Spatiotemporal Coupling Relationship between Land Use Multifunctionality and Multidimensional Relative Poverty in the Liupan Mountain Area of Gansu Province: Postprint

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Abstract

To investigate the degree and manner of mutual influence between land use multifunctionality and multidimensional relative poverty, and to clarify their spatiotemporal coupling relationship, this study focuses on the Gansu section of the Liupan Mountain area, constructs a coupling coordination model for land use multifunctionality and multidimensional relative poverty, explores the spatiotemporal distribution pattern of coupling coordination between land use multifunctionality and multidimensional relative poverty from 2010 to 2020, and classifies coupling coordination types based on coordination relationships. The results show that: (1) From 2010 to 2020, the level of land use multifunctionality and the degree of multidimensional poverty reduction in the Gansu section of the Liupan Mountain area improved significantly, both shifting from medium-low to medium-high levels, with prominent spatial agglomeration effects. (2) From 2010 to 2020, the coupling degree between land use multifunctionality and multidimensional relative poverty in the Gansu section of the Liupan Mountain area decreased slightly, but remained dominated by high-level coupling overall, with strong interaction between the two systems. Spatially, the coupling degree exhibited a pattern of high in the southwest and low in the northeast, with different degrees of coupling showing clustering patterns and obvious spatial differences. (3) From 2010 to 2020, the coupling coordination degree between land use multifunctionality and multidimensional relative poverty in the Gansu section of the Liupan Mountain area improved significantly, with continuously strengthening coordinated development between the two systems, though there remains considerable room for improvement in coordination levels. (4) From 2010 to 2020, the coupling coordination type between land use multifunctionality level and multidimensional relative poverty in the Gansu section of the Liupan Mountain area was mainly synchronous, but coordination levels were mostly in

disharmony. It is evident that the model of alleviating multidimensional relative poverty by improving land use multifunctionality efficiency still has considerable room for deepening in the Gansu section of the Liupan Mountain area.

Full Text

Spatiotemporal Coupling Relationship Between Multifunctional Land Use and Multidimensional Relative Poverty in the Gansu Section of Liupanshan

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Abstract: To explore the extent and mode of interaction between multifunctional land use and multidimensional relative poverty, and to clarify their spatiotemporal coupling relationship, this study focuses on the Gansu section of Liupanshan, constructs a coupling coordination model for multifunctional land use and multidimensional relative poverty, investigates the spatiotemporal distribution pattern of their coupling coordination from 2010 to 2020, and classifies the coupling coordination types based on the coordination relationship. The results show that: (1) From 2010 to 2020, the level of multifunctional land use and the degree of multidimensional poverty reduction in the Gansu section of Liupanshan improved significantly, with both transitioning from medium-low levels to medium-high levels, and exhibiting prominent spatial agglomeration effects. (2) From 2010 to 2020, the coupling degree between multifunctional land use and multidimensional relative poverty in the Gansu section of Liupanshan decreased slightly, but overall remained primarily at a high coupling level, indicating a strong degree of interaction between the two systems. Spatially, the coupling degree exhibited a pattern of being higher in the southwest and lower in the northeast, with different degrees of coupling showing agglomeration patterns and significant spatial differences. (3) From 2010 to 2020, the coupling coordination degree between multifunctional land use and multidimensional relative poverty in the Gansu section of Liupanshan increased significantly, with the degree of coordinated development between the two systems continuously strengthening, though there remains considerable room for improvement in the coordination level. (4) From 2010 to 2020, the coupling coordination type between multifunctional land use and multidimensional relative poverty in the Gansu section of Liupanshan was mainly synchronous, but the coordination level was mostly uncoordinated. It is evident that the model of reducing multidimensional relative poverty by improving the efficiency of multifunctional land use still has considerable room for deepening in the Gansu section of Liupanshan.

Keywords: multifunctional land use; multidimensional relative poverty; comprehensive index; coupling coordination degree; the Gansu section of Liupan-

