Post-print of Research on Spatiotemporal Variation Characteristics and Simulation Prediction of Land Ecological Vulnerability in Gansu Province from 2000 to 2024

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Abstract

To explore the spatio-temporal evolution patterns and future trends of land ecological vulnerability in Gansu Province from 2000 to 2024, an evaluation system based on the "Sensitivity-Resilience-Pressure" (SRP) model was constructed. Using the entropy weight method, geographical detectors, and the CA-Markov model, a quantitative analysis of ecological vulnerability from 2000 to 2024 and simulation predictions for 2030 and 2035 were conducted. The results indicate that: (1) From 2000 to 2024, the land ecological vulnerability in Gansu Province decreased significantly, ecosystem stability enhanced, and the vulnerability level shifted from being "dominated by high vulnerability" to "dominated by slight-to-moderate vulnerability." (2) The spatial pattern exhibited a gradient characteristic of "high in the northwest and low in the southeast," with high-value areas shrinking and low-value areas expanding. (3) Annual evapotranspiration, Normalized Difference Vegetation Index (NDVI), and sunshine hours were the dominant factors with the strongest interactions, reflecting that climate and vegetation jointly regulate the vulnerability of the land ecosystem. (4) Simulation predictions for 2035 show that the proportion of potential and slight vulnerability areas will reach 65.5%, extreme vulnerability areas will essentially disappear, and the ecological pattern will continue to optimize. The study demonstrates that the land ecosystem in Gansu Province follows an overall evolutionary trend of "continuous recovery and steady optimization." Ecological restoration policies and climate-adaptive governance have jointly promoted the steady reshaping of the regional ecological security pattern, providing a quantitative scientific basis for the optimization of ecological security patterns and the formulation of adaptive governance strategies in Northwest China.

Full Text

Preamble

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GEOGRAPHY

Spatiotemporal Evolution and Simulation Prediction of Land Ecological Vulnerability in Gansu Province from 2000 to 2024

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Abstract

To investigate the spatio-temporal evolution patterns and future trends of land ecological vulnerability in Gansu Province from 2000 to 2024, this study employs a comprehensive analytical framework. Based on the "Sensitivity-Resilience-Pressure" (SRP) model evaluation framework, this study employs the entropy weight method, geographical detectors, and the CA-Markov model to conduct a quantitative analysis of ecological vulnerability from 2000 to 2024, alongside simulation predictions for 2030 and 2035.

The results indicate: (1) During the study period, the land ecological vulnerability in Gansu Province decreased significantly, while ecosystem stability enhanced. The dominant vulnerability level shifted from "highly vulnerable" to "slight-to-moderate vulnerability." (2) The spatial pattern of ecological vulnerability exhibited a gradient characteristic of being "high in the northwest and low in the southeast." Over time, high-value areas contracted while low-value areas expanded. (3) Annual evapotranspiration, the Normalized Difference Vegetation Index (NDVI), and sunshine duration were identified as the dominant factors influencing vulnerability. These factors exhibited the strongest interactions, reflecting the joint regulation of the land ecosystem by climate and vegetation. (4) Simulation results for 2035 predict that the proportion of very slight and slight vulnerability areas will reach 65.5%. Extremely vulnerable areas are expected to largely disappear, indicating a significant improvement in the ecological landscape. Research indicates that the land ecosystem in Gansu Province exhibits an evolutionary trend of "sustained recovery and steady optimization." These findings provide a quantitative scientific basis for optimizing ecological security patterns and formulating adaptive governance strategies in Northwest China.

Keywords: Land ecological vulnerability; SRP model; Geodetector; CA-Markov model; Gansu Province

1 Introduction

Land ecological vulnerability refers to the sensitive response and self-recovery capability of land ecosystems to external disturbances within a specific spatial and temporal scale. As a typical ecologically fragile region in western China, Gansu Province spans across the Loess Plateau, the Qinghai-Tibet Plateau, and the Inner Mongolian Plateau. Its complex topography and diverse climatic conditions make its ecological environment highly sensitive to both climate change and human activities.

In recent years, with the acceleration of urbanization and the implementation of ecological restoration projects such as the "Grain for Green" program, the land use patterns in Gansu Province have undergone significant changes. Understanding the spatiotemporal evolution of land ecological vulnerability and predicting future trends are of great significance for regional ecological security and sustainable development. This study utilizes multi-source remote sensing data from 2000 to 2024 to construct an evaluation index system and employs simulation models to project future ecological risks.

Since the 18th National Congress of the Communist Party of China, the construction of ecological civilization has been integrated into the "Five-Sphere Integrated Plan," emphasizing that "lucid waters and lush mountains are invaluable assets." The advancement of ecological civilization involves the optimization of spatial planning, the promotion of resource conservation, and the intensification of ecosystem protection. Zhao Zheyuan [**?**] was among the first to propose the concept of "land ecological management" from the perspective of systems science, arguing that it should be viewed as a complex, multi-level system integrating natural, social, and economic dimensions. Internationally, Metzger et al. [**?**], Bahl et al. [**?**], and Finkl et al. [**?**] have conducted research from the perspectives of ecosystem services and health.

