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Coupling Coordination between Digital Economy and Urban Ecological Resilience in the Three Major Urban Agglomerations of the Yangtze River Economic Belt

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Abstract: This study conducts a theoretical exploration of the interaction mechanisms between the digital economy and urban ecological resilience. Based on data from 70 prefecture-level cities across the three major urban agglomerations in the Yangtze River Economic Belt from 2013 to 2023, it employs the entropy weighting method for quantitative measurement, utilizes the coupling coordination model to reveal patterns of their co-evolution, and further applies spatial auto correlation analysis to identify spatial differentiation characteristics, and finally, the GTWR model is used to identify the key drivers of coupled and coordinated development. The results indicate that scores for both the digital economy and the ecological resilience system show an upward trend but remain at relatively low levels overall; spatial heterogeneity and geographic differentiation are pronounced. Analysis of the spatial distribution of driving factors by hierarchy reveals that per ca pita GDP and general public budget expenditure exhibit phased spatial evolution, expanding from scattered high-value areas along the eastern coast of the Yangtze River Delta toward the middle reaches of the Yangtze River and the core cities of the Chengdu-Chongqing metropolitan area; At the same time, the positive effect of the urbanization rate continues to strengthen and extend into central and western regions, while the constraining effect of urban elevation as a natural geographic condition remains stable, revealing clear spatial boundaries for the coordination between the human-land system in digital economic development and ecological resilience construction. This study expands the theoretical framework of coupled and coordinated development in urban agglomerations, providing both theoretical and practical foundations for building sustainable urban agglomerations that promote the synergistic development of the digital economy and ecological resilience along the Yangtze River Economic Belt.

1. Introduction

Against the backdrop of the in-depth advancement of national strategies and the accelerated development of “Digital China,” urban agglomerations—as the core vehicles for high-quality

regional development—have seen the synergistic development of their digital economy and urban ecological resilience emerge as a key issue for achieving Chinese-style modernization characterized by harmony between humanity and nature. The Yangtze River Economic Belt spans 11 provinces and municipalities along the river, covering one-fifth of the country's land area and accounting for more than 40 percent of the nation's population and economic output; it is a major strategic region critical to the country's overall development [1]. However, urban development in this region has long been constrained by factors such as an over reliance on heavy and chemical industries, severe soil and water erosion, and frequent natural disasters, posing serious challenges to green and sustainable development [2]. The report of the 20th National Congress of China emphasized promoting the development of the Yangtze River Economic Belt, and in 2020, the Fifth Plenary Session of the 19th Central Committee of China included the concept of "resilient cities" in the 14th Five-Year Plan for the first time, providing a policy basis for leveraging digital technology to build ecological resilience [3]. As the primary form of new-type urbanization, the three major urban agglomerations—the Yangtze River Delta, the Middle Yangtze River, and Chengdu-Chongqing—each have a permanent resident population exceeding 100 million, serving as the core engines of population and economic agglomeration within their respective river basins [4]. The digital economy, as the core engine reshaping regional competitiveness, Chaos ET AL. (2024), based on panel data from 107 prefecture-level cities covering 2011–2020, confirmed that digital finance significantly enhances urban ecological resilience in both local and surrounding areas. It exerts this effect through two pathways: promoting technological innovation and reducing energy consumption intensity. The promotional effect is particularly pronounced in the lower Yangtze River region and in cities characterized by high levels of traditional financial development, high economic development, and stringent environmental regulations.

2. Study Area

This study focuses on the 70 prefecture-level cities within the three major urban agglomerations of the Yangtze River Economic Belt (Figure 1).

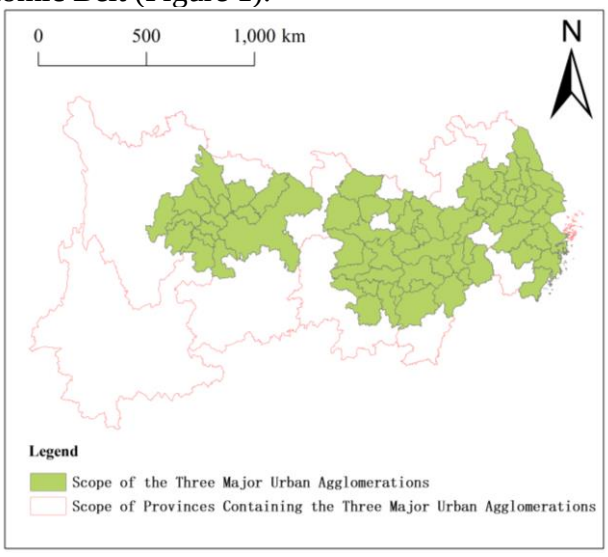


Figure 1: Study Area

3. Indicator System

The scope of the indicator system in this paper is shown in Table 1.

