Spatiotemporal Evolution of Ecological Vulnerability and Its Driving Forces in Xinjiang: Postprint

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Abstract

Ecological vulnerability assessment is an important approach to understanding regional ecological conditions. Scientific evaluation of ecological vulnerability levels and their changes is of great significance for regional ecological protection and construction, as well as for achieving sustainable regional development. This study constructs an ecological vulnerability assessment index system for Xinjiang using the SRP model, combines it with spatial principal component analysis to build an ecological vulnerability index evaluation model, and analyzes the spatiotemporal evolution characteristics of ecological vulnerability in Xinjiang. The results show that: (1) From 2000 to 2018, the overall ecological sensitivity in Xinjiang was moderately sensitive, showing a pattern of high in the southeast and low in the northwest, mainly influenced by landscape fragmentation and soil erosion degree; ecological resilience was greatly affected by vegetation coverage, showing an overall pattern of high in the northwest and low in the southeast, with small variation amplitude and weak resilience; ecological pressure generally exhibited high values in the mountainous areas of the south and north, as well as in the central oasis and mountainous regions, and low in the southeast, with the main influencing factors being per capita GDP, agricultural dependency, and population density. (2) From 2000 to 2018, the overall ecological vulnerability in Xinjiang ranged from moderate vulnerability to severe vulnerability. Areas with low vegetation coverage in the south and north had higher ecological vulnerability levels, while the central high-altitude regions with abundant forests and grasslands had relatively lower ecological vulnerability levels; the comprehensive ecological vulnerability index in Xinjiang showed a trend of first increasing and then decreasing from 2000 to 2018. (3) Regarding the main driving forces of ecological vulnerability, seven indicators including agricultural dependency, population density, and land reclamation rate as human activity factors, and habitat quality index, landscape fragmentation, landscape resilience index, and annual average precipitation as natural

environmental factors were the primary single factors for ecological vulnerability changes in Xinjiang from 2000 to 2018; the interaction between changes in habitat quality index, landscape resilience index, landscape fragmentation index, vegetation coverage rate, and regional human activities constitutes the main driving force of ecological vulnerability in Xinjiang.

Full Text

Spatio-temporal Variation and Driving Forces of Ecological Vulnerability in Xinjiang

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Abstract: Ecological vulnerability assessment is a crucial approach for understanding regional ecological conditions, and scientifically evaluating ecological vulnerability levels and their changes holds great significance for regional ecological protection, restoration, and sustainable development. This study constructs an ecological vulnerability evaluation index system for Xinjiang using the SRP model and develops an ecological vulnerability index evaluation model based on spatial principal component analysis to analyze the spatio-temporal evolution characteristics of ecological vulnerability in Xinjiang. The results indicate: (1) The overall ecological sensitivity was at a moderate level, exhibiting a pattern of high in the southeast and low in the northwest, primarily influenced by landscape fragmentation and soil erosion degree. Ecological resilience was largely affected by vegetation coverage, showing a northwest-high, southeast-low pattern with small variation amplitude and weak recovery capacity. Ecological pressure generally displayed high values in the southern and northern mountainous areas and central oasis regions, and low values in the southeast, with per capita GDP, agricultural dependence, and population density as the main influencing factors. (2) From 2000 to 2018, Xinjiang' s overall ecological vulnerability ranged between moderate and severe fragility. Areas with low vegetation coverage in southern and northern Xinjiang exhibited higher ecological vulnerability levels, while high-altitude regions with abundant forests and grasslands in central Xinjiang showed relatively lower ecological vulnerability levels. (3) Regarding the main driving forces of ecological vulnerability, seven indicators —agricultural dependence, population density, and land reclamation rate from anthropogenic factors, and habitat quality index, landscape fragmentation, landscape resilience index, and annual average precipitation from natural environmental factors—were the primary single factors driving changes in Xinjiang' s ecological vulnerability from 2000 to 2018. The interactions between changes in habitat quality index, landscape resilience index, landscape fragmentation

index, vegetation coverage, and regional human activities constitute the main driving forces of ecological vulnerability in Xinjiang.

