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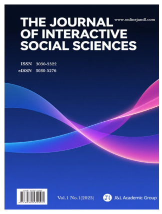

Analysis of the Spatiotemporal Evolution of Industrial Structure Level in the "Ji" Shape Bend of the Yellow River Urban Agglomeration

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ABSTRACT

Constructing an industrial structure indicator system, the weights of the industrial structure indicators are calculated by comprehensively applying the entropy method, the mean square deviation method, and the CRITIC method to measure the level of industrial structure in the "Ji" shaped bend of the Yellow River urban agglomeration from 2011 to 2022. Furthermore, the spatial-temporal evolution characteristics of the industrial structure are analyzed. The study concludes that the level of industrial structure in the "Ji" shaped bend of the Yellow River urban agglomeration shows an overall fluctuating upward trend, with significant differences within the region; spatially, it presents a distribution feature of low in the middle and high around the edges, with high-level areas clustering in the northeastern cities, exhibiting a significant spillover effect; finally, suggestions are proposed to facilitate the industrial transformation and upgrading of the "Ji" shaped bend of the Yellow River urban agglomeration.

1. Introduction

The industrial structure is formed by the specialization of the economy and social division of labor, specifically referring to the proportion of various production factors in different sectors and industries, as well as the interconnections between industries (Kuznets, 1966). The currently authoritative measures of evaluation mainly include two aspects: the upgrading of the industrial structure and the rationalization of the industrial structure. Baumgartinger-Seiringer et al., (2022) has a more comprehensive understanding of industrial renewal from the perspective of structure, focusing on the refinement and consistency as decisive characteristics of regional structural conditions, and empirically studies the upgrading process of the traditional automobile industry in Austria and Sweden. Fu (2010) measures the level of industrial structure upgrading and concludes

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that the transformation and upgrading of China's industrial structure is mainly driven by the total economic volume, while the promoting effect of industrial structure upgrading on economic growth is not significant. Gan et al., (2011) proposes that the Theil index can be used to measure the level of rationalization of the industrial structure, as it can better represent the relationship between the industrial structure and the employment structure. He et al., (2020) and Xu et al., (2021) establish an indicator system from three aspects of rationalization, upgrading, and efficiency of the industrial structure to measure and study the upgrading level of the regional industrial structure.

In recent years, the "Ji" shaped bend of the Yellow River metropolis circle has continuously promoted the upgrading of traditional industries and actively laid out emerging industries, achieving a significant improvement in the level of industrial structure. Ordos City relies on coal resources while actively developing new energy sources such as wind and solar power, generating 2 billion kilowatt-hours of green electricity annually, providing important support for the national energy supply; Bayannur City utilizes its water resources advantage, updates agricultural infrastructure, actively develops characteristic agriculture, cultivates modern agricultural industries, and forms advantageous characteristic industrial clusters such as wheat and sunflowers; Hohhot and Baotou actively explore tourism resources and develop new cultural and tourism industries. The total regional GDP of the 19 league cities in the metropolis circle in 2022 was 4.44 trillion yuan, accounting for about 3.6% of the national total; the population was 45 million, accounting for about 3.19% of the national total, and the per capita GDP was higher than the national average.

The industrial structure transformation of the "Ji" shaped bend of the Yellow River urban agglomeration still faces issues such as industrial homogeneity, insufficient innovation, and a shortage of talent. There are a few large cities within the urban agglomeration, which limits their ability to radiate influence, and there is a lack of motivation for industrial transfer. Moreover, the high proportion of the secondary industry within the urban agglomeration leads to homogeneous competition in energy extraction and energy industry development. Due to geographical and economic constraints, enterprises invest less in scientific research, resulting in inadequate innovation capabilities. The population size is relatively small, and technical talent tends to flow to more developed cities, leading to a scarcity of technical talent within the region. This article constructs an industrial structure indicator system to analyze the spatial and temporal evolution of the industrial structure, clarifying the characteristics of the urban agglomeration's industrial structure development, and providing a reference for regional industrial transformation and upgrading.

