Coupling Coordination of New-Type Urbanization and Ecological Security in Gansu Province and the Non-Stationarity of Their Driving Factors: Postprint

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Date: 2025-09-01T11:34:34+00:00

Abstract

Gansu Province holds a pivotal strategic position in national ecological construction. Investigating the coupling coordination between new urbanization and ecological security status in Gansu and their driving factors is of great significance for consolidating the ecological security barrier in Northwest China and even the entire nation. Taking the 14 prefecture-level cities and autonomous prefectures in Gansu Province as the study area, this study constructs evaluation index systems for new urbanization and ecological security based on the "Population-Economy-Society-Space" (PESS) model and the "Driving force-Pressure-State-Impact-Response-Management" (DPSIRM) model, respectively. The coupling coordination model is used to analyze the development trend of their coupling coordination, while the Geodetector and Geographically and Temporally Weighted Regression (GTWR) models are employed to reveal the main driving factors and their spatio-temporal non-stationarity. The results show that: (1) From 2012 to 2021, the new urbanization index in Gansu Province increased from 0.213 to 0.328, remaining at a relatively low level, while the ecological security index increased by 0.099, rising from low security to medium security. (2) From 2012 to 2021, the coupling coordination degree between new urbanization and ecological security in Gansu Province increased from 0.527 to 0.628, with the coordination state transitioning from barely coordinated to primary coordination, exhibiting a spatial distribution pattern of "low in the north and south, high in the middle." (3) Fixed asset investment, secondary industry employment, urban population density, per capita GDP, and the proportion of secondary industry in GDP are the main driving forces for their coordination. (4) The main driving factors exhibit non-stationarity in both temporal and spatial scales, with differences in driving directions and intensities. The research findings can provide decision-making references for promoting new urbanization

and maintaining regional ecological security in Gansu Province.

Full Text

Coupling Coordination of New Urbanization and Ecological Security and Spatial-Temporal Non-Stationarity of Its Driving Factors in Gansu Province

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Abstract

Gansu Province plays a pivotal strategic role in China's national ecological construction. Investigating the coupling coordination between new urbanization and ecological security status in Gansu Province, along with their driving factors, is crucial for establishing a robust ecological security barrier in northwest China and across the entire nation. This study examines 14 municipalities and prefectures in Gansu Province, constructing evaluation index systems for new urbanization and ecological security based on the "population-economy-society-space" model and the "driving force-pressure-state-impact-response-management" (DPSIRM) model, respectively. A coupled coordination model analyzes the synergistic development trends between these two systems, while Geodetector and spatiotemporal geographically weighted regression (GTWR) models reveal the main driving factors and their spatiotemporal non-stationarity. The results indicate: (1) From 2012 to 2021, Gansu's new urbanization index increased from 0.213 to 0.328, remaining at a relatively low level, while the ecological security index rose by 0.099, transitioning from low to moderate security. (2) The coupling coordination degree between new urbanization and ecological security in Gansu increased from 0.527 to 0.628 during 2012–2021, shifting from barely coordinated to primarily coordinated states, with a spatial distribution pattern characterized by "low in the north and south, high in the middle." (3) Fixed asset investment, secondary industry employment, urban population density, per capita GDP, and the proportion of secondary industry in GDP were the primary driving forces behind this synergy. (4) These driving factors exhibited non-stationarity across temporal and spatial scales, with variations in both direction and intensity. These findings provide decision-making references for advancing new urbanization while maintaining regional ecological security in Gansu Province.

Keywords: ecological security; new urbanization; coupling coordination; non-stationarity; driving factors

1. Introduction

The harmonious development of economic society and natural environment represents both a scientific discourse and a significant challenge. The 18th National Congress of the Communist Party of China proposed the new urbanization strategy, while the 20th National Congress explicitly called for its in-depth implementation. New urbanization, characterized by coordinated urban-rural development, industry-city interaction, harmonious development, and ecological livability, emphasizes the connotation, quality, and efficiency of urbanization rather than simple urban expansion and population concentration. The Third Plenary Session of the 20th CPC Central Committee further noted that China is currently in a critical period of accelerating new urbanization. As a key component and important foundation of sustainable development, ecological security—reflecting ecosystem integrity, health, and risk resistance capacity—constitutes the basic prerequisite for implementing people-centered new urbanization and building a new pattern of harmonious human-nature development. Coordinating new urbanization construction with ecological security has become an inevitable requirement for promoting high-quality regional development.