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Introduction

Land is the foundation of human survival and development, the source of all things, the basis of all wealth, and an important support for poverty-stricken areas to overcome difficulties [1]. Under the goals of balanced development and achieving comprehensive prosperity, the Gansu section of Liupanshan has become a core focus for policy formulation and resource allocation. The multifunctionality of land use in this area is reflected in the economic, social, and ecological functions demonstrated by different land types during development and utilization [2]. Currently, China' s economy has entered a stage of high-quality development, and the rural revitalization strategy has endowed land use with new era requirements [3]. Multidimensional relative poverty refers to the condition where, despite sufficient income to maintain basic survival needs, individuals or households still cannot meet other basic living needs recognized by local society (including infrastructure service benefits, social welfare security indicators, and personal subjective perceptions of these welfare benefits). With the victory of comprehensive poverty alleviation, China has historically eradicated absolute poverty. However, relative poverty remains widespread and exhibits significant regional differences [4]. Against this backdrop, studying the spatiotemporal coupling relationship between multifunctional land use and multidimensional relative poverty in the Gansu section of Liupanshan, exploring the extent and mode of interaction between the two, and analyzing the pathways for coupling coordination regulation are crucial for subsequently adjusting land use multifunctionality levels, consolidating poverty alleviation achievements, and aligning with the rural revitalization strategy [5].

Existing academic achievements in exploring multifunctional land use have primarily focused on analyzing conceptual frameworks and intrinsic meanings, developing classification and identification methods, and discussing evaluation systems and influencing factors [6-8]. These studies commonly adopt land use multifunctionality index models and comprehensive index methods to categorize functions into production, living, and ecological (environmental) functions [9-10]. Indicator selection primarily uses criteria such as agricultural production, economic development, employment levels, social security, resource supply, and ecological conservation [11-12], with common indicators including economic indicators like per-unit-area output value, grain yield, and cultivated land proportion; social indicators like per capita income, employment density, and urbanization rate; and environmental indicators like forest coverage, water network density, and fertilizer usage [13-14]. Research on multidimensional relative poverty mainly employs poverty alleviation development index models, multidimensional poverty index models, and comprehensive index methods to measure dimensions including housing conditions, basic needs, educational resource accessibility, sanitation facilities, residential environment, cooking energy types, land use rights security, and medical security system participation [15-16]. Com-

monly selected indicators include economic indicators like income-expenditure ratio, per capita loan balance, and tertiary industry proportion, as well as social indicators like per capita cultivated land area and social security levels [17-18], with slight adjustments according to the specific characteristics of the research object.

Reviewing existing achievements, scholars have primarily examined land use multifunctionality and multidimensional poverty from perspectives of influencing factors, spatiotemporal distribution characteristics, and relationships with other elements [19-21]. However, there remains room for expansion: from a data nature perspective, current research mainly relies on static data to explore land use multifunctionality or multidimensional relative poverty, while this study constructs a sample set through time series slices. Regarding coupling coordination relationships, existing achievements have focused more on the coupling between land use multifunctionality or multidimensional relative poverty and other elements [22-24], with limited research on the coupling coordination relationship between land use multifunctionality and multidimensional relative poverty itself. Therefore, this study explores the potential spatiotemporal connections between the two systems from the perspective of their relationship, aiming to provide references for implementing the rural revitalization strategy in the Gansu section of Liupanshan.

1.1 Study Area Overview

The Gansu section of Liupanshan includes multiple cities (prefectures) and counties (districts), covering a total area of 11.81×10^4 km^2, accounting for 27.75% of Gansu Province's total area. Located on the western edge of the Loess Plateau and adjacent to the Qinghai-Tibet Plateau, this region constitutes a critical part of the Yellow River system. The main stream of the Yellow River and several tributaries including the Taohe and Weihe rivers flow through this area. The terrain is highly undulating, with elevations ranging from 756 m to 4533 m. The region lies in a transitional zone between cold temperate semi-humid and semi-arid climates, with annual precipitation of 110–700 mm, annual average temperature of 5.2–10.4 °C, and significant diurnal temperature variation. By the end of 2010, cultivated land resources in the area accounted for 35.10% of the total regional area, grain output reached 703.00×10^4 t, and construction land area was 2785.78 km^2, representing 2.63% of the total regional area. Vegetation cover is sparse, with forest coverage reaching only 2.40%. By the end of 2020, the permanent population was 1589.70×10^4 people, accounting for 9.15% of the province' s total population; per capita GDP was 4.60×10^4 yuan; the added value of secondary and tertiary industries reached···; employees in secondary and tertiary industries numbered 403.00×10^4 people; and the urbanization rate was 63.58%.

1.2 Data Sources

This study selected the period 2010–2020 as the research timeframe. Administrative boundary data were obtained from the Data Center for Resources and Environmental Sciences of the Chinese Academy of Sciences. National land use/cover data were sourced from the National Catalogue Service for Geographic Information. Statistical data were derived from the *Gansu Development Yearbook* (2010–2020), *China County Statistical Yearbook* (2010–2020), statistical bulletins on national economic and social development from various cities and counties in the Gansu section of Liupanshan, and the *Gansu Rural Yearbook* (2010–2020).