2. Model Design

2.1 Construction of the Indicator System

A review of the literature on methods for measuring industrial structure reveals that current approaches to constructing indicators for industrial structure can be broadly categorized into two types: single-indicator methods and indicator system methods. In accordance with the principles for constructing indicators for industrial structure, and to more scientifically and systematically reflect the industrial structure, this article adopts the indicator system method for constructing indicators for industrial structure. Furthermore, based on a review of the literature defining the concept of industrial structure, it is evident that most scholars believe industrial structure refers to the transition process of the industrial structure from a lower-level form to a higher-level form.

The primary purpose of industrial structure is to ensure the quantitative upgrading of the industrial structure while achieving efficient resource allocation, promoting the advancement of the industrial structure towards a higher level, providing an internal driving force for high-quality economic growth, and fundamentally aiming to promote the quality upgrade of the industrial structure. In light of this, and drawing on the indicator construction approaches for industrial structure upgrading by Huang et al., (2013) and He et al., (2021), this article constructs an indicator system for industrial structure upgrading from the dual perspectives of the advancement and efficiency of the industrial structure. As shown in Table 1.

Table 1 Indicator System of Industrial Structure

Primary Indicator	Secondary indicators	Third-level indicators
Industrial structure	Advanced industrial structure	Tertiary industry/Secondary industry
		1*Proportion of primary industry output value + 2*Proportion of secondary industry output value + 3*Proportion of tertiary industry output value
	Efficient industrial structure	Primary industry efficiency
		Secondary industry efficiency
		Tertiary industry efficiency

2.2 Research Methodology

2.2.1 CRITIC Method

The CRITIC method is an objective weighting method that determines the weight of indicators based on the correlation coefficient and standard deviation. Its core idea is to assign weights according to the variability and conflict of indicators. Variability is represented by the standard deviation, where a larger standard deviation indicates greater data fluctuation and thus a larger weight, and vice versa. Conflict is represented by the correlation coefficient, where a larger correlation coefficient indicates stronger data conflict and thus a lower weight, and vice versa. Compared with the entropy method, the CRITIC method takes into account both the variability and conflict of indicators, making the determined weights more meaningful in reality. The specific calculation formula is as follows:

(1) Indicator standardization processing (same as the entropy method)

(2) Calculate the amount of information contained in the j-th indicator Cj:

$$C_j = \delta_j \sum_{i=1}^{n} (1 - r_{ij}), (j = 1,2,\cdots,m)$$

$$r_{ij} = \frac{COV(X_i, X_j)}{\sqrt{Var[X_i] Var[X_j]}}$$

The larger the value, the greater the amount of information contained in the indicator, and the higher the relative importance and weight of the indicator. Here, represents the standard deviation of indicator j, and represents the correlation coefficient between indicators.

(3) Calculate the weight Wj of the j-th indicator:

$$Wj = \frac{Cj}{\sum_{j=1}^{m} Cj}, (j = 1,2,\cdots,m)$$

(4) Calculate the comprehensive score of the sample Si:

$$S_i = \sum_{j=1}^{m} \left(W_j * X''_{ij}\right)$$

2.2.2 Mean Squared Error

(1) Calculate the mean of the random variable

$$\overline{X_j} = \frac{1}{n}\sum_{i=1}^{n} X_i$$

(2) Calculate the mean square deviation

$$\sigma_j = \sqrt{\frac{1}{N}\sum_{i=1}^{n}(X_i - \overline{X_j})}$$

(3) Calculate the index weights

$$W_j = \sigma_j / \sum_{j=1}^{m} \sigma_j$$

2.3 Data Sources

Limited by the availability of indicator data, the study period for this article is from 2011 to 2022. The industrial structure indicator data is sourced from the Statistical Yearbooks of various leagues and cities (2012-2023), the "China City Statistical Yearbook (2012-2023)", and the Statistical Communiqués on National Economic and Social Development.

3. Spatiotemporal Evolution Analysis of Industrial Structure Level in the "Ji" Shape Bend of the Yellow River Metropolitan Area

3.1 Calculation of Index Weights

3.1.1 Calculation of Index Weights

The indicators are calculated for weights using the entropy method, CRTIC weight method, and mean square deviation method, respectively. Then, the arithmetic mean is taken, and the results are shown in Table 2. From the results, it can be seen that the secondary indicators of industrial structure sophistication and industrial structure efficiency account for weights of 28.48% and 71.52%, respectively. This indicates that the efficient development of the industrial structure plays an important role in the development of the industrial structure in the "Ji" shape bend of the Yellow River metropolitan area.

