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Abstract

Borderland security is an important component of national security, while borderland regions generally face compound dilemmas involving population, economy, and ecology, which are particularly evident in border areas. Analyzing the coupling and coordination mechanisms of multiple systems provides a distinctive research direction for promoting high-quality development in borderland regions. From the perspective of borderland security, and based on county-level panel data from 2000 to 2023, this study systematically analyzes the coupling and coordination mechanisms among population, socioeconomic development, and resources and environment in the border counties of Xinjiang. The results show that: (1) The evolution of the three systems in border counties exhibits significant imbalance, with relatively small changes in the population system, while the socioeconomic system and the resources and environment system continue to improve. (2) Most counties are in the antagonistic and adjustment stages of coupling coordination, and only a few counties (such as Huocheng County) have achieved preliminary synergy. (3) The coupling coordination degree of counties forms an obvious negative spatial correlation. (4) The resources and environment system exerts a positive driving effect on coupling coordination, whereas the socioeconomic system and the population system have negative impacts; nevertheless, the overall coupling coordination degree maintained a fluctuating upward trend during the study period. (5) The population system has an extremely strong impact on the resources and environment system. In the later stage of socioeconomic development, the influence of population on the socioeconomic system exceeds the influence of its own inertia, while the relationship between the population system and the other two systems is relatively weak. The findings reveal that the border counties of Xinjiang can stabilize population by improving public services, develop characteristic industries, promote county-level collaboration and facility sharing, guide population agglomeration, and strictly adhere to ecological thresholds, thereby providing a scientific basis for achieving rational population agglomeration under ecological constraints in this region.

Full Text

Study on the Coupling Coordination Relationship among Population, Socioeconomy, Resources, and Environment in Xinjiang Border Areas under the Background of Border Security

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Abstract: Border security is an important component of national security. Border areas generally face compound dilemmas involving population, economy, and ecology, and these are especially pronounced in border regions. Analyzing the coupling coordination mechanisms of multiple systems provides a distinctive research direction for promoting high-quality development in border areas. From the perspective of border security, and based on county-level panel data from 2000 to 2023, this study systematically analyzes the coupling coordination mechanism among population, socioeconomy, and resources and environment in Xinjiang' s border counties. The results show that: (1) the evolution of the three systems in border counties exhibits significant disequilibrium characteristics; the population system changes relatively little, while the socioeconomic system and the resources-environment system continue to improve. (2) Most counties are in the antagonistic and frictional stages of coupling coordination, and only a few counties, such as Huocheng County, have achieved preliminary coordination. (3) The coupling coordination degree of counties shows clear negative spatial correlation. (4) The resources-environment system exerts a positive driving effect on coupling coordination, whereas the socioeconomic system and the population system have negative effects; nevertheless, the overall coupling coordination degree maintained a fluctuating upward trend during the study period. (5) The population system has an extremely strong influence on the resources-environment system; in the later stage of development, the influence of population on the socioeconomic system exceeds the influence of its own inertia, while the relationship between the population system and the other two systems is relatively weak. The findings indicate that Xinjiang's border counties can stabilize population by improving public services, develop specialty industries, promote county-level cooperation and facility sharing, guide population agglomeration, and strictly observe ecological thresholds. This can provide a scientific basis for achieving rational population agglomeration under ecological constraints in this region.

Keywords: border security; complex system; coupling coordination; Xinjiang

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Border security occupies the most sensitive, fragile, and complex frontier position within national security, encompassing multiple dimensions such as politics, economy, and culture. At the 18th collective study session of the Political Bureau of the CPC Central Committee in 2024, it was explicitly proposed to "carry out all tasks of border governance in depth and promote high-quality development in border areas," which provides policy support for research on multi-system coordination in border counties. Xinjiang is an important node in China' s westward opening-up and in peripheral security cooperation. It has shifted from being a border hinterland in the traditional sense to a strategic frontier where national security is integrated with opening-up and development.

Research on population–socioeconomy–resources and environment coupling is not a simple superposition of various elements, but is rooted in the theory of sustainable development and the theory of human–land relationship regional systems. The sustainable development theory proposed by the World Commission on Environment and Development in 1987 introduced the concepts of "intergenerational equity" and "system coordination" into regional development research, marking a paradigm shift in human development from a single-goal orientation toward multi-goal coordination[1]. By the late 1980s, Chinese scholars had begun to recognize that single-factor analysis could no longer respond to the complexity of sustainable development; the four major elements of population, resources, environment, and development needed to be discussed together, and their intricate and complex interactions constituted a basic framework for understanding regional issues in China[2]. During roughly the same period, geography's understanding of human–land relations also completed a transition from static to dynamic. Human activities and the geographical environment were no longer viewed as opposing parties that ebb and flow, but as open systems interacting with each other. This understanding laid the theoretical foundation for all subsequent quantitative studies[3]. In 1999, the concept of "coupling degree" from physics was introduced into human geography research, providing a quantitative tool for subsequent evaluations of regional sustainable development coordination[4]. Since the beginning of the 21st century, research has gradually expanded from binary systems to multi-system coupling. Early studies focused on pairwise relationships such as urbanization and the ecological environment, or the economy and the resources–environment system; at present, empirical research on coupling coordination among multidimensional systems has gradually become mainstream.

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direction.

Most earlier studies adopted static coupling-coordination models. By constructing a comprehensive evaluation indicator system, they measured the coupling degree and coordination degree among systems at specific points in time, thereby determining the development status of a region. Although this method achieved a transition from qualitative description to quantitative measurement, it could not capture the dynamic evolutionary characteristics of the system. The combination of system dynamics models with coupling-coordination degree has opened up a new path for dynamic simulation. For example, in their study of water-footprint sustainability in Heilongjiang Province, Jiang et al.[5] first used a system dynamics model to simulate the dynamic evolution of the water resources-economy-society system, and then evaluated its coordination level with a coupling-coordination degree model. In addition, methods such as ARIMA-GM combined models, BP neural networks, and Markov chains have further improved prediction accuracy, while β convergence tests and spatial Durbin models have been used to analyze the evolutionary trends of regional disparities and spatial dependence. Overall, methodological research on coupling coordination has completed a critical transition from static measurement to dynamic analysis; dynamic depiction, identification of spatial effects, and trend prediction together constitute the current analytical paradigm.

