Spatiotemporal Variation and Coupling Coordination of "Production-Living-Ecology" Functions in Xinjiang Counties and Cities: Postprint

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Abstract

An evaluation system was constructed based on the "production-living-ecological" function perspective, and a coupling coordination model was introduced to explore the spatiotemporal evolution patterns of land functions and the degree of interaction among functions in Xinjiang' s counties and cities, select key factors influencing regional development, and provide recommendations for regional development. The research results indicate that: (1) The spatiotemporal pattern distributions of production function, living function, ecological function, and the comprehensive evaluation of "production-living-ecological" functions in Xinjiang' s county-level units show significant differences, all exhibiting a spatial distribution characteristic of "high in the north and low in the south" , with the urban agglomeration on the northern slope of the Tianshan Mountains as the core high-value area. (2) The coupling coordination of "production-living-ecological" functions in Xinjiang' s counties and cities overall presents a spatial distribution pattern of "high in the north and low in the south" , and the coupling coordination relationship among county-level functions is gradually improving, laying a good foundation for subsequent regional development. (3) The selection of leading industries is crucial for the functional development of Xinjiang' s counties and cities, while macro-policy regulation helps enhance the coupling coordination among functions, promoting the coordinated and orderly development of county-level functions.

Full Text

Spatio-temporal Changes and Coupling Coordination Analysis of the "Production-Living-Ecological" Function in Xinjiang Counties and Cities

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Abstract: Based on the perspective of "production-living-ecological" function, this study constructs an evaluation system and introduces a coupling coordination model to explore the spatiotemporal evolution patterns of land functions and their interactions in Xinjiang counties and cities. The research identifies key factors affecting regional development and provides recommendations for regional planning. The results show that: (1) The production, living, ecological, and integrated "production-living-ecological" functions of Xinjiang counties and cities exhibit significant spatiotemporal heterogeneity, all showing a "high in the north, low in the south" spatial distribution pattern, with the urban agglomeration on the northern slope of the Tianshan Mountains as the core high-value area. (2) The coupling coordination of the "production-living-ecological" functions in Xinjiang counties and cities generally presents a "high in the north, low in the south" spatial distribution trend, with the functional coupling coordination relationships gradually improving and laying a solid foundation for subsequent regional development. (3) The selection of leading industries is crucial for functional development in Xinjiang counties and cities, while macro-policy regulation helps enhance functional coupling coordination and promotes coordinated and orderly functional development.

Keywords: "production-living-ecological" function; coupling coordination; counties and cities; Xinjiang

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1. Study Area Overview

The total area of Xinjiang Uygur Autonomous Region is approximately 160$×10^{4}$ km^2. The overall geomorphological pattern is characterized by "three mountains surrounding two basins" [Figure 160: see original paper]. The three major mountain systems and two large basins generally extend along latitudinal directions, showing distinct horizontal and vertical zonation, with clear zonal differences in resource endowments. According to the comprehensive natural regionalization of Xinjiang, the Tianshan Mountains divide the region into southern and northern Xinjiang, with northern Xinjiang belonging to the mid-temperate arid zone and southern Xinjiang belonging to the warm-temperate arid zone. Against a background of desert areas and irrigation characteristics dominated by snowmelt from high mountains, Xinjiang' s oases are the most typical in China, making Xinjiang the province with the widest distribution and largest area of oases in the country.

According to the Xinjiang Statistical Yearbook 2020, Xinjiang's total permanent population is approximately 25.85 million, including about 11.91 million rural residents. The population distribution shows significant spatial characteristics, with high and medium population density areas distributed in a southwest-northeast oriented belt. Southern Xinjiang's Bayingolin Prefecture, Kizilsu Prefecture, and Hotan region have relatively low population density, while northern Xinjiang' s Urumqi City and Ili region have higher population density. In terms of economic development level, northern Xinjiang has a more complete industrial structure, more developed economy, and better living security functions, with higher connectivity between counties and cities. In contrast, southern Xinjiang has a weaker industrial foundation, slower urbanization development, a higher proportion of agricultural output value in regional GDP, and urgently needs to adjust its industrial structure and development mode. Therefore, coordinating the interactions between county functions and promoting coordinated and efficient overall regional development are urgent issues in Xinjiang' s development and construction.

