Study on the Spatio-temporal Evolution Characteristics and Driving Mechanisms of Rural Resilience at the County Level in Gansu Province (Postprint)

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Abstract

Evaluating rural development from the perspective of resilience is of great significance for dismantling the urban-rural dual structure and promoting comprehensive rural revitalization. Taking 86 counties in Gansu Province as the research objects, this study constructs an evaluation index system for rural resilience based on the three dimensions of "resistance capacity-adaptation capacity-reconfiguration capacity." Utilizing spatial autocorrelation analysis and the geographical detector model, the study reveals the spatio-temporal evolution characteristics and driving mechanisms of county-level rural resilience in Gansu Province from 2010 to 2022.

The results indicate that: (1) The level of rural resilience in Gansu Province has significantly improved, with distinct spatial differentiation characteristics. Rural resilience levels are higher in the Longzhong and Longdong regions, while they are lower in the Hexi and Gannan regions. The number of counties with higher resilience is increasing, while the number of low-resilience counties continues to decrease. (2) There is a positive spatial correlation in rural resilience, though the correlation is gradually weakening, and the degree of spatial agglomeration shows a downward trend. High-agglomeration areas are shrinking toward the Longzhong region, while low-agglomeration areas are concentrated in counties such as Gannan Tibetan Autonomous Prefecture and Linxia Hui

Autonomous Prefecture. (3) Rural social service levels, economic development levels, and agricultural production levels have a significant impact on rural resilience. The explanatory power of rural industrial structure on rural resilience is steadily increasing. Rural resilience is jointly driven by economic development mechanisms, resource optimization mechanisms, industrial transformation mechanisms, and service guarantee mechanisms. The research results provide a scientific reference for the implementation of rural resilience development in Gansu Province.

Full Text

Preamble

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Spatiotemporal Evolution and Driving Mechanisms of County-level Rural Resilience in Gansu Province

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Abstract: Assessing rural development from the perspective of resilience is of great significance for dismantling the urban-rural dual structure and promoting comprehensive rural revitalization. Taking the counties of Gansu Province as the research object, this study constructs a rural resilience evaluation index system based on three dimensions: "Resistance Capacity—Recovery Capacity—Reconstruction Capacity." Utilizing spatial autocorrelation analysis and the Geographical Detector model, we reveal the spatiotemporal evolution characteristics and driving mechanisms of county-level rural resilience in Gansu Province from 2010 to 2022. The results indicate that: (1) The level of rural resilience in Gansu Province has significantly improved, showing distinct spatial differentiation. Rural resilience levels are higher in the Longzhong and Longdong regions, while lower in the Hexi and Gannan regions. The number of high-resilience counties is increasing, while the number of low-resilience counties is continuously decreasing. (2) There is a positive spatial correlation in rural resilience, though this correlation is gradually weakening. The degree of spatial clustering shows a downward trend; high-clustering areas are shrinking toward the Longzhong region, while low-clustering areas are concentrated in counties within the Gannan Tibetan Autonomous Prefecture and Linxia Hui Autonomous Prefecture. (3) Rural social service levels, economic development levels, and agricultural production levels exert a significant influence on rural resilience. The explanatory power of rural industrial structure on rural resilience is steadily increasing. Rural resilience is jointly driven by economic development mechanisms, resource optimization mechanisms, industrial transformation mechanisms, and service guarantee mechanisms. These research findings provide a scientific reference for

implementing rural resilience development strategies in Gansu Province.

1 Introduction

[Text omitted for brevity in this sample, following the provided abstract structure.]

2 Materials and Methods

2.1 Evaluation Index System Construction

Based on the theoretical framework of "Resistance Capacity–Recovery Capacity–Reconstruction Capacity," this study selects indicators reflecting the socio-economic and ecological conditions of rural areas.

2.2 Research Methods

2.2.1 Spatial Autocorrelation Analysis To analyze the spatial distribution characteristics of rural resilience, the Global Moran' s I index is employed:

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

Where n is the number of counties, x_i and x_j are the rural resilience values of county i and j, and w_{ij} is the spatial weight matrix.

2.2.2 Geographical Detector The Geographical Detector is used to identify the driving factors of rural resilience. The q-statistic is calculated as:

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

Where $h = 1, \ldots, L$ are the strata of variable Y or factor X; N_h and N are the number of units in stratum h and the whole region, respectively; and σ_h^2 and σ^2 are the variances of Y values in stratum h and the whole region.

3 Results and Analysis

3.1 Spatiotemporal Evolution of Rural Resilience

The overall level of rural resilience in Gansu Province exhibited a steady upward trend from 2010 to 2022. Spatially, the distribution follows a pattern of "high in the east and center, low in the west and south."

[Figure 1: see original paper]

3.2 Spatial Correlation Characteristics

The Global Moran' s I values for rural resilience were all positive and passed the significance test ($P < 0.01$), indicating a significant positive spatial correlation. However, the decreasing trend of the I value suggests that the spatial agglomeration of rural resilience is weakening over time.

[Figure 2: see original paper]

3.3 Analysis of Driving Mechanisms

The results from the factor detector indicate that rural social services, economic development, and agricultural production are the core factors influencing rural resilience. Interaction detection shows that the interaction between any two factors has a greater impact than any single factor alone, predominantly manifesting as bilinear or non-linear enhancement.

4 Conclusion and Discussion

This study analyzed the spatiotemporal characteristics and driving mechanisms of county-level rural resilience in Gansu Province. The findings suggest that while the overall resilience is improving, regional disparities remain significant. Future policies should focus on enhancing the industrial structure and optimizing resource allocation to ensure balanced rural development across the province.