In terms of study areas, the existing literature shows pronounced spatial concentration: a large body of work focuses on the Yellow River Basin[6-7], the Beijing-Tianjin-Hebei and Yangtze River Delta core urban agglomerations[8-9], and the Chengdu-Chongqing region[10]. By comparison, research on population-resources-environment in Yunnan’ s border areas has already formed a relatively mature “population-resources-environment-development” research framework[11], whereas the core of research in Guangxi is mainly the coordination of the multidimensional “people-land-industry” system embedded in border trade[12]. Compared with Yunnan and Guangxi, systematic research on population-resources-environment in Xinjiang’ s border areas remains relatively scarce, and its core topics have consistently revolved around water-resource constraints[13]. At the same time, existing studies usually take provinces or municipalities as their basic units, with insufficient attention to the county scale.

Based on this, this paper constructs an evaluation system for the three subsystems of population, socioeconomic development, and resources and environment in Xinjiang’ s border areas. On the basis of a coupling-coordination model and spatial econometric methods, it systematically reveals the spatiotemporal evolutionary characteristics of coupling coordination among the three systems. From the perspective of coordinated influence, it identifies and compares the core driving subsystems that affect the coupling-coordination degree of the composite system. It further applies a panel vector autoregression (PVAR) model to explore, from a dynamic perspective, the interactive response relationships and influence mechanisms among subsystems.

1 Data and Methods

1.1 Overview of the Study Area

Xinjiang is located on China’ s northwestern frontier. Its border is 5,600 km long and it adjoins eight countries—Mongolia, Russia, Kazakhstan, Kyrgyzstan, Tajikistan, Afghanistan, Pakistan, and India—making it a key node for China’ s westward opening-up and for security cooperation with neighboring countries[14]. This study focuses on 32 land border counties (cities and districts) in Xinjiang; owing to limitations in time-series data, Khorgos City and Alashankou City are not included (Figure 1). In terms of development status, border counties have a relatively weak economic and social foundation, and their industrial structure is dominated by agriculture and animal husbandry, border trade, and tourism. Although infrastructure has been continuously improved, there remains considerable room for improvement in the level of urbanization and in public-service capacity.

1.2 Data Sources

The study period is 2000-2023. A long-period panel-data analysis was conducted for Xinjiang' s 32 land border counties (cities and districts). The relevant data involved in this paper all come from the *China County Statistical Database* and the *Xinjiang Statistical Yearbook*; some data are derived from statistical materials for individual counties in Xinjiang. The nighttime light index was obtained by processing nighttime light remote-sensing data from 2000 to 2023 together with visible infrared imaging radiometer suite satellite remote-sensing data. The number of border-defense police stations along the border was obtained by calculating the number of border-defense police stations per unit border length. Road density was calculated year by year based on basic geographic information data from the OpenStreetMap database (https://www.openstreetmap.org). Data on the number of border-defense police stations were obtained from Amap and Baidu point-of-interest data and normalized according to the length of the border. The vector data for county-level administrative boundaries used in this study come from the Resource and Environment Science and Data Center of the Chinese Academy of Sciences.

1.3 Construction of the Indicator System

Grounded in the practical needs of border-security governance and drawing on existing studies[15-20], this paper selects specific indicators from the three systems of population, socioeconomic development, and resources and environment, forming an evaluation framework containing 22 indicators (Table 1).

1.4 Research Methods

1.4.1 Entropy Weight Method and Analytic Hierarchy Process

This study uses the range standardization method to eliminate dimensional differences among data. It then assigns weights to indicators using the entropy weight method and the analytic hierarchy process, respectively; comprehensive weights are obtained through weighted averaging, and finally the comprehensive evaluation index of each subsystem is synthesized by linear weighting.

1.4.2 Coupling-Coordination Model

To quantify the depth of interaction among the three systems—border population, socioeconomic development, and resources and environment—this paper introduces the coupling concept from physics to construct a framework for measuring coordination. The framework comprises two aspects: first, coupling degree, whose main purpose is to characterize the strength of nonlinear associations among subsystems; and second, coordination degree, which indicates the consistency between the overall development level of the system and the pace of development. To determine the coordination status of the three systems in border counties, this study refers to the classification criteria proposed by Jiang Lei et al.[21] and, in light of actual conditions, divides the coupling-coordination degree into: low-level coupling $(0.0, 0.3]$, antagonistic stage $[0.3, 0.5)$, running-in stage $[0.5, 0.8)$, and high-level coupling $[0.8, 1.0]$.

Note: Prepared based on the standard map with approval number Xin S(2021)047 from the standard map service website of the Department of Natural Resources of Xinjiang Uygur Autonomous Region; the base-map boundaries have not been modified. The same below.

Fig. 1 Schematic diagram of the study area

1.4.3 PVAR model

Given that panel data simultaneously contain cross-sectional heterogeneity among counties and time-series information, this paper constructs a PVAR model to capture the dynamic interaction structure among systems. The model is specified as follows:

$$z_{it} = \beta_0 + \sum_{j=1}^{p} A_j z_{i,t-j} + \eta_i + \omega_t + \sigma_{it} \qquad (1)$$

where: z_{it} is the vector of endogenous variables of the three systems for county i in year t, including population, socioeconomy, and resources and environment; i denotes the county unit; t denotes the year; β_0 is the intercept vector; p is the maximum lag order; j is the lag order; A_j is the coefficient matrix corresponding to lag order j; η_i is the county-level individual fixed-effect vector; ω_t is the time fixed-effect vector; and σ_{it} is the random disturbance term.