Existing research primarily focuses on four aspects: (1) New urbanization level evaluation, often employing entropy weight methods, principal component regression models, and constructing index systems from demographic, economic, social, and ecological dimensions. (2) Influencing factors and driving mechanisms, mainly using least squares estimation and spatial statistical analysis to explore determinants of urbanization levels. (3) Social, economic, and ecological effects of new urbanization, analyzed through spatial mixed models, dynamic spatial panel models, and difference-in-differences models to examine spatial spillover effects. (4) Coupling coordination studies, using coupling coordination degree models and Geodetector to explore relationships with rural revitalization, agricultural modernization, and environmental quality.

Ecological security research abroad emphasizes risk assessment and ecosystem service regulation, while domestic studies focus on ecological security level measurement and pattern construction. A research paradigm has emerged for ecological security pattern studies: "ecological source identification—resistance surface construction—ecological corridor and key node extraction." Under this paradigm, minimum cumulative resistance (MCR) models, matter-element models, and ecological footprint methods are primarily applied across administrative units (provinces, cities, counties) and natural regions (rivers, grasslands, oases, deserts). Recent scholarship has begun examining relationships between new urbanization and ecological security, yet three deficiencies remain: (1) Economic and social factors are rarely considered when constructing ecological security indices. (2) Few studies measure the coupling coordination level and dynamic evolution between new urbanization and ecological security. (3) Research has not adequately accounted for local effects and temporal correlations of spatial objects, neglecting variations in driving factor intensity and direction across spatiotemporal scales.

Building upon the DPSIRM model, this study adds driving force, impact, and management subsystems to construct a comprehensive DPSIRM model encompassing economic, social, environmental, and resource elements, aiming to more systematically describe the logical relationships among ecological security causes, changes, and consequences. Additionally, Geodetector and GTWR models analyze driving factors and their spatiotemporal non-stationarity, providing theoretical foundations for coordinated new urbanization and ecological security in Gansu.

1.1 Study Area

Gansu Province is located in northwest China between 92°13 –108°46 E and 32°11 –42°57 N, spanning 1,132 km east-west and 1,480 km north-south. The region features complex and unique climate conditions, including subtropical monsoon, temperate monsoon, temperate continental arid, and plateau mountain climates, with significant spatial variations in temperature (0–14 ℃) and precipitation (40–760 mm). The province exhibits diverse natural ecosystems with severe soil erosion and land desertification. Gansu governs 14 prefecture-level cities and 86 counties (cities, districts). In 2021, its GDP reached 1,186.38 billion yuan with a permanent population of 24.6548 million. The urbanization rate has steadily increased to 55.49%, though this remains below the national average. As an important water source conservation and supply area for the upper reaches of the Yangtze and Yellow Rivers, and a key component of China's "Two Screens and Three Belts" ecological security strategic pattern, Gansu's new urbanization process and ecological security status evolution profoundly impact regional sustainable development.

1.2 Data Sources

All data used in this study were obtained from publicly available domestic and international databases, covering the period 2012–2021. Elevation data were sourced from the Geospatial Data Cloud website. Annual average temperature and precipitation data came from the National Earth System Science Data Center. Socioeconomic data were derived from the *China City Statistical Yearbook* (2012–2021), *China Environmental Statistics Yearbook* (2012–2021), *Gansu Statistical Yearbook* (2012–2021), and statistical bulletins on national economic and social development from Gansu's prefecture-level city governments. Missing values in individual annual indicators were supplemented using linear interpolation.

1.3 Methods

1.3.1 Index System Construction As a typical western inland province, Gansu faces uneven population flow, relatively lagging economic development, insufficient social service resources, and increasing spatial development pressure.

This study selects Gansu as the research area and constructs evaluation index systems based on the "population-economy-society-space" model for new urbanization and the DPSIRM model for ecological security (Tables 1 and 2). The new urbanization indicators reflect demographic characteristics, economic development levels, social harmony, and spatial layout rationality. The ecological security evaluation DPSIRM model incorporates driving forces, pressures, state, impacts, and management subsystems, covering economic, social, environmental, and resource elements.