Table 2 Weights of Industrial Structure Indicators

Primary Indicator	Secondary indicators	Comprehensive weight(%)	Third-level indicators	Weight (%)
Industrial structure	Advanced industrial structure	28.48	Tertiary industry/Secondary industry	18.946
			1*Proportion of primary industry output value + 2*Proportion of secondary industry output value + 3*Proportion of tertiary industry output value	9.533
	Efficient industrial structure	71.52	Primary industry efficiency	40.62
			Secondary industry efficiency	18.326
			Tertiary industry efficiency	12.575

3.1.2 Calculation of Industrial Structure

Based on the availability of various indicators data on industrial structure, using the constructed industrial structure indicator system, according to the comprehensive evaluation model, the comprehensive index of industrial structure for the 19 cities in the "Ji" shape bend of the Yellow River urban agglomeration from 2011 to 2022 was calculated, and the results are shown in Table 3.

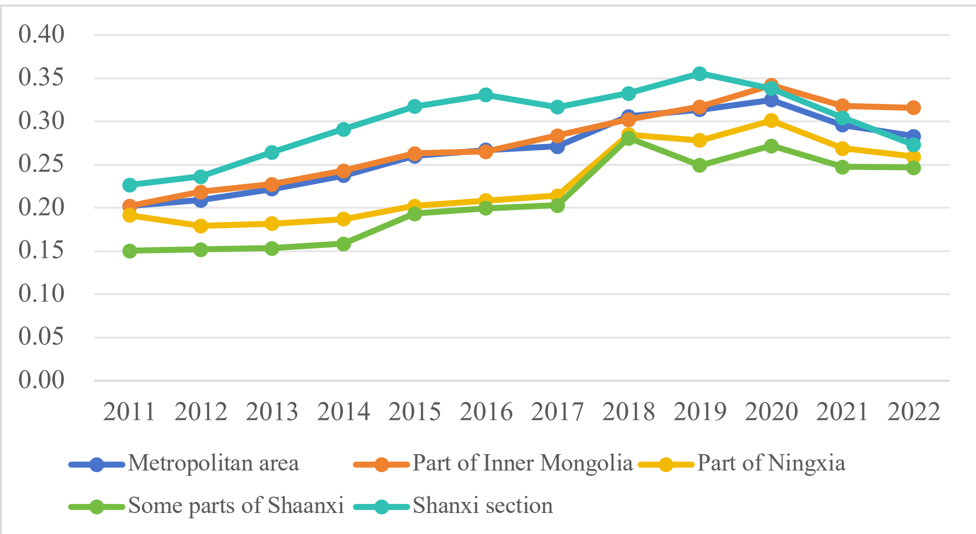

Figure 1 Temporal Trend of the Industrial Structure Level in the Metropolitan Area

Table 3 Industrial Structure Level of the Metropolitan Area around the “Ji”-shaped Bend of the Yellow River from 2011 to 2022

Table 3 Industrial Structure Level of the Metropolitan Area around the “Ji”-shaped Bend of the Yellow River from 2011 to 2022

