Multidimensional Evaluation and Spatiotemporal Evolution of Urban-Rural Integrated Development in Xinjiang from the Perspective of “People-Land-Industry”

Lu Zhiqiu, Lü Mingyang, Li Zhihui, Xu Liping

2026-08-24

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Abstract

Counties are an important entry point for urban-rural integrated development, as well as the main arena for implementing the rural revitalization strategy and promoting urban-rural integration. Taking 83 counties in Xinjiang Uygur Autonomous Region as the research objects, this study constructs a three-dimensional indicator system of "population-land-industry" and uses the entropy weight method to measure the level of urban-rural integrated development in Xinjiang counties from 2001 to 2021. Kernel density analysis and a transition matrix are employed to explore the evolutionary characteristics of the level of urban-rural integrated development, and a coupling coordination degree model is used to examine the coordination and constraint relationships among different dimensions. The results show that: (1) From 2001 to 2021, the development levels of all dimensions of urban-rural integration in Xinjiang counties, as well as the comprehensive level, increased significantly, generally showing a pattern of "higher in the north and lower in the south," but with different evolutionary characteristics. The level of "population integration" shifted from a spatial pattern of "low level across the whole region" to "gradient differentiation" ; the level of "land integration" improved relatively slowly, with a large gap between northern and southern Xinjiang; county-level disparities in the level of "industry integration" narrowed, and the spatial agglomeration of higher-value areas strengthened; the gap in the comprehensive level between northern and southern Xinjiang showed a trend of "first widening and then narrowing." (2) From 2001 to 2021, urban-rural integrated development in Xinjiang counties can be divided into three stages: the "low-speed development stage (2001–2006)," the "transition stage (2006–2016)," and the "rapid development stage (2016–2021)." (3) From 2001 to 2021, the coupling coordination level of "population-land-industry" continued to improve, spatially presenting a pattern of "higher in the north and lower in the south." The system coordination structure improved significantly, specifically manifested in the elimination of counties with severe imbalance, a sharp decline in the number of counties with moderate imbalance, and the emergence of counties with good coordination. Based on these findings, it is recommended to accurately identify the development weaknesses and lagging dimensions of disadvantaged areas, promote the targeted allocation of resource factors, and facilitate coordinated development across all dimensions; meanwhile, regional growth poles should be cultivated to build an urban-rural integrated development pattern of "driving overall progress through key points and advancing by gradients."

Full Text

Multidimensional Evaluation and Spatiotemporal Evolution of Urban-Rural Integrated Development in Xinjiang from the Perspective of "People-Land-Industry"

Lu Zhiqiu[1,2], Lü Mingyang[1,2], Li Zhihui[1,2], Xu Liping[1,2]

(1. College of Urban and Environmental Sciences, Shihezi University, Shihezi 832000, Xinjiang, China;
2. Key Laboratory of Oasis Towns and Mountain-Basin System Ecology, Xinjiang Production and Construction Corps, Shihezi 832000, Xinjiang, China)

Abstract: Counties are an important entry point for urban-rural integrated development, and they are also the main arena for implementing the rural revitalization strategy and promoting urban-rural integrated development. Taking 83 counties in the Xinjiang Uygur Autonomous Region as the research objects, this study constructs a three-dimensional indicator system of "people-land-industry" and uses the entropy weighting method to measure the level of urban-rural integrated development in Xinjiang' s counties from 2001 to 2021. Kernel density analysis and transition matrices are used to explore the evolutionary characteristics of the level of urban-rural integrated development, and a coupling coordination degree model is employed to examine the coordination and constraint relationships among different dimensions. The results show that: (1) From 2001 to 2021, the development levels of all dimensions and the comprehensive level of urban-rural integration in Xinjiang's counties increased significantly, with an overall pattern of "high in the north and low in the south," but the evolutionary characteristics differed. The level of "people integration" shifted from "low level across the whole region" to a spatial pattern of "gradient differentiation" ; the improvement in the level of "land integration" was relatively slow, and the gap between northern and southern Xinjiang remained large; the county-level gap in the level of "industry integration" narrowed, spatial agglomeration in high-value areas strengthened, and the comprehensive level in southern and northern Xinjiang showed a trend of "first expanding and then narrowing." (2) From 2001 to 2021, urban-rural integrated development in Xinjiang' s counties can be divided into three stages: "low-speed development stage (2001-2006)," "transition stage (2006-2016)," and "rapid development stage (2016-2021)." (3) From 2001 to 2021, the coupling coordination level of "people-land-industry" continued to improve, spatially presenting a pattern of "high in the north and low in the south." The system coordination structure improved significantly, as shown by the complete disappearance of severely imbalanced counties, a sharp decrease in the number of moderately imbalanced counties, and the beginning emergence of well-coordinated counties. Based on this, it is recommended to accurately identify the development shortcomings and lagging dimensions of weak areas,

promote the targeted allocation of resource elements, and advance coordinated development across all dimensions; at the same time, regional growth poles should be cultivated to build an urban-rural integrated development pattern of "driving areas through points and advancing by gradients."