1.3 Methodology

1.3.1 Entropy Weight Method Due to differences in dimensions and magnitude among sample data characteristics, indicators require standardization. This study employed the range method to process raw data. The calculation formulas are as follows:

For positive indicators:

$$\phi_{ij} = \frac{x_{ij} - \min(x_j)}{\max(x_j) - \min(x_j)}$$

For negative indicators:

$$\phi_{ij} = \frac{\max(x_j) - x_{ij}}{\max(x_j) - \min(x_j)}$$

where x_{ij} is the raw value of the jth evaluation indicator for the ith county; $\min(x_j)$ and $\max(x_j)$ are the minimum and maximum values of the jth indicator; ϕ_{ij} is the standardized value; $i = 1, 2, \ldots, m$; m is the number of counties; and n is the number of evaluation indicators.

The entropy weight method determines weights through objective data, effectively reducing subjective interference. This study used the entropy method to calculate weights. The calculation formulas are:

$$P_{ij} = \frac{\phi_{ij}}{\sum_{i=1}^{m} \phi_{ij}}$$

$$e_j = -\frac{1}{\ln(m)} \sum_{i=1}^{m} P_{ij} \ln(P_{ij})$$

$$W_j = \frac{1 - e_j}{\sum_{j=1}^{n} (1 - e_j)}$$

where P_{ij} is the proportion of the jth indicator for the ith county; e_j is the entropy value of the jth indicator; and W_j is the weight of the jth indicator.

1.3.2 Multifunctional Land Use Evaluation Indicator System Multifunctional land use reflects the economic, social, and ecological functions demonstrated by different land types during development and utilization [25]. Based on principles of comprehensiveness, regionalism, hierarchy, and scientific validity, and drawing on existing research [26-27], this study constructs a multifunctional land use evaluation indicator system combining the characteristics of land use in the Gansu section of Liupanshan. Focusing on reflecting economic output, living standards, and ecological environment, the system comprises three dimensions: production, living, and ecological functions (Table 1).

Production function reflects the ability to produce agricultural products and create economic value during land use. This study selected four indicators: grain yield per unit area, land reclamation rate, land output rate, and agricultural output value proportion. Grain yield per unit area represents agricultural production capacity, land reclamation rate represents cultivated land development intensity, land output rate represents land use efficiency, agricultural output value proportion represents agricultural economic output capacity, and fiscal contribution rate represents regional economic strength.

Living function reflects employment opportunities, improved living and production conditions, and regional development provided by land use. This study selected four indicators: rural residents' disposable income, construction land proportion, rural employment density, and urbanization level. Rural residents' disposable income represents living standards, construction land proportion represents residential carrying capacity, rural employment density represents employment security capacity, and urbanization level represents regional urbanization degree.

Ecological function reflects maintaining ecological balance and regulating human living environments. This study selected four indicators: forest coverage rate, water area proportion, major agricultural resource area, and chemical fertilizer use per unit area. Forest coverage rate represents ecological conservation capacity, water area proportion represents ecological environmental quality, major agricultural resource area represents resource supply level, and chemical fertilizer use per unit area represents ecological damage degree.

This study uses the multifunctional land use index to measure multifunctionality in the Gansu section of Liupanshan. The index value directly reflects the level of multifunctional land use. The calculation formula is:

$$F_i = \sum_{j=1}^{n} (W_j \times M_{ij})$$

where F_i is the multifunctional land use index value for the ith county; M_{ij} is

the standardized value of the jth indicator for the ith county; and W_j is the weight of the jth indicator.

1.3.3 Multidimensional Relative Poverty Evaluation Indicator System Multidimensional relative poverty refers to the condition where, despite sufficient income for basic survival, individuals or households cannot meet other basic living needs recognized by local society (including infrastructure service benefits, social welfare security indicators, and personal subjective perceptions). Drawing on existing research [28-30] and considering the characteristics of relative poverty in the Gansu section of Liupanshan, this study focuses on residents' income, transformation and upgrading of secondary and tertiary industries, employment rates and skill improvement, and public service facility coverage. The evaluation indicator system comprises four dimensions: economic status, three industries, employment conditions, and public services (Table 2).

Economic status reflects a region' s risk response capacity and development level, thereby indicating relative poverty conditions. Three indicators were selected: government risk resistance, resident risk resistance, and financial 宽松度 (looseness). Government and resident risk resistance represent regional economic risk response capacity, while financial looseness represents economic activity level.