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2. Data and Methods

2.1 Data Sources

The data required for this study are divided into two parts: land use data and economic statistical data. Land use data were obtained from the Chinese Academy of Sciences' Resource and Environmental Remote Sensing Survey Dataset. Economic statistical data were sourced from the Xinjiang Statistical Yearbooks for 2000, 2010, 2015, and 2020, as well as the Xinjiang Statistical Yearbook 2020. Due to the long study period and numerous changes in county-level administrative divisions, to ensure data collectability and continuity, the 2020 Xinjiang county-level administrative divisions were used as the standard.

2.2 Methods

2.2.1 Index System Construction The territorial space system is a dynamic, complex giant system formed by the interaction of multiple elements [1]. The functions of Xinjiang counties and cities are complex and diverse. Based on the "production-living-ecological" function theory [2], this study divides county and city functions into production function, living function, and ecological function from the perspective of land function. Land functions have hierarchical and regional characteristics, requiring the establishment of corresponding classification and evaluation index systems for different regional backgrounds and research scales [3]. Therefore, this study comprehensively analyzes existing research results on "production-living-ecological" functions [2-4,6,8-9,14-15,20] and selects key indicators for each function, supplemented according to the development history and current situation of Xinjiang counties and cities. Considering the scientificity, representativeness, and data availability of indicators, a total of 20 indicators were selected (Table 1).

Production Function: Production function refers to the function of producing various products and services through social production with land as the labor object, directly or indirectly using land as the carrier [4]. Combined with Xinjiang' s development reality and relevant references [4,8,20], this study evaluates county and city production functions based on regional resource utilization efficiency and production scale efficiency. It is divided into agricultural production function and non-agricultural production function. Agricultural production function is evaluated from four dimensions: cultivated land area, agricultural product output, agricultural production efficiency, and agricultural machinery application scale. Non-agricultural production function is evaluated from two dimensions: non-agricultural production scale and efficiency, with all selected indicators being positive indicators.

Living Function: Living function refers to the function of land providing various guarantees for human survival and development [5]. Combined with Xinjiang' s development reality and relevant references [3,8,28], this study comprehensively evaluates county and city living functions based on the basic security functions that counties and cities can provide, covering five aspects: medical care, education, income, consumption, and transportation. All selected indicators are positive indicators.

Ecological Function: Ecological function is the foundation for maintaining and stabilizing production and living functions [6]. Xinjiang is an important forest ecological function area and a northwest grassland desertification prevention and control area in China. Its vast grasslands are an important ecological security barrier in western China and also the foundation for animal husbandry economic development. Therefore, combined with Xinjiang' s ecological environment characteristics and relevant literature [10,14,20,29-30], this study selects newly desertified and salinized land area as a negative indicator for ecological function, and forest area proportion, grassland area proportion, per capita forest area, per capita grassland area, vegetation coverage index, and biological abundance index as positive indicators to jointly construct the ecological function evaluation index system for Xinjiang. The calculation methods for vegetation coverage index and biological abundance index refer to the Technical Specification for Eco-environmental Status Evaluation, calculated using the Chinese Academy of Sciences' Resource and Environmental Remote Sensing Survey Dataset.

2.2.2 Index Weight Determination The assignment of index weights directly affects research results and must ensure rigorous scientificity. This study adopts a combination of entropy method and analytic hierarchy process (AHP) for index weight determination. The entropy method originated from information theory, where information entropy represents the degree of system order. A higher degree of order corresponds to greater information entropy, while a higher degree of disorder corresponds to smaller information entropy. Based on this theory, Guo Xianguang [31] applied it to comprehensive evaluation system construction, calculating index weights based on the degree of variation in indicator values using information entropy tools. It has since been widely applied in various evaluation systems [32-34]. The Analytic Hierarchy Process (AHP), proposed by Saaty [35] in the 1970s, combines qualitative and quantitative analysis by decomposing complex multi-objective research objects into multi-level structures and conducting pairwise comparisons of evaluation indicators at each level to determine their relative contribution rates, which are then converted into index weights. Due to its simple principle and clear logic, AHP has been widely applied in various fields [36-38].