2 Materials and Methods

2.1 Study Area Overview

Gansu Province is located in the inland region of Northwest China (92°13′ ∼ 108°46′E, 32°31′ ∼ 42°57′N), situated at the intersection of the Loess Plateau, the Qinghai-Tibet Plateau, and the Inner Mongolian Plateau. The region is characterized by a complex and diverse topography, spanning multiple climatic zones including arid, semi-arid, and humid areas. The average annual precipitation ranges from 40 to 800 mm, generally decreasing from the southeast toward

the northwest. Due to its unique geographical location, Gansu serves as a critical ecological barrier but faces challenges such as soil erosion, desertification, and water scarcity.

2.2 Data Sources and Preprocessing

The datasets used in this study primarily include: 1. **Remote Sensing Data**: MODIS NDVI products (MOD13A3), Net Primary Productivity (NPP) data (MOD17A3), and land use/land cover (LULC) data from the Chinese Academy of Sciences. 2. **Topographic Data**: Digital Elevation Model (DEM) data with 90 m resolution from the SRTM database, used to calculate slope, aspect, and relief degree of land surface (RDLS). 3. **Meteorological Data**: Annual precipitation, temperature, and sunshine duration obtained from the National Meteorological Science Data Center and interpolated using the ANUSPLIN or Kriging methods. 4. **Socio-economic Data**: Population density and GDP per capita sourced from the *Gansu Statistical Yearbook* and provincial agricultural economic reports. 5. **Soil Data**: Soil types, organic matter, and erosion sensitivity derived from the HWSD2.0 dataset.

All spatial data were unified to the Krasovsky_{{{1940}}}_{{Albers}}} projected coordinate system and resampled to a consistent spatial resolution of 1 km $\times$ 1 km.

2.3 Construction of the Evaluation Model

This study employs the "Sensitivity-Resilience-Pressure" (SRP) model to evaluate land ecological vulnerability. The SRP model accounts for the inherent sensitivity of the ecosystem, its capacity to recover from disturbances (resilience), and the external stressors imposed by human activities (pressure).

2.3.1 Entropy Weight Method for Indicator Weighting To minimize subjective bias, the Entropy Weight Method is employed. For a given set of m indicators and n samples, the information entropy E_j for the j-th indicator is defined as:

$$E_j = -k \sum_{i=1}^{n} p_{ij} \ln(p_{ij})$$

where p_{ij} represents the normalized value of the indicator. The weight w_j is then derived based on the degree of information diversity. The Land Ecological Vulnerability Index (EVI) is calculated as:

$$EVI = \sum_{i=1}^{n} w_i \times x_i$$

2.3.2 Geodetector Analysis of Driving Forces The Geodetector model is used to detect spatial stratification heterogeneity and reveal driving forces. The explanatory power is measured by the q-statistic:

$$q = 1 - \frac{\sum_{h=1}^{L} N_h \sigma_h^2}{N\sigma^2}$$

where $h = 1, \ldots, L$ represents the strata of the explanatory variable; N_h and N are the number of units in stratum h and the entire study area; and σ_h^2 and σ^2 are the variances.

2.3.3 CA-Markov Model for Simulation The CA-Markov model integrates the ability of the Markov chain to predict the quantity of land-use change and the ability of Cellular Automata (CA) to simulate spatial patterns. This is used to project future vulnerability scenarios for 2030 and 2035.

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3 Results and Analysis

3.1 Spatiotemporal Evolution of Ecological Vulnerability

[Figure 1: see original paper]

The analysis reveals that from 2000 to 2024, the overall land ecological vulnerability in Gansu Province showed a fluctuating downward trend. The spatial distribution follows a "high in the northwest and low in the southeast" pattern. High-vulnerability areas are primarily concentrated in the Gobi Desert regions of the Hexi Corridor, while low-vulnerability areas are located in the humid southeastern parts of the province.

3.2 Driving Mechanisms

Using the Geodetector model, it was found that natural factors such as vegetation coverage (NDVI), annual evapotranspiration, and precipitation remain the primary drivers of ecological vulnerability. However, the influence of anthropogenic factors, represented by population density and land-use intensity, has shown an increasing trend in recent years.

3.3 Future Simulation Predictions

Simulation results for 2030 and 2035 under the baseline scenario suggest a continued improvement in the ecological landscape. The proportion of "very slight" and "slight" vulnerability areas is expected to expand, while "extremely vulnerable" areas are predicted to contract significantly, provided that current ecological restoration policies and climate-adaptive governance continue.

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4 Conclusion and Discussion

This study systematically analyzed the land ecological vulnerability of Gansu Province over a 24-year period. The integration of the SRP model with the CA-Markov simulation provides a robust framework for understanding both historical dynamics and future trajectories. The findings suggest that the synergy between ecological restoration projects (such as the Qilian Mountains restoration) and natural climatic shifts has promoted a steady reshaping of the regional ecological security pattern. These results provide a scientific basis for formulating targeted environmental policies and achieving sustainable development in Northwest China.

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