

Spatiotemporal Differentiation and Driving Forces of High-Quality Urbanization Development in the Yellow River “几”-shaped Bend Urban Agglomeration: Postprint

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Abstract

Promoting high-quality development of urbanization in the Yellow River “Ji” character bend metropolitan area constitutes an important support for building the growth pole of the Yellow River Basin. This study takes 15 prefecture-level cities in the Yellow River “Ji” character bend metropolitan area as the research object, constructs an evaluation index system for high-quality urbanization development from four dimensions of population, economy, society, and ecology, and employs research methods including the entropy method, Theil index, standard deviation ellipse, and geographical detector to analyze the spatio-temporal differentiation characteristics and driving forces of high-quality urbanization development from 2012 to 2021. The results show that: (1) From a temporal perspective, the level of high-quality urbanization development in the Yellow River “Ji” character bend metropolitan area exhibited an overall fluctuating upward trend during 2012-2021. (2) From a spatial perspective, significant spatial differences exist in the level of high-quality urbanization development in the Yellow River “Ji” character bend metropolitan area, presenting a “core-periphery” spatial distribution pattern; the overall difference in high-quality urbanization development level demonstrates a trend of first increasing and then decreasing, with intra-regional differences representing the primary source of the overall difference; the spatial distribution direction of the standard deviation ellipse shows a general “northeast-southwest” orientation, with the ellipse centroid located within Ordos City, indicating pronounced spatial agglomeration characteristics. (3) Economic foundation serves as the dominant factor in high-quality urbanization development, while market environment, government regulation capacity, and technological innovation capability play significant roles in promoting high-quality urbanization development. The research findings can provide theoretical support and reference basis for the high-quality development of urbanization

and regional coordinated development in the Yellow River “Ji” character bend metropolitan area.

Full Text

Spatial and Temporal Differentiation and Driving Forces of High-Quality Urbanization Development in the Jiziwan Metropolitan Area of the Yellow River

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Abstract: Promoting high-quality urbanization development in the Jiziwan metropolitan area of the Yellow River is essential for establishing a key growth pole in the Yellow River Basin. This study examines 15 prefecture-level cities in the Jiziwan metropolitan area, constructing an evaluation index system for high-quality urbanization development across four dimensions: population, economy, society, and ecology. Using the entropy method, Theil index, standard deviation ellipse, and geographic detector, we analyze the spatiotemporal differentiation characteristics and driving forces of high-quality urbanization from 2012 to 2021. The results indicate: (1) The overall level of high-quality urbanization in the Jiziwan metropolitan area shows a fluctuating upward trend during the study period. (2) Spatially, significant disparities exist in high-quality urbanization levels, exhibiting a “core-periphery” distribution pattern. Overall differences initially increase then decrease, with intra-regional disparities representing the primary source of total variation. The standard deviation ellipse demonstrates a northeast-southwest orientation, with its centroid located in Ordos City, indicating pronounced spatial clustering. (3) The economic base constitutes the dominant factor driving high-quality urbanization, while market environment, government regulatory capacity, and technological innovation capacity also play crucial roles. These findings provide theoretical support and reference for promoting high-quality urbanization and coordinated regional development in the Jiziwan metropolitan area of the Yellow River.

Keywords: high-quality urbanization; quality measurement; spatiotemporal pattern; geographic detector; Jiziwan metropolitan area of the Yellow River

Introduction

Urbanization represents the process of non-agricultural industries agglomerating in cities and rural populations concentrating in urban areas, serving as a critical indicator of national modernization. China's urbanization rate has reached 66.16%, yet accelerated urbanization has engendered traffic congestion, environmental pollution, social conflicts, and uncoordinated urban-rural development, severely constraining high-quality urbanization. Consequently, the 20th National Congress of the Communist Party of China explicitly called for accelerating the construction of a new development pattern and promoting high-quality development. High-quality urbanization emphasizes not only quantitative expansion but also qualitative improvement, becoming a central theme for China's sustained and healthy socioeconomic development and a focal point of current research.