Keywords: county; Xinjiang; urban-rural integration; "people-land-industry" ; coupling coordination degree

Article ID: 1000-6060(2026)08-1750-14(1750-1763)

With the advancement of global urbanization, industrialization, and informatization, the urban-rural gap has been widening, and countries are exploring measures suited to their own national conditions in order to balance urban-rural development[1]. As the largest developing country, China still faces at the current stage such problems as a prominent urban-rural dual structure and lagging modernization of agriculture and rural areas[2]. To narrow the urban-rural gap, the Chinese government has implemented a series of policies, focusing on promoting the two-way flow, equal exchange, and efficient allocation of factors so as to foster coordinated urban-rural development[3]. Population, land, and industry are the core elements of the urban-rural integration system, and the scientific and rational layout and feedback mechanism of urban-rural "people-land-industry" elements are key to promoting high-quality and sustainable urban-rural integrated development[4]. Among them, people are the direct driving force influencing and changing the urban-rural system; land is the carrier of the urban-rural system and the material basis for human activities; and industry is the internal driving force of development[5]. Therefore, based on the urban-rural system itself, promoting the coordination of "people-land-industry" elements is the key to breaking down the urban-rural dual structure. As a typical representative of underdeveloped border areas, Xinjiang possesses distinctive characteristics such as policy focus, ethnic diversity, cultural convergence, and numerous neighboring countries. It is not only a microcosm of urban-rural integration issues in underdeveloped regions of central and western China, but also occupies an important position in the national pattern of regional coordinated development and security. Accordingly, analyzing the spatiotemporal evolution of Xinjiang' s urban-rural integrated development from the perspective of "people-land-industry" is of great significance.

Received: 2025-10-18; **Revised:** 2025-11-04
Funding: Sponsored by the Science and Technology Program Project of the Corps (2023CB008-23); National Social Science Fund Youth Project (23CJY048)
Author biography: Lu Zhiqiu (2001-), female, master' s student, mainly engaged in research on urban-rural integrated development. E-mail: 15090026922@163.com
Corresponding author: Xu Liping (1978-), female, PhD, professor, mainly engaged in research on landscape ecology and urban-rural development. E-mail:

xlp alw@163.com

Urban-rural integrated development aims to achieve coordinated development of urban and rural areas in such domains as society, economy, and culture[^6]. Academic research on urban-rural integration has expanded from a single perspective to multidimensional analysis[^7]. As the core elements, "people-land-industry" constitute an important perspective for analyzing the intrinsic mechanism of urban-rural integration. At the level of individual elements, research has focused on fields such as urban-rural population mobility[^8], land-use transition[^9], land-use equity[^10], the empowerment of urban-rural integrated development by new-quality productive forces[^11], and industrial coordination[^12]. At the multi-element level, discussions have centered on the coordination mechanism and driving factors of the "people-land-industry" elements[^13]. Existing studies have mostly focused on the developed regions of central and eastern China and have been conducted around theoretical frameworks, level measurement, and path optimization[^14-15]. Evaluation systems have been constructed from traditional dimensions such as "economy, society, space, ecology, and population" [^16], covering multiple spatial scales including the national, provincial, urban agglomeration, municipal, and county levels[^17-20]. Quantitative analyses have been carried out using comprehensive index methods and coupling coordination degree models[^21], and weights have been determined using methods such as the entropy weight method, coefficient of variation method, and principal component analysis[^13,^22], in order to evaluate the level of urban-rural integrated development and the conditions of resource endowment[^23]. However, existing research lacks long-term dynamic monitoring; indicator systems are limited to traditional dimensions and have not yet formed a unified theoretical framework or universal evaluation system. Constrained by data availability, most studies are conducted at the provincial and municipal scales, while studies on counties and special typical regions remain insufficient. Research on Xinjiang is still deficient in terms of temporal span, research scale, and sample coverage[^24-25], and lacks discussion from the "people-land-industry" perspective.

As the basic unit of urban-rural integrated development and the link connecting urban and rural areas, the county is an important entry point for urban-rural integrated development and also the main arena for implementing the rural revitalization strategy and promoting urban-rural integrated development[^26]. China has achieved remarkable results in urban-rural integrated development, but in the central and western regions where the level of socioeconomic development is relatively low, rural development elements are seriously lost, endogenous development momentum is insufficient, the radiating role of cities is weak, and the development gap between counties and urban-rural areas remains large[^27]. Based on this, this study adopts the "people-land-industry" perspective; takes 83 counties in Xinjiang as the research objects; selects five time nodes—2001, 2006, 2011, 2016, and 2021—drawing on the advantages of a long temporal span, fine research scale, and comprehensive sample coverage; measures the level of urban-rural integrated development; and analyzes its spatial differentiation characteristics, element coordination relationships, and type-transition patterns. The aim is to reveal the unbalanced pattern and evolutionary characteristics of urban-rural development in Xinjiang and provide references for the formulation and regulation of relevant policies.