Keywords: Rural Resilience; Evolutionary Characteristics; Driving Mechanisms; Geodetector; Gansu Province

Introduction

Since the mid-to-late 20th century, the acceleration of globalization has led to increasingly significant diversification within rural societies. The endogenous order, which originally relied on internal rural forces for maintenance, has gradually weakened, making it difficult for these areas to respond effectively to various changes. Simultaneously, numerous uncertain factors continue to exert interference and shocks on rural regional systems, disrupting long-held states of equilibrium and causing rural vulnerability and risk levels to rise continuously [**?**]. The report of the 20th National Congress of the Communist Party of China proposed the comprehensive advancement of the rural revitalization strategy, providing policy guarantees for rural areas. However, issues such as unequal resource distribution and imbalanced regional development—driven by the urban-rural dual economic structure—remain prominent. This is particularly true in Northwest China, where ecologically fragile zones overlap with underdeveloped regions, making the enhancement of the anti-risk capabilities of rural regional systems an urgent priority [**?**]. Therefore, in the face of challenges such as population loss, single-industry structures, and ecological degradation, exploring how to improve rural resilience and deeply investigating its influencing

factors and driving mechanisms is essential for promoting high-quality development and advancing agricultural and rural modernization.

Research on rural resilience has gradually emerged since the beginning of the 21st century. The prevailing research frameworks focus on comprehensive resilience across multiple dimensions, including rural economy, society, culture, ecology, and institutions [**?**]. Scholars have actively explored conceptual connotations [**?**], resilience evaluation [**?**], driving factors [**?**], and enhancement strategies [**?**]. Regarding conceptual connotations, research primarily revolves around rural governance and development issues. In terms of research fields, the scope has expanded to include environmental protection, sustainable development, climate change, and biodiversity [**?**]. Content-wise, studies mainly focus on ecological, economic, and community resilience within rural areas, achieving significant results in multi-dimensional resilience evaluation [**?**].

The scale of research has also evolved; early studies focused predominantly on the scale of rural communities or individual households, emphasizing the resilience mechanisms of individuals and small-scale units. Later research expanded to the county or regional scale to explore the spatial differentiation characteristics of rural resilience [**?**]. Methodologically, researchers have employed a variety of approaches, including questionnaire surveys, in-depth interviews, the Delphi method, and structural dynamics methods [**?**].

Geng Yiwei et al. [ ] verified and deepened the systematic and regional connotations of rural resilience through case studies of agricultural areas. Currently, international research on rural resilience has formed a relatively complete framework system, with studies covering topics such as climate change, environmental protection, and biodiversity. Regarding the evaluation of rural resilience, some scholars have attempted to deconstruct resilience from multiple perspectives and levels. For instance, Qiu Mingli···

Introduction

The rural territorial system integrates ecological, economic, and social subsystems. To understand its dynamics, researchers have proposed various analytical frameworks. For instance, Hu et al. \cite{placeholder_{hu}} revealed the spatial and temporal differentiation of county-level rural resilience across five dimensions: ecology, economy, society, culture, and institutions. When internal and external risk sources disturb or impact rural spaces, they break the original stability of the rural territorial system. Rural resilience serves as a critical attribute and capability of these systems, enabling them to activate and optimize systemic elements through processes of buffering, adaptation, recovery, transformation, and reconstruction to achieve system upgrades and adjustments \cite{placeholder_{general}}.

Based on these theoretical foundations, rural resilience should encompass three core capabilities. First is **resistance capability**, which refers to the ability of the rural territorial system to withstand interference and maintain its basic

structure and functional stability when facing internal or external risks. Second is **adaptive capability**, which involves the system' s capacity to adjust its internal structure and behavioral patterns in response to change. Third is **reconstructive capability**, characterized by the optimization of resource allocation, innovation in governance models, and the realization of systemic functional upgrades.

While previous studies have proposed frameworks such as "resistance, absorption, and renewal" [**?**] or "resistance, adaptation, and transformation" [**?**], they have often overlooked the specific reconstructive capacity of the rural territorial system. Regarding the driving factors and enhancement strategies for rural resilience, factors such as the economic foundation, policy interventions, social capital, and the precise alignment of policies are considered crucial for improving resilience \cite{placeholder_{factors}}. Overall, existing research has made significant progress in deconstructing the connotation of rural resilience and constructing evaluation systems, providing a solid foundation for identifying pathways to enhance resilience.

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This research provides theoretical and practical support for identifying paths to improvement and serving the comprehensive revitalization of rural areas. However, ecologically fragile and economically underdeveloped provinces in Western China are constrained by a weak foundation for rural development, insufficient natural endowments, and prominent risks of natural disasters. Consequently, their resilient development paths exhibit significant differences. On one hand, it is necessary to evaluate the fundamental capacities and conditions for resilient development, identifying the characteristics of phased differences and evolutionary patterns. On the other hand, a deep analysis of constraints and driving factors is required to clarify the driving mechanisms of rural territorial system resilience. Only through such analysis can scientific support be provided for the precise implementation of rural revitalization policies at the county level. As the primary implementation body of the rural revitalization strategy and the bridgehead for urban-rural integrated development, the county level is critical.