Keywords: SRP model; ecological vulnerability; spatio-temporal distribution; driving force; Xinjiang

Introduction

Ecological vulnerability assessment represents an important pathway for understanding regional ecological status. Scientifically evaluating ecological vulnerability levels and their changes carries significant implications for ecological protection, restoration, and the achievement of sustainable regional development. Xinjiang serves as the core area of the Silk Road Economic Belt, and changes in its ecological conditions directly impact social and economic sustainability. Quantifying regional ecological vulnerability and conducting quantitative classification facilitates the implementation of targeted ecological protection and restoration measures.

Previous studies have employed various methodologies for vulnerability assessment. Mahapatra et al. [**?**] utilized comprehensive index and analytic hierarchy processes to calculate coastal comprehensive vulnerability indices. Cao et al. [**?**] examined the coordination degree between ecological vulnerability coupling and economic poverty based on the SRP model. Wang et al. [**?**] constructed an ecological environmental vulnerability evaluation index system for Nanchang using the SRP model to analyze spatio-temporal distribution characteristics and driving forces. However, comprehensive studies on Xinjiang' s ecological vulnerability remain limited. Wang and Fan [**?**] constructed a Tarim River basin ecological vulnerability index to objectively reflect the importance and quality of ecological environment improvement in the basin. Xie et al. [**?**] comprehensively assessed wetland ecological vulnerability in the Ebinur Lake region using an integrated wetland ecological vulnerability assessment model. Wan et al. [**?**] conducted a comprehensive evaluation of ecological vulnerability in the Bosten Lake wetland.

Xinjiang is located in the hinterland of the Eurasian continent, characterized by alternating mountains and basins with complex and diverse landform types. The region comprises 14 prefecture-level cities and prefectures [**?**], with poor ecosystem stability and weak resistance, making it a typical ecologically fragile area in northwest China [**?**]. This study establishes an ecological vulnerability evaluation index system based on the SRP model, constructs an evaluation model through multi-source spatial data overlay, quantitatively analyzes the distribution of ecological vulnerability levels at different stages, and examines the evolution process and driving forces. The findings provide a scientific basis for implementing Xinjiang' s "ecological function zoning" and "territorial main function zoning," thereby ensuring sustainable regional ecological development.

1 Data Sources

The study primarily utilized Xinjiang land use data, digital elevation model (DEM) data, meteorological data, socio-economic statistical data, normalized difference vegetation index (NDVI) data, aridity index data, and soil erosion data. Data sources and processing methods are detailed in Table 1. Landscape pattern indices were extracted from Xinjiang land use type data using Fragstats 4.2 software. The original data were standardized using the range method, with specific procedures described in reference [?]. Based on research findings by Ma et al. [?], the soil erosion degree was classified into five levels (slight, light, moderate, intense, and extreme) using a graded assignment method, with values assigned as 1, 3, 5, 7, and 9, respectively.

2 Research Methods

2.1 Construction of the Index System

The SRP model comprises three dimensions: ecological sensitivity, ecological resilience, and ecological pressure.

Ecological Sensitivity refers to the sensitivity status of the ecological environment when subjected to disturbances, reflecting the series of state responses that occur when regional ecology is affected by internal and external influences [?], primarily including natural environmental factors such as topography, landform, and meteorology. Elevation, slope, and terrain relief were selected to reflect topographic and geomorphic characteristics. Land reclamation rate reflects the degree of land resource development and utilization [?]. Landscape fragmentation and soil erosion degree were chosen to reflect land use conditions and soil loss characteristics [?]. Aridity index, annual average precipitation, and $ $10°C accumulated temperature were selected to reflect climate characteristic changes [?].

Ecological Resilience refers to the self-recovery capacity of the ecological environment when subjected to external disturbances, closely related to the internal structure of the ecosystem [?]. Xinjiang is located in a temperate continental climate zone with vast desert areas. Vegetation coverage index and landscape resilience index were selected to reflect ecological recovery capacity, while habitat quality index was chosen to reflect habitat anti-interference and buffering capacity.