1 Materials and Methods

1.1 Theoretical framework

The evolution of urban-rural relations generally exhibits stage characteristics of "dual segmentation-unidirectional flow-interactive integration" [^13]. Its core lies in promoting the bidirectional flow and cyclical allocation of such elements as "people-land-industry," narrowing the urban-rural gap, and promoting coordinated regional development[^28]. As core elements, population, land, and industry directly influence the process of sustainable urban-rural development through their evolutionary characteristics and coupling-coordination levels; they are the key to constructing a rational and orderly urban-rural territorial spatial pattern and realizing sustainable urban-rural development[^29-30]. The theory of human-land territorial systems points out that "people" and "land" combine within a specific region to form a complex, open megasystem encompassing subsystems such as nature, society, and economy, and possessing specific structures and functions[^31-32]. Industry, as the key link connecting "people" and "land," has structural characteristics that affect regional economic growth patterns[^33-34]. The three core elements of "people-land-industry" cover the three major core domains of "social livelihood, ecological space, and economic development," and integrate the traditional dimensions of urban-rural integration evaluation, including "economy, society, ecology, space, and population." Among them, "people" are the direct driving force that affects and changes the urban-rural system. As the main body of urban-rural economic activities and factor flows, people play a fundamental and decisive role in the process of urban-rural integration[^35-36]. "Land" possesses the triple attributes of resource, property, and capital; it is the material basis of human activities and the spatial carrier of industrial development, providing solid spatial support for regional development[^29-30]. "Industry" is the endogenous driving force for the development of the urban-rural system. Urban-rural industrial interaction can break down industrial segmentation and county-space barriers[^5,^37]; urban-rural industrial integration is not only an inevitable requirement of the upgrading of social productive forces and industrial structure, but also a key support for promoting comprehensive urban-rural integration[^38-39]. In view of this, this paper refines urban-rural integration into three dimensions: "people integration," "land integration," and "industry integration" (Fig. 1).

Fig. 1 System framework

Figure 1: Fig. 1 System framework

1.2 Overview of the study area

The Xinjiang Uygur Autonomous Region (73°40′-96°23′E, 34°25′-49°10′N) is located on China' s northwestern frontier. With a total area of 1.66 × 10^6 km^2, it is the provincial-level administrative region with the largest land area and the largest number of neighboring countries in China.

Fig. 1 System framework

(Fig. 2). Constrained by natural conditions, Xinjiang faces great difficulty in infrastructure construction, has a relatively single industrial structure, and encounters substantial challenges in economic and social development. As a result, it is relatively lagging behind in the national development process and shows a marked gap from developed regions in China; urban-rural development also exhibits considerable imbalance.

1.3 Data sources

The data used in this study include socioeconomic data, $PM_{2.5}$ concentration data, normalized difference vegetation index (NDVI), vector administrative division data, road network data, desert data, and oasis data (Table 1).

1.4 Analytical methods

1.4.1 Indicator system

This paper selects 17 indicators from the three dimensions of "people-land-industry" to construct an evaluation indicator system for the level of county-level urban-rural integrated development in Xinjiang (Table 2). The meanings of the indicators in each dimension are as follows: in terms of "people integration," population density measures differences in the spatial distribution of the regional population[40]; the urbanization rate reflects the transformation of population structure and residents' lifestyles[41]; residents' wealth status, educational development level, medical development level, and social security level characterize the degree of protection enjoyed by residents in terms of economic income, education, medical care, and other aspects[13]. In terms of "land integration," per-unit-area grain output measures the

Legend: national boundary; undetermined national boundary; provincial boundary; prefecture/state boundary; county boundary. Elevation/m: 7379 to −172. Scale: 0–200 km.

Note: Based on the standard map with approval number GS(2023)2767 from the Map Service website of the Ministry of Natural Resources; the base-map boundaries have not been modified. The same below.

Fig. 2 Schematic diagram of the study area

Table 1 Data sources

Data	Year	Source and resolution
Socioeconomic data	2001, 2006, 2011, 2016, 2021	*China County Statistical Yearbook*, *Xinjiang Statistical Yearbook*, and *Statistical Communiqué on National Economic and Social Development of Xinjiang Uygur Autonomous Region*
$PM_{2.5}$ concentration	2001, 2006, 2011, 2016, 2021	Atmospheric Composition Analysis Group, Dalhousie University (https://ghdx.healthdata.org); 1 km
NDVI	2001, 2006, 2011, 2016, 2021	Resource and Environment Science and Data Center, Chinese Academy of Sciences (https://www.resdc.cn); 1 km
Vector administrative division data	2023	Map Technology Review Center, Ministry of Natural Resources (https://www.zrzyst.cn)
Road network data	2021	OpenStreetMap (https://www.openstreetmap.org)
Desert data	2000	National Tibetan Plateau Scientific Data Center (https://data.tpdc.ac.cn)
Oasis data	2020	Data Center for Resources and Environmental Sciences in Arid Areas (https://data.dcxjegi.cn)

Note: NDVI is the normalized difference vegetation index. The same below.

land production functional efficiency [42], land urbanization rate, and urban spatial expansion reflect the orderly degree of land-use space and the integration of urban–rural space; air quality, agricultural non-point source pollution, and NDVI characterize the livability level of the regional ecological environment [43–44]. In terms of "industry integration,"per capita GDP reflects the overall state of urban–rural economic development [41]; industrial structure characterizes the level of urban–rural industrial coordination and structural optimization [45]; the level of agricultural development reflects the advancement of agricultural modernization [46]; the level of industrial development reflects the degree of industrialization and industrial competitiveness [47]; and the level of financial development, measured by the balance of loans from financial institutions at year-end per capita, characterizes the strength of regional capital demand and economic activity [48].

1.4.2 Entropy Weight Method

The entropy method is an objective weighting method that can avoid the arbitrariness of subjective weighting methods and objectively reflect the weights of evaluation indicators. Therefore, this study uses the entropy method to calculate indicator weights [49–50]. The process includes standardization of original data, non-negative translation, entropy calculation, entropy-weight calculation, and development-level index calculation [45].