Industry and employment selected four indicators: per capita cultivated land area, per capita primary industry output value, per capita secondary and tertiary industry output value, and industrial structure advancement level to reflect regional industrial development status. Additionally, rural employment rate and labor transfer capacity represent regional employment conditions.

Public services selected four indicators: education level, medical facility level, information access capacity, and social pension security level to reflect regional development in education, healthcare, communication, and elderly care.

This study measures the degree of multidimensional poverty reduction in the Gansu section of Liupanshan through the multidimensional poverty reduction index. Higher values indicate greater poverty reduction. The calculation formula is:

$$Z_i = \sum_{j=1}^{n} (W_j \times R_{ij})$$

where Z_i is the multidimensional poverty reduction index for the ith county; R_{ij} is the standardized value of the jth indicator for the ith county; and W_j is the weight of the jth indicator.

1.3.4 Coupling Degree Model The coupling degree model describes the interconnection and dependence among subsystems in a system [31]. This study uses the coupling degree model to measure the interconnection and dependence

between multifunctional land use and multidimensional relative poverty in the Gansu section of Liupanshan. The calculation formula is:

$$C = \frac{F(x) \times Z(y)}{[F(x) + Z(y)]^2}$$

where C is the coupling degree between multifunctional land use and multidimensional relative poverty; $F(x)$ is the multifunctional land use index; and $Z(y)$ is the multidimensional poverty reduction index. According to the range of C values, coupling degrees are classified as low coupling (0–0.3), moderate coupling (0.3–0.5), high coupling (0.5–0.8), and extremely high coupling (0.8–1.0).

1.3.5 Coupling Coordination Degree Model The coupling coordination degree model examines the synergistic progress between systems, quantifying the intensity of positive coupling forces to reveal the quality of coordination [32]. This study applies the coupling coordination degree model to systematically evaluate the synergistic progress between multifunctional land use and multidimensional relative poverty in the Gansu section of Liupanshan. The calculation formulas are:

$$T = \alpha F(x) + \beta Z(y)$$

$$D = \sqrt{C \times T}$$

where T is the coordination index between multifunctional land use and multidimensional relative poverty; D is the coupling coordination degree; α and β are undetermined coefficients ($\alpha + \beta = 1$). This study considers multifunctional land use and multidimensional relative poverty to be equally important, thus $\alpha = \beta = 0.5$.

Referencing existing research [33] and considering actual conditions in the Gansu section of Liupanshan, coupling coordination degrees are divided into seven grades: severe disorder, moderate disorder, mild disorder, primary coordination, moderate coordination, good coordination, and premium coordination. Additionally, based on the difference between the two system scores, coupling coordination types are classified as shown in Table 3.

Results

2.1 Measurement Results of Multifunctional Land Use and Multidimensional Relative Poverty

From 2010 to 2020, both the multifunctional land use index and multidimensional poverty reduction index in the Gansu section of Liupanshan showed increasing trends. The total growth rate of the multifunctional land use index

was 66.67%, with production, living, and ecological function indices increasing by 50.00%, 45.45%, and 50.00% respectively. This indicates that the region achieved remarkable success in promoting land productivity and economic benefits while paying greater attention to social and ecological sustainable development to improve residents' quality of life and social welfare, and strengthen rational land resource utilization and ecological protection.

Using the natural breaks method, multifunctional land use levels were classified as low (0.05–0.07), relatively low (0.07–0.09), medium (0.09–0.11), relatively high (0.11–0.16), and high (0.16–0.78). From 2010 to 2020, the overall level shifted from medium-low to medium-high, with southern counties generally higher than northern counties. Specifically, in 2010, only Linxia City and Qinzhou District had high levels, Baiyin District, Pingchuan District, and Yongjing County had relatively high levels, and all other counties were at medium or low levels. By 2015, the number of counties at medium-high levels increased to 15, with significant improvement in multifunctional land use levels. By 2020, only Anding District and Huan County remained at medium-low levels, while other counties reached medium-high or high levels, indicating further improvement.

The multidimensional poverty reduction index showed a total growth rate of 25.00%, with the economy and employment dimensions remaining relatively stable, while industry and public service dimensions grew by 33.33% and 60.00% respectively. This demonstrates that poverty reduction efforts achieved significant results, with strategies gradually adjusting and optimizing. While maintaining focus on economic income and employment, greater emphasis was placed on industry and public service dimensions.

