaining and regulating ecosystem stability. Taking the Ebinur Lake Basin, an ecologically fragile region, as the study area, and using the Geodetector model, this study investigates the influence of natural and anthropogenic factors and their interactions on spatiotemporal changes in vegetation coverage, and analyzes the suitable ranges (categories) of each influencing factor for promoting vegetation growth. The results indicate: (1) From 2000 to 2020, the Normalized Difference Vegetation Index (NDVI) in the Ebinur Lake Basin showed an increasing trend, with a growth rate of $0.035 \cdot (10a)^{-1}$, and the ecological environment was effectively improved. Improvements were mainly distributed in the central-western region, significantly enhanced areas were primarily located in the central part of Ebinur Lake, and severely degraded areas were scattered in the central position of the middle Ebinur Lake region. (2) Land use type, vegetation type, and soil type factors have greater influence on the spatial distribution of vegetation NDVI than other factors, and are the dominant influencing factors. The interactions between natural and anthropogenic factors on vegetation NDVI are primarily characterized by nonlinear enhancement and two-factor enhancement effects, with no independent relationships. (3) Cultivated land, cultivated vegetation, anthropogenic soil, medium-relief mountains, elevation of 2177~2558 m, annual precipitation of 228~245 mm, annual average temperature of 4.74~5.25 °C, slope aspect of 157.5°~202.5°, and slope gradient of 25°~35° are suitable for vegetation growth. The research results will provide a scientific basis for ecological protection in the Ebinur Lake Basin.

Full Text

Abstract

Vegetation serves as a sensitive indicator of terrestrial ecosystem changes and plays a crucial role in maintaining and regulating ecosystem stability. This study examines the Ebinur Lake Basin, an ecologically fragile region in northwestern Xinjiang, China, using the geographic detector model to investigate the impacts of natural and anthropogenic factors—and their interactions—on spatiotemporal vegetation coverage changes. The analysis identifies optimal ranges for various influencing factors that promote vegetation growth.

From 2000 to 2020, the Normalized Difference Vegetation Index (NDVI) in the Ebinur Lake Basin exhibited an increasing trend at a rate of $0.035 \cdot (10a)^{-1}$, indicating effective ecological improvement. Improved areas were concentrated in the central and western regions, with significant enhancement located primarily in the central basin, while severely degraded areas were scattered in the central core. Land use type, vegetation type, and soil type emerged as the dominant factors influencing vegetation spatial distribution, exerting greater influence than other variables. Interactions between natural and anthropogenic factors primarily manifested as nonlinear enhancement and dual-factor enhancement effects, with no independent relationships observed. Cultivated land, cultivated vegetation, anthropogenic soils, medium-undulating mountains, elevation ranges of 2177–2558 m, annual precipitation of 228–245 mm, mean annual temperature of 4.74–5.25 °C, slope aspects of 157.5°–202.5°, and slopes of 25°–35° were identified as conditions suitable for vegetation growth. These findings provide a scientific basis for ecological conservation in the Ebinur Lake Basin.

Keywords: Normalized Difference Vegetation Index (NDVI); vegetation change; geographic detector; Ebinur Lake Basin

1. Study Area Overview

The Ebinur Lake Basin is located in northwestern Xinjiang, China, between 43°02'–45°43' N and 79°53'–83°56' E, covering an area of 2.5×10^4 km². The basin encompasses Bole City, Jinghe County, Wenquan County, and Alashankou City. The Kuitun, Jing, and Bortala rivers constitute the three major tributaries (Fig. 1). Characterized by a temperate continental climate, the region experiences low precipitation (181 mm annually), high evaporation (1500–2000 mm), and a mean annual temperature of 5.6 °C. Ebinur Lake, the largest saline lake in Xinjiang, is gradually shrinking due to combined natural and anthropogenic factors, leading to reduced water storage and increasing aridification. The basin features diverse landforms, predominantly plains, with desert, grassland, and meadow as the main vegetation types. Soils are primarily composed of calcic, alpine, and desert soils, while land use is dominated by grassland and unused land. As a typical inland river basin in an arid region, the Ebinur Lake Basin experiences frequent wind-sand disasters, possesses a fragile ecological environ-

ment, and is highly sensitive to climate change and human activities.

2. Data and Methods

2.1 Data Sources and Preprocessing

This study utilized MODIS NDVI data (product: MOD13Q1) for the Ebinur Lake Basin from 2000 to 2020, obtained from NASA's LAADS website (<https://ladsweb.nascom.nasa.gov/>) with a spatial resolution of 250 m. Climate data, including mean annual temperature and precipitation, were derived from measured monthly data at nine meteorological stations (Yumin, Alashankou, Bole, Tuoli, Karamay, Wenquan, Jinghe, Wusu, and Paotai) from 2000 to 2020, interpolated using the inverse distance weighting method. Soil type, vegetation type, landform type, and land use data were obtained from the Chinese Academy of Sciences' Resource and Environmental Science Data Center (<http://www.resdc.cn/>). Digital Elevation Model (DEM) data with 30 m resolution were acquired from the Geospatial Data Cloud (<http://www.gscloud.cn/>), from which elevation, slope, and aspect were calculated. All datasets were masked to the Ebinur Lake Basin vector boundary and resampled to match the NDVI pixel size.