Table 1: System Indicators

Type	Subsystem	Indicators	Unit	Propert
Digital Economy	Digital Inclusive Finance	Coverage	—	+
		Level of Use	—	+
		Level of Digitization	—	+
	Digital Industry Development	Number of Employees in Information Transmission, Computer Services, and Software	10,000 people	+
		Total Volume of Telecommunications Services	10,000 yuan	+
	Digital Infrastructure Level	Number of Mobile Phone Subscribers per 10,000 People	10,000 households	+
		Number of Internet Users per 10,000 People	10,000 households	+
	Digital Innovation and Development	Number of Students Enrolled in Regular Higher Education	People	+
		Number of Research Scientists	People	+
Ecological Resilience	Land Use Structure	Proportion of Forested and Grassland Areas	—	+
		Proportion of Developed Land	—	-
	Ecosystem Services	Carbon Storage	C	+
		Annual Water Yield	m^3	+
		Soil Conservation	t/HM^2	+
		Habitat Quality	—	+
	Landscape Pattern	Patch Density	—	+
		Fragrance Uniformity Index	—	+
		Fragrance Diversity Index	—	+
		Clustering Index	—	+

4. Methods

4.1 Coupling Coordination Model

The coupling coordination model can be used to measure the interactions between multiple systems; the degree of coupling reflects the extent of interaction among the systems [5]. The formula is as follows:

$$C = \left\{ \frac{f(\alpha) \times f(\beta)}{\left[\frac{f(\alpha) \times f(\beta}{2} \right]^2} \right\} \frac{1}{2} \tag{1}$$

$$T = af(\alpha) + bf(\beta) \tag{2}$$

$$D = \sqrt{C \times T} \tag{3}$$

4.2 Spatial Auto correlation Analysis

This method is based on a spatial weight matrix and systematically quantifies the degree of spatial clustering of variables by constructing a model of the relationship between the variables and their geographic locations . Formula [6] is shown below:

$$Moran's \quad I = \frac{n}{\sum_i \sum_j W_{ij}} \cdot \frac{\sum_i \sum_j W_{ij}(x_i - \bar{x})(x_j - \bar{x})}{\sum_i (x_i - \bar{x})^2} \tag{4}$$

Moran's I assesses spatial autocorrelation (range [−1, 1]): values near 1 or −1 indicate significant positive or negative clustering, respectively, while 0 indicates random distribution.

4.3 Driving Force Analysis Mode

The GTWR model integrates temporal and spatial dimensions to form a key spatio-temporal kernel function, which allows data points of interest to be weighted in both space and time, while the resulting local parameter estimates exhibit a better bias-variance trade-off. The expression for the GTWR model [7] is as follows:

$$Y_i = \beta_0(u_i, v_i, t_i) + \sum_k \beta_k(u_i, v_i, t_i) X_{ik} + \varepsilon_i \tag{5}$$

In this equation,Y_i is the dependent variable,X_{ik} is the independent variable,(u_i,v_i,t_i)represent the spatiotemporal location; $\beta_k(u_i,v_i,t_i)$is the estimated parameter for each variable k at location i, ε_i is the random error term for observation i.The estimate of $\beta^k(u^i,v^i,t^i)$is given by the following equation:

$$\hat{\beta}(u_i, v_i, t_i) = \left[X^T W(u_i, v_i, t_i)\ X \right]^{-1} X^T W(u_i, v_i, t_i)\ Y \tag{6}$$

In this equation, The spatio-temporal weight matrix is defined as $W(u_i,v_i,t_i)$=diag(ai1,ai2,…,ain), where$\alpha ij(1\leq j\leq n)$ is the spatio-temporal distance decay function for(u_i,v_i,t_i).

5. Results

5.1 Spatial Distribution Characteristics of Coupling Coordination

As shown in Figure 2, in 2013, the degree of coupling and coordination among the three major urban agglomerations was predominantly “extremely weak” or “low.” By 2018, some areas in the Yangtze River Delta had moved up from the “low” category, but these improvements remained scattered. By 2023, the landscape had been restructured: the Yangtze River Delta had formed a contiguous cluster of high-level cities; hubs such as Wuhan had driven the formation of medium-level spheres of influence; medium-sized cities covered the eastern continuous belt; and areas of high coordination had been established, creating a multipolar, networked structure. Overall, the region had entered a new phase dominated by basic compliance and medium-level performance.