1.4.3 Kernel Density Analysis

Kernel density analysis is used to explain the positional relationship among elements [51]. The formula is as follows:

$$f(x) = \frac{1}{nh}\sum_{i=1}^{n} K\left(\frac{x_i - \bar{x}}{h}\right) \qquad (1)$$

where $f(x)$ is the density function of the random variable x; n is the number of counties in the study area; h is the bandwidth; K is the kernel function; x_i is the urban–rural integration level score of county i; and $\bar{x}$ is the mean urban–rural integration level score.

1.4.4 Transition Matrix

The transition matrix presents, in matrix form, changes in the number of different types across different periods and the direction of transitions [52]. The formula is as follows:

$$S_{ab} = \begin{bmatrix} S_{11} & \cdots & S_{1m} \\ \vdots & \ddots & \vdots \\ S_{m1} & \cdots & S_{mm} \end{bmatrix} \qquad (2)$$

where S_{ab} is the number of cases in which urban-rural integrated development level type a changes into urban-rural integrated development level type b; and m is the number of types of urban-rural integrated development levels.

1.4.5 Coupling Coordination Degree Model

Coupling degree characterizes the strength of interaction and the degree of mutual influence among systems, while coordination degree can reflect the harmony, influence, and constraint relationships among systems [53]. The calculation process of the coupling coordination degree model is as follows:

(1) Calculation of coupling degree:

$$C = \left[\frac{U_1 \times U_2 \times U_3}{(U_1 + U_2) \times (U_1 + U_3) \times (U_2 + U_3)}\right]^{\frac{1}{3}} \qquad (3)$$

where C is the coupling degree; U_1 is the level score of "people integration" ; U_2 is the level score of "land integration" ; and U_3 is the level score of "industry integration."

(2) Calculation of coupling coordination degree:

$$T = \beta_1 U_1 + \beta_2 U_2 + \beta_3 U_3 \qquad (4)$$

$$D = \sqrt{C \times T} \qquad (5)$$

where T is the comprehensive coordination index; β_1 is the weight of the "people" subsystem; β_2 is the weight of the "land" subsystem; β_3 is the weight of the "industry" subsystem; and D is the coupling coordination degree. Drawing on existing research [54], the evaluation grades of coupling coordination degree are classified (Table 3).

Table 2 Indicator System

Tab. 2 Indicator system

Target layer	Criterion layer	Indicator description	Unit	Attribute	Weight/%	References
People integration	Population density	Population quantity / regional area	people · km^{-2}	+	13.23	[7]

Target layer	Criterion layer	Indicator description	Unit	Attribute	Weight/%	References
People integration	Population urbanization rate	Urban population / total population × 100%	%	+	3.53	[14]
People integration	Residents' wealth status	Per capita savings deposit balance	yuan · person^{-1}	+	7.76	[44]
People integration	Education development level	Number of students in compulsory education / total population × 100%	%	+	1.87	[39]
People integration	Medical development level	Number of beds in medical and health institutions	beds · (10^3 persons)$^{-1}$	+	2.14	[13]
People integration	Social security level	Beds in social welfare institutions for adoption	beds · (10^3 persons)$^{-1}$	+	6.35	[49]

Target layer	Criterion layer	Indicator description	Unit	Attribute	Weight/%	References
Land integration	Average grain output per unit land	Grain output / sown area	$kg \cdot km^{-2}$	+	1.25	[42]
Land integration	Land urbanization rate	Built-up area / regional area × 100%	%	+	13.27	[13]
Land integration	Urban spatial expansion	Built-up area / cultivated land area × 100%	%	−	0.28	[43]
Land integration	Agricultural non-point source pollution	Fertilizer application amount / sown area	$kg \cdot km^{-2}$	−	0.55	[45]
Land integration	Air quality	$PM_{2.5}$ concentration	$\mu g \cdot m^{-3}$	−	0.69	[41]
Land integration	NDVI	Regional mean NDVI value	Dimensionless	+	5.13	[43]
Industry integration	Per capita GDP	Regional gross domestic product / regional population	$yuan \cdot person^{-1}$	+	7.70	[41]

Target layer	Criterion layer	Indicator description	Unit	Attribute	Weight/%	References
Industry integration	Industrial structure	(Secondary-industry output value + tertiary-industry output value) / primary-industry output value	Dimensionless	+	9.79	[24]
Industry integration	Agricultural development level	Total agricultural machinery power / sown area	$kW \cdot km^{-2}$	+	9.64	[46]
Industry integration	Industrial development level	Number of industrial enterprises above designated size	units	+	7.29	[47]
Industry integration	Financial development level	Per capita balance of loans from financial institutions at year-end	$yuan \cdot person^{-1}$	+	9.53	[48]

Note: + and − indicate positive and negative indicators, respectively.

Table 3 Coordination degree levels

Tab. 3 Coordination degree levels

Value range	Coordination level	Value range	Coordination level
$D \leq 0.2$	Severe imbalance	$0.5 < D \leq 0.6$	Barely coordinated
$0.2 < D \leq 0.3$	Moderate imbalance	$0.6 < D \leq 0.7$	Primary coordination
$0.3 < D \leq 0.4$	Mild imbalance	$0.7 < D \leq 0.8$	Intermediate coordination
$0.4 < D \leq 0.5$	On the verge of imbalance	$0.8 < D \leq 0.9$	Good coordination

Note: D is the coupling coordination degree.