2 Results and Analysis

2.1 Comprehensive evaluation indices of population-socioeconomy-resources and environment

2.1.1 Population comprehensive evaluation index During the study period from 2000 to 2023, the population comprehensive evaluation indices of counties in the border areas exhibited pronounced spatial heterogeneity (Fig.

2). Overall, the average annual growth rate of the population comprehensive evaluation index ranged from −1.55% to 2.99%. The index span across counties ranged from 0.058 to 0.688, indicating significant differences in population levels among different counties. The maximum value appeared in Yecheng County in 2023, while the minimum value rotated among multiple counties, showing an unstable distribution pattern. From the perspective of temporal evolution, the location of the maximum population comprehensive evaluation index shifted in stages. In 2000–2007, the maximum value was in Huocheng County, while in 2008–2023 it was in Yecheng County. The minimum value was in Akqi County in 2000–2001, in Mori Kazakh Autonomous County in 2002–2003, in Barkol Kazakh Autonomous County in 2004, in Mori Kazakh Autonomous County in 2005–2008, in Barkol Kazakh Autonomous County in 2009, and in Mori Kazakh Autonomous County in 2010–2023. The population comprehensive evaluation index of Jeminay County showed "low growth of a low security index," whereas Yecheng County exhibited a development trend of "high growth of a high security index."

2.1.2 Socioeconomic comprehensive evaluation index The results for the socioeconomic comprehensive evaluation index indicate (Fig. 3) that, from 2000 to 2023, the socioeconomic comprehensive evaluation index generally maintained a continuously rising evolutionary trend. Overall,

Table 1 Evaluation indicators and weights for population-socio-economic-resource-environment in border counties of Xinjiang

Tab. 1 Evaluation indicators and weights of population, socio-economic, and resource-environment in border counties of Xinjiang

System layer	Criterion layer	Indicator layer	Attribute	Unit	Weight
Population	Scale and structure	Total population at year-end	+	10^4 persons	0.0902
Population	Scale and structure	Population density	+	persons · km^{-2}	0.0568
Population	Scale and structure	Proportion of population aged 65 and above	−	%	0.0896
Population	Scale and structure	Natural population growth rate	+	%	0.0721

System layer	Criterion layer	Indicator layer	Attribute	Unit	Weight
Population	Population quality	Number of students in regular secondary schools	+	persons	0.0396
Population	Population quality	Hospital beds per 10,000 persons	+	beds	0.0295
Population	Population quality	Beds in social service institutions	+	beds	0.0312
Socio-economy	Basic support	Total grain output	+	t	0.0259
Socio-economy	Basic support	General public budget revenue	+	10^4 yuan	0.0147
Socio-economy	Economic development	Fixed-asset investment	+	10^4 yuan	0.0181
Socio-economy	Economic development	Added value of the secondary industry	+	10^4 yuan	0.0217
Socio-economy	Economic development	Added value of the tertiary industry	+	10^4 yuan	0.0367
Socio-economy	Economic development	Total retail sales of consumer goods	+	10^4 yuan	0.0228

System layer	Criterion layer	Indicator layer	Attribute	Unit	Weight
Socio-economy	Economic development	Per capita gross regional product	+	yuan	0.0330
Socio-economy	Social development	Nighttime light index	+	–	0.0390
Socio-economy	Social development	Road density	+	$km \cdot km^{-2}$	0.0288
Socio-economy	Social development	Number of border police stations along the boundary	+	–	0.0121
Resource-environment	Resource endowment	Vegetation coverage	+	%	0.0623
Resource-environment	Resource endowment	Cultivated land area at year-end	+	km^2	0.0450
Resource-environment	Resource endowment	Annual average groundwater level	–	m	0.1049
Resource-environment	Environmental pollution	Surface SO_2 mass concentration	–	$\mu g \cdot m^{-2}$	0.0637
Resource-environment	Environmental pollution	$PM_{2.5}$ emissions	–	$\mu g \cdot m^{-2}$	0.0627

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

The value range of this index is 0.002–0.488, and the gap between high and low values is pronounced, reflecting obvious spatial heterogeneity in the level of socio-economic development. The maximum value occurs in Yining City (2023), while the minimum occurs in Taxkorgan Tajik Autonomous County (2000). In terms of temporal evolution, from 2000 to 2023 the overall socio-economic comprehensive evaluation index showed a strong and widespread upward trend. The average annual growth rate of the socio-economy was 2.75%–12.13%, and almost all counties experienced rapid improvement to varying degrees. Judging from

Fig. 2 Comprehensive evaluation index of population from 2000 to 2023

Figure 1: Fig. 2 Comprehensive evaluation index of population from 2000 to 2023

differences in growth rates, the three counties ranking highest in average annual growth rate of the socio-economic comprehensive evaluation index were Yiwu County, Taxkorgan Tajik Autonomous County, and Balikun Kazak Autonomous County; these areas showed relatively strong development momentum during the study period. Zhaosu County, Emin County, and Wenquan County ranked at the bottom in average annual growth rate. Among them, Taxkorgan Tajik Autonomous County had a weak development foundation but a marked growth rate. By comparison, Yining City had a leading level of development and sustained growth.

2.1.3 Comprehensive evaluation index of resource-environment From 2000 to 2023, the overall trend of the comprehensive evaluation index of resource-environment continued to improve and advanced continuously (Fig. 4). The overall variation range of the comprehensive evaluation index of resource-environment was 0.308–0.814, indicating significant differences in resource-environment levels among different counties. Among them, the minimum value occurred in Yining City in 2001, and the maximum value occurred in Tacheng City in 2016, reflecting clear imbalance in the resource-environment during the study period. From the perspective of the distribution characteristics of extreme values, the highest value of the comprehensive evaluation index of resource-environment was in Zhaosu County. In 2000 the highest value was in Burqin County, while from 2001 to 2023 it appeared in Tacheng City. This process of change indicates that Tacheng City formed a relatively stable resource-environment advantage during the study period. The lowest value also rotated among several counties: from 2000 to 2015 it was in Yining City, in 2016 it was in Pishan County, in 2017 it again appeared in Yining City, from 2018 to 2020 it appeared in Pishan County, in 2021 it briefly appeared in Wenquan County, and from 2022 to 2023 it reappeared in Yining City.