Ecological Pressure refers to the ecological effects produced when the ecological environment is subjected to external disturbances, primarily influenced by socio-economic development conditions and human activities [?, ?]. Unreasonable human activities generate numerous ecological problems. Therefore, population density and per capita cultivated land area were selected to reflect the impact of human activity intensity on the ecological environment. Agricultural dependence reflects the influence of agricultural activities on the ecological environment. Per capita GDP and secondary industry proportion reflect economic development and the impact of economic activities on the ecological environment.

The standardized spatial raster data were subjected to spatial principal component analysis (SPCA) to calculate the indicator weights for ecological sensitivity, ecological resilience, and ecological pressure under the SRP model. Principal component analysis was performed on Xinjiang' s ecological vulnerability from 2000 to 2018. For each period, the first k principal components with cumulative contribution rates greater than 85% were selected to construct the Xinjiang ecological vulnerability index model. The specific calculation formula is:

$$EVI_n = x_{1PC1}n + x_{2PC2}n + x_{3PC3}n + x_{4PC4}n + x_{5PC5}n + ... + x_{kPCk}n$$

where EVI_n represents the ecological vulnerability index for a given year (larger values indicate more fragile ecological environments and more obvious ecosystem damage), x_k represents the first k principal components with cumulative contribution rates greater than 85%, and n represents the year. $PC1, PC2, ..., PCk$ are the principal components.

2.2 Ecological Vulnerability Classification Standards

Following standardization to facilitate measurement and comparison, and referencing existing domestic and international ecological vulnerability evaluation standards [?], the ecological sensitivity index, ecological resilience index, ecological pressure index, and ecological vulnerability were classified into five levels according to Xinjiang's ecological environment characteristics (Table 5). Larger values indicate stronger degrees.

2.3 Ecological Vulnerability Level Area Transfer Matrix

The transfer matrix can quantitatively describe transitions between system states, containing both static data of ecological vulnerability in a region during a certain period and dynamic data of conversions between various types [?]. The mathematical expression of the ecological vulnerability transfer matrix is:

$$\begin{bmatrix} S_{11} & S_{12} & \cdots & S_{1n} \\ S_{21} & S_{22} & \cdots & S_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ S_{n1} & S_{n2} & \cdots & S_{nn} \end{bmatrix}$$

where i represents the ecological vulnerability type before transition, j represents the type after transition, and S_{ij} is the area converted from vulnerability type i to type j. Each row element in the matrix represents information about the ecological vulnerability type before transition to type j.

2.4 Ecological Vulnerability Driving Force Analysis

The Geodetector method proposed by Wang et al. [?] is a novel approach for revealing driving factors of spatial heterogeneity. The single-factor detection module uses factor explanatory power (q value) to measure the contribution of independent variable factors to dependent variable changes, testing whether spatial differentiation is caused by specific geographical factors. The factor interaction detection module [?] compares the sum of single-factor explanatory powers of two influencing factors with their interactive explanatory power to determine the impact on geographical phenomena after interaction. Among the five enhancement types, the nonlinear enhancement type has the strongest influence on ecological vulnerability changes. The factor detection formula is:

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

where q represents the explanatory power, indicating the degree to which a factor explains the spatial distribution of ecological vulnerability; $h = 1, \dots, L$ is the number of strata of the variable factor; 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 ecological vulnerability intensity in stratum h and the whole region, respectively. The value range of q is [0,1], and larger q values indicate greater influence on the spatial distribution of ecological vulnerability.

Factor detection and interaction detection were used to identify driving factors and their interactions for ecological vulnerability changes in Xinjiang. The difference in ecological vulnerability index between 2000 and 2018 served as the dependent variable, while the differences in the corresponding original index system served as independent variables for factor analysis. Following the data discretization method proposed by Wang et al. [?], the 15 influencing factors were discretized using the natural breaks classification method into 9 levels. A 10 km × 10 km fishnet grid was created, sample point data were extracted, and the data were imported into the Geodetector software for driving force analysis of spatial changes in Xinjiang' s ecological vulnerability.