These capacities do not exist in isolation but rather exhibit a progressive, iterative, and cyclical feedback relationship. Resistance capacity acts as the "firewall" of resilience, providing buffer space for adaptation and reconfiguration by strengthening the system' s foundation. Adaptation capacity involves

adjustments and optimizations built upon the foundation of resistance, while simultaneously accumulating elements for system reconfiguration. Reconfiguration capacity drives the upgrading of resilience, stabilizes the system structure, and feeds back into resistance and adaptation capacities. Therefore, this study defines rural resilience as the resistance, adaptation, and reconfiguration capacities demonstrated by a rural territorial system after encountering internal or external risks. These capacities constitute the core driving force for ensuring the stable and healthy development of the rural territorial system.

Rural areas serve as a vital link and a key driver for regional development. In light of this, the present study focuses on the county-level units of Gansu Province as the primary research object. We construct a comprehensive measurement index system for rural resilience based on three dimensions: resistance capacity, adaptation capacity, and restructuring capacity. By measuring the rural resilience of Gansu' s counties from 2011 to 2020, this paper reveals the spatio-temporal evolution patterns of rural resilience levels and explores the underlying influencing factors and driving mechanisms. The objective of this research is to provide a theoretical basis and policy support for enhancing rural development resilience within Gansu Province.

1 乡村韧性的概念内涵

The term "resilience" originally stems from the field of engineering, where it was used to describe the ability of an object to return to its original state after being subjected to pressure or deformation. In the 1970s, Canadian ecologist C. S. Holling introduced this concept into ecological research to explain the characteristics of ecosystems in maintaining the stability of their structures and functions when facing external disturbances. This perspective emphasizes the self-regulation, adaptation, and recovery capabilities of ecosystems.

[Figure 1: see original paper] Concept connotation of rural resilience

The rural regional system refers to an organic whole with specific structures and functions formed by the interaction and interconnection of natural, economic, social, and cultural elements within a specific rural geographical area. It includes core subsystems such as the social subsystem, economic subsystem, and ecological subsystem. In the process of evolution, rural regional spaces are subjected to various pressures from economic development, environmental changes, and social transitions. Rural resilience, therefore, represents the capacity of these systems to absorb, recover from, and adapt to such disturbances while maintaining their essential functions and developmental trajectory.

2.1 研究区概况

External risk sources, such as technological innovations and policy adjustments, along with internal shocks including population loss, localized ecological imbalances, and shifts in industrial structure, significantly impact regional stability.

Gansu Province is situated at the intersection of the Loess Plateau, the Qinghai-Tibet Plateau, and the Inner Mongolian Plateau. Its topography is complex and diverse, encompassing distinct physical geographical units such as the Hexi Corridor oases, the Longzhong loess hills, the Gannan plateau grasslands, and the Longnan mountains. The regional climate is predominantly arid and semi-arid.

In [YEAR], the total agricultural output value of the province···

11 元，相比于

5.99$×$10

11 元，全省乡村人口

As a core hub for China' s Western Development Strategy, this region fulfills the dual function of undertaking industrial transfers from the East while radiating development across the West. It serves as a strategic demonstration zone for rural revitalization, urban-rural integration, and ecological civilization construction in western China.

Although Gansu Province achieved poverty alleviation in tandem with the rest of the nation by 2020, rural infrastructure and public services remain lagging. The economic foundation is relatively weak, and the challenge of relative poverty remains prominent. Consequently, rural areas lack sufficient resilience to withstand external shocks, which constrains resilient development. This study takes 86 county-level units (Anning District is excluded as it has no agricultural registered population) and Jiayuguan City as research objects. Note: Based on the standard map service website of the Ministry of Natural Resources, drawing number GS(2024)0650; the base map boundaries have not been modified. The same applies hereafter.

Based on the characteristics of natural geographical differentiation in Gansu Province, the study area is divided into five regions: the Hexi region (Wuwei, Zhangye, Jinchang, Jiuquan, and Jiayuguan), the Longzhong region (Lanzhou, Baiyin, Linxia Hui Autonomous Prefecture, and Dingxi), the Longdong region (Pingliang and Qingyang), the Longnan region (Tianshui and Longnan), and the Gannan region (Gannan Tibetan Autonomous Prefecture) (Figure 2).

[Figure 2: see original paper]

2.2.1 乡村韧性评价指标体系构建研究遵循科学

Following the principles of scientific rigor, operability, and data accessibility, this study constructs a rural resilience evaluation index system for Gansu Province across three dimensions: resistance capacity, adaptation capacity, and restructuring capacity .

Resistance capacity primarily reflects the foundational support capabilities—such as economic level and physical capital—available to a region when facing

internal and external risks. [Figure 2: see original paper] provides a schematic diagram of the study area. This capacity is characterized by specific indices designed to measure the robustness of rural systems against potential disruptions.

2.2.2 乡村韧性评价模型

1.2 Research Methodology

1) Standardization of Evaluation Indicators Given the variations in dimensions and directional orientations (positive vs. negative) among the rural resilience evaluation indicators, this study employs the range standardization method to perform dimensionless processing on all indicators.

2) Weight Setting for Evaluation Indicators To mitigate the influence of negligible differences between indicators, the entropy weight method is utilized to determine the weight of each indicator [**?**]. The process involves first constructing a correlation matrix based on the values of each indicator. Subsequently, the weights are determined according to the proportion of each indicator' s principal component contribution relative to the total contribution value.

In this framework, production capacity is characterized by metrics such as average agricultural output value per unit of land, rural per capita arable land resources, and grain yield per unit area. Adaptive capacity is primarily reflected in the adjustments and contributions made to accommodate external disturbances.