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Annual average
Yinchuan City	0.2085	0.2082	0.2109	0.2107	0.2201	0.2298	0.2368	0.2668	0.2807	0.2990	0.2829	0.2608	0.2429
Wuzhong City	0.1639	0.1395	0.1521	0.1552	0.1643	0.1634	0.1639	0.3497	0.2398	0.2439	0.2266	0.2684	0.2026
Shizuishan City	0.1476	0.1605	0.1634	0.1719	0.1990	0.2020	0.1930	0.2090	0.2743	0.3601	0.2535	0.2175	0.2127
Zhongwei City	0.2463	0.2084	0.2014	0.2103	0.2249	0.2391	0.2627	0.3137	0.3169	0.3006	0.3130	0.2899	0.2606
Yan'an City	0.1260	0.1313	0.1392	0.1518	0.1898	0.2199	0.2361	0.3638	0.2842	0.3165	0.3018	0.3184	0.2316
Yulin City	0.1750	0.1727	0.1671	0.1649	0.1967	0.1790	0.1699	0.1979	0.2144	0.2273	0.1930	0.1746	0.1860
Hohhot City	0.3257	0.3527	0.3794	0.3946	0.4081	0.4116	0.4170	0.4119	0.4310	0.4727	0.3499	0.3481	0.3919
Ordos City	0.1870	0.1845	0.1900	0.2020	0.2420	0.2132	0.2284	0.2390	0.2541	0.2965	0.2105	0.2222	0.2225
Bayannur City	0.1149	0.1346	0.1511	0.1677	0.1905	0.2135	0.2575	0.3053	0.2770	0.2977	0.3022	0.2897	0.2251
Wuhai City	0.1445	0.1715	0.1937	0.2059	0.2432	0.2417	0.2295	0.2211	0.2021	0.1912	0.1609	0.1551	0.1967
Ulanqab City	0.2307	0.2493	0.2135	0.2646	0.2876	0.2943	0.3245	0.3761	0.4066	0.4248	0.6790	0.5895	0.3617
Baotou City	0.2342	0.2517	0.2680	0.2607	0.2662	0.2731	0.3049	0.3031	0.3953	0.3768	0.3243	0.4276	0.3072
Alxa League	0.1787	0.1864	0.1966	0.2043	0.2037	0.2078	0.2243	0.2578	0.2520	0.3334	0.1986	0.1775	0.2184
Taiyuan City	0.2866	0.3158	0.3163	0.3432	0.3617	0.3718	0.3571	0.3584	0.3961	0.3982	0.3738	0.3391	0.3515
Lüliang City	0.1711	0.1632	0.2527	0.2915	0.3127	0.3071	0.2530	0.3002	0.2917	0.2491	0.2165	0.2023	0.2509
Shuozhou City	0.1809	0.1771	0.1911	0.2026	0.2588	0.2704	0.3133	0.3427	0.2986	0.2965	0.2598	0.2373	0.2524
Jinzhong City	0.2392	0.2528	0.2766	0.3199	0.3525	0.3602	0.3308	0.3279	0.4191	0.4049	0.3611	0.2959	0.3284
Datong City	0.2577	0.2821	0.3113	0.3362	0.3489	0.3939	0.3813	0.3931	0.3693	0.3625	0.3398	0.3229	0.3416
Xinzhou City	0.2240	0.2275	0.2377	0.2537	0.2702	0.2813	0.2642	0.2721	0.3585	0.3165	0.2753	0.2391	0.2683
Average value	0.2022	0.2089	0.2217	0.2375	0.2600	0.2670	0.2710	0.3058	0.3138	0.3246	0.2959	0.2829	0.2659

Overall, the industrial structure upgrading of the Yellow River "Ji" character bend metropolis circle shows a fluctuating upward trend, with the annual average increasing from 0.2022 in 2011 to 0.2659 in 2022, with an average annual growth rate of 3.26%. The level of industrial structure upgrading plays an important role in promoting the economic growth of the Yellow River "Ji" character bend metropolis circle. In terms of the level of industrial structure upgrading, the cities of Hohhot, Jinzhong, and Datong have consistently been above the average. Hohhot, Jinzhong, and Datong have a better economic level, with an industrial structure that adapts to the employment structure and a higher level of industrial structure upgrading. However, the cities of Wuhai and Yulin have consistently been below the average, with a significant gap from the metropolis circle's average level of industrial structure upgrading, indicating a lower level of industrial structure upgrading.

In terms of development speed, there is a significant difference in the average annual growth rate of industrial structure upgrading among the cities in the Yellow River "Ji" character bend metropolis circle, with considerable regional differences in the level of industrial structure upgrading. Among them, the annual average growth rate of industrial structure upgrading in Ulanqab reached 10.37%, with a fast development speed, far above the average growth rate. The annual average growth rates of industrial structure upgrading in Hohhot, Yulin, and Wuhai were 1.11%, 0.5%, and 1.21% respectively, below the average growth rate, indicating slower development in industrial structure upgrading. Overall, the level of industrial structure upgrading in various cities shows a clear fluctuating upward trend, but due to conditions such as economic status, labor, and resources, there are significant differences in the state of industrial structure upgrading, with good prospects for industrial synergy development.

