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Coupling coordination between urban human settlement environment and economic resilience

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Abstract

With the acceleration of urbanization, urban systems show varying degrees of vulnerability when facing external shocks. Existing studies on urban economic resilience and human settlements are mostly single-dimensional analyses, lacking a systematic evaluation of the coupling mechanism between the two, making it difficult to provide a scientific basis for comprehensive urban governance and coordinated development. To this end, this paper introduces the entropy weight method and coupling coordination model, integrates the multidimensional indicator system and spatiotemporal data analysis method, and establishes a comprehensive evaluation framework with "human settlement environment-economic resilience" as the core, aiming to enhance the ability to fine-tune monitoring and regulation of urban development coordination. Based on the panel data of 31 cities in the middle reaches of the Yangtze River urban agglomeration from 2016 to 2024, an index system with a three-dimensional structure of housing, ecology, culture and education, public services and economic resilience is constructed. The entropy method is used to calculate the weights and obtain the level of human settlement environment and economic resilience. The interaction intensity and degree of coordination between the two are quantified through the modified coupling coordination model. At the same time, Kernel density estimation is introduced to depict the dynamic distribution characteristics and evolution trend of coupling coordination degree, so as to achieve a detailed description of regional coordination differences. The research results show that the overall living environment and economic resilience levels of the Yangtze River Middle Reaches Urban Agglomeration have shown an upward trend during the study period, but there are significant regional differences in the improvement of coordination. Wuhan and Changsha's living environment and economic resilience scores are both at the top of all cities, 0.842 and 0.879, 0.791 and 0.823, respectively, indicating that the two cities have shown strong comprehensive development capabilities in terms of living environment and economic resilience, and the score gap between the two is small, reflecting their high level of coordinated development.

Keywords: Urban living environment and economic resilience, Coupled coordination model, Entropy weight method, Kernel density estimation, Yangtze river middle reaches urban agglomeration

1.Introduction

With the acceleration of global urbanization, comprehensive growth and the resilience of cities have become core issues of concern to academia and policymakers. The potential of an entire town to preserve its foundational and functional stability in the face of outside shocks like catastrophic storms, economic downturns, and social unrest is known as resilience in the city. The interactive relationship between the various subsystems in the urban system, such as the human living environment, economic system, and ecological system, is crucial to urban resilience. In recent years, scholars have tried to explore the interaction and coordination mechanism between various urban subsystems from the perspective of coupling coordination, so as to provide theoretical support for promoting comprehensive urban governance and balanced regional development.

To address this research gap, this work builds a multifaceted resilient urban areas system for assessment using the TOPSIS approach, sensitivity weight method, and connection synchronization model. By analyzing the panel data of the Yangtze River Middle Reaches Urban Agglomeration from 2016 to 2024, the coupling degree and coordination between urban living environment and economic resilience are evaluated, aiming to provide more scientific decision-making basis and policy recommendations for achieving urban resilience improvement and sustainable development.

Related work

In recent years, with the acceleration of urbanization and the deepening of economic globalization, the coordination between regional economic resilience and ecological system has become an important topic of concern in the academic community. In the study of resilience in different regions and fields, many scholars have adopted the perspective of coupling coordination and combined multiple methods for

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analysis in order to reveal the complex relationship between urban development, ecological environment and economic system.

Wu et al. empirically examined the urban resilience features of eight metropolitan areas in the Yangtze River Delta between 2016 and 2024 and developed an evaluation method for urban recovery based on the collaboration coordination approach. The results showed that urban resilience and coupling coordination fluctuated in time and showed a "high center and low periphery" distribution in space, and there was a long-term stable relationship between the two [1]. Lingdi and Zhaoxu examined the naturalistic features of the collaborated development of resilient ecosystems and income quality in 53 Chinese coastal cities between 2003 and 2020 using the coupling partnership model and the entropy weight-TOPSIS (Technique for ordering preference by Similarity to Ideal Solution) method. The results showed that the overall fluctuation of coordination increased, showing a northeast-southwest distribution trend, with significant regional differences and spatial convergence [2]. Deng et al. took Dali Prefecture as an example to construct a coupling coordination model of ecological resilience and urbanization, and evaluated the urbanization process and ecological environment changes in the Erhai Lake Basin from 2016 to 2024. The results showed that urbanization was advancing rapidly, ecological resilience was declining overall, and coupling coordination showed obvious temporal and spatial differences [3]. Based on the perspective of sustainable development, Gai and Yang used the Haken model to study the synergy mechanism between Agricultural Green Efficiency (AGE) and Agricultural Economic Resilience (AER) in Northeast China from 2010 to 2020. The results showed that AER dominated the system, and the synergy level was mainly at a high and advanced stage, with significant temporal and spatial differences [4].