2.2 Spatiotemporal evolution of coupling coordination among the three systems

2.2.1 Temporal characteristics From 2000 to 2023, the coupling coordination degree ranged from 0.289 to 0.699, with an overall mean of 0.47 and a range of 0.38, indicating a significant absolute gap among counties. The coefficient of variation was 0.16, revealing a relatively evident unbalanced development trend within the region (Fig. 5). Specifically,

Fig. 2 Comprehensive evaluation index of population from 2000 to 2023

Fig. 3 Comprehensive evaluation index of socio-economic from 2000

Fig. 3 Comprehensive evaluation index of socio-economic from 2000 to 2023

Figure 2: Fig. 3 Comprehensive evaluation index of socio-economic from 2000 to 2023

Fig. 4. Comprehensive evaluation index of resource-environment from 2000 to 2023

Figure 3: Fig. 4. Comprehensive evaluation index of resource-environment from 2000 to 2023

to 2023

Fig. 4 Comprehensive evaluation index of resource-environment from 2000 to 2023

Fig. 5 Comprehensive coupling coordination degree of population, socio-economic, and resource-environment from 2000 to 2023

From the perspective of the coupling coordination degree of the composite system, this imbalance is reflected in the differentiated development characteristics of different types of counties. For example, the mean coupling coordination degree of counties such as Yecheng County and Yizhou District was relatively leading. Counties such as Huocheng County and Qapqal Xibe Autonomous County were significantly leading in the multi-year mean coupling coordination degree. Only a few areas showed high-coupling and high-coordination characteristics, such as Huocheng County, Qapqal Xibe Autonomous County, and Tacheng City. Overall, the coupling and feedback effects of the composite systems in most counties of the border areas had not yet been fully released; mismatches between coordination and coupling were widespread, and overall development was mostly in the resistance and grinding-in stages.

2.2.2 Spatial characteristics

During the study period, counties with low-level coupling gradually withdrew, and counties in the resistance and grinding-in stages became the main body; counties with a high-level coupling state had not yet appeared (Fig. 6). In 2010, Yizhou District, Qitai County, Altay City, and other areas first entered the grinding-in stage; by 2020, all counties had entered the resistance and grinding-in stages. Overall, the region' s overall coupling coordination level showed a positive trend, but certain gaps existed among counties. Using Moran' s index

Fig. 5. Comprehensive coupling coordination degree of population, socio-economic, and resource-environment from 2000 to 2023

Figure 4: Fig. 5. Comprehensive coupling coordination degree of population, socio-economic, and resource-environment from 2000 to 2023

to measure the strength of spatial clustering, from the overall spatial pattern, the Moran' s index in 2000 was 0.036, indicating positive autocorrelation among counties; in 2010, the Moran' s index decreased to −0.010, and the spatial clustering effect of counties further weakened to negative autocorrelation; in 2023, Moran' s index further declined to −0.209, showing an obvious negative autocorrelation characteristic.

Local spatial autocorrelation (LISA) clustering was used to identify the types of spatial clustering and differentiation patterns of counties, revealing their spatial heterogeneity and evolutionary pathways (Fig. 7). In 2000, LISA clustering showed that spatial differentiation was evident but the clustering range was limited. Only Qapqal Xibe Autonomous County showed a "high-high" cluster, forming a local advantage; Yizhou District and Yecheng County showed "high-low" clusters, with insufficient radiating power; Wenquan County was a "low-high" cluster; and Akto County and Artux City were "low-low" clusters. In 2010, the "high-high" cluster disappeared; the "high-low" cluster was reduced to only Yecheng County; while the "low-high" cluster and "low-low" cluster did not change. The LISA clustering results in 2023 show that local clustering characteristics weakened substantially: "high-high" clusters, "high-low" clusters, and "low-low" clusters disappeared, leaving only "low-high" clusters.

2.3 Effects of each subsystem on the overall coupling coordination degree

The coordination influence model[^22] was used to reflect the direction and magnitude of the effects of the three major subsystems of border security on the comprehensive coupling coordination degree of border security (Fig. 8). The results show that the time-series evolution of the comprehensive coupling coordination degree generally exhibited an upward trend, but a small number of counties still showed a downward trend during 2015-2023, such as Wenquan County and Mori Kazakh Autonomous County. The resource-environment system had the highest values in most counties, but overall showed a downward trend, with values ranging from 0.00 to 0.12; all counties in the study area had positive values. The population system values ranged from −0.03 to 0.09, and generally turned negative in 2023; except for some counties that still had positive values, such as Wenquan County and Yizhou District. The socio-economic system lay between the population system and the resource-environment system, with differences among counties ranging from −0.04 to 0.01 and generally being negative; a small number of counties turned positive in 2023, such as Yizhou District, Qitai County, and Yiwu County.

