Spatiotemporal Evolution of Eco-economic Value and Its Influencing Factors in Resource-Dependent Regions: A Case Study of Counties in Inner Mongolia (Postprint)

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Abstract

Ecological civilization construction represents a major contemporary challenge, and research on the spatiotemporal differentiation of ecological economic value and its influencing factors holds significant importance for coordinated regional economic growth and ecological protection. Utilizing remote sensing monitoring data of land use from 1983 to 2023, this study employs the equivalent factor method to quantitatively assess ecological economic value at the county scale in Inner Mongolia and analyze its spatiotemporal evolution characteristics, while investigating the factors influencing spatial differentiation of ecological economic value through the Geographical Detector and Geographically Weighted Regression model. The results demonstrate that: (1) From 1983 to 2023, substantial changes occurred in land use types across Inner Mongolia, with grassland exhibiting the largest transferred-out area and serving as the primary conversion source for cropland. (2) During this period, ecological economic value in Inner Mongolia declined from 663.41×10^8 yuan to 650.40×10^8 yuan, representing a total loss of 13.01×10^8 yuan; spatially, ecological economic value displays an overall pattern of "higher in the north and lower in the south" and "higher in the east and lower in the west." (3) Annual average temperature and Normalized Difference Vegetation Index (NDVI) emerge as the dominant factors influencing ecological economic value in Inner Mongolia, with annual average temperature exhibiting a negative correlation with ecological economic value, while NDVI' s influence shows a trend of increasing from west to east and transitioning from negative to positive values. These findings can inform ecological protection policy formulation in Inner Mongolia, emphasizing the need to balance mutual transformations among different land use types to synergistically advance economic and social development alongside ecological and environmental protection.

Full Text

Spatio-temporal Evolution of Ecological-Economic Value and Influencing Factors in Resource-Dependent Regions: A Case Study of Inner Mongolia Counties

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Abstract: Ecological civilization construction represents a critical challenge of our era, and investigating the spatio-temporal differentiation of ecological-economic value and its driving factors holds significant importance for coordinating regional economic growth with ecological protection. Based on land-use remote sensing monitoring data from 1983 to 2023, this study employs the equivalent factor method to quantitatively assess ecological-economic value at the county scale in Inner Mongolia and analyze its spatio-temporal evolution characteristics. Geodetector and geographically weighted regression models are utilized to explore the influencing factors underlying spatial differentiation in ecological-economic value. The results demonstrate that: (1) Land-use types in Inner Mongolia underwent substantial changes between 1983 and 2023, with grassland experiencing the largest area reduction and serving as the primary source for cultivated land conversion. (2) The region' s ecological-economic value decreased from 663.41 billion yuan in 1983 to 650.40 billion yuan in 2023, representing a total loss of 13.01 billion yuan. Spatially, ecological-economic value exhibited a distinct pattern of "high in the north and low in the south" and "high in the east and low in the west." (3) Mean annual temperature and the Normalized Difference Vegetation Index (NDVI) emerged as the dominant factors influencing ecological-economic value in Inner Mongolia, with temperature showing a negative correlation while NDVI demonstrated a positive relationship that increased from west to east, transitioning from negative to positive values. These findings provide a scientific reference for formulating ecological protection policies in Inner Mongolia, emphasizing the need to balance transformations among different land-use types to synergistically advance economic development and ecological conservation.

Keywords: ecological-economic value; ecological value equivalent; spatio-temporal analysis; geographically weighted regression; Inner Mongolia

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1 Introduction

Rapid urbanization in recent years has fundamentally altered regional land-use structures, severely impacting ecosystem spatial patterns and consequently exerting adverse effects on regional ecological-economic value. The 19th National Congress of the Communist Party of China first explicitly identified ecological civilization construction as a millennium-long project crucial to the sustainable development of the Chinese nation. The 20th Party Congress report further emphasized that "we must firmly establish and practice the concept that lucid waters and lush mountains are invaluable assets, and plan development from the perspective of harmonious coexistence between humanity and nature." This creative "Two Mountains" theory pursues the coordinated unification of economic development and environmental protection, becoming an essential component of Xi Jinping' s Thought on Ecological Civilization. The positive interaction between socioeconomic development and ecological environments is intimately connected to human sustainable development. Against the backdrop of global sustainable development goals, exploring the characteristics and patterns of ecological-economic value changes holds significant importance for regional sustainability.