High-quality urbanization integrates high-quality urban construction, infrastructure, public services, living environments, and urban management, representing a people-centered approach toward civilized, harmonious, livable, and low-carbon urban development with Chinese characteristics. Current research primarily focuses on conceptual connotations, quality evaluation, internal coordination, and influencing factors. Regarding theoretical frameworks, studies have evolved from focusing on urban spatial expansion and population migration to emphasizing intensive and efficient urban development, employment growth, and population quality improvement, shifting from high-consumption, high-pollution, and high-risk traditional drivers to new urban dynamics characterized by new consumption, new industries, and new ecology.

In terms of indicator systems and evaluation methods, scholars have constructed evaluation frameworks based on administrative or watershed scales, examining dimensions such as urban-rural integration, infrastructure, green development, and development dynamics, or employing the new development concepts of innovation, coordination, green development, openness, and sharing. These studies utilize mathematical methods including the entropy method, spatial analysis, and coupling coordination models for comprehensive evaluation. Research on influencing factors reveals that population foundations, location constraints, economic drivers, and government regulation interactively promote high-quality urbanization. However, most existing studies examine inter-regional, inter-provincial, or inter-city differences, leaving research on urbanization quality measurement within metropolitan areas insufficient, with indicator systems requiring further refinement from diverse perspectives.

In 2019, President Xi Jinping emphasized at the Yellow River Basin Ecological Protection and High-Quality Development Symposium that the Yellow River Basin holds vital importance for China's socioeconomic development and ecological security. The 14th Five-Year Plan explicitly proposes developing and strengthening urban agglomerations and metropolitan areas. As an essential stage in urban agglomeration formation, metropolitan areas have secured a clear

strategic supporting position in high-quality urban agglomeration development. In October 2021, the Central Committee of the Communist Party of China and the State Council issued the Yellow River Basin Ecological Protection and High-Quality Development Plan Outline, proposing a “one axis, two zones, five poles” development pattern, with the Jiziwan metropolitan area representing one of the “five poles” and serving as a strategic support for ecological protection and high-quality development in the Yellow River Basin. Consequently, research on high-quality urbanization in this area urgently needs strengthening.

This study selects 15 prefecture-level cities in the Jiziwan metropolitan area as research objects, constructing an evaluation index system from population, economic, social, and ecological dimensions. Employing the entropy method, Theil index, standard deviation ellipse, and geographic detector methods, we analyze the spatiotemporal evolution characteristics and influencing factors of high-quality urbanization from 2012 to 2021. This research enriches the theoretical framework and content of high-quality urbanization studies, providing references for urban, economic, and social development in the study area.

1.1 Study Area

The Jiziwan metropolitan area of the Yellow River (104°13 ~114°23 E, 35°06 ~42°50 N) represents a critical node in the Yellow River Basin. Based on previous research and considering data availability and practical research needs, we define the study area to include Taiyuan, Hohhot, Yinchuan, Wuzhong, Zhongwei, Shizuishan, Baotou, Ordos, Wuhai, Bayannur, Yulin, Yan’ an, Shuozhou, Xinzhou, and Lüliang—15 prefecture-level cities in total [Figure 1: see original paper]. The region spans elevations from 377 to 3,505 meters, encompassing the Ningxia Plain, Hetao Plain, and parts of the Loess Plateau, with temperate monsoon and temperate continental climates.

In 2021, the study area had a permanent population of 35.6336 million and a regional GDP of 3,904.261 billion yuan, accounting for 12.68% of the entire Yellow River Basin. The primary, secondary, and tertiary industries contributed 220.802 billion yuan, 1,492.444 billion yuan, and 2,208.019 billion yuan respectively, representing 56.55% and 38.23% of the basin’ s totals.

1.2 Data Sources

Data primarily derive from the *China City Statistical Yearbook* (2012–2021), municipal statistical yearbooks, the *China Urban Construction Statistical Yearbook*, and municipal national economic and social development statistical bulletins. Missing values were interpolated. Drawing on previous research and considering data availability, operability, and representativeness, we constructed an evaluation system from four dimensions: population urbanization, economic urbanization, social urbanization, and ecological urbanization. Population urbanization is characterized by population composition and employment; economic urbanization by industrial structure, fiscal revenue, and economic scale;

social urbanization by infrastructure and public services including power supply, water supply, healthcare, education, and roads; and ecological urbanization follows green and low-carbon development concepts reflecting livable urban environments. Indicator weights were calculated using the entropy method .