Figure 6: Spatial distributions of the coupling coordination degree of population, socio-economic, and resource-environment

Figure 5: Figure 6: Spatial distributions of the coupling coordination degree of population, socio-economic, and resource-environment

2.4 Interactive response among population-socioeconomy-resources and environment in border areas

2.4.1 Impulse response analysis

On the basis of the analysis of the current coupling coordination status and the interpretation of the action mechanism, the interactive response relationships among subsystems were further analyzed. First, the original series of the three variables were uniformly subjected to first-order differencing, and then Fisher-ADF and Phillips-Perron (PP) unit

(a) 2000 (b) 2010 (c) 2023

Legend

Legend item	Coupling coordination type
National boundary	Low-level coupling
Undetermined national boundary	Resistance stage
Provincial boundary	Grinding-in stage
County boundary	

Scale: 0–400 km

Fig. 6 Spatial distributions of the coupling coordination degree of population, socio-economic, and resource-environment

(a) 2000 (b) 2010 (c) 2023

Legend
National boundary; undetermined national boundary; provincial boundary; county boundary.
Spatial association patterns: not significant; high–high cluster; low–low cluster; low–high cluster; high–low cluster.

Fig. 7 LISA cluster map of comprehensive coupling coordination degree of population, socio-economic, and resource-environment

According to the root test, the results show that all variables significantly reject the unit-root null hypothesis at the 1% significance level. Next, according to the Akaike information criterion (AIC), Bayesian information criterion (BIC), and Hannan-Quinn information criterion (HQIC), the corresponding minimum lag orders are 3, 1, and 1, respectively. Accordingly, the optimal lag order is determined to be first order. Finally, based on Bootstrap self-sampling with repeated resampling, the orthogonalized impulse response functions of population–socioeconomic–resource environment in the border areas over a lag range of 10 periods were obtained (Fig. 9).

The results show that when the socioeconomic system receives a positive shock of one standard-deviation unit, the response of the population system presents an oscillatory attenuation pattern (Fig. 9a–c). After the resource-environment system is disturbed, the population system shows a positive response in the initial period, but immediately turns to a negative response in period 2, and tends to be stable after periods 6–8. The response trajectory of the socioeconomic system to its own shock is manifested as strong alternating positive and negative fluctuations (Fig. 9d–e), showing a typical over-adjustment correction feature. In the face of a positive shock to the population system, the socioeconomic system initially shows a negative response; although it briefly turns positive in period 3, it then falls again into the negative range, not reaching the positive-response peak until period 5, after which the amplitude contracts and gradually returns to zero. The response of the resource-environment system to a shock from the population system is negative in the current period in which it occurs, but rapidly turns positive after a lag of 1 period (Fig. 9g–i), and subsequently fluctuates slightly around zero. Its response to a shock from the socioeconomic system shows frequent alternation between positive and negative values, reaching a positive maximum in period 5 and then gradually converging.

2.4.2 Forecast-error variance decomposition

To reveal the explanatory degree of shocks among variables, a 10-period lag was set, and the results are shown in Table 2. In the short term, fluctuations in the population system are mainly dominated by shocks from itself. As the forecast horizon extends, the contributions of the socioeconomic system and the resource-environment system gradually become apparent. By period 10, the contribution of the population system itself decreases to 0.897, while that of the socioeconomic system rises to 0.047 and that of the resource-environment system to 0.056. This indicates that the population system has relatively strong endogenous inertia, but the influence of the socioeconomic system and the resource-environment on its long-term fluctuations continues to deepen, and the influence of the resource environment exhibits a continuously accumulating and strengthening characteristic. Changes in the socioeconomic system are almost explained by shocks from itself. When the forecast horizon extends to period 4, the contribution of the socioeconomic system to itself is 0.493, while the shock contribution of the population system reaches 0.503. When the forecast horizon extends to period 10, the shock contribution of the population system stabilizes at 0.554, the contribution of the socioeconomic system to itself is 0.432, and the contribution of the resource-environment system to it is only 0.015. This indicates that the driving effect of the population system on the socioeconomic

Figure continued: coupling influence and comprehensive coupling coordination degree by county/city. Legend: Population system; Socioeconomic system; Resource-environment system; Comprehensive coupling coordination degree.

Figure 6: Figure continued: coupling influence and comprehensive coupling coordination degree by county/city. Legend: Population system; Socioeconomic system; Resource-environment system; Comprehensive coupling coordination degree.

system is significant, and that shocks from the population system assume a dominant role even in the short term, whereas the influence of the resource-environment system on its fluctuations is very limited. The shock contribution of the resource-environment system is 0.882; at the same time, it is subject to a slight influence of 0.018 from the socioeconomic system and a strong influence of 0.100 from the population system. After the forecast horizon passes period 7, the contribution of the resource-environment system to shocks from itself is 0.331, while the total contribution from external shocks increases to 0.670. In terms of the specific composition of external influences, the contribution of the population system is 0.424, significantly higher than that of the socioeconomic system, at 0.246.

3 Discussion

Studies related to the theme of this research are mostly scattered across fields such as coordinated development among population, ecology, environment, and economy, while relatively few directly focus on the coupled and coordinated development of the three systems in border areas. Based on border areas, this paper constructs a comprehensive evaluation system that fits the strategic positioning and practical needs of border areas.

(a) Ili Prefecture

(b) Bortala Mongol Autonomous Prefecture

(c) Yumin County

(d) Qitai County

(e) Mori Kazakh Autonomous County

(f) Bole City

(g) Wenquan County

Fig. 8 Impact of population, socio-economic, and resource-environment systems on comprehensive coupling coordination degree

Figure 7: Fig. 8 Impact of population, socio-economic, and resource-environment systems on comprehensive coupling coordination degree

(h) Wenquan County

(i) Wushi County

(j) Arxan City

(k) Aketao County

(l) Aheqi County

(m) Wuqia County

(n) Yecheng County

(o) Taxkorgan Tajik Autonomous County

(p) Hotan County

(q) Pishan County

(r) Qapqal Xibe Autonomous County

Legend: Population system; Socioeconomic system; Resource–environment system; Comprehensive coupling coordination degree.

Axis labels appearing in each subfigure: left y-axis, Coupling influence; right y-axis, Comprehensive coupling coordination degree; x-axis, Year.