Current scholarly research on ecosystems primarily focuses on ecosystem service value, eco-economic system coordination, and ecological product value realization, examining perspectives from wetlands, forests, grasslands, lakes, and cultivated land at national, provincial, municipal, and county scales. Despite substantial achievements in ecosystem service value accounting, notable limitations persist: first, county-level unit studies remain insufficient, accounting for less than 15% of research, making it difficult to capture administrative boundary permeability effects and spatial lags in policy response; second, the regulatory role of cultural elements in ethnic regions has long been marginalized, such as the spatial equilibrium effect of Mongolian seasonal rotational grazing systems on grassland carrying capacity, with estimated ecological-economic contribution deviations reaching as high as 19.3%. This underscores the urgency of constructing localized assessment frameworks.

As China' s largest and most comprehensive ecological functional zone in the north, Inner Mongolia has long maintained the dual phenomena of decreasing forest and grassland areas alongside "desert-to-oasis" transformations in sandy land. However, as a typical resource-dependent region, Inner Mongolia faces a special "resource curse" effect. On one hand, its reserves of 17 mineral resources, including coal and rare earths, rank first nationally (accounting for 28.7% of the national total), forming a significant "coal-gold" industrial chain path dependency. On the other hand, this development model has led to prominent ecological threshold effects, with every 10,000 tons of coal extraction triggering 0.33 hectares of land degradation and an ecosystem service value decay rate ($1.8\% \cdot a^{-1}$) far exceeding the national average ($0.9\% \cdot a^{-1}$). To address these challenges, Inner Mongolia issued the "14th Five-Year Plan for Ecological Environmental Protection" in 2021, promoting high-quality socioeconomic development and ecosystem quality improvement through four dimensions: ecological environmental quality, green development, ecosystem development, and environmental risk prevention. Against this backdrop, deeply investigating the spatio-temporal evolution patterns of ecological-economic value in resource-dependent regions holds important theoretical and practical significance for resolving the "development-protection" dilemma.

Drawing inspiration from Liu Chunla et al.' s research approach to ecological-economic value, this study examines 101 county-level units in Inner Mongolia as research objects. To address limitations in the traditional ecological value equivalent method' s regional applicability (such as unquantified water stress in arid zone vegetation), we innovatively revise Xie Gaodi' s equivalent factor standards by introducing Inner Mongolia' s main grain crop yields and market prices (e.g., corn, wheat) to recalculate unit equivalent factor values, making them more aligned with regional ecological-economic realities. Building upon Geodetector and geographically weighted regression models, the study further breaks through traditional static evaluation paradigms, revealing the spatially heterogeneous driving mechanisms of mean annual temperature and NDVI on ecological-economic value, providing precise targets for zonal governance. In summary, through theoretical revision, methodological innovation, and practical application, this research not only deepens scientific understanding of ecological-economic value evolution patterns in arid and semi-arid regions but also constructs a "data-driven + culturally-empowered" governance framework, offering quantifiable and operable decision-making tools for regional ecological security and high-quality development.

1.1 Study Area Overview

Inner Mongolia Autonomous Region is located along China' s northern border, spanning approximately 2,400 km from east to west and 1,700 km from north to south, with a total area of 118.3×10^{4} km^2. The administrative system comprises 12 prefecture-level cities and 103 banners and counties. Geomorphologically, the region' s average elevation ranges between 1,000-1,500 m, with terrain rising stepwise from east to west, forming significant natural geographic gradients: the eastern Greater Khingan Mountains host cold-temperate coniferous and temperate deciduous broad-leaved forests; the central Hulunbuir and Xilingol typical grassland belts; and the western Alxa Plateau transitions to desert steppe and desert landscapes.

Note: Based on the standard map with review number GS(2024)0650 from the Ministry of Natural Resources Standard Map Service website, with no modifications to base map boundaries. The same applies below.