Using the natural breaks method, multidimensional poverty reduction levels were classified as low (0.05–0.09), relatively low (0.09–0.15), medium (0.15–0.24), relatively high (0.24–0.40), and high (0.40–0.69). From 2010 to 2020, the degree shifted from medium-low to medium-high (Fig. 3). In 2010, Baiyin District, Pingchuan District, Lingtai County, and Xifeng District had high levels, 8 counties had medium or relatively high levels, and the rest were at relatively low or low levels. By 2015, high-level areas increased to 6 counties with no low-level counties. By 2020, only Zhang County and Dongxiang Autonomous County remained at low levels, while Jingtai County, Lingtai County, and Jingchuan County reached high levels, showing significant improvement in multidimensional poverty reduction.

2.2 Coupling Coordination Relationship Between Multifunctional Land Use and Multidimensional Relative Poverty

From 2010 to 2020, the average coupling degree between multifunctional land use and multidimensional relative poverty in the Gansu section of Liupanshan decreased from 0.85 to 0.81, indicating a slight decline but remaining at a high coupling level overall, with strong interaction between the two systems. According to coupling degree classification standards, the region was primarily

characterized by high coupling (Fig. 4). In 2010, 23 counties exhibited high coupling, including Yuzhong County, Baiyin District, and Maiji District. By 2015, some counties showed decreased coupling, with high coupling counties reducing to 18, including Yongdeng County, Gaolan County, and Baiyin District. By 2020, the coupling degree remained at high levels, with only Gaolan County, Anding District, and Huan County showing moderate coupling and no low coupling counties.

Spatially, the coupling degree displayed a pattern of higher values in the southwest and lower values in the northeast, with different coupling levels showing agglomeration patterns and significant spatial differences. This suggests that the coupling relationship between the two systems is generally favorable, though some counties like Anding District, Gaolan County, and Huan County still have room for improvement.

From 2010 to 2020, the average coupling coordination degree between multifunctional land use and multidimensional relative poverty increased from 0.41 to 0.55, showing a clear upward trend with spatial agglomeration effects (Fig. 5). The coordination level shifted from being primarily disorder to primarily mild disorder. In 2010, 19 counties were in a state of disorder, including 11 severely disordered counties, with only Baiyin District and Qinzhou District in coordination. By 2015, coordination levels improved significantly, with severely disordered counties reducing to 7 and coordinated counties increasing to 8, adding Yongjing County, Maiji District, and Chongxin County. By 2020, severely disordered counties further decreased to 4, with coordinated counties reaching 12, including newly coordinated Jingtai County, Lingtai County, Jingchuan County, and Hui County. Although most coordinated counties remained at primary coordination level, the overall coordination level showed a positive trend with clear spatial agglomeration.

2.3 Coupling Coordination Types

Based on the classification standards (Table 3), spatial distribution maps of coupling coordination types were produced (Fig. 6). The results show:

From 2010 to 2020, the number of synchronous-type counties decreased fluctuatingly but remained dominant. Synchronous-type counties decreased from 27 in 2010 to 24 in 2020, accounting for 58.70% of the total, mainly distributed in central and southwestern areas. The coordination level was primarily disorder, indicating that the two systems were mainly in a state of mutual inhibition.

The number of multifunctional land use lagging-type counties showed a pattern of first decreasing then increasing. From 2010 to 2015, these counties decreased from 10 to 7, then increased to 12 by 2020, mainly distributed in northwestern and northeastern areas. Among them, Lintao County, Gulang County, and Longxi County shifted from synchronous-type to multifunctional land use lagging-type, Qinzhou District shifted from multidimensional relative poverty lagging-type to multifunctional land use lagging-type, and Yuzhong County

shifted out of multifunctional land use lagging-type to synchronous-type. This indicates that under poverty alleviation policies, these counties achieved faster progress in poverty reduction than in improving land use multifunctionality.

The number of multidimensional relative poverty lagging-type counties was small. In 2010, only Qinzhou District and Linxia City were in this category, with good and premium coordination respectively. By 2015, Qinzhou District shifted to primary coordination synchronous-type, while Min County and Linxia City remained multidimensional relative poverty lagging-type. By 2020, only Linxia City remained as premium coordination multidimensional relative poverty lagging-type, indicating that its multidimensional relative poverty reduction progressed faster than its land use multifunctionality improvement, while the interactive coordination between the two systems remained at a high level.