Rural Resilience Index Calculation

The capacity for industrial adjustment and social security reflects a system' s adaptive capacity. To characterize this, we selected indicators such as agricultural production structure, grain self-sufficiency rate, and the intensity of pesticide and fertilizer use. Furthermore, restructuring capacity is primarily manifested in the adjustments made to economic development, human capital investment, and agricultural production to achieve structural upgrades and system renewal. For this dimension, we selected indicators including the proportion of agricultural output value, the proportion of rural employees, and the multiple cropping index.

Based on the data standardization and weight calculations derived from the aforementioned rural resilience evaluation index system, a weighted summation model was employed to calculate the respective scores for resistance capacity, adaptive capacity, and restructuring capacity. The calculation formula is as follows:

County-level rural resilience evaluation index system

Criterion Layer (Weight)	Indicator Layer (Weight)	Direction
Resistance Capacity	Agricultural output value per unit land area (10^4 yuan/hm^2)	+
	Rural per capita arable land resources (hm^2/person)	+
Adaptive Capacity	Agricultural production structure (%)	+
	Grain self-sufficiency rate (%)	+
	Intensity of pesticide and fertilizer use (kg/hm^2)	−
Transformative Capacity	Proportion of agricultural output value (%)	+
	Proportion of rural practitioners (%)	+
	Agricultural mechanization level (kW/hm^2)	+

Note: "+" indicates a positive indicator; "−" indicates a negative indicator.

Total Rural Population, Total Grain Production, Sown Area of Grain Crops, Area of Cash Crops, Total Sown Area of Crops, Total Grain Production (Permanent Population ×400 kg), Consumption of Pesticides and Fertilizers, Total Sown Area of Crops, Output Value of Secondary and Tertiary Industries, Total Rural Economic Income, Rural Practitioners, Total Rural Population, Total Sown Area of Crops.

$$R_d = \sum_i Z_i W_i$$

$$R_s = \sum_i Z_i W_i$$

$$R_c = \sum_i Z_i W_i$$

In these equations: R_d represents the score for resistance capacity; R_s represents the score for adaptive capacity; and R_c represents the score for restorative capacity. Furthermore, Z_i denotes the score of evaluation factor i, W_i denotes

the weight assigned to evaluation factor i, and n represents the total number of evaluation factors. Finally, the comprehensive index model is employed to calculate the overall rural resilience index.

The calculation formula is as follows:

$$R = \sum_{j=1}^{n} R_j$$

In the formula: R represents the rural resilience index value; R_j represents the dimensional values (where j denotes resistance capacity, adaptation capacity, and transformation capacity).

2.2.3 空间自相关研究为进一步探析甘肃省县域

To analyze the evolution of rural resilience, this study employs Exploratory Spatial Data Analysis (ESDA). Specifically, the Global Moran' s I index and Local Moran' s I index are utilized to reveal the spatial distribution and correlation characteristics of rural resilience across Gansu Province.

The formulas for Global Moran' s I and Local Moran' s I are defined as follows:

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

In these equations, n represents the number of research units; x_i and x_j denote the observed values at spatial locations i and j, respectively; $\bar{x}$ is the mean of the observed values; S^2 is the variance of the scores; and w_{ij} represents the spatial weight matrix. This study adopts a spatial adjacency criterion, where the weight is assigned as 1 if two regions are adjacent and 0 otherwise. The value of the Moran' s I index ranges from $[-1, 1]$. A positive value indicates a positive spatial correlation, a negative value indicates a negative correlation, and a value of 0 suggests a random spatial distribution.

2.2.4 地理探测器模型本研究运用地理探测器模

The explanatory power of driving factors on rural resilience is expressed as:

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

In this formula, q represents the explanatory power of a driving factor on the level of rural resilience. A higher value of q indicates that the factor has a greater influence on rural resilience. The variables N_h and σ_h^2 represent the sample size and variance of the h-th stratum, respectively, while N and σ^2 denote the total sample size and variance across the entire study area.

Nm、$ $2

2.3 数据来源

The data utilized in this study include vector data of county-level administrative units in Gansu Province and corresponding socioeconomic development data. The vector data for county-level administrative divisions were obtained from the Resource and Environmental Science and Data Center of the Chinese Academy of Sciences (resdc.cn). Socioeconomic data were sourced from the *Gansu Rural Yearbook*, the *Gansu Development Yearbook*, and the *China County Statistical Yearbook*. Any missing data were supplemented using national economic and social development statistical bulletins from various localities and relevant county-level statistical yearbooks.

3.1 甘肃省县域乡村韧性时空演化过程

From the perspective of rural resilience sub-dimensions (Table 2), the levels of resistance, adaptive capacity, and restructuring capacity all improved during the study period. Among these, resistance showed the most rapid growth and contributed most significantly to the overall enhancement of rural resilience, a trend driven by the accelerating pace of rural construction in Gansu Province in recent years. While adaptive capacity improved steadily, restructuring capacity increased at a slower rate. To further analyze these trends, the comprehensive rural resilience index for counties in Gansu Province was calculated across three periods. Using the Natural Breaks (Jenks) method in ArcGIS 10.8, the evaluation units were classified into four types (Figure 3). Between 2010 and 2022, the overall rural resilience in Gansu Province was characterized by a continuous increase in the number of high-resilience counties and a decrease in low-resilience counties; specifically, high-resilience counties increased by 11, while low-resilience counties decreased by 13.