1.3 Research Methods

1.3.1 Entropy Method The entropy method provides a comprehensive and objective evaluation approach. The calculation formula is:

$$Sti = \sum_i$$

where Sti represents the comprehensive index of high-quality urbanization development for city i in year t ; w_j denotes the weight of indicator j ; x'_{tij} represents the standardized value of indicator j for city i in year t ; and n is the number of research units.

1.3.2 Theil Index The Theil index measures inter-regional and intra-regional disparities. Following provincial administrative divisions, we divided the study area into four groups—Shanxi, Shaanxi, Inner Mongolia, and Ningxia—to analyze inter-group and intra-group differences:

$$T = \sum_k \frac{Y_k}{Y} \ln \left(\frac{Y_k}{Y} \right) + \sum_k \frac{Y_k}{Y} \sum_{i \in k} \frac{Y_i}{Y_k} \ln \left(\frac{Y_i}{Y_k} \right)$$

where T is the Theil index (higher values indicate greater disparities), T_b and T_w represent inter-regional and intra-regional differences respectively, n is the number of prefecture-level cities, k is the number of groups, n_k is the number of cities in group k , g_k is the urbanization index for city i in group k , Y_k is the sum of urbanization indices for group k as a proportion of the total sum, and Y_i is city i 's urbanization index as a proportion of the total sum.

1.3.3 Standard Deviation Ellipse We employ standard deviation ellipse analysis to examine spatial equilibrium, with migration centroids representing spatial trajectories of regional development:

$$(X, Y) = \left(\frac{\sum_i P_{ti} X_i}{\sum_i P_{ti}}, \frac{\sum_i P_{ti} Y_i}{\sum_i P_{ti}} \right)$$

where (X, Y) are the centroid coordinates, (X_i, Y_i) are the geographic coordinates of city i , and P_{ti} is the urbanization development index for city i in year t .

1.3.4 Geographic Detector The geographic detector identifies spatial heterogeneity and its driving factors. Factor detection and interaction detection are used to analyze urbanization drivers:

$$q = 1 - \frac{\sum_{h=1}^L N_h \sigma_h^2}{N \sigma^2}$$

where L is the number of city domains, N_h and σ_h^2 are the sample size and variance of subregion h , N and σ^2 are the sample size and variance of the entire region, and q represents the explanatory power of factors on high-quality urbanization (range [0,1]), with higher values indicating stronger influence.

Results and Analysis

2.1.1 Overall Temporal Evolution Characteristics

From 2012 to 2021, the mean comprehensive index of high-quality urbanization in the Jiziwan metropolitan area increased from 0.31 to 0.48, with an average annual growth rate of 4.55%. This fluctuating upward trend indicates improving economic development, infrastructure, and ecological governance [Figure 2: see original paper]. All dimensional indices showed overall growth [Figure 3: see original paper]. Economic urbanization index increased from 0.31 to 0.43 (38.94% growth), social urbanization from 0.32 to 0.48 (50.00% growth), and ecological urbanization from 0.21 to 0.37 (76.35% growth), while population urbanization grew only 38.15%. The top three cities in 2021 were Taiyuan (0.68), Ordos (0.66), and Baotou (0.58). Taiyuan, as Shanxi's economic, transportation, cultural, educational, and innovation center, benefits from complete infrastructure, policy advantages, and high population concentration. Ordos, a central city in the Hubao-Eyu urban agglomeration, has developed leading industries in energy chemicals, clean energy, new materials, and equipment manufacturing, with continuously improving collaborative innovation capacity and infrastructure.

2.1.2 City-Level Temporal Evolution Characteristics

All 15 cities exhibited upward trends in high-quality urbanization from 2012 to 2021, though significant inter-city differences persist. The highest and lowest comprehensive indices shifted from Ordos and Zhongwei in 2012 to Taiyuan and Zhongwei in 2021. Population urbanization indices ranged from Wuhai (0.71) to Zhongwei (0.22), with a 0.49 difference. Economic urbanization showed the largest gap, with Taiyuan (0.72) exceeding Zhongwei (0.18) by 0.54. Social urbanization was highest in Ordos (0.60) and lowest in Lüliang (0.25), while ecological urbanization peaked in Ordos (0.64) and bottomed in Yan' an (0.20).