Discussion

As a natural-economic complex, land fulfills diverse economic, social, ecological, and cultural service functions and serves as an important carrier for poverty alleviation [34]. Multifunctional land use can promote socioeconomic development, enhance comprehensive land benefits [35], and strengthen land' s multiple efficiencies. Through optimized allocation and strategic utilization of land capital, promoting simultaneous optimization of agricultural production, ecological balance, and social welfare not only helps increase farmers' income but also significantly improves rural community quality of life. Given that existing research on the coupling coordination between multifunctional land use and multidimensional relative poverty is limited, this study obtained research data through multiple cross-sections from 2010 to 2020 and examined the two subsystems at the county scale, then measured their coupling coordination status. The research shows that the spatial patterns of the two systems differ significantly in the Gansu section of Liupanshan, and the model of alleviating multidimensional relative poverty by improving multifunctional land use efficiency has considerable room for deepening. The coupling coordination type is mainly synchronous, but the coordination state is mostly disordered, indicating a mutual inhibition relationship.

The Gansu section of Liupanshan is one of China' s deeply impoverished "Three Regions and Three Prefectures" areas, with dense and complex development constraints, weak foundations, and limited capacity for industrial development and stable employment. Compared with research on economically developed impoverished counties in Guangdong Province [36], this study area shows different patterns. The Guangdong study found that coupling coordination types were primarily multifunctional land use lagging, all three coordination types were in coordination rather than disorder, and the two systems showed a mutually promoting evolution trend. In contrast, this study' s findings can provide references for policy optimization in relatively backward areas.

To achieve positive interaction between multifunctional land use and multidi-

mensional relative poverty, greater emphasis should be placed on balancing the "production-living-ecological" systems. Based on ensuring production functions, land use should enhance employment opportunities, improve living conditions, promote regional development, and maintain ecological balance. Scientific and rational land resource allocation strategies should be adopted to ensure long-term sustainable development while preventing excessive land capitalization from negatively affecting production efficiency. Additionally, government should increase investment in capital, technology, and talent to improve sustainable industrial development capacity, help low-income populations increase employment and income, strengthen regional revitalization support, and promote multidimensional sustainable development to ultimately reduce relative poverty.

Due to differences in research scale and indicator selection, this study' s measurement results differ from previous research [37-38] but show similar overall patterns. However, improvements are needed: the multifunctional land use evaluation indicator system requires further refinement. While this study selected indicators from production, living, and ecological perspectives based on existing research [39-40], secondary indicators still have expansion potential. The evaluation process used the comprehensive index method, which is relatively simple; future research could employ the Alkire-Foster model for more comprehensive assessment. This study focused on temporal and spatial drivers, but coupling coordination relationships are influenced by multiple factors requiring further investigation.

Conclusions

1. From 2010 to 2020, both multifunctional land use level and multidimensional poverty reduction degree in the Gansu section of Liupanshan improved, with the multifunctional land use index growing faster. Both shifted from medium-low to medium-high levels, with prominent spatial agglomeration effects. Future efforts should continuously enhance land use multifunctionality and strengthen multidimensional poverty reduction effects.

2. From 2010 to 2020, the coupling degree between multifunctional land use and multidimensional relative poverty in the Gansu section of Liupanshan was primarily characterized by high coupling, indicating strong interaction between the two systems. High coupling counties numbered 23 in 2010, decreasing to 18 in 2020, with the coupling degree generally remaining at high levels. Spatially, coupling degree showed a pattern of higher values in the southwest and lower values in the northeast, with significant spatial differences.

3. From 2010 to 2020, the coupling coordination degree between multifunctional land use and multidimensional relative poverty in the Gansu section of Liupanshan significantly improved, with spatial agglomeration effects.

The coordination level was primarily disordered, with severely disordered counties decreasing from 11 in 2010 to 4 in 2020. Coordinated counties increased from 2 to 12, with the overall coordination level showing a positive trend. However, coordination grades still require improvement. Therefore, land use patterns should be continuously optimized to enhance multidimensional poverty reduction from multiple dimensions and improve coordination grades.

4. From 2010 to 2020, the coupling coordination type between multifunctional land use and multidimensional relative poverty in the Gansu section of Liupanshan was mainly synchronous. The proportion of multifunctional land use lagging-type counties in coordinated states increased, enhancing positive interaction. However, synchronous-type counties were primarily in disordered states, showing mutual inhibition. In 2020, only Linxia City was premium coordination multidimensional relative poverty lagging-type. The positive mechanism of reducing multidimensional relative poverty by improving multifunctional land use efficiency to promote regional sustainable development still has considerable room for deepening in the Gansu section of Liupanshan.

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