2 Results and Analysis

2.1 Level of urban-rural integrated development

Using the standard deviation method, with the mean as the reference and the standard deviation as the interval, the urban-rural integrated development index was divided into four grades: low-value areas, relatively low-value areas, medium-value areas, and relatively high-value areas[43].

2.1.1 Level of "people integration" From 2001 to 2021, the mean level of urban-rural "people integration" in Xinjiang' s counties increased from 0.1135 to 0.2112, a growth of 0.86 times. The spatial pattern gradually evolved from "low level across the whole region" to "gradient differentiation" (Fig. 3). In 2001, only a small number of counties were in medium- and relatively high-value areas, while 93.98% of counties were in relatively low-value and low-value areas; from 2006 to 2016, the number of counties in relatively high-value and medium-value areas increased steadily, while relatively low-value and low-value areas continued to shrink. By 2021, the level of "people integration" had increased significantly: counties in the relatively high-value area increased to 17, counties in the medium-value area increased to 38, and the proportion of counties in relatively low-value and low-value areas fell to 33.73%.

2.1.2 Level of "land integration" From 2001 to 2021, the mean level of urban-rural "land integration" in Xinjiang' s counties increased from 0.1477 to 0.2047, a growth of 0.39 times, showing a spatial pattern of "high in the north and low in the south" (Fig. 4). In 2001, only Kashi City and Kuitun City were relatively high-value areas; there were 9 counties in the medium-value area, and relatively low-value and low-value counties accounted for 86.75%. From 2006 to 2016, the number of relatively high-value counties remained consistently small, medium-value counties gradually expanded, and relatively low-value and low-value counties gradually shrank, though the overall evolution process was relatively slow. In 2021, counties in the relatively high-value area increased to 6, counties in the medium-value area increased to 25, and the proportion of relatively low-value and low-value counties fell to 62.65%. The overall level of "land integration" improved, but the magnitude of improvement was limited, and regional imbalance was prominent.

2.1.3 Level of "industry integration" From 2001 to 2021, the mean level of urban-rural "industry integration" in Xinjiang' s counties increased from 0.0417 to 0.1526, a growth of 2.66 times. It showed a spatial pattern of "high in the north and low in the south," with interregional disparities gradually narrowing and the agglomeration effect of relatively high-value areas strengthening (Fig. 5). In 2001, only Korla City, Shanshan County, and Kuitun City were medium-value areas, while the remaining 96.39% of counties were relatively low-value and low-value areas. From 2006 to 2016, the number of medium-value and relatively high-value counties gradually increased, and the proportion of low-value and relatively low-value counties fell to 75.90%. By 2021, counties in the relatively high-value area increased to 16, counties in the medium-value area increased to 22, and the proportion of relatively low-value and low-value counties fell to 54.22%. The level of "industry integration" achieved a staged leap.

2.1.4 Comprehensive level of urban-rural integration From 2001 to 2021, the mean comprehensive level of urban-rural integration in Xinjiang' s counties increased from 0.0892 to 0.1841, a growth of 1.06 times, presenting a spatial pattern of "high in the north and low in the south," with the north-south Xinjiang gap "first increasing and then decreasing" (Fig. 6). In 2001, only Kashi City was a relatively high-value area, Kuitun City and Yining City were medium-value areas, and the remaining 96.39% of counties were in relatively low-value and low-value areas. In 2006, relatively low-value and low-value–

(a) 2001

(b) 2006

(c) 2011

(d) 2016

(e) 2021

Legend

Boundary/area type	"People integration" level
National boundary	Low-value area
Undetermined national boundary	Relatively low-value area
Provincial boundary	Medium-value area

Boundary/area type	"People integration" level
Prefecture boundary	Relatively high-value area
County boundary	Non-study area

Fig. 3 Level of "people integration"

(a) 2001 (b) 2006 (c) 2011

(b) 2016 (e) 2021

Legend "Land integration" level

Line/Area	Meaning
—	National boundary
—	Undelimited national boundary
—	Provincial boundary
—	Prefecture boundary
—	County boundary
	Non-study area

Color class	Meaning
Light green	Low-value area
Pale green	Relatively low-value area
Green	Medium-value area
Dark green	Relatively high-value area

Fig. 4 Level of "land integration"

(a) 2001 (b) 2006 (c) 2011

(b) 2016 (e) 2021

Legend "Industry integration" level

Line/Area	Meaning
—	National boundary
—	Undelimited national boundary
—	Provincial boundary
—	Prefecture boundary
—	County boundary
	Non-study area

Color class	Meaning
Light pink	Low-value area
Pink	Relatively low-value area
Rose	Medium-value area
Dark rose	Relatively high-value area

Fig. 5 Level of "industry integration"

The proportion of counties in these categories still reached as high as 92.77%; during 2011–2016, the number of counties in the medium-value and relatively high-value areas increased steadily, while the proportion of counties in the relatively low-value and low-value areas fell to 73.49%; by 2021, the number of counties in the relatively high-value area had increased to 13, and the number of counties in the medium-value area had increased to 34, while the proportion of counties in the relatively low-value and low-value areas had declined to 43.37%, indicating a marked improvement in the level of urban–rural integrated development.