The entropy weight-TOPSIS method assessed new urbanization and ecological security levels in Gansu, with classification standards shown in Table 3. The coupling coordination model, combining coupling degree and coordination degree models, evaluates the correlation and synergy between two or more systems (Table 4).

1.3.2 Coupling Coordination Model The coupling coordination model integrates coupling degree and synergy degree models to evaluate the correlation and coordination among systems. The formulas are as follows:

$$C = 2\sqrt{(Ua \times Ub)} / (Ua + Ub)$$
$$T = \alpha Ua + \beta Ub$$
$$D = \sqrt{(C \times T)}$$

where Ua and Ub represent new urbanization and ecological security indices, respectively; C and T denote coupling degree and synergy degree; α and β are weighting coefficients (both set to 0.5); and D is the coupling coordination degree ranging from 0 to 1, where higher values indicate better coordination. Reference studies established the classification criteria for coupling coordination degrees (Table 4).

1.3.3 Geodetector Geodetector quantitatively investigates driving factors behind the coupling coordination between new urbanization and ecological security. The factor detection formula is:

$$q = 1 - (\Sigma(Nh \times \sigma h^2)) / (N \times \sigma^2)$$

where q measures the explanatory power of driving factors on spatial differentiation; Nh and σh^2 represent intra-layer variance and total variance; N is the number of samples; and $h = 1, 2, \ldots, L$ indicates stratification. Based on Gansu's development context and existing research, this study selected urban population density (X_1), proportion of secondary industry in GDP (X_2), normalized difference vegetation index (NDVI) (X_3), annual precipitation (X_4), secondary industry employment (X_5), and fixed asset investment (X_6) as driving factors.

1.3.4 Spatiotemporal Geographically Weighted Regression (GTWR) Model The GTWR model extends the geographically weighted regression (GWR) model by introducing temporal dimensions, revealing spatiotemporal non-stationarity through parameter variation. The formula is:

$$Yi = \beta_0(ui, vi, ti) + \Sigma \ \beta\ (ui, vi, ti)gik + \ i$$

where Yi is the sample value; β_0 is the constant term; (ui, vi, ti) represents the spatiotemporal coordinates of sample point i; gik is the value of independent variable k at point i; β is the regression parameter; and i is the residual. The regression parameter estimation formula is:

$$\beta(ui, vi, ti) = (Z\ W(ui, vi, ti)Z)^{-1}Z\ W(ui, vi, ti)Y$$

where Z is the matrix of independent variables and W is the spatiotemporal weight matrix.

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2. Results

2.1 New Urbanization and Ecological Security Indices

From 2012 to 2021, Gansu's new urbanization index increased from 0.213 to 0.328, remaining at a relatively low level. The ecological security index rose by 0.099, shifting from low to moderate security status (Table 5).

Table 5 New urbanization and ecological security levels in Gansu Province from 2012 to 2021

2.2 Coupling Coordination Degree

The coupling coordination degree between new urbanization and ecological security in Gansu increased from 0.527 in 2012 to 0.628 in 2021, transitioning from barely coordinated to primarily coordinated states. Specifically, in 2012, Lanzhou City and Gannan Tibetan Autonomous Prefecture (hereafter Gannan Prefecture) showed the highest and lowest coordination degrees, respectively. By 2021, Lanzhou's coordination degree reached 0.781, exhibiting intermediate coordination. Except for Jiayuguan, Zhangye, Gannan, Baiyin, Dingxi, and Pingliang, all other prefectures improved their coordination levels. In 2015, Jiayuguan's coordination degree increased to 0.533, shifting from barely to primarily coordinated, while Tianshui's decreased to 0.540. By 2018, Baiyin, Tianshui, Zhangye, Dingxi, and Longnan upgraded to primary coordination, while Gannan improved to 0.430, shifting from near-imbalance to barely coordinated. The spatial disparity in coupling coordination across the province gradually narrowed (Table 6).

Table 6 Coupling coordination between new urbanization and ecological security in different cities/prefectures of Gansu Province from 2012 to 2021

The coupling coordination degree exhibited a spatial pattern of "low in the north and south, high in the middle" (Figure 1). Trend surface analysis revealed that east-west differences gradually diminished, while north-south differentiation became more pronounced (Figure 2).