Sutton et al. reviewed 168 papers on regional economic resilience from 2000 to 2022 to evaluate the development status of the concept. The study found that although the concept was considered vague in the early days, regional economic resilience has now become a mature concept with clear connotations and a complete system [5,12]. He et al. studied the impact of technological system structural characteristics on considering complexities of technology, regional economic durability. The results showed that higher technological complexity helps to improve regional economic resilience, but its positive effect has a marginal decreasing trend [6]. Zhang et al. constructed a dual evaluation system of urban Tourism Development (TD) and human settlement environment (HE), and used the PVAR (Panel Vector Autoregressive Model) model and the coupling coordination model to analyze the dynamic relationship between the two in the Yangtze River Delta urban agglomeration from 2001 to 2020. The results showed that TD and HE promoted each other and the trend of synergistic evolution was enhanced [7].

Dai and Khan examined the relationship and coordinate of China's urban environmental systems between 2011 and 2020 and developed an environmental capacity- carrying the index based on the pressure-state-response model. Taking Nanchang as an example, the results showed that its ecological coordination degree increased year by year, and the safety index changed from unsafe to relatively safe [8]. Lemke et al. reviewed the concept of regional economic resilience and its application, pointing out that there are three major problems in current research: excessive focus on enterprises, neglect of social-ecological relationships, and insufficient understanding of social-spatial relationships [9]. Peng et al. studied the dynamic relationship between the development of shellfish aquaculture and environmental quality in China and found that about 78% of the regions conformed to the environmental Kuznets curve, and 89% of the regions were in a coupled and coordinated state, indicating that the healthy development of shellfish aquaculture can help alleviate environmental pressure [10]. Kalvelage and Tups, through case studies of the Sino-Tanzania soybean and Dana green hydrogen projects, revealed that the state promotes the participation of emerging regions in the global supply chain through coercion and incentives in friendly shore outsourcing [11].

Existing research mainly focuses on single-dimensional analysis and lacks a comprehensive and dynamic assessment of the coupling relationship between subsystems within the urban system, resulting in limitations in the understanding of regional coordinated development.

Method

3.1 Indicator system construction

This paper builds a comprehensive evaluation index system that includes two subsystems that are urban residential settings and economic resilience, from the standpoint of systematicity and measurable outcomes in order to measure the coordinated growth level of both.

In terms of urban living environment, based on multi-dimensional standards such as livability, infrastructure and social services, four dimensions of "living environment, ecological environment, cultural and educational environment, and social public environment" are set, and 16 specific indicators are selected to form the evaluation system. The living environment dimension includes per capita living area, proportion of residential investment, per capita heating area, gas penetration rate, water supply penetration rate, domestic waste removal and energy conservation and protection funding, etc.; the ecological environment dimension considers comprehensive energy consumption and per capita park green space area; the cultural and educational environment dimension covers cultural and educational funding, patent authorization, number of libraries and cultural and educational practitioners; the social public environment dimension selects indicators such as social security investment, natural population growth rate, per capita road area, postal and telecommunications business income and number of urban health institutions. These indicators can better reflect the spatial carrying capacity, public service supply and sustainability of the urban human settlement system.

In terms of the economic resilience system, with reference to relevant research, it is divided into three dimensions: "resistance and resilience, adaptation and adjustment, response and reconstruction", covering 12 indicators including GDP, per capita GDP, registered unemployment rate, loan-to-deposit ratio of financial institutions, urbanization level, per capita disposable income, number of students in ordinary colleges and universities, total retail sales of social consumer goods, industrial structure upgrading index, fixed asset investment, fiscal expenditure and R&D funding. This system depicts the ability foundation and transformation potential of cities to cope with risk shocks from multiple aspects such as economic aggregate, structural transformation, innovation capability and social stability.