3.2 Analysis of Temporal Evolution of Industrial Structure in the Yellow River "Ji" Bend Metropolitan Area

Firstly, from an overall perspective, the temporal changes in the level of industrial structure of the Yellow River "Ji" Bend metropolitan area are explored, with the results shown in the following Figure 1. From the perspective of the overall metropolitan area, the level of industrial structure shows a fluctuating upward development trend. During the study period, the development trend of the industrial structure level was relatively slow. Looking at the regions individually, the annual average level of industrial structure in each region shows a fluctuating upward development trend, with significant development differences among the regions. The levels of industrial structure, from highest to lowest, are the Shanxi part, Inner Mongolia part, Shaanxi part, and Ningxia part, with the level of industrial structure in the Ningxia part being slightly lower than the other three regions. Over time, the gap in industrial structure levels between the Ningxia part and the other three parts has been expanding, while the gap between the Shanxi part and the Inner Mongolia part, and the Shaanxi part has remained relatively stable.

3.3 Analysis of the Spatial Evolution of the Industrial Structure in the Yellow River "Ji" Character Bend Metropolitan Area

3.3.1 Characteristics of Spatial Agglomeration

Using the hot spot analysis function in ArcGIS 10.7 software, the spatial distribution pattern and evolution trend of the cold and hot spots of the industrial structure in the Yellow River "Ji" character metropolitan area at four research time points in 2011, 2015, 2019, and 2022 were analyzed from three confidence intervals of 90%, 95%, and 99%. The aggregation locations of high-value and low-value areas were observed and visualized (see Figure 2) to further analyze the agglomeration patterns of the industrial structure level within the region.

It can be seen that the differentiation of cold and hot spots in the industrial structure of the Yellow River "Ji" character bend is distinct, with a certain stability and continuity in the spatial pattern. The hot spot areas are mainly concentrated in the regions of Shanxi and Inner Mongolia, forming a growth pole centered around Taiyuan. The distribution of cold spot areas is relatively sparse, mainly concentrated in the regions of Ningxia and Shanxi, forming a cold spot aggregation area centered around Ningxia, with significant changes over time.

Specifically, the spatial distribution of hot spot areas in the four years shows obvious continuity. In 2011, the hot spot areas were mainly distributed in Shanxi, expanding to Inner Mongolia by 2015, with an increased range. By 2019, the range narrowed, and the high-confidence area shifted northward, covering all cities in Shanxi and some cities in Inner Mongolia, forming a hot spot aggregation area centered around Ulanqab. By 2022, the range of the area narrowed, and the confidence level decreased. The distribution of cold spot areas is concentrated with similar confidence levels. In both 2011 and 2019, they were distributed in the region of Ningxia, with the confidence level improving over time, and the range being relatively small. By 2022, the range of the cold spot area further narrowed, with only Shizuishan and Yulin cities being the cold spot areas.