2.2 Kernel density analysis of the level of urban–rural integrated development

The results of the kernel density analysis show that the level of urban–rural integrated development in Xinjiang's counties exhibited an overall upward trend (Fig. 7). In terms of temporal evolution characteristics, the center line of the kernel density curve shifted to the right and was distributed with a right skew overall, but the counties were always dominated by medium- and low-value areas; the height of the main peak decreased and the width of the curve increased, indicating that the degree of dispersion in urban–rural integrated development levels among counties expanded and spatial differences intensified; the pattern changed from "one main peak with multiple secondary peaks" to a "single peak," indicating that the characteristics of gradient differentiation weakened.

(a) 2001 (b) 2006 (c) 2011

(b) 2016 (e) 2021

Legend

Legend	Comprehensive level
National boundary	Low-value zone
Undemarcated national boundary	Relatively low-value zone
Provincial boundary	Medium-value zone
Prefecture boundary	Relatively high-value zone
County boundary	Non-study area

Fig. 6 Comprehensive level of urban–rural integration

Fig. 6 Comprehensive level of urban-rural integration

Fig. 7 Kernel density estimation of the comprehensive level

Fig. 7 Kernel density estimation of the comprehensive level

Fig. 8 Proportion of counties in different value zones of urban–rural integration development

Fig. 8 Proportion of counties in different value zones of urban-rural integration development

2.3 Transition matrix of the development level of urban-rural integration in Xinjiang counties

Analysis of the proportions of counties in different value zones and of the transition matrix for the development level of urban–rural integration in Xinjiang counties from 2001 to 2021 shows (Figs. 8–9) that most counties achieved a leap toward higher-value zones. In 2021, the number of counties in the low-value zone fell to zero, while the proportions of counties in the relatively low-value, medium-value, and relatively high-value zones were 43.37%, 39.76%, and 16.87%, respectively. Over time, the evolutionary trends in the proportions of counties in each value zone differed: the low-value zone declined continuously; the relatively low-value zone first rose and then fell; the medium-value zone fluctuated upward; and the relatively high-value zone increased slowly.

On this basis, the development of urban-rural integration in Xinjiang counties can be divided into three stages. In the slow-development stage (2001–2006), counties in the low-value and relatively low-value zones predominated; the proportions of counties in each value zone changed little, and the overall structure showed no obvious adjustment. In the transitional stage (2006–2016), the proportions of counties in all value zones changed markedly and the structure changed significantly: the proportion of low-value counties declined sharply, the proportion of relatively low-value counties rose to first place, and the proportion of medium-value counties rose to second place. In the rapid-development stage (2016–2021), the low-value zone disappeared; the proportion of counties in the relatively low-value zone declined, while the proportions of counties in the medium-value and relatively high-value zones increased markedly, and the system achieved an overall leap.

2.4 Coupled and coordinated development level of "people-land-industry"

From 2001 to 2021, the coupled and coordinated development level of the "people–land–industry" dimensions of urban–rural integration in Xinjiang counties increased significantly, with the mean value rising from 0.2717 to 0.4804, an increase of 0.77 times; overall, it showed a spatial pattern of "high in the north

Figure: transition matrix of urban-rural integration development level, with stages labeled "low-speed development stage," "transition stage," and "rapid development stage" ; legend: low-value area, relatively low-value area, medium-value area, relatively high-value area.

Figure 2: Figure: transition matrix of urban-rural integration development level, with stages labeled "low-speed development stage," "transition stage," and "rapid development stage" ; legend: low-value area, relatively low-value area, medium-value area, relatively high-value area.

and low in the south" (Fig. 10). The proportion of coordinated counties gradually increased, but uncoordinated counties always remained dominant (Fig. 11). In 2001, only Kashi City, Yining City, and Kuitun City were in a coordinated state, while the remaining 16 counties were severely uncoordinated. From 2006 to 2016, the number of coordinated counties gradually increased, and the number of moderately uncoordinated and severely uncoordinated counties gradually ...

Fig. 9 Transition matrix of urban-rural integration development level

decreased; by 2016, the number of coordinated counties had increased to 10, and only Moyu County remained seriously imbalanced; by 2021, the number of coordinated counties had increased to 29, and seriously imbalanced counties had been eliminated, indicating that the overall and structural levels of coupling and coordinated development had improved.

3 Discussion

3.1 Policy implications of the spatiotemporal evolution characteristics of urban-rural integration development in Xinjiang

The study finds that the evolutionary trend of the level of urban-rural integration development in Xinjiang' s counties is basically consistent with the findings of existing studies[^24,^43]. Driven by policies such as rural revitalization and urban-rural equalization, the level of urban-rural integration development in Xinjiang has improved, but overall it remains low. As a typical oasis distribution area in China' s arid regions, Xinjiang' s urban-rural settlement pattern and socioeconomic activities are strongly influenced by natural background and locational factors, and spatial differentiation is significant[^55]. High-value areas are mainly concentrated in the "economic belt on the northern slope of the Tianshan Mountains" and the "industrial belt on the southern slope of the Tianshan Mountains" (Fig. 12a). The autonomous-region capital Urumqi, the transportation hub city of Korla in northern and southern Xinjiang, Aksu City, Hami City at the "eastern gate of Xinjiang," Yining City as an "important gateway opening to Central Asia," and Bole City as a "gateway on the northern Xinjiang border" serve as key growth poles, generating relatively strong radiation and driving effects on surrounding counties. By contrast, the "areas along the

Figure: five maps labeled (a) 2001, (b) 2006, (c) 2011, (d) 2016, and (e) 2021, showing coupling coordination levels. Legend includes: national boundary, undetermined national boundary, provincial boundary, prefecture/state boundary, county boundary, non-study area; coupling coordination levels: serious imbalance, moderate imbalance, mild imbalance, near imbalance, reluctant coordination, primary coordination, intermediate coordination, good coordination.