Figure 1 Spatiotemporal evolution of the coupling coordination between new urbanization and ecological security in Gansu Province from 2012 to 2021 [Figure 1: see original paper]

Figure 2 Trends of new urbanization and ecological security coupling coordination in Gansu Province from 2012 to 2021 [Figure 2: see original paper]

2.3 Driving Factor Detection

2.3.1 Single-Factor Detection Results Fixed asset investment, secondary industry employment, urban population density, per capita GDP, and the proportion of secondary industry in GDP were the core driving forces. Among these, fixed asset investment showed the highest explanatory power, followed by secondary industry employment and urban population density. Per capita GDP and the proportion of secondary industry in GDP also significantly influenced coupling coordination.

Table 7 Detection results for single driving factor of coupling coordination of new urbanization and ecological security in Gansu Province

2.3.2 Interactive Detection Results Interactive detection revealed that coupling coordination was influenced by factor interactions, with dominant interaction types varying annually (Figure 3). In 2012, the strongest interaction was between secondary industry proportion and fixed asset investment; in 2015, urban population density and secondary industry employment; and in 2021, secondary industry proportion and secondary industry employment.

Figure 3 Interactive detection results of driving factors for the coupling coordination of new urbanization and ecological security in Gansu Province [Figure 3: see original paper]

2.4 Spatiotemporal Non-Stationarity Analysis

2.4.1 Data Testing and Model Selection To avoid multicollinearity, variance inflation factor (VIF) tests confirmed no collinearity among factors. Model selection compared ordinary least squares (OLS), geographically weighted regression (GWR), and GTWR models. GTWR showed the best fit with an adjusted R^2 of 0.921 and lowest AICc value, making it the optimal choice for local estimation of driving factors (Table 8).

Table 8 Model comparison

2.4.2 Temporal Non-Stationarity of Driving Factors Urban population density, secondary industry proportion, and annual precipitation consistently showed negative correlations with coupling coordination, though effect magnitudes fluctuated interannually. Annual average temperature positively correlated with coordination, with gradually decreasing coefficients indicating weakening promotional effects. NDVI's impact shifted from negative to positive correlation, with strengthening effects over time. Secondary industry employment showed positive correlation with the highest regression coefficients, indicating its substantial influence. Per capita GDP's promotional effect increased significantly after 2015, peaking in 2020 before slightly declining. Fixed asset investment maintained positive correlation, though its promotional effect gradually weakened (Table 9).

Table 9 Regression coefficients of driving factors in the GTWR model

2.4.3 Spatial Non-Stationarity of Driving Factors Urban population density positively affected coupling coordination in Lanzhou, Longnan, Linxia Hui Autonomous Prefecture (hereafter Linxia Prefecture), and Gannan Prefecture, but negatively impacted other regions. The proportion of secondary industry negatively affected all prefectures, particularly strongly inhibiting coordination in Gannan and Linxia. Annual precipitation promoted coordination in Jinchang, Wuwei, and Zhangye—typical arid regions—while inhibiting other areas. Annual average temperature negatively affected Jiayuguan and Jiuquan but positively influenced other prefectures. NDVI showed varying effects across prefectures, with the strongest inhibition in Gannan and strongest promotion in Pingliang. Secondary industry employment inhibited coordination in Jiayuguan, Jiuquan, and Zhangye but promoted it elsewhere. Per capita GDP positively affected all prefectures, while fixed asset investment only slightly negatively impacted Qingyang (Figure 4).

Figure 4 Spatial non-stationary for driving factors of new urbanization and ecological security coupling coordination in Gansu Province [Figure 4: see original paper]

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3. Discussion

3.1 Coupling Coordination Analysis

During the study period, Gansu's new urbanization and ecological security coordination shifted from barely to primarily coordinated, though uneven across prefectures. In 2021, the top three coordinated prefectures were Lanzhou, Qingyang, and Tianshui. As the provincial capital, Lanzhou's higher socioeconomic development and ecological governance capacity provided a solid foundation for coordinated development. Qingyang's abundant oil and gas resources (total oil resources of 5.974 billion tons, proven reserves of 1.797 billion tons, and natural gas reserves accounting for 17.97% of the Ordos Basin total) ensured energy security while balancing development with ecological protection. Tianshui's "industry-strengthened city" strategy effectively coordinated industrial upgrading with environmental protection. Gannan Prefecture's coordination improved from near-imbalance to barely coordinated, the lowest in Gansu, reflecting its special ecological function as a critical water source conservation area for the Yellow and Yangtze Rivers where new urbanization lags behind ecological security.