In terms of spatial distribution, the rural resilience of Gansu Province exhibited distinct regional differentiation in 2010. Resilience levels were higher in the Longzhong and Longdong regions, while levels in the Hexi and Gannan regions were generally lower. Low-resilience counties were primarily concentrated in ecologically fragile areas constrained by resource and environmental factors. By 2015, resilience levels in areas such as Ganzhou District, Minle County, Yongchang County, and Wudu District in the Hexi region rose to "high" or "relatively high" levels. Conversely, the resilience levels of counties such as Qingcheng, Tongwei, and Gulang dropped to "medium," indicating that rural areas underwent adaptive adjustments under the guidance of relevant policies, leading to significant localized fluctuations in resilience. By 2022, rural resilience levels in parts of the Hexi and Longzhong regions improved significantly, with the proportion of counties at or above "medium" resilience reaching 82.4%, further consolidating the advantages of high-resilience counties. This progress is largely attributable to the effective transition between the Poverty Alleviation Campaign and Rural Revitalization strategies. Since the 18th National Congress of the CPC, Gansu has mobilized provincial resources to win the battle against poverty, laying a solid foundation for rural development. However, due to con-

straints imposed by the physical geographical environment and socio-economic development conditions, certain counties in the Linxia Hui Autonomous Prefecture, Gannan Tibetan Autonomous Prefecture, and the Qilian Mountains of the Hexi region have remained in a state of low resilience.

Evaluation values of rural resilience sub-dimensions in counties of Gansu Province from 2010 to 2022. Factor detection and interaction detection models were employed to conduct an in-depth analysis of the influence factors. Li Qianguo et al.: Research on the Spatio-temporal Evolution Characteristics and Driving Mechanisms of Rural Resilience at the County Level in Gansu Province. [Figure 3: see original paper] Spatial patterns of rural resilience levels in counties of Gansu Province from 2010 to 2022.

3.2 甘肃省县域乡村韧性空间关联特征

The global Moran' s I for county-level rural resilience in Gansu Province was calculated using GeoDa. The results reveal significant spatial clustering characteristics of rural resilience across the counties of Gansu. The global Moran' s I values indicate a downward trend in the overall clustering level. Further analysis of the local spatial autocorrelation of rural resilience shows that the number of county units exhibiting significant positive correlation decreased between 2011 and 2020. Conversely, the number of units with negative correlation increased slightly, suggesting an intensification of negative agglomeration effects. This indicates that the disparity in rural resilience levels between neighboring county units in Gansu Province is widening.

In 2011, High-High (H-H) clusters were primarily distributed in counties such as Yuzhong, Jingyuan, Jingning, and Minqin. By 2020, the number of H-H clusters had decreased, with Jingning and Jingyuan transitioning to non-significant status. However, during the same period, H-H clusters expanded within the counties of Zhangye City in the Hexi region. Low-Low (L-L) clusters were mainly concentrated in the Linxia Hui Autonomous Prefecture and Gannan Tibetan Autonomous Prefecture. The overall number of these clusters remained relatively stable. Due to the constraints of natural conditions, industrial structures, and geographic location, agricultural economic development in these areas is limited, and there is an urgent need to enhance their rural resilience levels.

In 2011, Low-High (L-H) clusters were primarily distributed in Sunan Yugur Autonomous County, Tianzhu Tibetan Autonomous County, and Gaolan County in the Hexi region. While the overall number of these clusters decreased, the total count remained small. By 2015, Yongchang County had transitioned into a High-High cluster, and by 2020, Tianzhu County had become non-significant. Moving forward, it is essential to fully leverage the driving role of neighboring high-resilience counties to improve the resilience levels of these lagging areas.

In 2011, High-Low (H-L) clusters were exclusively located in the Wudu District of the Longnan region. Compared to its surrounding counties, Wudu exhibits higher resilience; however, this advantage is primarily confined to its agricul-

tural industry. Consequently, its capacity to drive and enhance the resilience of neighboring counties is limited, and it even faces the risk of "assimilation" by the surrounding low-resilience areas.

3.3.1 影响因子的选取乡村韧性是一个多维度概

The concept of rural resilience encompasses multiple dimensions, including economic, social, and resource-based aspects. Based on the principles of representativeness and data availability, this paper selects influencing factors from six dimensions: rural social service levels, rural economic development levels, agricultural production levels, rural human resources, rural energy power, and rural industrial structure (Table 3).

[Figure 4: see original paper] LISA cluster distributions of rural resilience in counties of Gansu Province from 2010 to 2022

Selection of influencing factors

Dimension	Indicator	Description
Rural social service level	Number of medical and health institution beds per 10,000 rural residents (X_1)	Reflects rural social service levels
Rural economic development level	Per capita disposable income of rural residents (X_3)	Reflects rural economic development levels
Agricultural production level	Number of farmer cooperatives (X_2)	Reflects agricultural production levels
Rural human resources	Per capita consumption expenditure of rural residents (X_4)	Reflects rural human resource status
Rural energy power	Total power of agricultural machinery (X_5)	Reflects rural energy utilization status
Rural industrial structure	Total rural labor resources (X_6)	Reflects rural production capacity

Social service institutions play a critical role in responding to risks; therefore, the number of medical and health institution beds per 10,000 rural residents (X_1) and the number of farmer cooperatives (X_2) are selected to reflect rural social service levels. The income and consumption levels of rural residents are core indicators for measuring the economic development of rural areas, as they determine the rural system' s ability to resist external shocks and recover. Consequently, per capita disposable income (X_3) and per capita consumption expenditure (X_4) are chosen to represent rural economic development levels.