Following normalization as well as the entropy weight approach is used to assign each indicator's weight with objectivity, preventing individual prejudice and enhancing the assessment's scientific inquiry and repeatability. Finally, two comprehensive evaluation indicator systems with internal logical self-consistency and horizontal comparison capabilities are formed, laying the foundation for subsequent coupling analysis.

3.2 Data source and processing

This paper examines 31 cities in the middle reaches of the Yangtze River urban agglomeration that are at or above the province's degree. The study period spans from 2010 to 2024. The data has good regional representativeness and temporal continuity.

The relevant data are mainly from authoritative statistical materials such as *China City Statistical Yearbook, China Regional Economic Statistical Yearbook, China Urban Construction Statistical Yearbook, Hubei Statistical Yearbook, Hunan Statistical Yearbook, Jiangxi Statistical Yearbook*, etc. In order to ensure the integrity and continuity of the data, for a small amount of missing data, mean interpolation method, growth rate estimation method or reference to local statistical bulletins are used to supplement. Finally, a complete city-year panel data set is constructed to meet the basic conditions for subsequent empirical analysis.

3.3 Research methods

3.3.1 Entropy weight method

The information stochastic concept serves as the foundation for the entropy weight approach. By computing the discrete degree of indicator information, it establishes the weight. The greater the variability of the indicator, the more significant its role in comprehensive evaluation. The degree of entropy weight approach has the advantages of great impartiality and broad applicability over other methods, such as factor analysis and principal component examination, because it does not rely on correlations between components.

The specific operation process includes: normalizing the extreme values of the original data, calculating the entropy and redundancy of the indicators, determining the weight of each indicator, and finally constructing a comprehensive score of the urban living environment (X) and economic resilience (Y). This method effectively improves the accuracy and robustness of the evaluation results.

3.3.2 Coupling coordination model

This research presents a coupling management model that reveals the fluid connection between the resilient economic system and the average human agreement landscape. The degree of reciprocal connection and interaction between the two ecosystems is measured by the coupling degree (C), while the degree of collaborative growth between the two is reflected by the coordination degree (D).

The following is the linking coefficient assessment formula:

$$C=\left[\frac{X.Y}{\left(\frac{X+Y}{2}\right)^2}\right]^{1/2} (1)$$

X and Y are the comprehensive evaluation indexes of urban living environment and economic resilience, respectively, $C\in[0,1]$. The larger the value, the stronger the coupling degree.

On this basis, a comprehensive coordination model is constructed:

$$T=\alpha X+\beta Y (2)$$

$$D=\sqrt{C.T} (3)$$

T represents the system comprehensive index, and α and β are the system contribution coefficients. Referring to existing research results and combining with actual analysis, this paper takes $\alpha=\beta=0.5$, which means that the human living environment and economic resilience contribute equally to the system. The coupling coordination degree D finally obtained can be used to divide the stages and levels of regional coordinated development.

3.3.3 Kernel density estimation

To further explore the distribution dynamic characteristics of human settlement environment, economic resilience and the coupling coordination level between different cities, this paper introduces the kernel density estimation method to fit and visualize its spatiotemporal evolution trend.

The kernel density function is defined as follows:

$$f(z)=\frac{1}{nh}\sum_{i=1}^{n} K\left(\frac{z-Z_i}{h}\right) (4)$$

K(.) is the kernel function, h is the bandwidth parameter, Z_i is the observation value, and n is the number of samples. This paper selects the Gaussian kernel function as the kernel density function to ensure smoothness and robustness. This method can present the dynamic evolution form and aggregation effect of the coupling coordination degree within the urban agglomeration without relying on any prior distribution assumptions.

4. Results and Discussion

4.1 Empirical process

This study uses the following five steps to conduct empirical analysis:

Step 1: Data standardization and entropy weight assignment

The original panel data is normalized in positive and negative directions;

The entropy method is used to assign weights to each indicator and calculate the comprehensive evaluation index of the living environment (X) and economic resilience (Y).

Step 2: Coupling level of cooperation computation

Determining the association degree C between X and Y of every city in various years using the connectivity degree model;

Constructing the coordination degree model and further obtain the comprehensive coordination index DD to evaluate the level of system synergy;

Dividing the development level according to the coordination degree (excellent, good, medium and low).