3 Results and Analysis

3.1 Spatio-temporal Distribution of Ecological Sensitivity Index

The ecological sensitivity index was calculated and classified to obtain the spatial distribution of different sensitivity levels in Xinjiang across various periods (Fig. 2). Overall, Xinjiang exhibited increasing area of moderate sensitivity and decreasing area of extreme sensitivity, indicating a gradual reduction in ecological sensitivity. The southern Xinjiang region consistently showed higher sensitivity than northern Xinjiang across all periods, primarily dominated by severe sensitivity. Eastern Xinjiang' s ecological sensitivity was relatively moderate during 2000-2005 and 2010-2015, with sensitivity increasing from light and moderate to moderate and severe levels during 2005-2010 and 2015-2018, before decreasing again in 2018. Northern Xinjiang' s ecological sensitivity also decreased.

Xinjiang' s ecological sensitivity displayed distinct spatial distribution patterns. High-sensitivity areas (including extreme and severe sensitivity zones) were mainly distributed in southern Xinjiang, characterized by high temperatures, low precipitation, sparse vegetation, susceptibility to wind erosion, harsh natural conditions, and numerous ecological problems. Moderate sensitivity zones were concentrated in eastern and northern Xinjiang. Low-sensitivity areas (including light and slight vulnerability zones) were primarily distributed along the Altai Mountains, Tianshan Mountains, and Karakoram Mountains, where high vegetation coverage, relatively abundant precipitation, fewer extreme high-temperature events, and relatively intact forest and grassland ecosystems contribute to more stable ecosystem functions and stronger anti-interference capacity. Topography and landform determine soil texture and water distribution, thereby affecting vegetation growth and ecosystem stability [?], representing important factors influencing ecological vulnerability.

In the ecological sensitivity index, landscape fragmentation and soil erosion degree accounted for relatively large weights, indicating significant impacts from land use conditions and surface condition changes, followed by elevation and aridity index. Under similar natural conditions, human activities exert substantial influence on landscape fragmentation changes. Therefore, sensitivity in different regions is primarily affected by anthropogenic factors. Urban expansion occupies land, while construction projects and mineral resource development increase ecological sensitivity, consistent with findings by Huang et al. [?] and Ai et al. [?].

3.2 Spatio-temporal Distribution of Ecological Resilience Index

The ecological resilience index was calculated and classified to obtain the spatial distribution of different resilience levels across periods (Fig. 3). Overall, Xinjiang' s ecological resilience was weak, reflecting the region' s inherently dry and fragile ecological conditions. During the study period, areas with level 1 resilience (weak resilience) were dominant, accounting for the largest proportion but showing a fluctuating decline trend. The proportion of level 5 resilience areas (strong resilience) was smallest but increased annually, with a relative increase of 126.70%—the largest relative growth—indicating gradual improvement in Xinjiang' s ecological resilience.

From 2000 to 2018, Xinjiang' s ecological resilience exhibited a northwest-high, southeast-low pattern with small variation amplitude and relative stability. However, areas with strong ecological resilience showed a sporadic increasing trend, suggesting progressive environmental improvement and gradually enhanced resilience. The spatial distribution pattern of ecological resilience was broadly similar to vegetation coverage distribution—regions with high vegetation coverage, abundant forest and grass resources, and high biodiversity demonstrated strong ecological resilience. High-resilience areas (levels 4-5) were concentrated in the 喇叭口-shaped region of western-central Xinjiang (Yili Prefecture counties and cities), northern Altai, and northwestern Tacheng, particularly evident in 2018. These areas feature mountain forest and grassland ecosystems with high biodiversity and strong recovery capacity. Moderate-resilience areas (level 3) were scattered, mainly distributed around high-resilience areas and in central Changji Hui Autonomous Prefecture, Hami City, Turpan City, and parts of Kezhou, primarily in oasis zones, indicating significant impacts of human ecological engineering projects on ecological resilience. Low-resilience areas (levels 1-2) had the largest distribution area, mainly in Aksu Prefecture, Hotan Prefecture, Bayingolin Mongol Autonomous Prefecture, Turpan City, and Hami City, where simple underlying surfaces, sparse vegetation, and low habitat quality index [?] result in weak tolerance and slow recovery when subjected to external disturbances.