2.2 Methodology

2.2.1 NDVI Maximum Value Compositing The maximum value compositing (MVC) method is currently the most widely used approach for NDVI synthesis. To minimize atmospheric effects, the maximum NDVI value within a specific time period is selected as the representative value. This study generated annual NDVI images by compositing daily NDVI data using the MVC method, with multi-year averages calculated as mean annual NDVI values.

2.2.2 NDVI Classification Based on MODIS NDVI data, vegetation coverage was classified into five levels using the equal-interval method: low (0.0–0.2), medium-low (0.2–0.4), medium (0.4–0.6), medium-high (0.6–0.8), and high (0.8–1.0).

2.2.3 NDVI Trend Analysis The unary linear trend analysis method was employed to examine vegetation change trends through linear regression. Using ArcGIS raster calculator, a unary linear regression was performed on annual NDVI images from 2000 to 2020. Trends were categorized into seven classes using the natural breaks method: severe degradation, moderate degradation, slight degradation, basically unchanged, slight improvement, moderate improvement, and significant improvement. The trend slope was calculated using the formula:

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

where n is the number of study years ($n = 21$), i is the year index, and NDVI_i is the NDVI value for year i . A positive slope indicates increasing vegetation cover, a negative slope indicates decreasing cover, and zero indicates no significant change.

2.2.4 Sampling Design Using ArcGIS, a fishnet tool created $7 \text{ km} \times 7 \text{ km}$ grids across the entire basin, generating sampling points at grid centers. Corresponding values for NDVI and all influencing factors were extracted at each point for geographic detector analysis.

2.2.5 Factor Classification Based on the basin's characteristics, ten factors were selected: slope, aspect, elevation, soil type, vegetation type, landform type, mean annual temperature, annual precipitation, and land use type. The natural breaks method was used to classify each factor: soil type into 11 classes, vegetation type into 7 classes, landform type and slope into 6 classes, aspect and elevation into 5 classes, and land use type into 6 classes (Fig. 2).

2.2.6 Geographic Detector Model The geographic detector model, proposed by Wang et al., comprises four components:

1. **Factor Detector:** Quantifies the spatial heterogeneity of vegetation NDVI and measures each factor's influence using the q statistic, where larger q values indicate stronger influence.
2. **Interaction Detector:** Assesses interactions between factor pairs, evaluating whether their combined effect enhances or diminishes their individual influences (Table 1).
3. **Risk Detector:** Identifies optimal ranges or categories of factors that promote vegetation growth.
4. **Ecological Detector:** Determines whether differences between factors' influences on vegetation NDVI are statistically significant.

3. Results

3.1 Spatiotemporal Variation of Vegetation NDVI

From 2000 to 2020, mean NDVI in the Ebinur Lake Basin showed an increasing trend at $0.035 \cdot (10a)^{-1}$ (Fig. 3). The maximum NDVI occurred in 2017 and the minimum in 2001, with values fluctuating around the mean toward increasing vegetation cover. Area proportions across NDVI classes shifted significantly: low coverage (0.0–0.2) decreased from 41.0% to 28.5%, while medium (0.4–0.6), medium-high (0.6–0.8), and high (0.8–1.0) coverage areas increased substantially. High NDVI values were concentrated in the central and north-western basin, dominated by meadows and cultivated vegetation, while low values were distributed in the northeastern desert regions. Overall, vegetation showed improvement, particularly in central and western areas, with significant

enhancement in the central basin. However, severely degraded patches remained scattered in the central core, likely related to land use changes (Figs. 4–5).

3.2 Factor Analysis

3.2.1 Factor Detection Factor detection results (Fig. 6) revealed the following order of influence on vegetation NDVI: land use type ($q = 0.58$) > vegetation type ($q = 0.48$) > soil type ($q = 0.42$) > elevation ($q = 0.25$) > annual precipitation ($q = 0.11$) > mean annual temperature ($q = 0.09$) > landform type ($q = 0.08$) > slope ($q = 0.05$) > aspect ($q = 0.04$). Land use, vegetation, and soil types were the dominant factors, each explaining over 40% of NDVI spatial variation. Elevation was a secondary factor, while landform, temperature, slope, and aspect had relatively minor direct effects.