[Figure 1: see original paper] Schematic diagram of the study area

1.2 Data Sources

Land-use data were obtained from the Resources and Environmental Science Data Center of the Chinese Academy of Sciences (https://www.resdc.cn/), including Landsat TM/ETM remote sensing image interpretation data from 1983-2023 with 30 m $\times$ 30 m spatial resolution. Referencing Xie Gaodi et al.' s ecological value equivalent land classification system, ArcGIS software was used to extract land-use raster images for Inner Mongolia using the administrative boundary as a mask, with secondary types reclassified. Crop planting area and yield data were sourced from the *Inner Mongolia Statistical Yearbook* and *China Statistical Yearbook*, while national grain average prices were derived from the *National Agricultural Product Cost-Benefit Data Compilation*.

1.3 Methods

1.3.1 Ecological-Economic Value Accounting Based on Ecological Value Equivalents (1) Ecological Value Equivalent and Ecological-Economic Value

Based on Xie Gaodi et al.' s ecological value equivalent standards for different ecosystems (Table 1), this study calculates the economic value of one ecological service equivalent factor in Inner Mongolia by combining regional socioeconomic development conditions. The economic value created by main grain yields per unit area is revised according to the standard that "the economic value of one standard unit equals one-seventh of the market value of national average grain yield." The calculation formula is:

$$E_a = \frac{1}{7}\sum_{i=1}^{n}\frac{m_i p_i q_i}{M}$$

where E_a represents the value of one equivalent factor (yuan · hm^{-2}); n is the number of grain crop types; m_i, p_i, and q_i are the area (hm^2), average price (yuan · kg^{-1}), and yield (kg · hm^{-2}) of the i-th grain crop, respectively; and M is the total planting area of all grain crops. This yields an economic value of 2,894.03 yuan per standard unit ecological service value equivalent factor in Inner Mongolia.

(2) Ecological-Economic Value Accounting

According to theoretical elaborations on ecological value equivalents, the total ecological value equivalent for each county in Inner Mongolia is calculated based on the respective value equivalents of six ecosystem types: forestland, grassland, cultivated land, wetland, rivers/lakes, and desert. In actual quantification, the ecological-economic value of each county is obtained by summing the value equivalents of individual ecosystems at the county level:

$$Q = \sum_{j=1}^{6} S_j \times E_j$$

$$H = Q \times U$$

where Q represents the ecological value equivalent of a county; j denotes a specific ecosystem; S_j is the area of ecosystem j; E_j is the ecological value equivalent of ecosystem j; H is the ecological-economic value of the county; and U is the economic value of one ecological service value equivalent factor.

1.3.2 Spatial Autocorrelation Analysis Global Moran' s I index is used to analyze the spatial agglomeration characteristics of ecological-economic values in Inner Mongolia. The formula is:

$$I = \frac{n\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}(x_i - \bar{x})(x_j - \bar{x})}{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}\sum_{i=1}^{n}(x_i - \bar{x})^2}$$

where I is the spatial covariance sum; n is the number of regional objects; i is the target region; j is the neighboring region; w_{ij} is the spatial weight matrix between regions i and j; x_i is the ecological-economic value of county i; $\bar{x}$ is the arithmetic mean of attribute values across spatial units; x_j is the ecological-economic value of county j; and s^2 is the population variance.

1.3.3 Geodetector Geodetector is an analytical model for detecting relationships between geographic phenomena and their influencing factors under spatial differentiation, effectively identifying dominant factors. The formula is:

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

where q represents spatial heterogeneity; n is the sample size; σ^2 is the variance; L is the number of zones; h is a specific region; n_h is the sample size in subregion h; and σ_h^2 is the variance within subregion h.

1.3.4 Geographically Weighted Regression Model The geographically weighted regression model is a spatial linear regression model improved from traditional linear regression, incorporating spatial weight matrices to account for spatial non-stationarity. It explores relationships between spatial variation and driving factors at certain scales:

$$y_i = \beta_0(V_i) + \sum_{k=1}^{n} \beta_k(V_i)x_{ik} + \varepsilon_i$$

where y_i is the dependent variable; $\beta_0(V_i)$ is the intercept constant for sample i; n is the number of grid cells; k is the total number of grid cells involved in spatial analysis; $\beta_k(V_i)$ is the regression coefficient for sample i at the k-th spatial variable; x_{ik} is the standardized influencing factor; and ε_i is the random error.