To represent the foundational level of agricultural production, the total power of agricultural machinery (X_5) is selected. Labor is the core element of rural production and recovery, and its quantity and quality are directly related to the adaptation and reconstruction capabilities of the rural system; thus, the total number of rural labor resources (X_6) is used to reflect local human resource conditions. Total rural electricity consumption (X_7) is selected to represent rural energy power. Regarding industrial structure, agricultural output value (X_8) serves as the foundation of the rural economy, and its stability is vital for resilience. Furthermore, forestry output value (X_9) and animal husbandry output value (X_{10}) perform functions such as ecological restoration, soil and water conservation, and income generation, thereby promoting the diversified development of rural industries.

Analysis of the spatial distribution shows that changes in Maqu County were relatively minor, though it shifted from a non-significant area to a Low-Low (L-L) cluster. Conversely, Dongxiang Autonomous County and Lintan County shifted from Low-Low clusters to non-significant areas. This indicates that Linxia Hui Autonomous Prefecture and Gannan Tibetan Autonomous Prefecture are significantly influenced by natural conditions. The resilience levels in these areas exhibited a trend of decreasing before increasing, though they remain relatively low. This suggests that while Gansu Province has introduced a series of policies to bolster rural development, the inherent geographical and environmental constraints continue to pose challenges to resilience.

3.3.2 甘肃省县域乡村韧性影响因素将乡村韧性

Using the index value as the explained variable, we employed the geographical detector model via ArcGIS 10.8 to measure the explanatory power of various influencing factors. The results indicate that each explanatory variable exerts a significant effect on rural resilience [FIGURE:N].

Overall, the impact of rural social service levels (X_n) on rural resilience is the most pronounced. The explanatory power for the years [YEARS] was [VALUES], respectively, exhibiting a "U-shaped" trend characterized by an initial decline followed by a subsequent increase. The steady rise in explanatory power during the latter period suggests that improvements in rural social service levels play a proactive role in enhancing rural resilience.

The explanatory power of X_m across the sampled years was [VALUES]. This influence gradually increased alongside the growth of per capita income and consumption levels in rural areas, indicating that economic factors contribute more significantly to rural resilience as regional wealth grows. Conversely, while a series of policies supporting rural human resource development have been implemented, their effectiveness has been mediocre, resulting in an insignificant impact on the enhancement of rural resilience.

The explanatory power of X_i was [VALUES], showing a significant downward trend. This suggests that the industrial structure of rural areas is currently

transitioning from traditional high-energy-consumption models to low-energy, high-value-added industries; consequently, the influence of electricity consumption on rural resilience has diminished. Furthermore, the explanatory power of X_j showed a rapid downward trend, while X_k increased year by year. This indicates that the impact of forestry output value on rural resilience has gradually weakened in recent years, whereas the development of agriculture and animal husbandry has become increasingly vital for the promotion of rural resilience.

3.3.3 影响因子交互探测结果对县域乡村韧性影

Interaction detection was performed on the influencing factors (Figure 6), revealing that various factors interact with one another. Note: The q-value represents explanatory power; the same applies hereafter. Economic growth exerts a strong promotional effect on the enhancement of rural resilience. The explanatory power of X_1 similarly exhibits a "U-shaped"trend, with an overall increasing trajectory, indicating its sustained positive impact on the improvement of rural resilience. The explanatory power of X_2 initially showed a specific trend.

[Figure 5: see original paper] Fig. 5 Changes in q-value of influencing factors on rural resilience in counties of Gansu Province from 2010 to 2022

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[Figure 6: see original paper] Fig. 6 Interactive detection results of influencing factors from 2010 to 2022

The interaction detection results indicate that the explanatory power regarding rural resilience is significantly strengthened after factors interact, demonstrating that the enhancement of county-level rural resilience is the result of the combined influence of multiple factors. This suggests that the supporting role of traditional agricultural energy and power for rural resilience has continuously weakened, facilitating the upgrading of rural production methods and the optimization of industrial structures.

Based on the interaction detection results, the interaction between X_1 and other influencing factors is the strongest, indicating that economic development, in conjunction with other factors, directly affects the level of rural resilience. The interaction between X_2 and other factors is also relatively strong, suggesting that production efficiency and energy dynamics provide critical support for the development of rural industries.

Furthermore, the industrial transformation mechanism serves as the internal driving force for the improvement of rural resilience. The explanatory power of X_3 regarding rural resilience has consistently remained at a high level and has steadily increased (with explanatory power rising to a specific value). As the foundational industry of the rural economy, the stable development of agriculture has accumulated core strength for rural resilience. While X_4 showed

relatively weak explanatory power in the single-factor detection (with explanatory power increasing annually to a certain level), its explanatory capacity was significantly enhanced after interacting with multiple other factors. This is particularly evident in its interaction with X_1, where the explanatory power reached specific values in different years. This indicates that rural human resources are closely related to economic development, and their combined effect can significantly improve the level of rural resilience.

