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Research on the Coupling and Coordination of Ecological Resilience and New Urbanization in the Yangtze River Economic Belt

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Abstract
With the rapid advancement of industrialization and urbanization, cities are facing ecological and environmental challenges such as environmental degradation, resource depletion, and ecological pollution. The ability of cities to resist ecological risks has declined, which restricts their sustainable development. This study selects the urban agglomerations of the Yangtze River Economic Belt as the research area. Employing methods such as the CRITIC weighting approach, comprehensive weighted model, coupling coordination model, and grey relational analysis, the findings reveal that the coupling coordination degree between ecological resilience and new urbanization in these urban agglomerations remains in the adaptation phase. The coupling coordination degree between ecological resilience and new - type urbanization is affected by factors such as per capita GDP, per capita urban consumption expenditure, urban road network density, and per capita built - up area. Therefore, it is proposed that while improving the level of new urbanization, the level of ecological resilience and the coupling coordination between the two should continue to be enhanced. At the same time, the improvement of the coupling coordination degree should be promoted according to local conditions and classified measures.

Keywords: Yangtze River Economic Belt; ecological resilience; new urbanization; coupling.

Introduction
In recent years, China's urbanization has progressed rapidly, yet frequent natural disasters have subjected urban development to severe acute shocks. Meanwhile, chronic pressures from "urban diseases," such as environmental pollution and traffic congestion, have also posed significant security threats to cities. A pressing issue in contemporary society is how to enhance cities'capacity for absorption, resistance, adaptation, and resilience against diverse disturbances that threaten urban development and introduce uncertainties.Ecological resilience, as a novel approach to urban risk governance, has emerged as a new conceptual paradigm for cities to cope with uncertain risks. It provides valuable guidance for improving urban resilience and disaster response capabilities [1]. In 2020, China's 14th Five-Year Plan (2021–2025) and the Long-Range Objectives Through 2035, adopted at the Fifth Plenary Session of the 19th Central Committee of the Communist Party of China, introduced the concept of "resilient cities" for the first time. This initiative aims to enhance urban governance and establish a robust risk prevention and control system for city management.Therefore, scientifically assessing the coupling coordination degree between ecological resilience and new urbanization, as well as identifying the key influencing factors, serves as an effective pathway for constructing high-quality, safe, and resilient new urbanization cities.

Nordgard R's theory of coordinated development posits that there exists a strong correlation between the level of economic development and the quality of the ecological environment in a country, region, or city. Over time, their relationship evolves from antagonism to coordination, achieving a balanced state through continuous interaction and feedback (Interprise) [2]. Ecologist Holling first introduced the concept of ecological resilience, arguing that a system, after being subjected to shocks, can stabilize into a new equilibrium state [3]. Following Holling's foundational work, the application of resilience expanded into human ecology, giving rise to the concept of urban resilience [45].Current research on urban resilience primarily focuses on three directions:First,Defining Urban Resilience: Urban resilience refers to the capacity of urban systems to self-coordinate and self-recover under uncertain risks [6].Second,Quantifying Urban Resilience: Based on its definition and characteristics, researchers employ methods such as the comprehensive index approach and geographical detector models to measure urban resilience across multiple dimensions [7].Third,Planning Resilient Cities: Studies explore structural frameworks for building resilient cities[8].In terms of evaluation and measurement, current assessments of urban ecological