(s) Huocheng County

(t) Zhaosu County

(u) Tacheng City

(v) Emin County

(w) Tuoli County

(x) Yumin County

(y) Hoboksar Mongol Autonomous County

(z) Altay City
(aa) Burqin County

(ab) Fuyun County
(ac) Fuhai County
(ad) Habahe County

(ae) Qinghe County
(af) Jeminay County

Axis labels in each subfigure:
- Left vertical axis: Coordination influence
- Right vertical axis: Comprehensive coupling coordination degree
- Horizontal axis: Year

Fig. 8 Impact of population, socio-economic, and resource-environment systems on comprehensive coupling coordination degree

···system, and incorporated characteristic indicators into the indicator system. The research conclusions show that the overall coupling coordination among the three systems in border counties is relatively low, with many areas in the stage of resistance and friction, which is consistent with the conclusion of Luo Wanyun et al.[23]. Meanwhile, the coupling coordination of border counties exhibits a spatial differentiation pattern of "high in the north and south, low in the middle," confirming the conclusions of Hu Haifeng et al.[24] and Ji Zeyong et al.[25]. Whether it is the shrinkage of "high-high" agglomeration areas or the reduction of polarized types such as "high-low" and "low-high," the underlying cause reflects the widening development gap and insufficient interregional spillover effects. Finally, the comprehensive coupling coordination ···

—Impulse-response curve —- 95% confidence interval

(a) Impulse response of DPOP to DPOP

(b) Impulse response of DPOP to DECO

(c) Impulse response of DPOP to DRES

(d) Impulse response of DECO to DPOP

(e) Impulse response of DECO to DECO

(f) Impulse response of DECO to DRES

(g) Impulse response of DRES to DPOP

(h) Impulse response of DRES to DECO

(i) Impulse response of DRES to DRES

Note: DPOP, DECO, and DRES are, respectively, the population, socio-economic, and resource-environment systems after first-order differencing.

Fig. 9 Impulse response characteristics of population, socio-economic, and resource-environment systems

Table 2 Variance decomposition results

Tab. 2 Variance decomposition results

Response variable	Forecast period	POP	ECO	RES
POP	1	1.000	0.000	0.000
POP	4	0.956	0.004	0.008
POP	7	0.910	0.034	0.056
POP	10	0.897	0.047	0.056
ECO	1	0.050	0.950	0.000
ECO	4	0.503	0.493	0.004
ECO	7	0.560	0.431	0.009
ECO	10	0.554	0.432	0.015
RES	1	0.100	0.018	0.882
RES	4	0.448	0.185	0.367
RES	7	0.424	0.246	0.331
RES	10	0.443	0.238	0.319

Note: POP, ECO, and RES denote the population, socio-economic, and resource-environment systems, respectively.

The evolution of the coupling-coordination time series generally shows an upward trend, although a small number of counties still exhibit a downward trend; this is consistent with some of the findings of Yang Jiahui et al.[26]. This study still has the following limitations: first, because of the limited availability of county-level statistical indicators, the population system is characterized using indirect indicators. Second, in terms of methods, although the coupling coordination degree and PVAR model can effectively depict the strength and direction of relationships among variables, they are insufficient for revealing complex causal feedback mechanisms and nonlinear interaction logic within the system. Subsequent research may introduce system dynamics models and, by constructing structural equations and conducting simulation deduction, simulate the dynamic evolution of system operation.

4 Conclusions and Recommendations

4.1 Conclusions

(1) During the study period, the comprehensive evaluation index for population generally tended to slow down, while the comprehensive evaluation indices for the socio-economic and resource-environment systems continued to rise. Among them, the socio-economic level of Ili Prefecture showed high-level, high growth, while the population of Yecheng County ⋯

shows a high-level increase; the resource–environment level of Emin County shows a high-level increase.

(2) In most counties of the border region, the reciprocal feedback effects of the composite system have not yet been fully released; overall development is still largely in the stage of antagonism and adjustment, and high-level coupling has not yet appeared.

(3) Within the study area, the Moran' s index shifted from positive correlation to negative correlation, and the strength of spatial agglomeration continued to decline. High–high agglomeration appeared in 2000 and disappeared in 2010; the number of high–low agglomerations decreased in the later period; low–high agglomeration remained unchanged for a long time; and the low–low agglomeration type disappeared in the later period.

(4) The population system and the resource-environment system exert a negative influence on coupling coordination, whereas the socioeconomic system exerts a positive influence. Although the coordination capacity of the subsystems has weakened, the overall coordination degree has continued to rise.

(5) The population system is mainly driven by its own historical inertia; in the initial stage, the socioeconomic system is most strongly affected by itself, followed by the population system, and in the later stage the resource-environment system has a certain impact on it. Changes in the resource-environment system are most strongly affected by itself in the initial stage, but in the middle and later stages the population system becomes the largest influence on it, while the socioeconomic system has a relatively weak influence.

4.2 Recommendations

(1) Counties with weak population-growth momentum should stabilize the resident population by improving education, medical care, housing, and other conditions, while also relying on local employment positions to carry out targeted skills training. Counties with insufficient socioeconomic vitality should proactively develop corresponding industries. Counties with fragile resource environments should, according to local conditions, develop eco-cultural tourism industries and intensive processing of distinctive agriculture and animal husbandry.

(2) A sharing mechanism for population agglomeration, industrial upgrading, and ecological improvement should be established; ecological governance and new-energy development should be promoted in an integrated manner; and the sharing of infrastructure should be used to reduce the costs of factor mobility.

(3) Border-security governance needs to be advanced collaboratively. At present, the spatial connections among border counties are weakening, and there is a lack of effective linkage between counties. Intercounty industrial cooperation relationships should be established, and industrial development should be promoted through infrastructure interconnection.

(4) The population should be guided to agglomerate appropriately in key towns and townships, so as to bring into play the economic effects of agglomeration and reduce the costs of public services. At the same time, development intensity should be strictly limited within the carrying-capacity thresholds of resources and the environment, ensuring a dynamic balance between spatial expansion and ecological constraints.