Since the entropy method objectively assigns weights based on the physical characteristics of indicators while AHP can subjectively assign weights, this study adopts a combination of subjective and objective weighting methods. This approach integrates the objective characteristics and subjective importance of weights [39-41], reducing the uncertainty of index weights to a certain extent and making the weight assignment more scientific. The weight determination method in this study combines the two methods, with specific weights shown in Table 1.

2.2.3 "Production-Living-Ecological" Function Comprehensive Evaluation Model The comprehensive evaluation model for the "production-living-ecological" function is established as follows:

$$Q = \chi_1 P + \chi_2 L + \chi_3 E$$

where: Q is the comprehensive evaluation value of the county' s "production-living-ecological" function; P, L, and E are the evaluation values of production function, living function, and ecological function, respectively; and χ_1, χ_2, and χ_3 are the 待定 coefficients for production, living, and ecological functions. The weight setting of the "production-living-ecological" function evaluation model should be combined with the development situation of Xinjiang counties and cities, and refer to the weight division results in the construction of relevant "production-living-ecological" function evaluation systems [20,42-44] and expert opinions. The values of χ_1, χ_2, and χ_3 are determined as 0.35, 0.35, and 0.30, respectively.

2.2.4 Functional Coupling Coordination Model This study introduces the coupling coordination model [20,45] to analyze the overall development and changes of functional coupling coordination in counties and cities by calculating the coupling coordination index between county functions. The specific calculation formulas are as follows:

$$C = 3 \times \sqrt[3]{\frac{P \times L \times E}{(P + L + E)^3}}$$

$$D = \sqrt{C \times T}, \quad T = \chi_1 P + \chi_2 L + \chi_3 E$$

where: C is the coupling degree of the "production-living-ecological" functions, with a value range of [0, 1]. The magnitude of this value is jointly determined by the evaluation values of production, living, and ecological functions, and it only reflects the degree of interaction and influence, without distinguishing advantages or disadvantages [46]. Pi, Li, and Ei are the evaluation values of production, living, and ecological functions for each county, respectively; D is the coupling coordination index of the county' s "production-living-ecological" functions.

To further analyze the interaction degree between each pair of the three functions, a pairwise coupling coordination model for the "production-living-ecological" functions was constructed according to formula (3). The weight determination method is the same as aforementioned. When calculating the coupling coordination index between production and living functions, the 待定 coefficients are set as $\partial = 0.45$, $\chi = 0.55$; when calculating between production and ecological functions, $\partial = 0.55$, $\chi = 0.45$; and when calculating between living and ecological functions, both ∂ and χ are set as 0.50. The calculation formulas are as follows:

$$D_{12} = \sqrt{C_{12} \times T_{12}}, \quad T_{12} = \partial P + \chi L$$

$$D_{13} = \sqrt{C_{13} \times T_{13}}, \quad T_{13} = \partial P + \chi E$$

$$D_{23} = \sqrt{C_{23} \times T_{23}}, \quad T_{23} = \partial L + \chi E$$

where: D_{12} is the coupling coordination index between production and living functions; D_{13} is the coupling coordination index between production and ecological functions; and D_{23} is the coupling coordination index between living and ecological functions. Referring to existing research results [20,46-49] and combining with the actual situation of this study, the coupling coordination index results of county "production-living-ecological" functions are divided into six levels (Table 2).