Step 3: Time series analysis

Drawing the changing trends of X, Y, C, and D in each city from 2016 to 2024;

Comparing the development speed and coupling level changes in different stages to reveal the succession of system development stages.

Step 4: Spatial heterogeneity analysis

Using GIS spatial visualization method, draw the annual distribution map of coupling coordination degree D;

Analyzing the spatial aggregation, diffusion and change path of high-value and low-value areas;

Combined with urban functional zoning and economic development level, exploring the influencing factors.

Step 5: Kernel density analysis

Estimating the kernel density of X, Y and D, respectively;

Analyzing the distribution changes of the three types of indicators (such as the evolution from single peak to multi-peak, the convergence of extreme values, etc.);

Exploring the trend of widening or narrowing the gap between cities and verifying the dynamic evolution of the overall coordination level of urban agglomerations.

4.2 Analysis tools and technical routes

Data analysis tools: Excel 2019 (data normalization and entropy weight calculation), Stata 16.0 (panel data processing), ArcGIS 10.6 (spatial visualization), OriginPro 2021 (trend and kernel density map drawing);

Technology roadmap

Original panel data (2016-2025) → Data standardization → Entropy weight assignment → Calculation of X, Y comprehensive index → Coupling degree calculation (C) → Coordination degree calculation (D) → Grading and classification → Time series change + Spatial analysis + Distribution evolution

4.3 Zoning and classification standards

To further identify the characteristics of urban differences, this paper intends to use the natural breakpoint method or K-means clustering to group the coupling coordination degree D of the sample cities and divide them into the following four types of development:

High coupling and high coordination type (H-H): X and Y are both at a high level, with strong development synergy;

High coupling and low coordination type (H-L): X and Y are unbalanced in development, coupled but with system dislocation;

Low coupling and high coordination type (L-H): The overall development level is low, but the internal coordination of the system is good;

Low coupling and low coordination type (L-L): The interaction between systems is weak and the development foundation is weak.

4.4 Data analysis results

In order to systematically assess the concerted growth level and Darwin's theory characteristics of cities in the middle to upper reaches of the Yangtze River urban agglomeration, this study occupies the financial durability score, coupling degree (C value), level of collaboration (D value), and expansive score of urban dwelling conditions as core metrics.

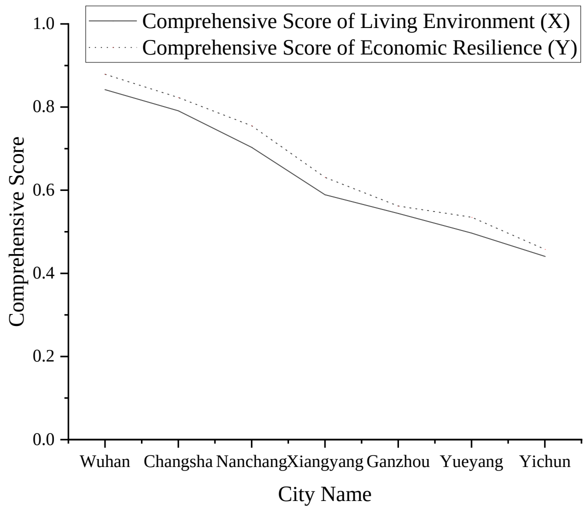

Figure 1. Comprehensive score of urban living environment and economic resilience under the entropy weight method (example year: 2024)
Note: Each value is calculated after normalization and entropy weighting. The higher the value, the stronger the level of development

Based on the exponential weight technique, Figure 1 displays the cities' overall scores for economic resilience (Y) and human impact on the environment (X) in the Yangtze River Middle Reaches Urban Agglomeration in 2024. From the data, it can be seen that the scores of human settlement environment and economic resilience of Wuhan and Changsha are both at the top of all cities, 0.842 and 0.879, 0.791 and 0.823, respectively, indicating that the two cities have shown strong comprehensive development capabilities in human settlement environment and economic resilience, and the score gap between the two is small, reflecting their high level of coordinated development. As one of the core cities in the region, Nanchang scored 0.703 for living environment and 0.755 for economic resilience, showing a relatively balanced development status. However, compared with Wuhan and Changsha, Nanchang's score in living environment has declined, which may reflect that the city still has room for improvement in infrastructure, public services and other aspects. In contrast, cities such as Xiangyang, Ganzhou, Yueyang and Yichun scored relatively low, especially Yichun, with a human settlement environment score of 0.441 and an economic resilience score of 0.458, indicating that its development level in both dimensions is relatively lagging. This may be directly related to the city's economic foundation, industrial structure and infrastructure construction level, and it is worth further exploring the key bottleneck factors in improving the human settlement environment and economic resilience of these cities.