3.3 Spatio-temporal Distribution of Ecological Pressure Index

The spatial distribution variation of Xinjiang' s ecological pressure index from 2000 to 2018 shows that level 1 ecological pressure (low pressure) exhibited an overall increasing trend, while level 5 ecological pressure (high pressure) showed a decreasing trend. Level 3 ecological pressure accounted for the largest area proportion, level 2 showed fluctuating minor decreases, and level 4 ecological pressure increased significantly.

Xinjiang' s ecological pressure index was generally at a relatively low level from 2000 to 2018, with level 3 ecological pressure dominating. This is related to Xinjiang' s location in the western borderland with relatively low socio-economic development levels. The spatial distribution pattern showed high pressure in southern and northern mountainous areas, central oasis zones, and mountainous regions, and low pressure in eastern and southern desert hinterlands, closely associated with human socio-economic activities. Areas with intense socio-economic activities experienced greater ecological pressure, and vice versa. High ecological pressure zones were mainly distributed in Yili Prefecture, northern Altai, northwestern Tacheng, Urumqi City, southern Changji Prefecture, and Hotan Prefecture, Kashgar Prefecture, and southern Bayingolin Autonomous Prefecture. In 2000 and 2005, ecological pressure in the Karakoram Mountains of southern Xinjiang was relatively high, alleviating somewhat after 2010, which relates to gradually increased attention to ecological protection.

3.4 Ecological Vulnerability Index

3.4.1 Temporal Changes in Xinjiang' s Ecological Vulnerability Ecological vulnerability is determined by the comprehensive interaction of ecological sensitivity, ecological resilience, and ecological pressure. From 2000 to 2018, Xinjiang' s ecological vulnerability was overall above the moderate fragility level, closely related to high ecological sensitivity, weak ecological resilience, and high ecological pressure.

As shown in Fig. 5, ecological vulnerability in northern Xinjiang intensified from 2000 to 2018, particularly in Altai and southern Tacheng, while remaining relatively stable elsewhere. This relates to Altai and Tacheng being important agricultural and pastoral areas with high ecological pressure. Xinjiang' s ecological vulnerability distribution generally exhibited low vulnerability in northwestern and central mountainous and oasis areas, and high vulnerability in southeastern desert areas. High-vulnerability zones were mainly distributed in central Bayingolin Autonomous Prefecture, Hotan Prefecture, northern Kashgar Prefecture, southern Aksu Prefecture, southern Turpan and Hami cities, and eastern Altai and Tacheng regions. These areas are significantly influenced by the Gurbantünggüt Desert and Taklimakan Desert, with extensive gobi distribution in the Turpan-Hami Basin, located in wind outlets with strong wind erosion and high ecological vulnerability. Moderate-vulnerability zones were scattered, mainly in oasis belts around deserts with strong human disturbance and high ecological pressure. Low-vulnerability zones were concentrated in Yili Prefecture counties and cities, western Tacheng, northern Altai, and Changji Hui Autonomous Prefecture.

Xinjiang's ecological vulnerability is primarily influenced by ecological sensitivity and ecological pressure. Areas with low vegetation coverage, low precipitation, and high aridity exhibit high ecological vulnerability. Central high-altitude forest and grassland areas with rich biodiversity and relatively stable ecosystems show relatively low ecological vulnerability. The spatial distribution of ecological vulnerability is closely related to water resource distribution [**?**, **?**]. The southeastern desert region is a rainless center in Xinjiang, with widespread desert and gobi distribution, strong wind action, and severe desertification problems [**?**, **?**, **?**], resulting in high vulnerability. The Kunlun Mountains along southern Xinjiang have high altitudes but low vegetation coverage, also showing high regional ecological vulnerability. In oasis areas with better water resource conditions, human activities become the dominant factor affecting vulnerability [**?**].