2.2.1 Spatial Pattern Evolution Characteristics

Using ArcGIS 10.8 equal-interval classification, we categorized urbanization levels as high (>0.51), relatively high (0.41–0.50), medium (0.31–0.40), relatively low (0.21–0.30), and low (<0.20) [Figure 5: see original paper]. From 2012 to 2021, the number of high and relatively high-level cities increased by 2 each, medium-level decreased by 1, relatively low increased by 1, and low decreased by 4. In 2012, only Taiyuan, Hohhot, Baotou, and Ordos reached medium level, while others remained at relatively low or low levels. By 2016, Taiyuan, Hohhot, and Ordos advanced to relatively high level, with Yinchuan and Yulin reaching medium level. In 2021, Taiyuan and Ordos achieved high level, while Yulin rose to relatively high level.

Cities at relatively high level and above are primarily provincial capitals and central cities of the Hubao-Eyu urban agglomeration. Taiyuan, Hohhot, and Yinchuan, as provincial capitals, leverage political, economic, and policy advantages to optimize industrial structure and enhance innovation capacity, gradually widening gaps with surrounding cities. The Hubao-Eyu urban agglomeration, as a regional urban cluster in the Yellow River Basin, constitutes the economic core and high-level urbanization zone, with its urbanization rate (71.37%) exceeding the Jizhuan metropolitan area average (66.16%). In contrast, relatively low and low-level cities such as Bayannur, Zhongwei, and Xinzhou suffer from weak development foundations and lack distinctive advantages, gradually becoming marginalized. Overall, a clear “core-periphery” pattern emerged, with Taiyuan and Ordos forming the core and Bayannur, Zhongwei, and Xinzhou constituting the periphery.

2.2.2 Theil Index Analysis

The Theil index for high-quality urbanization exhibited a fluctuating upward trend from 2012 to 2016, peaking in 2016 before declining continuously through 2021, showing an inverted “U” pattern. Intra-regional disparities contributed over 75.68% to total variation, representing the primary source of spatial inequality. All four provinces exhibited polarization, with inter-city differences within each province significantly impacting overall disparity.

2.2.3 Standard Deviation Ellipse Analysis

From 2012 to 2021, the standard deviation ellipse of high-quality urbanization maintained a northeast-southwest orientation, with its centroid located in Ordos City, indicating pronounced spatial clustering [Figure 6: see original paper]. The ellipse area decreased, suggesting enhanced agglomeration. The centroid shifted westward from 2012 to 2016, then southeastward from 2016 to 2021, reflecting improved urbanization quality in the southeast. The 2016–2021 southeastward shift correlates with afforestation programs in Shanxi Province, where afforestation area reached 15.52×10^4 hm² in 2016 but decreased to 10.19×10^4 hm² by 2021, transitioning from quantity-focused to quality-

focused ecological restoration.

Population urbanization' s standard deviation ellipse area first increased then decreased, indicating shifting from dispersion to agglomeration. The seventh national census shows population continuously concentrating in Taiyuan within Shanxi, while Yinchuan' s population share increased by 8.07% compared to the sixth census. Economic urbanization' s centroid migrated southeastward overall, while social urbanization' s centroid in Ordos shifted southwestward. Ecological urbanization' s centroid in Ordos moved northeast then southwest, with its ellipse area first decreasing then increasing, reflecting ecological protection transitioning from agglomeration to dispersion as overall environmental quality improved [Figure 7: see original paper].

2.3.1 Factor Selection

High-quality urbanization results from multiple interacting factors. Drawing on existing literature, we selected seven categories: economic base, government regulatory capacity, market environment, human capital, industrial structure, technological innovation capacity, and openness. Using ArcGIS 10.8 natural breaks classification, we categorized these factors and applied geographic detectors to analyze driving forces .