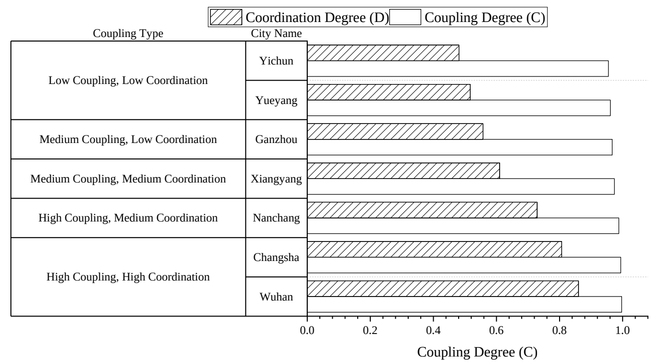

Figure 2 Calculation results of coupling degree (C) and coordination degree (D) between human settlement environment and economic resilience in each city (2024)
Note: C value close to 1 indicates strong system interactivity; D value reflects the coordination level, >0.8 is "high coordination", 0.6-0.8 is "medium coordination", and <0.6 is "low coordination"

The coupling degrees of Wuhan and Changsha are both close to 1, 0.997 and 0.994, respectively, which shows that there is a very close connection and synergy between the living environment and economic resilience of these two cities. The coordination degrees of these two cities are 0.860 and 0.807, respectively, both in the "high coordination" range, indicating that they have outstanding performance in the balanced development of these two systems and are typical high-coupling and high-coordination cities. Wuhan, in particular, ranks first in both coupling and coordination, showing its high synergy in living environment and economic resilience. Nanchang, another important city in the region, has a coupling degree of 0.988, showing strong system interactivity, but its coordination degree is 0.729, which is in the "medium coordination" range. This shows that although Nanchang has a relatively balanced development in terms of human settlement environment and economic resilience, there is still a certain lack of coordination in the interaction between the two, and it may be necessary to further enhance the synergy between systems to achieve a higher level of overall development (as shown in Figure 2).

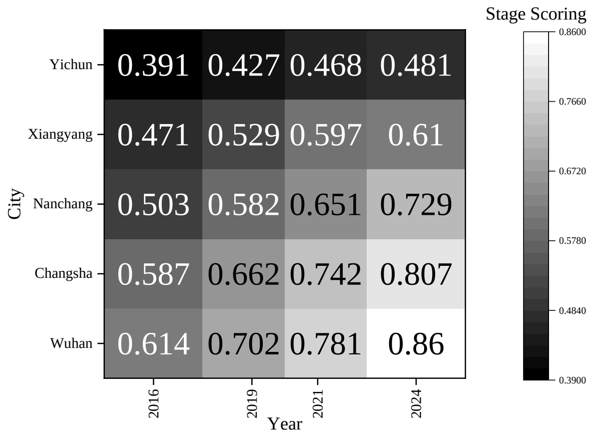

Figure 3. Evolution of the coordination between human settlement environment and economic resilience from 2016 to 2024 (selected cities)
Note: The coordination degree shows a continuous growth trend. Wuhan and Changsha maintain their leading advantages. Yichun has the lowest coordination level but is rising slowly.

Figure 3 shows the evolution trend of the coordination degree (D) between human settlement environment and economic resilience in some cities in the middle reaches of the Yangtze River from 2016 to 2024. Through the longitudinal analysis of the data, we can clearly see the dynamic changes and development trends of the coordination degree of each city.