3.4.2 Conversion Characteristics of Ecological Vulnerability Levels in Xinjiang Based on the transfer matrix formula, the transfer matrix of different ecological vulnerability levels in Xinjiang was calculated (Table 7). The results show significant conversions between different levels, particularly between adjacent levels. Slight vulnerability areas mainly converted to light vulnerability areas. Light vulnerability areas showed both negative and positive conversions, with a relatively large proportion converting to slight vulnerability areas. Approximately 21.92% of moderate vulnerability areas converted to light vulnerability areas, while 9.07% converted to severe and extreme vulnerability areas. Severe vulnerability areas mainly converted to extreme vulnerability and moderate vulnerability areas, with similar conversion proportions. The increase in extreme vulnerability area primarily originated from severe vulnerability areas, with 42.81% of extreme vulnerability converting to severe vulnerability, representing one of the main sources of increased severe vulnerability area. The increase in severe vulnerability area mainly came from conversions from extreme vulnerability and moderate vulnerability areas, accounting for 30.13%.

3.4.3 Changes in the Comprehensive Ecological Vulnerability Index

The comprehensive ecological vulnerability index in Xinjiang showed an initial increasing trend followed by a decreasing trend (Fig. 6). The maximum value appeared in 2010, with the largest increase amplitude from 2000 to 2005. After 2010, the growth rate slowed and stabilized, indicating that Xinjiang' s overall ecological environment has been gradually improving over the past 18 years, though continued ecological protection efforts are needed.

3.5 Driving Force Analysis of Ecological Vulnerability

3.5.1 Single-Factor Detection Analysis Geodetector single-factor detection uses the influence q value to represent the explanatory degree of each index to ecological vulnerability changes. The detection results show q values in descending order: agricultural dependence (0.68), landscape fragmentation (0.65), habitat quality index (0.61), landscape resilience index (0.58), population density (0.52), annual average precipitation (0.49), land reclamation rate (0.45), per capita GDP (0.42), per capita cultivated land area (0.38), secondary industry proportion (0.35), soil erosion degree (0.32), elevation (0.28), terrain relief (0.25), vegetation coverage (0.22), slope (0.18), and aridity index (0.15). Other factors had negligible q values.

The q values indicate that agricultural dependence, landscape fragmentation, habitat quality index, landscape resilience index, population density, annual average precipitation, and land reclamation rate had relatively large explanatory degrees for changes in Xinjiang' s ecological vulnerability from 2000 to 2018, while other factors had relatively minor explanatory degrees.

3.5.2 Multi-Factor Interaction Detection Analysis Ecological vulnerability changes typically result from the combined effects of social, vegetation, surface, topographic, and meteorological factors, with no single determinant factor capable of explaining Xinjiang' s ecological vulnerability changes, demonstrating the complexity of ecosystem changes. Geodetector interaction detection revealed that the interaction between agricultural dependence and landscape fragmentation had the strongest explanatory power for Xinjiang' s ecological vulnerability changes. Additionally, the synergistic effects of agricultural dependence with habitat quality index, vegetation coverage, landscape resilience, and land reclamation rate also showed strong influence. Single-factor detection results indicated that agricultural dependence had a substantial impact on Xinjiang' s ecological vulnerability changes, and its combination with landscape fragmentation index and habitat quality index produced even greater influence.

In pairwise interactions, the interactions between habitat quality index, landscape resilience index, landscape fragmentation index, vegetation coverage, and regional human activities constitute the main driving forces of ecological vulnerability changes in Xinjiang.

Discussion

Evaluation results are relative, and ecological vulnerability assessment is influenced by various factors including indicator selection and evaluation method choices. Landscape fragmentation and soil erosion degree are the two indicators with the largest weights in sensitivity, followed by elevation, aridity index, and terrain relief. Under similar natural conditions, human activities significantly impact landscape fragmentation changes. Therefore, sensitivity in different regions is primarily influenced by anthropogenic factors. Urban expansion occupies land, while construction projects and mineral resource development increase ecological sensitivity, consistent with findings by Huang et al. [?] and Ai et al. [?].

Analysis of Xinjiang' s ecological pressure index weights and spatial changes revealed that population growth exerts considerable pressure on urban development, thereby continuously increasing pressure on ecosystems, consistent with research by Huang et al. [?] and Yu [?]. In recent years, Xinjiang' s economy has developed rapidly, with per capita GDP increasing substantially, but this has simultaneously increased ecological environmental pressure. The inherently harsh natural environment leads to severe soil erosion, low vegetation coverage, and small habitat quality index values in Xinjiang, resulting in high ecological sensitivity, weak resilience, and high ecological vulnerability [?].