3.3.4 驱动机制解析基于地理探测器对关键影响

The results of the factor identification reveal that rural resilience at the county level in Gansu Province is influenced by the interaction of multiple factors. Based on these findings, the driving mechanisms of rural resilience in Gansu Province are constructed as follows: 1) The economic development mechanism serves as the core driving force for enhancing rural resilience. Within the level of rural economic development, the explanatory power of X increased continuously to ..., primarily because Gansu Province has formed a diversified rural industrial system centered on modern agriculture and specialized industries by undertaking industrial transfers and optimizing investment structures. Simultaneously, the explanatory power of X shifted from ... to .... These developments have increased the income and consumption levels of rural residents, improved rural infrastructure, and strengthened the risk-resistance capacity of rural areas to a certain extent. 2) The resource optimization mechanism provides the material foundation for enhancing rural resilience. Improvements in this area have mitigated the threat of natural disasters to food security and promoted the diversified development of rural industries, becoming a significant growth point for resilience enhancement. Although the explanatory power of X is relatively low, it exhibits a fluctuating upward trend after interacting with other factors. This structural optimization model of "stabilizing the foundation through agriculture, increasing efficiency through animal husbandry, and empowering through forestry" has injected endogenous momentum into the improvement of rural resilience in Gansu Province. 3) The service guarantee mechanism acts as the fundamental support for rural resilience. Its explanatory power regarding rural resilience is particularly prominent and has shown significant improvement. This is mainly attributed to the series of policies issued by Gansu Province since the implementation of the Rural Revitalization Strategy, aimed at improving primary healthcare networks and strengthening the link between farmers and agricultural enterprises. This has created a complementary pattern of livelihood security and production empowerment, effectively reducing the impact of public health events on rural systems and enhancing the resistance and adaptive capacity of rural society.

In summary, the economic development mechanism and the industrial transformation mechanism constitute the "dual engines" of rural resilience, while the resource optimization mechanism and the service guarantee mechanism form the "dual supports." Under the joint action of these mechanisms, the rural ter-

ritorial system can be optimized, promoting integration and feedback between various subsystems and enhancing rural resilience at a deeper level.

4 讨论

This study constructs an evaluation index system based on the county scale, focusing on three dimensions: resistance, adaptive capacity, and restorative capacity. It analyzes the rural resilience of Gansu Province. However, in the analysis of rural resilience driving mechanisms, although geographical detectors were employed to reveal the relationships between various factors and rural resilience, these findings are limited to the county level.

There remains an insufficient exploration of resilience differences and influencing factors at smaller scales within rural areas. Consequently, the research does not fully explain the complex causal relationships and underlying mechanisms of action. Future research should further draw upon rural resilience theories and fully account for the heterogeneity between different communities and villages within rural areas. By deeply excavating the driving factors that influence rural resilience, more nuanced strategies and pathways for rural resilience development can be proposed.

5 结论

From 2011 to 2020, the overall level of rural resilience in the counties of Gansu Province significantly improved, characterized by distinct spatial differentiation. The number of counties with high resilience levels has continuously increased, with their regional proportion reaching a substantial share, while the number of low-resilience counties has steadily decreased. Due to economic agglomeration effects and infrastructure improvements, the Longzhong region has emerged as a core area of high resilience. Conversely, several counties in the Gannan and Hexi regions remain in a state of low resilience. Determining how to enhance the rural resilience of these specific areas is critical to improving the overall resilience of Gansu Province.

[Figure 7: see original paper] **Fig. 7 Driving mechanisms for rural resilience in counties of Gansu Province**

The spatiotemporal evolution and driving mechanisms of rural resilience in Gansu provide an important empirical basis for sustainable rural development in Western China. Diverging from previous assessments that focused on single economic or ecological dimensions [**?**, **?**], this paper constructs a reconstruction capability analysis framework to more comprehensively reveal the evolutionary process of rural resilience. The study finds that rural resilience levels in Gansu Province are highly coupled with regional economic development gradients and differences in resource endowments. Some counties in the Longzhong and Hexi regions have achieved rapid improvements in resilience through the development of specialized rural industries. However, the Gannan Plateau and certain eco-

logically fragile counties remain at low resilience levels due to natural resource constraints and monolithic industrial structures. This confirms the "resilience trap" theory proposed by Sharifi, which suggests that natural constraints can create path dependencies that inhibit the enhancement of resilient capacities.

Furthermore, this study finds that the contribution of rural industrial structures to rural resilience is gradually rising. This reflects a significant reduction in rural economic dependence on single industries. The resulting structural optimization has effectively enhanced the rural system' s ability to adapt to natural risks and market fluctuations. This aligns with the sustainable development orientation of "ecology first, economic adaptation" for ecologically fragile and underdeveloped regions, providing a feasible industrial path for similar areas to break through the "resilience trap."

The spatial analysis reveals a significant positive spatial correlation in the rural resilience of Gansu' s counties, although this correlation has weakened annually (as indicated by a declining Global Moran' s I). The degree of spatial clustering has decreased; High-High (H-H) clusters have contracted toward the Longzhong region, while Low-Low (L-L) clusters are concentrated in ecologically fragile areas such as the Gannan Tibetan Autonomous Prefecture and Linxia Hui Autonomous Prefecture. The distribution of High-Low (H-L) and Low-High (L-H) clusters has remained largely stable. Future efforts should focus on leveraging the radiation and driving effects of high-resilience counties in rural development while avoiding negative assimilation effects.

The driving factor analysis indicates that rural social service levels, rural economic development levels, and agricultural production levels have significant impacts on rural resilience. In contrast, rural human resources and agricultural energy power exert a lower influence. Notably, the explanatory power of rural industrial structure regarding rural resilience is steadily increasing. The enhancement of rural resilience is the result of the synergistic action of multiple factors, with significant non-linear enhancement interaction effects between them. In this framework, economic development serves as the core engine, resource optimization provides the material support, industrial transformation acts as the internal driving force, and service provision functions as the fundamental guarantee.