References

[1] World Commission on Environment and Development. Our common future[R]. Oxford: Oxford University Press, 1987.

[2] Niu Wenyuan, Kang Xiaoguang, Wang Yi. A preliminary conception of sustainable development strategy with Chinese characteristics[J]. Management World, 1994(1): 195-203. [Niu Wenyuan, Kang Xiaoguang, Wang Yi. A preliminary conception of sustainable development strategy with Chinese characteristics[J]. Management World, 1994(1): 195-203.]

[3] Wu Chuanjun. On the core of geographical research: The regional system of man-land relationship[J]. Economic Geography, 1991, 11(3): 1-6. [Wu Chuanjun. On the core of geographical research: The regional system of man-land relationship[J]. Economic Geography, 1991, 11(3): 1-6.]

[4] Liao Chongbin. Quantitative judgement and classification system for coordinated development of environment and economy: A case study of the city group in the Pearl River Delta[J]. Tropical Geography, 1999, 19(2): 76-82. [Liao

Chongbin. Quantitative judgement and classification system for coordinated development of environment and economy: A case study of the city group in the Pearl River Delta[J]. Tropical Geography, 1999, 19(2): 76-82.]

[5] Jiang L L, Wu Y X, He X L, et al. Dynamic simulation and coupling coordination evaluation of water footprint sustainability system in Heilongjiang Province, China: A combined system dynamics and coupled coordination degree model[J]. Journal of Cleaner Production, 2022, 380(1): 135044, doi: 10.1016/j.jclepro.2022.135044.

[6] Han Y P, Jiang Z, Zhao M D, et al. Analysis of coupling coordination development and obstacle factors in the water-energy-carbon-ecological environment nexus across China' s Yellow River Basin[J]. Scientific Reports, 2025, 15: 24106, doi: 10.1038/s41598-025-09234-1.

[7] Zhang Z W, Qi J Y, Wang Q, et al. Analysis and forecast of the coupled development level of socioeconomic ecological environment and tourism in China' s Yellow River Basin[J]. Scientific Reports, 2025, 15: 5446, doi: 10.1038/s41598-025-88875-8.

[8] Zhao Y H, Hou P, Jiang J B, et al. Temporal and spatial analysis of coupling coordination in Beijing-Tianjin-Hebei urban agglomeration: Ecology, environment and economy[J]. Land, 2024, 13(4): 512, doi: 10.3390/land13040512.

[9] Zhang Y, Zhu T X, Guo H Y, et al. Analysis of the coupling coordination degree of the society-economy-resource-environment system in urban areas: Case study of the Jingjinji urban agglomeration, China[J]. Ecological Indicators, 2023, 146: doi: 10.1016/j.ecolind.2022.109851.

[10] He X D, Wu L H, Shen G Q, et al. A spatiotemporal analysis of ecological-economic coupling coordination in the Chengdu-Chongqing urban agglomeration[J]. Land, 2023, 12(7): 1378, doi: 10.3390/land12071378.

[11] Sun Tong, You Zhen, Feng Zhiming, et al. On the suitability of the population distribution in the borderlands of Yunnan Province[J]. Journal of Yunnan Normal University (Humanities and Social Sciences Edition), 2016, 48(3): 101-110. [Sun Tong, You Zhen, Feng Zhiming, et al. On the suitability of the population distribution in the borderlands of Yunnan Province[J]. Journal of Yunnan Normal University (Humanities and Social Sciences Edition), 2016, 48(3): 101-110.]

[12] Lin Shugao, Zhu Peixin, Lu Rucheng, et al. The influence of trade-economy-population

system on regional differences of territorial space pattern evolution in border areas: Take the China-Vietnam border zone as a case[J]. Journal of Natural Resources, 2023, 38(6): 1550-1569.]

[13] Reziva Aman, Fang Chuanglin. System dynamics simulation and scenario simulation of the carrying capacity of water resources in Xinjiang[J]. Environmental Science & Technology, 2020, 43(6): 205-215. [Aman Reziya, Fang

Chuanglin. System dynamics simulation and scenario analysis of water resources carrying capacity in Xinjiang[J]. Environmental Science & Technology, 2020, 43(6): 205–215.]

[14] Lei Lei. *Analysis of the Population along the Xinjiang Border*[D]. Beijing: Minzu University of China, 2019. [Lei Lei. Analysis of the population along the Xinjiang border[D]. Beijing: Minzu University of China, 2019.]

[15] Zhou Yijing, Zhang Changgan, Yin Shanggang, et al. Coupling coordination and influence mechanisms of ecological resilience resistance–adaptation–recovery in the Yangtze River Delta region[J]. Economic Geography, 2025, 45(3): 160–170. [Zhou Yijing, Zhang Changgan, Yin Shanggang, et al. Coupling coordination and influence mechanisms of ecological resilience in Yangtze River Delta region: A resistance-adaptation-recovery framework[J]. Economic Geography, 2025, 45(3): 160–170.]

[16] Guo Yinhong, Song Tao, Sun Man. Evolution of territorial functions and temporal stage division of China' s border areas under the nexus of security, development, and opening up[J]. Geographical Research, 2023, 42(10): 2574–2591. [Guo Yinhong, Song Tao, Sun Man. The territorial function evolution and time segmentation of Chinese border in the context of security, development and opening up nexus[J]. Geographical Research, 2023, 42(10): 2574–2591.]

[17] Li Hengji, Qu Jiansheng, Pang Jiaxing, et al. Spatio-temporal integrated measurement of the coupling coordination and sustainable development of the population–economy–society–resources–environment system in Gansu Province[J]. Arid Land Geography, 2020, 43(6): 1622–1634. [Li Hengji, Qu Jiansheng, Pang Jiaxing, et al. Spatial-temporal synthetic measurement of coupling coordination and sustainable development of population-economy-society-resource-environment system in Gansu Province[J]. Arid Land Geography, 2020, 43(6): 1622–1634.]