2 Results and Analysis

2.1 Spatio-temporal Evolution Characteristics of Ecological-Economic Value

2.1.1 Ecological Value Equivalent and Ecological-Economic Value As shown in Table 2, Inner Mongolia's ecological-economic value demonstrates a significant "high in the east, low in the west" gradient differentiation pattern. Eastern regions (Hulunbuir City, Hinggan League, and eastern Tongliao City) account for 63.7% of ecological value equivalents and 58.9% of ecological-economic value; central regions (Hohhot City, Ulanqab City agro-pastoral ecotone) account for 22.1% of ecological value; while western regions (Ordos City, Bayannur City, and Alxa League) account for less than 14.2%. High-value clusters concentrate in the east, such as Oroqen Autonomous Banner (493.06$\times10^{8}$ yuan) and Ergun City (421.86$\times10^{8}$ yuan); medium-value transition zones dominate the center, such as Wuchuan County (240.88$\times10^{8}$ yuan) and Helin 格尔 County (21.86$\times10^{8}$ yuan); low-value areas concentrate in the west, such as Wuda District (14.98$\times10^{8}$ yuan) and Alxa Right Banner (0.64$\times10^{8}$ yuan).

Ecological value equivalent and ecological-economic values of Inner Mongolia counties

2.1.2 Ecological-Economic Value of Different Land-Use Types Land-use structure in Inner Mongolia from 1983 to 2023 (Table 3) reveals that grassland is the dominant land type, accounting for approximately 44% of the total area, followed by desert and forestland at about 21% and 15%, respectively. River and lake areas are the smallest, constituting roughly 1% of the total area. During the study period, the overall trend showed decreases in forestland, grassland, and wetland areas, while cultivated land, rivers/lakes, and desert areas increased. Grassland experienced the largest reduction at 13,939 km^2; cultivated land increased the most by 2,895 km^2; desert area expanded by 2,238 km^2; forestland decreased by 1,488 km^2; and wetland area decreased by 1,487 km^2. In terms of change rates, cultivated land showed the greatest fluctuation, while wetland area change ranked second with a reduction of 1,487 km^2.

Structure of land use in Inner Mongolia from 1983 to 2023

2.1.3 Temporal Changes in Ecological-Economic Value Based on Inner Mongolia' s ecological-economic values from 1983 to 2023, temporal intervals of 1983-2003, 2003-2013, and 2013-2023 were selected to analyze overall changes across different periods (Figure 2). The results show that ecological-economic value decreased significantly between 1983 and 2023. Specifically, 73 counties exhibited negative changes, with the maximum decrease reaching 1.8$\times10^{8}$ yuan, while 28 counties showed positive changes with maximum growth of 0.25$\times10^{8}$ yuan, distributed sporadically.

Ecological-economic values for different land-use types in Inner Mongolia reached 660.97$\times10^{8}$ yuan, 652.12$\times10^{8}$ yuan, 703.18$\times10^{8}$ yuan, and 650.40$\times10^{8}$ yuan in 1983, 1993, 2003, and 2023, respectively (Table 4), showing a generally decreasing trend. Grassland is the primary contributor to ecological-economic value among land-use types, followed by forestland and wetland. Additionally, cultivated land, rivers/lakes, and desert showed overall positive growth in ecological-economic value, while grassland and wetland values declined gradually. The ecological-economic value increase driven by cultivated land and desert area expansion could not offset the decrease caused by grassland and wetland area reduction, resulting in an overall negative ecological effect from Inner Mongolia' s land-use structure.

Ecological-economic values of different land use types in Inner Mongolia from 1983 to 2023

[Figure 2: see original paper] Temporal variation of ecological-economic values in Inner Mongolia

2.1.4 Spatial Changes in Ecological-Economic Value Figure 3 illustrates that Inner Mongolia' s ecological-economic value exhibits a "high in the north and low in the south, high in the east and low in the west" spatial distribution pattern. Low-value areas are concentrated in southern Inner Mongolia, such as Wuda District, Bayan Obo Mining District, Qingshan District, Huimin District, Kangbash District, Xincheng District, and Jining District. High-value areas are mainly distributed in eastern and northern regions, including Xin Barag Right Banner, Xin Barag Left Banner, East Ujimqin Banner, West Ujimqin Banner, Abag Banner, Sonid Left Banner, Sonid Right Banner, Siziwang Banner, Urad Middle Banner, and Urad Rear Banner. Medium-value areas are scattered throughout eastern, central, and western Inner Mongolia.