3.2.2 Interaction Analysis Interaction detection (Table 3) demonstrated that all factor pairs exhibited enhanced combined effects, either through nonlinear enhancement or dual-factor enhancement, with no independent relationships. Land use type combined with any other factor (except soil and vegetation types) showed nonlinear enhancement, amplifying its influence on NDVI distribution. Vegetation type interactions with elevation, soil type, landform type, and land use type exhibited dual-factor enhancement. Soil type interactions with slope, aspect, temperature, and precipitation also showed nonlinear enhancement. Even slope and aspect, which had weak individual effects, substantially enhanced other factors' influences through interaction.

3.2.3 Significance Testing Ecological detection results (Table 4) indicated that land use type had significantly different effects compared to all other factors, confirming its dominant role. Vegetation type showed significant differences from slope, aspect, and elevation, but not from soil type, suggesting similar influence levels. Landform type, temperature, and precipitation all differed significantly from land use, soil, and vegetation types, while slope and aspect differed significantly from most factors, reinforcing their minor individual influence.

3.2.4 Factor Suitability Analysis Risk detection identified optimal factor ranges for vegetation growth (Table 5). The highest mean NDVI values occurred under the following conditions: slope of 25°–35°, aspect of 157.5°–202.5°, elevation of 2177–2558 m, medium-undulating mountains, mean annual temperature of 4.74–5.25 °C, and annual precipitation of 228–245 mm. Detailed analysis revealed that cultivated land, cultivated vegetation, and anthropogenic soils produced the highest NDVI values (Tables 6–8). Cultivated land showed no significant difference from forest land but differed significantly from other land uses, indicating its suitability for vegetation growth. Among vegetation types, cultivated vegetation, meadows, and grasslands exhibited the highest NDVI values. Anthropogenic soils (primarily irrigated desert soils) showed no signifi-

cant difference from semi-hydromorphic soils but differed from other soil types, demonstrating that human-modified soils support better vegetation growth.

4. Discussion

The Ebinur Lake Basin's topography deepens from southeast to northwest, with plains dominating the landscape and mountainous terrain distributed along the northern, western, and southern edges. Elevation significantly influences vegetation distribution: NDVI increased with elevation up to 2177 m, then decreased at higher altitudes where natural conditions deteriorate. The optimal elevation range of 2177–2558 m coincides with medium-undulating mountains where hydrothermal conditions are favorable and human disturbance is minimal. Slope aspects of 157.5°–202.5° and slopes of 25°–35° also supported higher vegetation cover, as these conditions represent relatively gentle slopes with reduced human activity compared to flatter areas where human settlement concentrates.

As an arid region, the Ebinur Lake Basin's vegetation is influenced by both temperature and precipitation, with precipitation showing slightly greater impact than temperature, consistent with findings from Jiang et al. and Sun et al. The spatial distribution of temperature shows minimal latitudinal variation but decreases from east to west with elevation. Precipitation increases with altitude from west to east, providing moisture for vegetation growth. The optimal ranges of 4.74–5.25 °C for temperature and 228–245 mm for precipitation were located primarily in the northwestern basin.

Human activities dominate vegetation dynamics in the Ebinur Lake Basin, a finding consistent with Wang et al. The establishment of nature reserves and afforestation programs has enhanced vegetation protection. Cultivated land and anthropogenic soils (irrigated desert soils) demonstrate how human intervention can create favorable conditions for vegetation growth through irrigation and fertilization. However, increasing cultivated land area also reflects intensified human impact on the basin's ecosystem. As ecological awareness improves and conservation measures expand, the basin's ecological vulnerability may be alleviated.

5. Conclusions

This study analyzed spatiotemporal vegetation changes and their driving forces in the Ebinur Lake Basin from 2000 to 2020 using MODIS NDVI data and the geographic detector model. Key conclusions are:

1. **Vegetation improvement:** NDVI showed a significant increasing trend at $0.035 \cdot (10a)^{-1}$. Medium, medium-high, and high coverage areas expanded substantially, with improvement concentrated in central and western regions. Significant enhancement occurred in the central basin, though severely degraded patches persisted in the core area.
2. **Dominant driving factors:** Land use type, vegetation type, and soil

type were the primary factors influencing vegetation spatial distribution, with elevation as a secondary factor. Precipitation, landform, temperature, slope, and aspect had relatively minor direct effects. Human factors played a leading role compared to natural factors.

3. **Factor interactions:** All factor pairs exhibited enhanced interactive effects through nonlinear or dual-factor enhancement, without independent relationships. Land use type, in particular, showed significant differences from other factors and strongly enhanced their combined influence.
4. **Optimal conditions:** The most suitable conditions for vegetation growth included cultivated land, cultivated vegetation, anthropogenic soils, medium-undulating mountains, elevation of 2177–2558 m, precipitation of 228–245 mm, temperature of 4.74–5.25 °C, aspect of 157.5°–202.5°, and slope of 25°–35°.

These findings provide scientific guidance for ecological protection and restoration strategies in the Ebinur Lake Basin, highlighting the importance of sustainable land management and human-mediated vegetation recovery in this fragile arid environment.

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