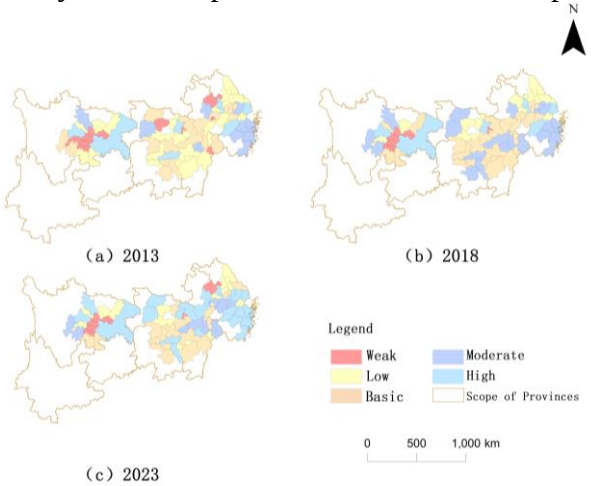


Figure 2: Diagram of the degree of coupling and coordination

5.2 Spatial Aggregation Characteristics of Coupling Coordination

From the perspective of spatial clustering (Figure 3), the figure shows that in 2013, only the Yangtze River Delta exhibited a “high-high” pattern, while Wuhan, Chengdu, and Chongqing were “high-low”; starting in 2018, these four cities transitioned toward a “high-high” pattern; by 2023, a three-tier nested structure emerged—coastal, inland, and peripheral—with polarization and balance coexisting. The degree of coordination has been gradually improving but remains low overall. In the future, efforts should focus on strengthening digital infrastructure, ecological governance, and green transformation, while enhancing radiating and driving effects through cross-regional coordination and the flow of production factors.

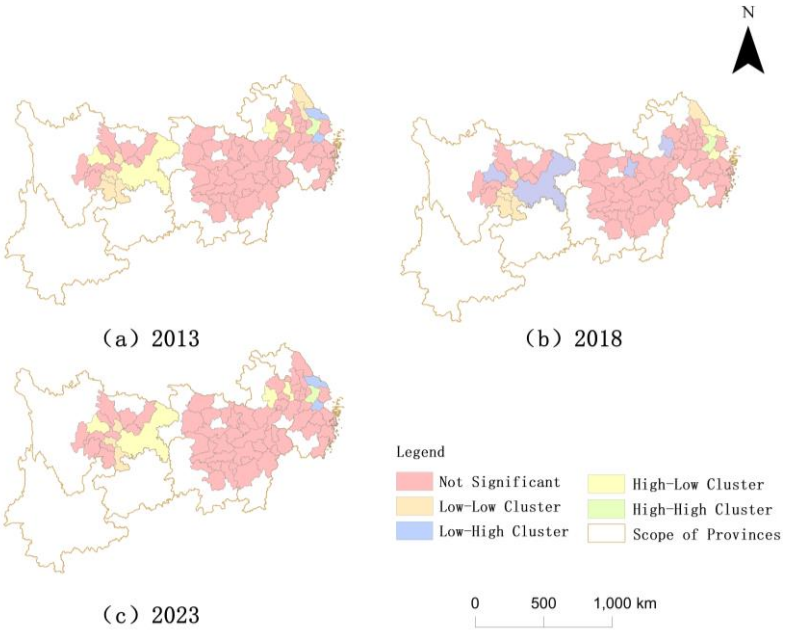


Figure 3: Spatial clustering map of the two systems

6. Driving Force Analysis

This study selected six driving factors, including GDP, the proportion of value added by the secondary and tertiary industries [8] (SVA), the urbanization rate (UR), and urban elevation (UE) [9] , general public budget expenditure] (GPBE), total retail sales of consumer goods [10] (TRS). The spatial heterogeneity of the levels of each driving factor was visualized using the natural breakpoint method (Figure 4).

Per capita GDP and fiscal expenditure show a converging distribution, with high values extending from the Yangtze River Delta toward the central and middle regions, and the pattern of “high in the east, low in the west” narrowing. This indicates that the economy and fiscal policy are coupled, jointly driving both systems. Retail sales and the proportions of the secondary and tertiary sectors exhibit similar distributions, with high values expanding into the central and western regions. The Chengdu-Chongqing region displays a “dual-core high, low in the periphery” pattern, revealing regional differences in the drivers of industrial structure optimization. The patterns of urbanization rates and elevation differ. Urbanization rates expand toward the central and western regions, forming a core-periphery structure, while high elevation values remain stable in the western regions. Overall, this indicates that the driving force of urbanization is strengthening and expanding spatially, while the influence of elevation remains stable, and there are regional differences in the effects of these factors.