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Due to limitations in data accessibility, several factors that significantly impact rural resilience have not yet been considered in this study. Future research could integrate field surveys and case studies to further optimize the rural resilience evaluation index system. This would involve incorporating micro-level and qualitative indicators that are difficult to quantify but essential for assessing resilience, such as rural social networks, cultural heritage, and innovation capacity. Such enhancements would allow the index system to more comprehensively and accurately reflect the connotations and characteristics of rural resilience.

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References and Literature Review

The study of rural resilience has become a significant focus in contemporary geography and ecology, reflecting a shift from theoretical exploration to practical

application. Recent bibliometric analyses using CiteSpace have highlighted the evolving hotspots and trends within this field, emphasizing the transition of resilience science from its roots in ecological theory to its current application in urban and rural planning [**?**, **?**].

Regional Assessments of Rural and Agricultural Resilience

Research has increasingly focused on the spatial and temporal dynamics of resilience across diverse Chinese landscapes. In Northeast China, studies have evaluated the resilience systems of Heilongjiang Province, providing insights into how rural areas adapt to environmental and economic shifts [**?**]. Similarly, in the arid regions of Northwest China, researchers have characterized the spatial-temporal changes and functional zoning of cultivated land resilience in Xinjiang, offering a framework for sustainable land use in fragile ecosystems [**?**].

In the eastern coastal regions, such as Zhejiang Province, scholars have developed measurement frameworks to assess rural resilience levels and identify specific development paths suitable for highly developed maritime economies [**?**]. These regional studies demonstrate that resilience is highly context-dependent, requiring localized indicators for accurate assessment.

Resilience in Specialized Contexts

Beyond general rural assessments, specific attention has been paid to traditional agricultural zones and tourism destinations: - **Traditional Agricultural Areas:** Research in typical counties of Hebei Province has explored paths for urban-rural integrated development through the lens of rural economic resilience, suggesting that economic robustness is a prerequisite for successful integration [**?**]. - **Tourism and Ethnic Settlements:** In mountainous ethnic tourism destinations, studies have assessed the resilience of rural settlements and examined scale correlations, revealing how tourism impacts the adaptive capacity of indigenous communities [**?**].

Conceptual Frameworks and Evaluation

The theoretical foundation of this field continues to expand, with comprehensive reviews addressing the conceptual definitions, influencing factors, and evaluation methodologies of resilience [**?**]. These reviews synthesize findings from both ecological and urban perspectives, providing a robust basis for the development of the multi-dimensional evaluation indices used in current rural resilience research. Together, these studies form a comprehensive knowledge map that informs both academic discourse and policy-making for rural revitalization.

References and Literature Review

Zheng Qiaoya, Yang Meng, et al. provided a comprehensive review of the definitions, influencing factors, and assessment methodologies of urban resilience

[?]. Building upon the conceptual framework of resilience, recent scholarship has shifted focus toward the rural dimension. Song Guandong, Tang Chengli, and Zhou Guohua conducted an analysis of rural resilience measurement and its influencing factors at the county scale, using Hunan Province as a case study [?]. Their work emphasizes the necessity of understanding how local socio-economic structures respond to external shocks.

Further expanding the geographical scope, He Jiahui, Wu Yingmei, Yu Lijiao, et al. explored the spatio-temporal evolution and driver detection of rural resilience across Western China [?]. This research utilizes spatial analysis tools to identify the mechanisms that govern rural stability and transformation in ecologically sensitive and economically developing regions. Additionally, the identification of rural regional system resilience types and their driving factors has become a critical area of inquiry for regional development.

The relationship between administrative governance and rural development is also a key factor in regional resilience. Zhu Sujia, Wu Jianmin, and Liang Ziyi analyzed the intersection of rural revitalization and administrative division adjustments at the county level, specifically focusing on Hebei Province [?]. Their findings suggest that optimizing administrative boundaries and governance structures can significantly impact the effectiveness of rural revitalization strategies and the overall resilience of the rural regional system.

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Spatiotemporal Evolution Characteristics and Driving Mechanisms of Rural Resilience in Gansu Province

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Abstract: Evaluating rural development through the lens of resilience is of great significance for dismantling the urban-rural dual structure and promoting comprehensive rural revitalization. This study focuses on 86 counties in Gansu Province, constructing a rural resilience evaluation index system based on three dimensions: "resistance, adaptability, and transformability." Utilizing spatial autocorrelation analysis and geodetector models, the paper reveals the spatiotemporal evolution and driving mechanisms of rural resilience across Gansu' s counties from 2010 to 2022. The results indicate that: (1) The level of rural resilience in Gansu Province has improved significantly, exhibiting distinct spatial differentiation. Resilience levels are relatively high in central and eastern Gansu, whereas certain counties in the Hexi Corridor, Gannan, and Linxia exhibit lower resilience.

The number of high-resilience counties continues to increase, while the number of low-resilience counties contin- ues to decrease. (2) There is a spatial positive correlation in rural resilience, and the correlation is gradually weak- ening. The degree of spatial agglomeration is declining, with high-agglomeration areas shrinking toward the cen- tral Gansu region and low-agglomeration areas concentrated in counties such as Gannan and Linxia. (3) The level of rural social services, economic development, and agricultural production has a significant impact on rural resil- ience. The explanatory power of rural industrial struc-

ture for rural resilience is steadily increasing, and rural resil- ience is driven by economic development, resource optimization, industrial transformation, and service guarantee mechanisms. This study' s results provide scientific reference for the implementation of rural resilience develop- ment in Gansu Province.

Keywords: rural resilience; evolutionary characteristic; driving mechanism; geographic detector; Gansu Prov-

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