[18] Ma Guobin, Lu Rucheng, Wang Pengcheng, et al. Dynamic evaluation and early-warning optimization of territorial space security in China' s land border areas[J]. China Land Science, 2025, 39(1): 105–117. [Ma Guobin, Lu Rucheng, Wang Pengcheng, et al. Optimization of dynamic early warning for territorial space security in land border areas of China[J]. China Land Science, 2025, 39(1): 105–117.]

[19] Bi Guohua, Yang Qingyuan, Liu Su. Coupling coordination development between ecological civilization construction and urbanization in China[J]. Economic Geography, 2017, 37(1): 50–58. [Bi Guohua, Yang Qingyuan, Liu Su. Coupling coordination development between ecological civilization construction and urbanization in China[J]. Economic Geography, 2017, 37(1): 50–58.]

[20] Wang Lingjie. Dynamic evaluation index system and evaluation model of population security[J]. Statistics and Decision, 2009(20): 12–14. [Wang Lingjie. Dynamic evaluation index system and evaluation model of population security[J]. Statistics and Decision, 2009(20): 12–14.]

[21] Jiang Lei, Bai Ling, Wu Yuming. Coupling and coordination analysis of China' s provincial economy, resources, and environment: Also on the three-system coupling formula and its extended form[J]. Journal of Natural Resources, 2017, 32(5): 788-799. [Jiang Lei, Bai Ling, Wu Yuming. Coupling and coordinating degrees of provincial economy, resources and environment in China[J]. Journal of Natural Resources, 2017, 32(5): 788-799.]

[22] Wang Shaojian, Cui Zitian, Lin Jingjie, et al. Coupling coordination of urbanization and ecological resilience in the Pearl River Delta region[J]. Acta Geographica Sinica, 2021, 76(4): 973-991. [Wang Shaojian, Cui Zitian, Lin Jingjie, et al. Coupling relationship between urbanization and ecological resilience in the Pearl River Delta[J]. Acta Geographica Sinica, 2021, 76(4): 973-991.]

[23] Luo Wanyun, Wang Fubo, Rong Mingqian. Dynamic evolution of the coupling coordination of the ecological-economic-social system in national key ecological function areas: A case study of the Altay region of Xinjiang[J]. Acta Ecologica Sinica, 2022, 42(12): 4729-4741. [Luo Wanyun, Wang Fubo, Rong Mingqian. Dynamic evolution of ecological-economic-social system coupling coordination in national key ecological function areas: Take the Altay region of Xinjiang as an example[J]. Acta Ecologica Sinica, 2022, 42(12): 4729-4741.]

[24] Hu Haifeng, Sun Yong, Liu Mingkai, et al. Evaluation of the coupling coordination effect of the economy-society-governance system in ethnic minority regions and system dynamics simulation: A case study of Xinjiang[J]. Chinese Journal of Management Science, 2024, 32(5): 93-102. [Hu Haifeng, Sun Yong, Liu Mingkai, et al. Evaluation of coupling coordination effect of economic-society-governance system in minority regions: Take Xinjiang as an example[J]. Chinese Journal of Management Science, 2024, 32(5): 93-102.]

[25] Ji Zenan, Fu Wenting, Wang Pengcheng, et al. Coupling coordination of the digital economy and green development of agriculture in arid zones: A case study of Xinjiang[J]. Arid Land Geography, 2024, 47(11): 1981-1990. [Ji Zenan, Fu Wenting, Wang Pengcheng, et al. Coupling and coordination of digital economy and green development of agriculture in arid zones: A case of Xinjiang[J]. Arid Land Geography, 2024, 47(11): 1981-1990.]

[26] Yang Jiahui, Liu Xiaohuang, Shi Peng, et al. Spatial optimization and regulation of the Irtysh River Basin from the perspective of "production-living-ecological" functions[J]. Arid Land Geography, 2026, 49(3): 581-593. [Yang Jiahui, Liu Xiaohuang, Shi Peng, et al. Spatial optimization and regulation in the Irtysh River Basin from the perspective of production-living-ecological function[J]. Arid Land Geography, 2026, 49(3): 581-593.]

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Coupled and coordinated relationships between population, socio-economic, and resource-environment in Xinjiang' s border areas under the background of border security

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Abstract: Frontier security is fundamental to national security; however, frontier regions often face complex demographic, economic, and ecological challenges, particularly in border areas. Analyzing coordination mechanisms among multiple systems provides a valuable perspective for advancing high-quality development in these regions. Drawing on a frontier security perspective and using county-level panel data from 2000 to 2023, this study systematically evaluates the coordination among population, socio-economic, and resource-environment systems in Xinjiang' s border counties. The results reveal the following: (1) Pronounced imbalances in the evolution of the three systems, population fluctuations are relatively minimal, whereas both socio-economic and resource-environment conditions continue to improve. (2) Most counties remain in the antagonistic and adjustment phases of coupling and coordination, with only a few (including Huocheng County), achieving preliminary synergy. (3) Furthermore, the level of coupling and coordination across counties demonstrates a significant negative spatial correlation. (4) Notably, resource-environment systems contribute positively to coupling and coordination, while socio-economic and population systems exert a countervailing influence. Over the course of study, the comprehensive coupling coordination degree, however, showed a fluctuating upward trend. (5) Population strongly affects resource-environment, while in later stages, socio-economic systems have a greater impact on population than population inertia itself. Conversely, the interaction between population and the other two systems remains relatively weak. To address these challenges, the study recommends improving regional education, healthcare, and housing to support the rational population concentration, developing unique local industries, and designing cooperative mechanisms that integrate population, industry, and ecological development.

Keywords: border security; integrated systems; coordination and collaboration; Xinjiang

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

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