Figure 3: Figure: five maps labeled (a) 2001, (b) 2006, (c) 2011, (d) 2016, and (e) 2021, showing coupling coordination levels. Legend includes: national boundary, undetermined national boundary, provincial boundary, prefecture/state boundary, county boundary, non-study area; coupling coordination levels: serious imbalance, moderate imbalance, mild imbalance, near imbalance, reluctant coordination, primary coordination, intermediate coordination, good coordination.

Fig. 11 Proportion of coupling coordination level

Figure 4: Fig. 11 Proportion of coupling coordination level

border and in high-cold regions" lack central cities with comprehensive carrying capacity and radiating leadership, and their overall development level is relatively low. The levels of urban–rural integration development in Kashgar City and Hotan City are relatively high, but constrained by the weak connectivity of transport infrastructure in the "three prefectures of southern Xinjiang," their radiation and driving capacity for surrounding counties is limited (Fig. 12b). Southern Xinjiang has a poor natural foundation (Fig. 12c), and population density is low and highly concentrated in oases. This distribution characteristic objectively shortens the urban–rural geographical distance, promotes population mobility and factor circulation, and results in a relatively high level of "people integration" in some counties.

Based on this, differentiated policies should be implemented: by promoting the tilt of resources toward the "areas along the border and in high-cold regions" and the "three prefectures of southern Xinjiang," cultivating regional growth poles, strengthening infrastructure connectivity, and building a development pattern of "point-driven area promotion and stepwise advancement." Specifically, the "economic belt on the northern slope of the Tianshan Mountains" and the "industrial belt on the southern slope of the Tianshan Mountains" should rely on their existing industrial foundations to promote green and digital transformation, while strengthening ecological constraints so as to achieve a dynamic balance between industrial development and ecological security; the "three prefectures of southern Xinjiang" must focus on promoting infrastructure interconnection and compensating for shortcomings in education, medical care, and social security.

Fig. 10 Coupling coordination level

Fig. 11 Proportion of coupling coordination level

and other basic public-service shortcomings, and effectively improve the level of livelihood security; the "high-cold areas along the border" should rely on local resources to develop characteristic industries such as ecological farming and animal husbandry, ice-and-snow tourism, and port economies, cultivate central cities, enhance the capacity for factor agglomeration, and coordinate border stability with economic and social development.

3.2 Mechanisms and Obstacles of Coupling Coordination among "People-Land-Industry"

There is a close feedback relationship among the urban–rural "people–land–industry" elements: the orderly movement and rational distribution of population can promote urban–rural information and technological exchange, drive the intensive and efficient use of land, and lay a foundation for agricultural modernization and the urbanization of rural towns; the optimized allocation of urban–rural land provides a carrier for industrial transformation and upgrading and spatial expansion, while disorderly urban expansion weakens the resource base and spatial-use efficiency. By relying on the city' s advantages in technology and talent, and combining them with rural land and ecological resources, coordinated urban–rural industrial development can not only create jobs and raise residents' income and quality of life, but also further strengthen the population agglomeration effect, providing sustained momentum for integrated urban–rural development. The analysis in this paper of the coordination and constraint relationships among "people–land–industry" shows that counties with a higher coupling coordination level also have a higher level of urban–rural integrated development. Further kernel-density analysis was conducted for the three dimensions of "people–land–industry" in each year (Fig. 13). The results show that in 2001 and 2006, "industrial integration" lagged markedly behind "population integration" and "land integration," and 95.18% of counties were in a state of imbalance. As "industrial integration" gradually caught up, systemic coordination strengthened; by 2021, the share of counties in an imbalanced state had fallen to 65.06%. For counties with unbalanced development, it is necessary to accurately identify the lagging dimension and implement targeted policy support, so as to promote mutual coordination among all dimensions and advance comprehensive urban–rural integration.

3.3 Research Limitations and Prospects

The core contribution of this study lies in its in-depth analysis of the level of urban–rural integrated development in Xinjiang' s counties from 2001 to 2021 and its spatiotemporal evolution characteristics. With the aid of kernel-density analysis, transition matrices, and the coupling coordination degree model, it explores the dynamic changes in the level of urban–rural integrated development and the "people–"

Fig. 12 Zoning of urban-rural integration development level and spatial development conditions in Xinjiang

Figure 5: Fig. 12 Zoning of urban-rural integration development level and spatial development conditions in Xinjiang

Fig. 13 Kernel density analysis of "people-land-industry"

Figure 6: Fig. 13 Kernel density analysis of "people-land-industry"

(a) Two zones and two belts

(b) Road network

(c) Natural background

Legend

Symbol	Meaning	Symbol	Meaning
–	National boundary	–	Boundary line of two zones and two belts
–	Undemarcated national boundary		Desert
–	Provincial boundary		Gobi
–	Prefecture/state boundary		Oasis
–	County boundary		Non-study area
	Railway		Urban–rural integration level
	Expressway		Relatively low-value area
–	Trunk road		Medium-value area
–	Main road		Relatively high-value area