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resilience often adopt composite indicator methods, analyzing resilience features across social, economic, and natural dimensions [9]. Research on the Interaction Between New Urbanization and Ecological Resilience in China leverages theories such as systems theory and coupling theory, alongside big data, AR, and data integration techniques, to reveal spatiotemporal patterns and simulate dynamic interactions between urbanization and the ecological environment [10].Chinese scholars have conducted extensive quantitative research on the interplay between new urbanization and the ecological environment, integrating insights from ecology, sociology, management, and economics. Among these studies, coupling models have emerged as a prominent analytical tool."Li Yanling, Li Minliang, and others believe that the coupled and coordinated development of new urbanization and ecological resilience involves complex mechanisms, with both promoting and constraining influences coexisting between the two. They point out that the development levels of both new urbanization and ecological resilience are not high, and there are significant regional development differences, which weaken the mutual influence between the two and sever the relationship between the systems. Based on this, they propose that a coordinated development mechanism for new urbanization and ecological resilience should be built, taking resource and environmental carrying capacity as the foundation [11]. Guo Haihong and Liu Xinmin, through a coupling coordination degree model, found that there is a close coupling coordination relationship between ecological resilience and new urbanization in the central cities along the Yellow River. Firstly, in the process of ecological capacity consumption and encroachment, new urbanization affects ecological resilience, population pressure, economic pressure, social pressure, ecological environment pressure, and other aspects, causing changes in the ecological state, and the ecology begins to respond. In addition, ecological resilience has both an entraining and a feedback effect on new urbanization [12]. He Xiaorong, Shi Caixia, and others believe that the demand growth brought about by new urbanization cannot be separated from the support of ecological resilience with strong coordination and renewal capabilities, and the strengthening of ecological resilience depends on the resource agglomeration brought about by the promotion of new urbanization[13]. Xia Chunhong selected the entire Yunnan Province and its 16 prefectures and cities as objects, and studied the spatial and temporal evolution of the overall urban ecological resilience and the urban ecological resilience subsystem at two levels, analyzing the spatial differentiation characteristics and temporal evolution characteristics of the urban coupling coordination degree of the entire Yunnan Province and its 16 prefectures and cities [14]."

While the aforementioned scholars have explored the relationship between ecological resilience and new urbanization from various perspectives, certain gaps remain to be addressed. There exists an intrinsic linkage between the coordinated development of ecological resilience and new urbanization.First, early research predominantly focused on traditional urbanization and its relationship with ecological recovery or single-factor analyses, with limited discussion on new urbanization. However, as urbanization accelerates and national policy support intensifies, studies on ecological resilience and coordinated development have increasingly introduced the concept of new urbanization—a paradigm better aligned with contemporary national conditions.Second, most existing studies on coupling and synergistic development are confined to individual provinces or cities. Few adopt a macro perspective of the entire Yangtze River Basin to examine the spatiotemporal patterns of coupling coordination between new urbanization and ecological resilience, with the majority concentrating on the Yangtze River Delta urban agglomeration.To bridge these gaps, this paper selects 24 cities along the Yangtze River Basin from 2018 to 2022 as research subjects. It investigates the spatiotemporal evolution of the coupling coordination degree between ecological resilience and new urbanization, along with its influencing factors,and it puts forward corresponding strategic suggestions for improving the ecological resilience of cities in the Yangtze River Basin, strengthening ecological environment governance, and promoting the adaptation of ecological protection and high - quality economic development in the Yangtze River Basin.

Material & Methods

2.1 Overview of the Research Area and Data Sources

The Yangtze River Economic Belt encompasses 11 provinces and municipalities, including Shanghai, Jiangsu, Zhejiang, Anhui, Jiujiang, Yueyang, Huangshi, Yibin, and Luzhou, covering over two million square kilometers, which accounts for one-fifth of China's total land area. It is one of the country's three major national strategies. Therefore, this paper selects 24 cities within the Yangtze River Economic Belt to study the coupling coordination between ecological resilience and new urbanization, exploring their development and changes, which holds profound significance for urban development. This research utilizes panel data from the urban agglomerations of the Yangtze River Economic Belt from 2018 to 2022 as the foundational dataset. The data primarily comes from the China Statistical Yearbook, China City Statistical Yearbook, China Urban Construction Statistical Yearbook,

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and the statistical yearbooks of the 24 selected cities. After standardizing the data, interpolation methods were applied to fill in any missing values.

2.2 Research Methods

2.2.1 CRITIC Weighting Method

This study employs the CRITIC weighting method to assign weights to the indicators in the ecological resilience and new urbanization evaluation index systems. This approach helps mitigate the influence of variations among different indicators on weight determination, thereby making the weights of each indicator more objective and reasonable. The CRITIC weighting method is an objective weighting technique that assigns weights by comprehensively evaluating the indicators. It fully considers both the variability of the indicators and their intercorrelations.

The comparative strength of the indicators is measured by the standard deviation, which reflects the numerical differences of the same indicator across different evaluation scenarios. A larger standard deviation indicates greater variability in the indicator, meaning the values differ more significantly across scenarios, thus warranting a higher weight. The degree of conflict between indicators is measured by the correlation coefficient—the closer the coefficient is to 1, the weaker the conflict and the stronger the association between the two indicators. In the CRITIC weighting method, when the conflict between indicators is low, their weights are relatively smaller, whereas higher conflict leads to larger weights.