3. Results and Analysis

3.1 Spatiotemporal Characteristics of "Production-Living-Ecological" Functions in Xinjiang Counties and Cities

Based on the evaluation system from the perspective of "production-living-ecological" functions, this study obtained the evaluation results of each function and the comprehensive "production-living-ecological" function for Xinjiang counties and cities. The natural breaks method was used to classify the evaluation results into four types: high value, medium-high value, medium-low value, and low value. The classification results were connected with spatial vector units to obtain spatial distribution maps (Figure 2) and quantity change distribution maps (Figure 3) of each function and the comprehensive "production-living-ecological" function at the county level.

Production Function: In 2000, Urumqi City, Karamay City, and Shawan County were high-value counties and cities. As the capital of Xinjiang, Urumqi had a relatively high comprehensive development level of production function. Karamay City is an important energy city in Xinjiang with strong industrial production capacity due to abundant oil and gas resources. Shawan County has vast cultivated land area, with its agricultural production 总值 and grain output ranking among the top in Xinjiang, indicating strong agricultural production capacity. Shihezi City, Yumin County, Qitai County, Manas County, and Korla City were medium-high value counties and cities, with overall production function development inferior to high-value counties but with balanced agricultural and non-agricultural production development. Huocheng County, Yining City, Xinyuan County, and Baicheng County were medium-low value counties with certain agricultural production capacity but weak non-agricultural production development. The remaining counties and cities had weak development in both agricultural and non-agricultural production.

In 2010, the spatial distribution pattern of production function levels changed slightly, with the spatial distribution range of low-value counties further reduced to 5.61% of the total. The proportion of medium-low value counties increased to 64.04%, with newly added counties such as Yutian County, Hotan County, and Minfeng County. The proportion of medium-high value counties slightly expanded to 23.60%, with newly added counties including Jimsar County, Gaochang District, and Yizhou District. Additionally, Shihezi City and Wujiaqu City were newly added as high-value counties and cities. The promulgation and implementation of the "Xinjiang Uygur Autonomous Region Main Functional Area Planning" had a positive impact on the development of county production functions, further clarifying the development direction of counties and cities.

In 2020, the spatial distribution pattern of production function levels changed minimally. Korla City, Altay City, Burqin County, and Habahe County were newly added as high-value counties and cities, with the proportion of high-value counties increasing to 33.71%. The number of medium-high value counties slightly increased, while the spatial distribution range expanded eastward and extended north-south, with newly added counties such as Ruoqiang County, Toksun County, and Shanshan County forming a continuous spatial distribution range. The number of medium-low value counties slightly decreased, while low-value counties remained basically unchanged. Overall, production function shows a "high in the north, low in the south" spatial distribution trend, with the urban agglomeration on the northern slope of the Tianshan Mountains as the core high-value area for production function development in Xinjiang. Due to different development foundations, the ways of production function improvement also vary, with significant differences in development changes among Xinjiang's counties and cities. Counties and cities such as Urumqi, Karamay, Korla, and Hotan have strong non-agricultural production functions, driving production function improvement through industrial and service development; while counties such as Shache, Qitai, Shawan, and Manas have significant agricultural production function driving effects on county production functions.

Living Function: In 2000, Urumqi City and Karamay City had complete transportation, medical, and education security services, with high income and consumption levels for urban and rural residents. Balikun County ranked among the top in Xinjiang in terms of transportation, medical security services, and consumption levels. These three counties and cities were high-value areas. Medium-high value counties accounted for 15.73%, mainly distributed on the northern slope of the Tianshan Mountains. Medium-low value counties accounted for 38.20%, represented by Qiemo County, Ruoqiang County, Wuqia County, and Bole County, where urban and rural residents had relatively low income and consumption levels but relatively better medical, education, and transportation security compared to low-value counties. Low-value counties accounted for 28.10%, widely distributed in Kashgar, Hotan, and Kizilsu prefectures in southern Xinjiang, with significant room for improvement in various security service functions and residents' income and consumption levels.