[Figure 3: see original paper] Spatial distribution of ecological-economic values in Inner Mongolia

2.2 Spatial Autocorrelation Analysis

To further analyze spatial agglomeration effects of ecological-economic value, GeoDa software was used to calculate the global Moran' s I index for county-level ecological-economic values in Inner Mongolia from 1983 to 2023 (Table 5). The results show that the global Moran' s I values ranged between 0.409-0.447, with all P-values passing significance tests at the 0.01 level, indicating that county-level ecological-economic values in Inner Mongolia are not randomly distributed but exhibit high spatial positive correlation with obvious spatial clustering effects that remained relatively stable over time.

Global Moran' s indices for ecological-economic values in Inner Mongolia from 1983 to 2023

2.3 Analysis of Influencing Factors

2.3.1 Factor Selection Changes in ecological-economic value result from the combined effects of multiple factors, with natural, social, and economic factors playing key roles. Drawing upon previous research and considering data availability, this study selected 10 factors (Table 6) to construct a "natural-social-economic" influencing factor indicator system.

Detection factors for spatial evolution of ecological-economic values in Inner Mongolia

2.3.2 Model Construction and Factor Identification Table 7 shows that elevation, total population, urbanization rate, gross regional product, per capita disposable income of all residents, and total retail sales of consumer goods failed to pass significance tests at the 0.05 level and were therefore excluded. The remaining four factors significantly influence the spatial distribution of ecological-economic value in Inner Mongolia. Ranked by explanatory power (q-value), the factors are: mean annual temperature > NDVI > mean annual precipitation > population density.

Geo-detector results

Based on Geodetector results, the remaining four factors were linearly regressed with ecological-economic value (Table 8). Mean annual precipitation and population density showed P-values greater than 0.05 and were excluded. After conducting linear regression again with mean annual temperature and NDVI, model fit improved substantially, passing probability tests. Therefore, mean annual temperature and NDVI were identified as the dominant driving factors of ecological-economic value in Inner Mongolia. This approach draws upon Fotheringham et al.' s "global-local modeling" framework.

Results of linear regression

2.3.3 Spatial Heterogeneity Analysis Based on GWR Model A geographically weighted regression model was fitted using the two dominant driving factors, with results shown in Table 9. The model demonstrates excellent fit with an adjusted R^2 of 0.9727, indicating that the two dominant driving factors jointly explain 97.27% of the spatial variation in the dependent variable. The model is highly reliable without overfitting, and the extremely high explanatory power proves significant spatial non-stationarity in variable relationships.

Results of the geographically weighted regression model

Visualized results of dominant factor impact coefficients (Figure 4) reveal significant heterogeneity in how mean annual temperature and NDVI affect county-level ecological-economic value distribution in Inner Mongolia. Temperature shows a globally negative correlation with ecological-economic value. NDVI exhibits positive correlations in central and eastern regions but negative correlations in western regions, with impact coefficients in the east significantly higher than in central and western areas, displaying a spatial pattern of decreasing from east to west.

[Figure 4: see original paper] Spatial heterogeneity of influencing factors on ecological-economic values in Inner Mongolia

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3 Discussion

As both a critical ecological barrier zone and resource-based economy in northern China, Inner Mongolia’ s spatio-temporal evolution of ecological-economic value profoundly reflects the complex interplay of human-environment relationships under multiple pressures including climate change, policy intervention, and regional development demands. Between 1983 and 2023, the region’ s total ecological-economic value showed an overall declining trend (a loss of 13.01 billion yuan), similar to the attenuation pattern of ecosystem service values in China’s northern agro-pastoral ecotone during the same period, yet with distinct resource-region characteristics in its underlying driving mechanisms.

Grassland, as the primary contributor to ecological value (accounting for 44%-48%), experienced continuous area reduction (13,939 km^2) and quality degradation, becoming the core driver of value loss. Although cultivated land and desert expansion generated partial ecological gains (cultivated land increased by 2,895 km^2), their per-unit value equivalents are only one-third to one-half of grassland’ s, resulting in a situation where “low-quality expansion” cannot offset “high-quality contraction.” This aligns with findings on the unsustainable substitution effects of agricultural reclamation on natural ecosystems in semi-arid regions. Notably, wetland area reduction (-9.2%) further weakened regional hydrological regulation and carbon sequestration capacity, confirming the threshold effects of water resource constraints on ecosystem functions in arid zones, particularly in the Hetao Irrigation District and Hulun Lake Basin where groundwater decline and salinization intensification have breached wetland ecological thresholds, leading to irreversible service value attenuation.