Wuhan and Changsha have always performed better than other cities in the coordination between human settlement environment and economic resilience. Wuhan's coordination degree has rapidly increased from 0.614 in 2016 to 0.860 in 2024, showing a strong upward trend. Changsha's coordination degree has increased from 0.587 in 2016 to 0.807 in 2024. Although it is slightly lower than Wuhan, the increase is also significant. The coordination degree of the two cities has always maintained a leading position, indicating that the two cities have made significant progress in the two-way optimization of human settlement environment and economic resilience, and the benign interaction between the systems has gradually strengthened.

Nanchang's coordination degree shows a steady upward trend, increasing from 0.503 in 2016 to 0.729 in 2024. Although the overall level is still somewhat lower than that of Wuhan and Changsha, the increase is obvious, reflecting the city's improvement in the coordination of human settlement environment and economic resilience. However, compared with the two provincial capitals, Nanchang's coordination degree still has room for improvement, indicating that it has not yet reached the optimal state in terms of the depth and breadth of its coordination mechanism.

The coordination degree of Xiangyang and Yichun increased slowly, especially that of Yichun, which increased from 0.391 in 2016 to 0.481 in 2024, but the growth rate is small, indicating that Yichun still faces many challenges in promoting the coordination between human settlement environment and economic resilience. Its low initial value and slow growth trend suggest that the city may have major structural problems, such as lagging infrastructure, industrial structure or policy implementation.

Table 1. Distribution of cities with different coordination levels (2024)

Coordination Level	D Value Range	Number of Cities	Representative Cities
High Coordination	D ≥ 0.80	3	Wuhan, Changsha, Yichang
Medium Coordination	0.60 ≤ D < 0.80	12	Nanchang, Jingzhou, Zhuzhou
Low Coordination	0.40 ≤ D < 0.60	13	Xiangyang, Ganzhou, Yueyang
Very Low Coordination	D < 0.40	3	Pingxiang, Suizhou, Xinyu

Note: Highly coordinated cities are mostly concentrated in provincial capitals and core second-tier cities, while low-coordinated cities are mainly distributed in small and medium-sized cities with relatively backward economic development

Table 1 shows the distribution of cities with different coordination levels in the Yangtze River Middle Reaches Urban Agglomeration in 2024. By grouping the coordination level (D value), we can further reveal the different development types of cities in the region and their corresponding characteristics.

Highly coordinated cities (D value ≥ 0.80) are mainly concentrated in provincial capitals and core second-tier cities, such as Wuhan, Changsha and Yichang. These three cities have shown strong coordinated development capabilities in terms of living environment and economic resilience, reflecting their comprehensive advantages in resource allocation, industrial upgrading, infrastructure construction, etc. The number of highly coordinated cities is relatively small, indicating that they play a very prominent leading role in regional development. Secondly, there are 12 cities in the moderately coordinated category ($0.60 \leq D < 0.80$), of which Nanchang, Jingzhou and Zhuzhou are representative cities. These cities' living conditions and economic resilience are only somewhat coordinated, suggesting that while their urban systems have originally attained a certain amount of coordination, much more can be done. This kind of city is widely dispersed, including some significant regional core cities as well as some second-tier cities in the middle Yangtze River stretches.

5. Conclusion

This work, which is based on the coupling coordination perspective, builds a comprehensive assessment system for assessing the connection between resilient urban communities and the person's living environment by combining the coefficient of entropy weight approach and the TOPSIS method. By analyzing the panel data of the middle reaches of the Yangtze River urban agglomeration from 2016 to 2024, this paper systematically evaluates the urban resilience characteristics of different cities and their coupling degree with the human living environment. The experimental results show that the coordination between urban resilience and human settlement environment in core cities (such as Wuhan and Changsha) is relatively high, indicating that they have strong comprehensive capabilities in achieving sustainable development and regional coordination. However, relatively lagging cities (such as Yichun and Ganzhou) have a large coordination gap between human settlement environment and economic resilience, and urgently need to promote the synergy of the system through policy promotion. Although the coupling coordination model can effectively evaluate the interactive relationship between urban systems, the selection and parameter setting of the model may affect the accuracy and stability of the results. Future research can expand the sample range, combine more variables, and further improve the refined design of the coupling coordination model. At the same time, combined with data analysis over a longer time span, it will help reveal the long-term evolution trend of coordination between urban systems and provide more in-depth theoretical support for achieving more efficient sustainable urban development.

Funding

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