In 2010, the implementation of the Western Development Strategy gradually accelerated the construction of transportation and other infrastructure, improving Xinjiang's overall education and medical and health levels. However, the income gap between northern and southern Xinjiang counties remained significant. Shihezi City and Yizhou District were newly added as high-value counties and cities. The proportion of medium-high value counties increased to 26.97%, while their spatial distribution gradually shifted eastward and expanded north-south, with newly added counties such as Ruoqiang County, Toksun County, and Shanshan County. The number of medium-low value counties increased significantly, accounting for 47.72%, represented by Pishan County, Yecheng County, and Artux City, where urban residents' income increased significantly, but rural residents' income and consumption levels increased weakly, widening the income gap between urban and rural residents.

In 2020, with the further implementation of the Western Development Strategy, multiple medical, health, education, and service security measures were orderly carried out in Xinjiang' s counties and cities, gradually narrowing the gap in education and medical security functions between counties and cities. The construction of transportation and other infrastructure was further strengthened, improving travel convenience in counties and cities. However, the gap in income and consumption levels between counties and cities further expanded, making the polarization phenomenon in living function development significant, with increases in both high-value and low-value counties and decreases in medium-low and medium-high value counties. High-value counties and cities represented by Urumqi, Karamay, Korla, Shihezi, and Yizhou saw synchronous improvements in medical care, education, and income and consumption levels for urban and rural residents, gradually narrowing the urban-rural income gap. Medium-high value counties represented by Aksu City, Tacheng City, and Ruoqiang County saw significant improvements in basic security services such as medical care, education, and transportation, with some increase in urban and rural residents' income but without significantly narrowing the urban-rural income gap. Medium-low value counties represented by Hotan City and Kashgar City saw small improvements in basic security services such as medical care, education, and transportation, but still had considerable room for improvement overall, with significant increases in urban residents' income but rural residents' income remaining at low levels, widening the urban-rural income gap. Overall, living functions in all counties and cities have improved to varying degrees, but the magnitude of improvement varies significantly. The gap in living functions between counties and cities first narrowed and then widened. The factors affecting changes in living function growth are complex and diverse. The growth and change of a single indicator cannot improve the living function of counties and cities. During the development process, high-value and medium-high value counties saw narrowed urban-rural development gaps, while low-value and medium-low value counties still had large urban-rural income gaps, with poor urban-rural development coordination. Therefore, narrowing the urban-rural income gap and improving urban-rural development coordination are crucial for enhancing the overall development level of living functions in counties and cities.

Ecological Function: Xinjiang has a weak underlying geographical environment and is a typical ecologically fragile oasis area in China. In 2000, ecological functions were mainly low-value and medium-low value, accounting for 28.09% and 34.83% respectively, mainly distributed in Hotan and Kashgar regions with high proportions of desertified land. High-value and medium-high value counties and cities were mainly distributed in Ili, Altay, and Tacheng regions, with significant differences in ecological functions between northern and southern Xinjiang. In 2010, development and construction proceeded alongside ecological protection measures. While farmland area in counties and cities continued to expand, unsuitable cultivated and pastoral lands were converted back to forest and grassland through the Grain for Green and Grazing Withdrawal programs. The overall change in county ecological functions was small, with no significant change in the spatial distribution characteristics of functional levels. In 2020, ecological protection efforts in Xinjiang' s counties and cities continued to intensify. With the promulgation and implementation of the "Comprehensive Management Planning Outline for Key Ecological Areas in Western China," comprehensive management focusing on grassland restoration and windbreak and sand fixation was gradually carried out, with further results in ecological restoration. County ecological functions improved significantly, with the proportion of low-value counties decreasing from 28.09% to 20.22%, and medium-low value counties decreasing from 34.83% to 29.21%. The number of medium-high and high-value counties increased to varying degrees, with medium-low value counties showing the most significant improvement. Zhaosu County, Huocheng County, Emin County, Tuoli County, and Fuyun County were newly added as high-value counties and cities. Overall, ecological functions are closely related to topography and hydrothermal climate conditions, with obvious ecological environment gaps between counties and cities. The effective implementation of ecological protection measures has promoted the overall improvement of the ecological environment in counties and cities.