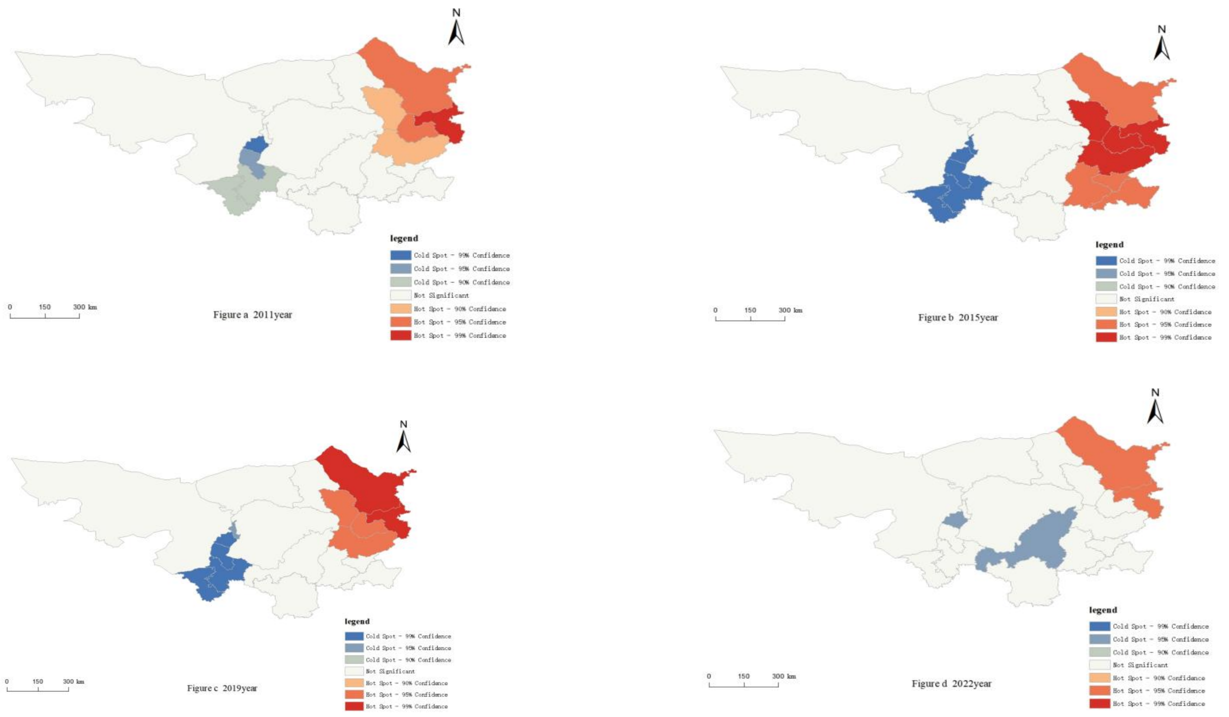

Figure 2 Distribution of Cold and Hot Spots of the Industrial Structure from 2011 to 2022

3.3.2 Spatial Classification Characteristics

To explore the spatial evolution characteristics of the industrial structure based on the "Ji" bend of the Yellow River metropolis circle, this article further utilized ArcGIS 10.8 software to depict the spatial evolution trend of the industrial structure, as shown in Figure 3.

Overall, the industrial structure level of the Yellow River "Ji" bend metropolis circle presents a characteristic of "low in the middle, high around the edges," with the low-level area shrinking and the medium-low and medium-high level areas expanding. Specifically, the low-level area was concentrated in distribution in 2011, accounting for 84%, with most cities in the metropolis circle at a low level of industrial structure. By 2015, the low-level area had shrunk, with the proportion decreasing to 50%, distributed in the regions of Ningxia and Inner Mongolia; the medium-low level area was mainly distributed in the regions of Inner Mongolia and Shanxi in 2011, with a scattered distribution and only 16% of the proportion. By 2015, it had extended northward and southward, with the proportion increasing to 42%, with nearly half of the cities in the metropolis circle at a medium-low level of industrial structure, mainly distributed in the regions of Shanxi and Inner Mongolia. By 2019, the area expanded and migrated, distributed around the metropolis circle, with the proportion increasing to 58%. By 2022, the range had somewhat shrunk; the medium-high level area did not appear in 2011, and only Hohhot's industrial structure was elevated to the medium-high level by 2015. By 2019, it expanded northward, with the proportion increasing to 16%, mainly distributed in the regions of Shanxi and Inner Mongolia. By 2022, the area extended eastward and westward, with the proportion decreasing; the high-level area did not appear in 2011, 2015, and 2019, and by 2022, the industrial structure of Ulanqab was elevated to a high level, with the area range expanding. In summary, the industrial structure level of the Yellow River "Ji" bend metropolis circle has been generally improved during the study period, with a small number of high-level areas. During the study period, the low-level areas gradually shifted to be dominated by medium-low level areas.