Spatially, the study reveals a significant “high in the east, low in the west” differentiation pattern. Eastern regions such as the Greater Khingan forest area and Hulunbuir grassland maintain high ecological-economic values due to high forest coverage, intact wetland preservation, strict control of national nature reserves, and low-intensity grazing traditions. In contrast, western regions like Alxa League and Ordos City exhibit “dual-low” characteristics under the dual impacts of mining development and desertification, forming a typical “resource curse” phenomenon. This spatial differentiation essentially results from the coupling of three gradients: natural endowment, human activity, and policy response. For example, coal mining in Otog Banner has caused surface subsidence over 150 km^2, with groundwater system destruction reducing productivity in adjacent grasslands by 30%, demonstrating strong ecological resilience in

Mongolian-inhabited banners under similar natural conditions—possibly related to grassland resilience maintained by traditional pastoral culture.

The study further reveals temporal lag effects and regional adaptability differences in policy interventions. The brief value rebound in 2003 (an increase of 51.06 billion yuan) synchronized highly with the implementation of the "Returning Grazing to Grassland" project and grassland ecological compensation policies, but policy marginal benefits diminished after 2013 with values declining again, indicating that single fiscal compensation cannot sustain long-term conservation dynamics. Additionally, while strict control in eastern nature reserves safeguards ecological foundations, it also suppresses community participation (e.g., insufficient development of Naadam culture-related ecotourism), leading to a "protection-development" disconnect. Meanwhile, the "destroy-first, restore-later" model in western mining areas incurs restoration costs as high as 3-5 times mining revenues, highlighting insufficient regional refinement in institutional design. These findings echo UNEP's advocacy for "adaptive governance"—ecological policies must embed local cultural capital and livelihood patterns. For instance, Mongolian rotational grazing traditions' spatial equilibrium effects on grassland carrying capacity remain inadequately incorporated into current policies, with potential ecological-economic contribution estimation deviations of 19.3%.

Notably, the study found that Mongolian-inhabited banners (such as Xin Barag Right Banner) exhibit higher ecological values under identical natural conditions, possibly related to rotational grazing traditions maintaining grassland resilience. Although data limitations prevented direct quantification of cultural elements, this finding provides new perspectives for understanding the particularity of ecological-economic systems in ethnic regions. The lag effect is most pronounced in Mongolian-Han intermingling zones (such as Horqin Right Front Banner), reflecting cross-administrative coordination needs in ecological management. It should be noted that due to data availability constraints, ethnic cultural elements are primarily represented through economic indicators indirectly; future research should construct a "culture-ecology" coupled indicator system for deeper investigation.

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4 Conclusions

This study reveals four key findings: (1) Land-use types in Inner Mongolia changed significantly between 1983 and 2023. Except for decreases in grassland, forestland, and wetland areas, cultivated land, rivers/lakes, and desert areas increased to varying degrees, with grassland experiencing the largest area transfer as the main source for cultivated land conversion. In terms of value contribution across land-use types, grassland is the primary contributor to ecological-economic value, forestland has the highest per-unit ecological-economic value, and desert has the smallest value contribution.

(2) Inner Mongolia' s ecological-economic value decreased from 663.41 billion

yuan in 1983 to 650.40 billion yuan in 2023, representing a total loss of 13.01 billion yuan. Spatially, ecological-economic value exhibits a "high in the north and low in the south, high in the east and low in the west" distribution pattern. County-level ecological-economic values show high spatial positive correlation with obvious spatial clustering effects that remained relatively stable over time.

(3) Geodetector results indicate that mean annual temperature and NDVI are the dominant factors influencing ecological-economic value in Inner Mongolia. Geographically weighted regression model results show that temperature is negatively correlated with ecological-economic value, while NDVI demonstrates a positive relationship that increases from west to east, transitioning from negative to positive values.

(4) The study constructs a "data-driven + culturally-empowered" governance framework that provides quantifiable and operable decision-making tools for ecological security and high-quality development in similar resource-dependent regions. Future research should establish a "culture-ecology" coupled indicator system to deepen understanding of the particularity of ecological-economic systems in ethnic regions.

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