The spatial distribution pattern of “low in the north and south, high in the middle” reflects regional differences. Southern Gansu’s Qilian Mountains and Hexi Corridor feature fragile ecosystems with low environmental carrying capacity, relying on traditional agriculture and resource-based industries with limited modern industrial support. Northern regions possess some resource advantages but face greater ecological pressure due to single economic structures. Central Lanzhou’s flat terrain, complete infrastructure, diversified industrial structure, and relatively developed economy facilitate coordinated new urbanization and ecological security development.

3.2 Driving Factors and Spatiotemporal Non-Stationarity

Socioeconomic factors significantly influence the spatial differentiation of coupling coordination, consistent with existing research. Fixed asset investment promotes coordination, though its positive effect gradually weakens. Short-term investment increases provide employment and accelerate industrial development, but long-term continuous growth fails to concentrate market resources in greener, more innovative enterprises or stimulate optimal asset allocation and operational efficiency improvements. Urban population density inhibits coordination, as excessive population pressure threatens ecological security when exceeding regional carrying capacity. However, Lanzhou, Longnan, Linxia, and Gannan showed positive coefficients due to decreasing population density in Lanzhou and relatively low densities in the other three prefectures.

Industrial factors like secondary industry proportion and employment substantially impact coordination. Secondary industry expansion typically increases energy consumption and pollutant emissions, intensifying environmental pressure and limiting ecological security. However, moderate expansion with efficient resource use and environmental technology can harmonize economic development with ecological protection. The negative impact of secondary industry proportion was particularly prominent in Gannan and Linxia, indicating an urgent need for industrial transformation to reduce ecological impacts. Secondary industry employment positively affected all prefectures, promoting industrial structure optimization and environmental investment.

Natural environmental factors also showed spatiotemporal heterogeneity. Annual precipitation promoted coordination in Jinchang, Wuwei, and Zhangye—arid regions where increased precipitation improved water supply and alleviated desertification, providing ecological safeguards for sustainable urbanization. Zhangye’s precipitation increased by approximately 40 mm from 2012–2021, benefiting irrigation and ecological restoration. However, precipitation increases in other areas caused flooding disasters that negatively affected ecological security. Rising temperatures exacerbated water shortages and land degradation, particularly constraining coordination in arid regions like Jiayuguan and

Jiuquan.

In conclusion, both natural and socioeconomic factors influence Gansu's new urbanization and ecological security coupling coordination with spatiotemporal non-stationarity. Policy recommendations include: (1) Strengthening urban planning and population regulation to guide orderly population distribution, allowing moderate population concentration within ecological carrying capacity in Longnan, Gannan, and Linxia; (2) Implementing differentiated industrial transformation policies to develop eco-friendly industries, particularly accelerating green transitions in Gannan and Linxia while optimizing industrial structures in Jiayuguan and Jiuquan; (3) Optimizing investment structures to improve efficiency, directing capital toward green industries and ecological projects, particularly strengthening investment evaluation and supervision in Qingyang to promote positive interactions between economic development and ecological security.

4. Conclusion

From 2012 to 2021, Gansu's new urbanization index increased from 0.213 to 0.328, remaining at a relatively low level, while ecological security index rose by 0.099, transitioning from low to moderate security. Their coupling coordination degree increased from 0.527 to 0.628, shifting from barely coordinated to primarily coordinated states. Gannan and Linxia prefectures showed relatively low coordination levels, particularly where new urbanization lagged behind ecological security.

The synergy between new urbanization and ecological security is driven by combined socioeconomic and natural factors, with fixed asset investment, secondary industry employment, urban population density, per capita GDP, and secondary industry proportion as primary drivers. Gansu's new urbanization and ecological security coupling coordination is influenced by multiple interacting factors, though dominant interactions varied annually. All driving factors demonstrated spatiotemporal non-stationarity with varying directions and intensities.

Future research should incorporate national macro-control policies, local regulations, and landscape types to deeply analyze how industrial restructuring guides the internal mechanisms of new urbanization and ecological environment coupling coordination. It should also comprehensively examine external driving forces by integrating important opportunities such as rural revitalization, western development, and Belt and Road Initiative implementation.

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