"Production-Living-Ecological" Function: The comprehensive "production-living-ecological" function is a comprehensive evaluation of the overall land function of counties and cities, so its spatial distribution integrates the characteristics of each functional spatial distribution and spatiotemporal changes. In 2000, high-value counties and cities for the comprehensive "production-living-ecological" function were Urumqi, Karamay, Yumin County, and Shawan County. The spatial distribution of medium-high value counties and cities was mainly in the Ili region and the urban agglomeration on the northern slope of the Tianshan Mountains. Medium-low value counties accounted for 14.77%, scattered around medium-high value counties. Low-value counties accounted for 81.81%, mainly distributed in southern Xinjiang. In 2010, the number of low-value counties decreased significantly, with Korla City, Altay City, Burqin County, and Habahe County newly added as high-value counties and cities. The proportion of high-value counties increased to 28.10%, forming a continuous spatial distribution range. The proportion of medium-low value counties increased to 43.82%, with Changji City, Hutubi City, and Qitai City newly added as high-value counties and cities. In 2020, the spatial distribution was dominated by basically coordinated counties and cities, with high-level basically coordinated counties accounting for 39.77% and low-level basically coordinated counties accounting for 48.86%. Overall, the evaluation results of the "production-living-ecological" function show a "high in the north, low in the south" spatial distribution trend, with functional levels in all counties and cities showing improvement.

3.2 Spatiotemporal Differentiation of "Production-Living-Ecological" Function Coupling Coordination

Based on the spatial differentiation of functional coupling coordination indices from the "production-living-ecological" perspective, this study applied formula (3) to calculate the coupling degree and coupling coordination index of the "production-living-ecological" functions of counties and cities. Using ArcGIS, the values were connected with spatial vector units to create spatial distribution maps (Figure 4) and quantity evolution distribution maps (Figure 5) of the coupling coordination indices between pairs of "production-living-ecological" functions for Xinjiang counties and cities in 2000, 2010, and 2020.

Production-Living Coupling Coordination: In 2000, Urumqi City and Karamay City were moderately coordinated counties and cities. Manas County, Shawan County, Shihezi City, and Korla City were high-level basically coordinated counties and cities. Low-level basically coordinated counties accounted for 20.45%, mainly distributed on the northern slope of the Tianshan Mountains. Mildly uncoordinated counties were widely distributed, accounting for 54.55%. Severely uncoordinated counties were mainly distributed in Hotan, Kashgar, and Kizilsu prefectures, accounting for 19.31%. In 2010, county coupling coordination improved significantly. Severely uncoordinated counties such as Moyu County, Hotan County, and Minfeng County transformed into mildly uncoordinated, while Ruoqiang County, Qiemo County, and Gaochang District transformed from mildly uncoordinated to low-level basically coordinated. The proportion of mildly uncoordinated counties decreased to 38.64%, while low-level basically coordinated counties increased to 44.32%. In 2020, the spatial distribution was dominated by basically coordinated counties and cities, with high-level basically coordinated counties accounting for 39.77% and low-level basically coordinated counties accounting for 48.86%. Overall, Urumqi City was moderately coordinated in all stages. Counties and cities on the northern and southern slopes of the Tianshan Mountains gradually transformed from low-level basic coordination to high-level basic coordination, while other counties and cities gradually transformed from mild uncoordination to low-level basic coordination. The improvement in coupling coordination between production and living functions benefits from the strong economic driving effect of production functions. When production functions can bring higher economic benefits, urban and rural residents' income grows faster and has higher consumption capacity, and the medical care and public services of counties and cities also develop better. The improvement of living functions further promotes the development and enhancement of production functions, creating a better benign interaction between production and living functions. Overall, the coupling coordination relationship between production and living functions in Xinjiang' s counties and cities is gradually improving.