Based on Xinjiang's ecological vulnerability evaluation and driving force analysis results, the spatial distribution ranges and main ecological problems vary across the five vulnerability levels, necessitating differentiated ecological protection and construction strategies.

Conclusions

Under the dual effects of climate change and human activities, ecosystems in arid desert regions are undergoing significant changes. This study employs spatial principal component analysis to construct evaluation models for sensitivity, resilience, pressure, and ecological vulnerability in Xinjiang, analyzing their spatio-temporal distribution characteristics and driving forces. The main conclusions are as follows:

(1) From 2000 to 2018, landscape fragmentation and soil erosion degree were the main factors affecting Xinjiang' s ecological sensitivity, which was generally at a moderate level with a southeast-high, northwest-low pattern. Xinjiang' s ecological resilience was primarily influenced by vegetation coverage, remaining at a relatively low level with a northwest-high, southeast-

low pattern and small, stable variation amplitude. Xinjiang' s ecological pressure index was mainly influenced by per capita GDP, agricultural dependence, and population density, showing a pattern of high pressure in southern and northern mountainous areas and central regions, and low pressure in the southeast.

(2) From 2000 to 2018, Xinjiang' s ecological vulnerability ranged between moderate and severe fragility. Areas with low vegetation coverage, low precipitation, and high aridity in southern and northern Xinjiang exhibited high ecological vulnerability intensity. In contrast, high-altitude areas dominated by woodlands and grasslands in central Xinjiang, with rich biodiversity and relatively stable ecosystems, showed relatively low ecological vulnerability intensity.

(3) Significant conversions occurred between different vulnerability levels in Xinjiang from 2000 to 2018, particularly between adjacent levels. The comprehensive ecological vulnerability index showed an initial increase followed by a decrease, indicating that Xinjiang' s overall ecological environment has gradually improved over the past 18 years.

(4) Among anthropogenic factors, agricultural dependence, population density, and land reclamation rate, and among natural environmental factors, habitat quality index, landscape fragmentation, landscape resilience index, and annual average precipitation were the primary single factors influencing ecological vulnerability changes in Xinjiang from 2000 to 2018. The interactions between changes in habitat quality index, landscape resilience index, landscape fragmentation index, vegetation coverage, and regional human activities constitute the main driving forces of ecological vulnerability in Xinjiang.

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Figures

Figure 1: Figure 1

Source: ChinaXiv —Machine translation. Verify with original.

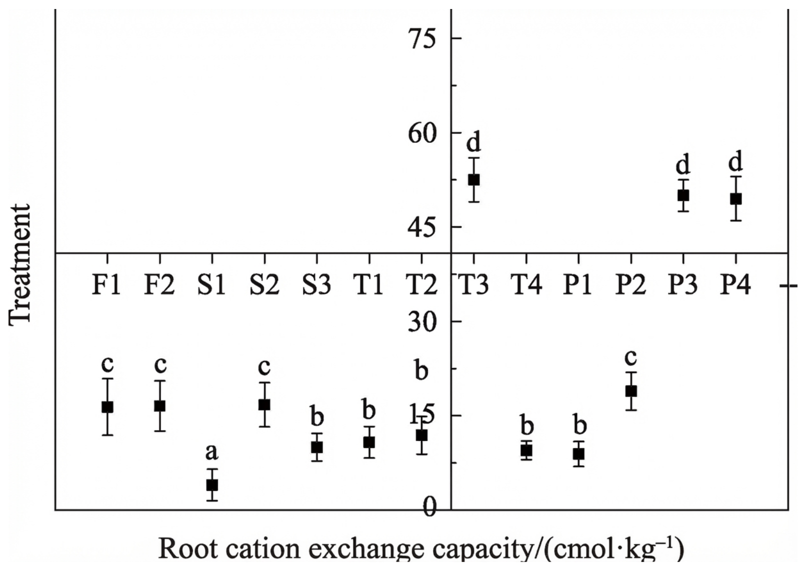

Figure 2: Figure 4