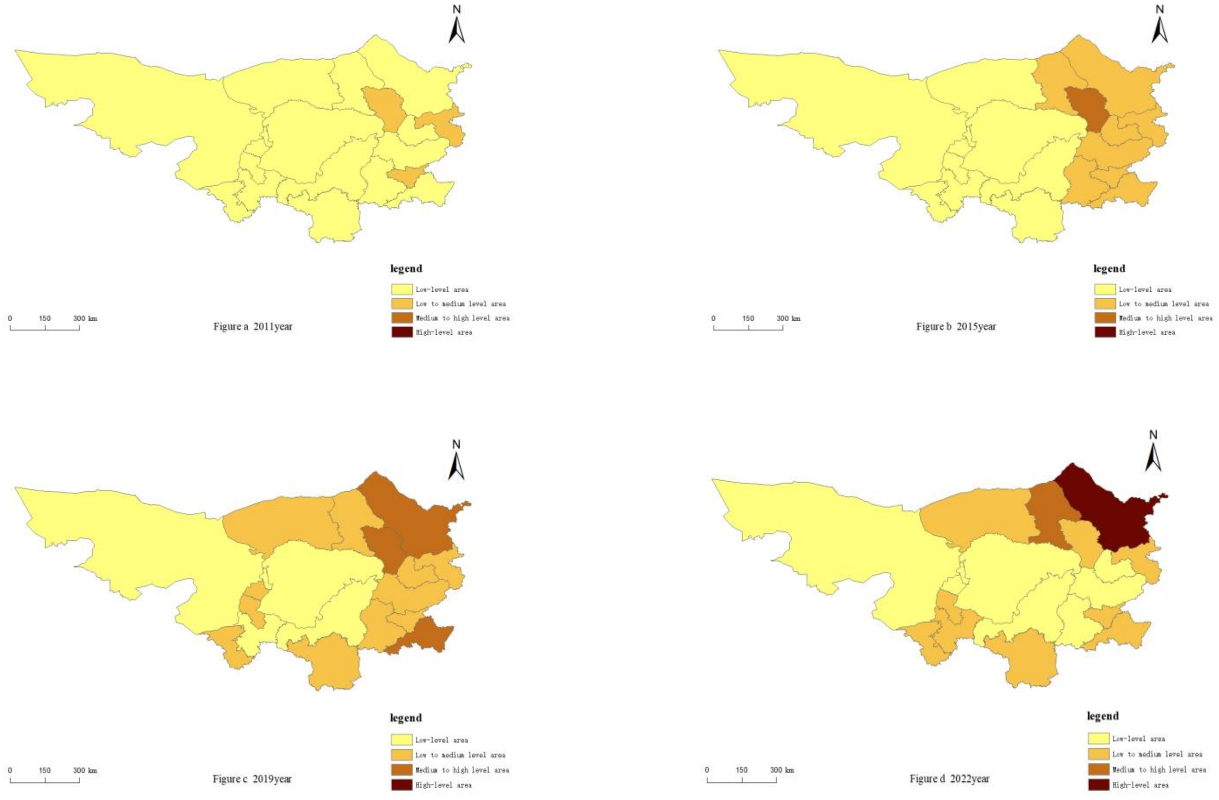

Figure 3 Spatial Classification of the Industrial Structure from 2011 to 2022

4. Conclusion

4.1 Conclusion

By constructing an indicator system from two aspects of industrial upgrading and industrial efficiency, and comprehensively applying the entropy method, the mean square deviation method, and the CRITIC method to measure the industrial structure of the Yellow River "Ji" bend metropolitan area, and analyzing the level of industrial structure from both temporal and spatial dimensions, the following conclusions can be drawn:

The development of the digital economy in the Yellow River "Ji" bend metropolitan area showed an overall fluctuating upward trend during the study period, with significant internal differences within the region; the level of industrial structure in the southern and eastern cities is 明显 higher than in other cities, and the northeastern cities show a significant high-level aggregation, with a significant positive spillover effect; there is a strong correlation between the level of industrial structure and the level of regional economic development, with high-level areas concentrated in regions with faster economic growth.

4.2 Suggestions

First, accelerate the construction of infrastructure to leverage the agglomeration effect of industrial clusters. In the context of high-quality development, existing infrastructure struggles to meet the requirements of industrial development, necessitating the acceleration of new infrastructure construction. Good infrastructure can attract the agglomeration of enterprises within the industrial chain, reduce corporate costs, fully leverage the agglomeration effect of industrial clusters, and enhance corporate competitiveness.

Second, coordinate the planning of regional resources to promote regional industrial transfer and upgrading. The Yellow River "Ji" bend metropolitan area covers 19 cities in four provinces, with significant differences in regional development. First, it is necessary to combine the current development status and future development to promote the construction of transportation, energy, computing power infrastructure, and information communication networks, providing a solid foundation for the transfer of industries and the layout of emerging industries.

Third, increase investment in scientific and technological innovation to leverage the multiplier effect of production factors. Emphasize technology and talent, increase investment in scientific and technological innovation, establish a platform for the transformation of research results from universities and research institutes, and actively cultivate applied talents. Strengthen exchanges among regional technology, industry, and talent to promote the full flow of production factors, promote high-quality industrial development, and provide important support for the high-quality economic development of the Yellow River basin.

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