Fig. 12 Zoning of urban-rural integration development level and spatial development conditions in Xinjiang

Fig. 13 Kernel density analysis of "people-land-industry"

…the coordination and constraint relationships of "land–industry." However, this study still has certain limitations: (1) the time-node data fail to present a continuous dynamic process; (2) the excavation of obstructing factors and internal driving mechanisms is insufficient, and the contribution of macro policies to the level of coupled and coordinated development has not been quantitatively analyzed; (3) the indicator system has limited coverage of dimensions such as "cultural integration" and "governance integration." Future research may be deepened in the following aspects: (1) carrying out year-by-year continuous measurement to deepen understanding of evolutionary trajectories and fluctuation characteristics; (2) applying obstacle-degree models, geographically weighted regression, and other methods to identify the constraining factors and driving mechanisms of urban–rural integrated development in different counties, thereby providing a basis for differentiated and precise policymaking; (3) supplementing dimensions such as "cultural integration" and "governance integration," and introducing interactive indicators such as road-network density and population migration, so as to build a more comprehensive evaluation system for urban–rural integrated development.

4 Conclusions

(1) From 2001 to 2021, the development levels of all dimensions and the comprehensive level of urban-rural integration in Xinjiang's counties increased significantly, and showed a spatial pattern of "high in the north and low in the south," but the evolutionary characteristics of each dimension differed. The level of "people integration" evolved from an "overall low level" to a pattern of "gradient differentiation" ; the level of "land integration" grew slowly, with a significant north-south Xinjiang gap; the inter-county gap in the level of "industry integration" narrowed, and spatial agglomeration in high-value areas strengthened; the north-south Xinjiang gap in the comprehensive level "first increased and then decreased."

(2) From 2001 to 2021, the development of urban-rural integration in Xinjiang's counties can be divided into three stages: 2001-2006 was the "low-speed development stage," during which the proportions of counties in each value zone changed little and the overall pattern changed insignificantly; 2006-2016 was the "transition stage," during which the proportions of counties in each value zone changed greatly and the structure changed markedly; 2016-2021 was the "rapid development stage," during which urban-rural integrated development achieved an overall leap.

(3) From 2001 to 2021, the coupling and coordination level of the county-level urban-rural "people-land-industry" system in Xinjiang continued to improve, presenting a spatial pattern of "high in the north and low in the south." The structure of system coordination improved significantly, as manifested specifically by the disappearance of counties with severe imbalance, a substantial reduction in counties with moderate imbalance, the initial emergence of counties with good coordination, and a marked increase in the proportion of coordinated counties.

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Multi-dimensional evaluation and temporal evolution of urban-rural integration development in Xinjiang from the perspective of "people-land-industry"

LU Zhiqiu^1,2, LYU Mingyang^1,2, LI Zhihui^1,2, XU Liping^1,2

(1. College of Urban and Environmental Sciences, Shihezi University, Shihezi 832000, Xinjiang, China;
2. Key Laboratory of Ecological Corps of Oasis Town and Mountain Basin System, Shihezi 832000, Xinjiang, China)

Abstract: Counties are crucial entry points for urban-rural integration development. They form the primary arenas for implementing the rural revitalization strategy and advancing urban-rural integration development. This study takes 83 counties in the Xinjiang Uygur Autonomous Region as the research subjects and constructs a three-dimensional indicator system that encompasses "people-land-industry". We employ the entropy weight method for the measurement of the level of urban-rural integration development in Xinjiang' s counties from 2001 to 2021. Kernel density analysis and transition matrices are adopted to explore the characteristics of the evolution of this development level. A coupling coordination degree model is used to investigate the coordination and constraints across the different dimensions. The results indicate that: (1) From 2001 to 2021, all of the dimensions and the comprehensive level of urban-rural integration in Xinjiang counties improved significantly, exhibiting a pattern of "higher in the north and lower in the south", with distinct evolutionary characteristics. The degree of "people integration" shifted from "low across all regions" to a "gradient differentiation" pattern; the "land integration" level improved relatively slowly, showing a significant gap between northern and southern Xinjiang. The disparity in the level of "industrial integration" among counties has narrowed, and spatial clustering in regions that have higher values intensified; the comprehensive level gap between northern and southern Xinjiang exhibits a trend of "first expanding, then narrowing". (2) The urban-rural integration development in Xinjiang counties from 2001 to 2021 can be divided into three stages: A "slow development phase (2001–2006)", a "transition stage (2006–2016)", and a "rapid development stage (2016–2021)". (3) From 2001 to 2021, the coordination level of "people-land-industry" continued to improve, exhibiting a spatial pattern that is "higher in the north and lower in the south". The systemic coordination structure has significantly improved, which is reflected in: The elimination of severely imbalanced counties, a sharp decrease in moderately imbalanced counties, and the emergence of well-coordinated counties. From this,

it is recommended to precisely identify the development gaps and lagging dimensions in weaker regions, promote targeted resource allocation, and foster all of the dimensions that coordinate development. Simultaneously, regional growth poles should be cultivated and urban-rural integration development should be "driven by a point-to-area approach" .

Keywords: county territory; Xinjiang; urban-rural integration; "people-land-industry" ; coupling coordination degree

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