2.3.2 Factor Analysis

In 2012, primary influencing factors were regional GDP, local general public budget revenue, and total retail sales of consumer goods, with q-values of 0.71, 0.68, and 0.65 respectively. By 2016, financial institution loan balances were added as a major factor. In 2021, key factors were financial institution loan balances, total retail sales of consumer goods, regional GDP, local general public budget revenue, and education/science/technology expenditure . Economic base dominates, while market environment, government regulation, and technological innovation play significant roles. Interaction detection reveals that pairwise factor interactions enhance explanatory power, with all interaction q-values exceeding single-factor values.

Financial institution loan balances, reflecting consumer credit demand and consumption capacity, represent core indicators of financial development and urban comprehensive strength. From 2012 to 2021, loan balances increased from 281.5804 billion to 491.0264 billion yuan, directly supporting urbanization development. Under China' s administrative hierarchy, cities form a gradient "ranking system" in resource concentration, development authority, and policy preferences, with provincial capitals and central cities in national urban agglomerations receiving priority support. These cities optimize market access, improve government services, and create livable environments, enhancing soft power for high-quality urbanization. Technological innovation improves resource utilization efficiency, breaks resource constraints, fosters new industries and markets,

and facilitates industrial restructuring, demonstrating spatial positive correlation with high-quality development in urban agglomerations.

Discussion

This study analyzed spatiotemporal patterns and driving forces of high-quality urbanization in the Jizhiwan metropolitan area. Geographic detection reveals the economic base as fundamental, consistent with previous research. The Jizhiwan area, based on advantageous mineral and energy resources, contributed 11.98% of the Yellow River Basin's GDP in 2021. The economic urbanization centroid's southeastward migration aligns with the basin's economic development direction. However, most cities are resource-based with homogeneous industries dominated by equipment manufacturing and traditional energy chemicals, leading to a "resource curse." Industrial convergence, single structures, high transformation costs, water shortages, and ecological constraints hinder industrial upgrading and high-quality development.

The study found that social urbanization centroids in all three phases gradually migrated southwestward, with western cities ranking among the top 5 in social urbanization index increasing from 1 to 3, led by Ordos. However, Ordos' s permanent and urban populations in 2021 were only about 1/3 of Taiyuan' s, yet its per capita road area was 2.3 times Taiyuan' s, potentially introducing measurement bias. Future research should employ more comprehensive indicators for social urbanization.

Conclusions and Recommendations

4.1 Conclusions

From 2012 to 2021, the mean comprehensive index of high-quality urbanization in the Jizhiwan metropolitan area increased from 0.31 to 0.48, showing a fluctuating upward trend with significant overall improvement. Spatially, a "core-periphery" pattern emerged, with Taiyuan and Ordos forming the core and Bayannur, Zhongwei, and Xinzhou constituting the periphery. Overall disparities first increased then decreased, with intra-regional differences as the main source of variation. The standard deviation ellipse maintained a northeast-southwest orientation with its centroid in Ordos, demonstrating clear spatial clustering. The economic base represents the dominant driving factor, while market environment, government regulation, and technological innovation significantly influence spatial pattern evolution.

4.2 Recommendations

The Jizhiwan metropolitan area should strengthen financial development in provincial capitals and central cities to support ecological and real economies, enhancing financial services for high-quality urbanization. Flexible and reasonable government policies should leverage spillover effects from central

cities to improve peripheral city development, breaking administrative barriers and establishing contractual governance mechanisms for regional coordinated development.

Provincial capitals should enhance scientific and technological innovation capacity to drive industrial diversification and upgrading, radiating development to peripheral cities through “trickle-down effects.” Through “siphon effects,” major cities should advance talent introduction and household registration reform, improving population agglomeration. The region should improve talent evaluation and incentive mechanisms, optimize innovation and living conditions, and accelerate cultivation of high-level talents, particularly for energy and chemical industries. Inter-city talent exchange should be encouraged through cadre exchange programs. The metropolitan area should deeply integrate with the Belt and Road Initiative and the national Yellow River Basin strategy to create a high-level opening-up platform, focusing on cross-regional infrastructure planning, co-construction, and sharing of public services and social security policies.

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