Production-Ecological Coupling Coordination: In 2000, only Urumqi City was moderately coordinated. High-level basically coordinated counties and cities were mainly distributed on the northern and southern slopes of the Tianshan Mountains and in Altay and Tacheng regions, accounting for 20.45%. Low-level basically coordinated counties accounted for 46.59%. Mildly uncoordinated counties were mainly distributed in Kashgar and Hotan regions in southern Xinjiang, accounting for 30.68%. In 2010, Karamay City, Changji City, Korla City, and Shihezi City were newly added as moderately coordinated counties and cities. High-level basically coordinated counties accounted for 34.09%, with a large spatial distribution range. Low-level coordinated counties decreased to

26.14%, and mildly uncoordinated counties accounted for 38.64%. In 2020, Shawan County was downgraded from moderately coordinated to high-level basically coordinated. High-level basically coordinated counties accounted for 47.73%, with a large spatial distribution range. Low-level coordinated counties decreased to 7.95%, and mildly uncoordinated counties accounted for 38.64%. The gradual improvement in coupling coordination between production and ecological functions benefits from the promulgation and implementation of macro-control policies. Measures such as the Grain for Green program, grazing withdrawal, and grassland desertification prevention and control projects have effectively promoted the transformation of abandoned agricultural and pastoral land into ecological land. While construction land and agricultural land gradually expanded, the area of artificial ecosystems also maintained corresponding growth [50], maintaining the overall stability of regional ecosystems. This weakened the negative impact of production function improvement on ecological functions and enhanced the coupling coordination degree between the two. Due to natural conditions limiting development in some Xinjiang counties and cities, industrial structure adjustment can mitigate the impact of ecological environment on production function development. For example, vigorously developing tourism and cultural industries and exploiting regional human and historical resources can effectively utilize regional characteristics and reduce the impact on the ecological environment during county development. This enables production functions to develop under ecological environment constraints, promoting the gradual improvement of coupling coordination between ecological and production functions.

Living-Ecological Coupling Coordination: In 2000, only Urumqi City and Shawan County were moderately coordinated counties and cities. High-level basically coordinated counties accounted for 15.91%, and low-level basically coordinated counties accounted for 48.86%. Mildly uncoordinated counties accounted for 34.09%, showing a circular spatial distribution structure. In 2010, the spatial change range was small, with spatial distribution dominated by low-level basically coordinated counties accounting for 46.59%. Overall, due to the obvious spatiotemporal volatility of living functions, the coupling coordination between living and ecological functions in some counties and cities also showed significant fluctuations. In 2020, the spatial distribution was dominated by basically coordinated counties, with high-level basically coordinated counties accounting for 45.45% and low-level basically coordinated counties accounting for 38.64%. The number changes were small, but spatial distribution changes were significant. Counties such as Hejing County, Zhaosu County, and Tuoli County changed from high-level to low-level basic coordination, while Fuhai County, Fuyun County, and Kuqa County changed from low-level to high-level basic coordination. Low-level coordinated counties were mainly distributed in southern Xinjiang, accounting for 11.36%. Overall, the coupling coordination between living and ecological functions in Xinjiang' s counties and cities is gradually improving, with obvious phased characteristics in spatial change processes, and the urban agglomeration on the northern slope of the Tianshan Mountains as the core high-value area.

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4. Discussion and Conclusions

4.1 Discussion

Currently, many studies have consistently shown from the perspective of economic development and urbanization that the urban agglomeration on the northern slope of the Tianshan Mountains is the core development area of Xinjiang [25-26,51-52]. The economic development of some southern Xinjiang counties and cities such as Korla City and Aksu City is also relatively good [53]. Some southern Xinjiang counties and cities overly rely on agricultural production for industrial development, resulting in relatively backward economic development [54], which is consistent with the evaluation results of production and living functions in this study. This analysis also proposes that the effective implementation of beneficial policies has gradually narrowed the gap in basic security functions between counties and cities, and the effective implementation of ecological governance measures has gradually improved the ecological environment of counties and cities, which is also consistent with existing research conclusions [50,58]. Therefore, the selection of leading industries in counties and cities and policy regulation are crucial for the development of Xinjiang' s "production-living-ecological" functions and the improvement of their coupling coordination. Future Xinjiang development needs to continue strengthening the implementation of macro-control policies, while reasonably adjusting the industrial structure under the premise of comprehensively considering regional resources and environment, narrowing the development gap between counties and cities, and guiding the overall orderly development of the region.