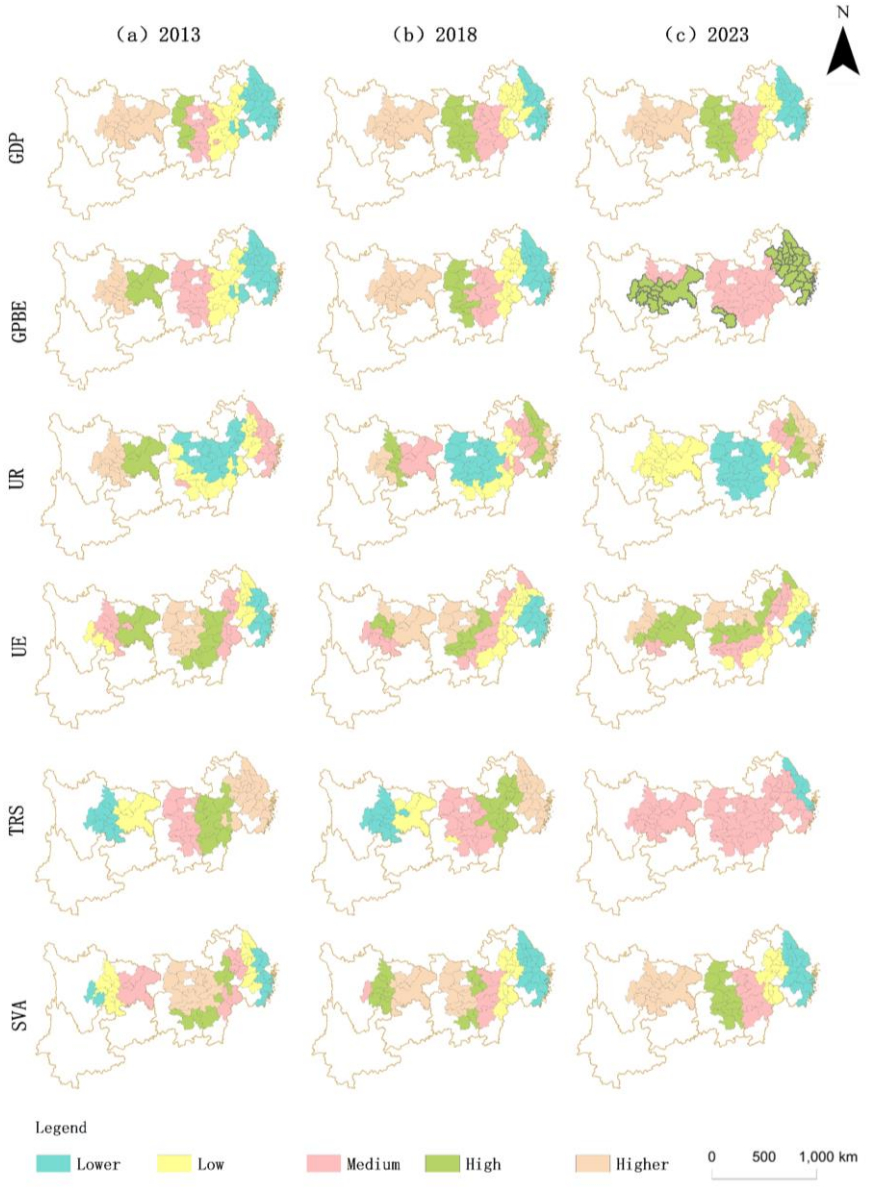


Figure 4: Spatial Distribution of Driver Factor Levels

7. Conclusion

Based on data from 2013 to 2023 for 70 prefecture-level cities across the three major urban agglomerations in the Yangtze River Economic Belt, this study constructs an evaluation system comprising 20 indicators for the digital economy and ecological resilience, and analyzes the level of coupling and coordination, spatial clustering, and heterogeneity of driving factors. Key findings: (1) Both systems have shown steady improvement, but the digital economy has outpaced ecological resilience. Digital inclusive finance and industrial scale have expanded rapidly, while improvements in ecological indicators have been limited. This framework provides a basis for synergistically advancing digital transformation and green development. (2) The degree of coupling and coordination has generally improved, transitioning from disharmony to harmony, but regional disparities remain significant. (3) The impact of driving factors varies. GDP and GPBE correlate with high coordination levels and play a significant promotional role; UR shows an expansion of high values but clusters of low values at the periphery; UE remains stable and constrains peripheral cities; TRS and SVA show

weak correlations. Excessive urbanization and industrial monoculture weaken ecological buffers, while high altitudes constrain infrastructure development. In the future, efforts should focus on balancing the digital economy with ecological conservation, controlling the expansion of urbanization, optimizing industrial structures, increasing fiscal and digital infrastructure investments in central and western regions, protecting natural ecosystems, and enhancing the overall level of coordination.

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