4.2 Conclusions

This study constructs an evaluation system and introduces a coupling coordination model to evaluate the development status of production, living, and ecological functions in Xinjiang counties and cities from 2000 to 2020, and uses the coupling coordination model to explore the interaction relationships between the "production-living-ecological" functions. The main conclusions are as follows:

1. From 2000 to 2020, the comprehensive evaluation results of the "production-living-ecological" functions generally showed a "high in the north, low in the south" distribution pattern at the spatial scale, with the urban agglomeration on the northern slope of the Tianshan Mountains as the core high-value area. At the temporal scale, the development levels of production, living, ecological, and comprehensive "production-living-ecological" functions in counties and cities all improved. Among them, production function improved most significantly, with significant differences in functional development changes among counties

and cities, showing an overall "high in the north, low in the south" spatial distribution pattern with the urban agglomeration on the northern slope of the Tianshan Mountains as the main high-value area. Living function development showed certain volatility, with the urban agglomeration on the northern slope of the Tianshan Mountains and Hami City, Turpan City, and Ruoqiang County as the core high-value areas. Ecological function is highly correlated with topography and landforms, with Tacheng, Ili Prefecture counties, Altay region, and the urban agglomeration on the northern slope of the Tianshan Mountains as the main high-value areas. Meanwhile, the continuous and effective implementation of ecological protection measures has promoted the overall improvement of the ecological environment in counties and cities.

2. From 2000 to 2020, the coupling coordination among production, living, ecological, and comprehensive "production-living-ecological" functions improved significantly. The spatial distribution all took the urban agglomeration on the northern slope of the Tianshan Mountains as the main high-value area. The coupling coordination relationships between county functions gradually improved, laying a good foundation for subsequent regional development. Overall, the high coupling coordination between production and living functions mainly depends on the strong economic driving effect of production functions. The gradual improvement in coupling coordination between production and ecological functions benefits from the effective implementation of macro-control policies.

3. The selection of regional leading industries and macro-policy regulation are crucial for the development of Xinjiang' s "production-living-ecological" functions and the improvement of their coupling coordination. Therefore, future Xinjiang development needs to continue strengthening the implementation of macro-control policies, while reasonably adjusting the industrial structure under the premise of comprehensively considering regional resources and environment, narrowing the development gap between counties and cities, and guiding the overall orderly development of the region.

4.3 Limitations and Prospects

The limitations of this study mainly come from the selection of evaluation indicators, index weights, and data uncertainty.

1. **Indicator Selection:** Water resources are an important factor restricting Xinjiang' s development, and their influence mechanism on county functional development is complex [59]. However, due to the lack of water resources data at the county scale, it is impossible to include water resources indicators in the evaluation system, which needs to be supplemented and improved in subsequent research.

2. **Weight Determination:** The establishment of index weights is a key point in building the evaluation system and has a significant impact on

evaluation results. This study refers to weight selection in existing literature and uses a combination of objective entropy method and subjective AHP to assign weights to indicators. This 弥补了 the defect that the entropy method only assigns weights based on mathematical characteristics of data rather than for the specific region of Xinjiang, while strengthening the theoretical basis of AHP, making it scientifically sound. However, evaluation weights are not equivalent to real situations and cannot be verified, so evaluation results may have certain errors.

3. **Data Issues:** Due to the large research scope and long time span, there were many changes in county-level administrative divisions during the study period, especially with many new counties added in Xinjiang between 2015 and 2020. Although statistical yearbook data have relatively high overall continuity and validity over long time scales [60], the lack of data for many newly added counties made it impossible to evaluate them. Therefore, to reduce uncertainty in evaluation results caused by missing data and unclear correspondence, this study used the 2020 county-level administrative divisions as the statistical basis for functional evaluation. Due to the selection of county-level divisions, some newly added counties could not be evaluated, which may affect the classification of functional levels for some counties and cities.

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