The specific calculation method is as follows:

(1) Dimensionless Data Processing

This study first performs dimensionless data processing based on the nature of the indicators to improve the accuracy of measurement results and avoid the influence of different dimensions of the indicators on evaluation results.

1) Positive Indicators (larger values are better)

$$X'_{ij}=\frac{X_j\text{-}min(X_j)}{max(X_j)\text{-}min(X_j)} \tag{1}$$

2) Negative Indicators (smaller values are better)

$$X''_{ij}=\frac{X_j^{1}\text{-}min(X_j^{1})}{max(X_j^{1})\text{-}min(X_j^{1})} \tag{2}$$

(2) Information Carrying Capacity Calculation

1) Volatility

$$\sigma_j=\sqrt{\frac{\sum_{i=1}^{m}(X_{ij}\text{-}\overline{X}_j)^2}{n\text{-}1}} \tag{3}$$

Where σ_j is the standard deviation of the j-th indicator (indicating the variability of the indicator), and $\overline{X}_j$ is the average value of the j-th indicator.

2) Conflict

$$A_j=\sum_{i=1}^{n}\left(1\text{-}r_{ij}\right) \tag{4}$$

Where r_{ij} is the correlation coefficient between the i-th and j-th indicators (both i and j represent indicators)

3) Information Capacity

$$C_j=\sigma_j\times A_j \tag{5}$$

Where C_j is the information capacity of the j-th indicator, i.e., its influence on the system.

(3) Weight Calculation

$$W_j=\frac{C_j}{\sum_{j=1}^{n}C_j}(j=1,2,\ldots,n) \tag{6}$$

Where W_j is the weight of the corresponding indicator in the ecological resilience and new-type urbanization evaluation system.

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2.2.2 Comprehensive Weighted Model

The comprehensive weighted model is used to calculate the overall score of ecological resilience and new-type urbanization systems.

$$F_i=\sum_{j=1}^{n} X'_{ij} W_j (i=1,2,\ldots,24) \tag{7}$$

Where F_i is the overall evaluation score of ecological resilience or new-type urbanization for year i,and X'_{ij} is the dimensionless value of each indicator in the two indicator systems.

2.2.3 Coupling Coordination Model

(1) Coupling Degree Model

In physics, the concept of coupling refers to the phenomenon where multiple systems interact with each other and their external environments. Coupling is used to assess the degree of association and the strength of interaction between systems or elements. This paper uses this concept to explore the interaction between ecological resilience and new-type urbanization in the Yangtze River Economic Belt. The coupling interaction model is as follows:

$$C=2\times\left[\frac{U_1\cdot U_2}{(U_1+U_2)^2}\right]^{\frac{1}{2}} \tag{8}$$

Where C represents the coupling degree between ecology and new-type urbanization, indicating their interaction level; U_1 and U_2 epresent the comprehensive scores of ecological resilience and new-type urbanization, respectively. When C increases, it indicates a stronger connection between the two systems, leading to a high level of coupling and greater order and stability. Conversely, a decrease in C means weaker interaction and a shift toward disorder.

(2) Coupling Coordination Model

The coupling degree C can only measure the degree of coordinated development between ecological resilience and new-type urbanization but cannot reflect the coordination within each system or between systems accurately. For instance, even if U1 and U2 re both low, the coupling degree C may still be high. While this suggests some coupling exists, it is only superficial and does not reveal the essence of a "low-low" development level. To address this, this study introduces the development degree T to reflect the overall coordination effect of the two systems. The coupling coordination degree D is then constructed by taking the geometric mean of coupling degree C and development degree T. This approach more accurately reflects the interaction between ecological resilience and new-type urbanization systems, assessing the quality of their interaction. The coupling coordination degree model is as follows:

$$D=\sqrt{C\times T} \tag{10}$$

Where D represents the coupling coordination degree, and T is the comprehensive coordination index. The coefficients α and β reflect the relative importance of the two subsystems, with $\alpha=\beta=0.5$ in this study, assuming both systems are equally important. When D approaches 1, the systems' positive coupling increases; when D approaches 0, the coordination deteriorates.

The coupling coordination degree (D) ranges between [0, 1].When D approaches 1, the positive coupling between systems strengthens, indicating a higher level of coordinated interaction.Conversely, as D approaches 0, the coupling coordination between systems deteriorates, reflecting weaker synergy. Drawing on the research of Wang Shaojian[15] and Liang Longwu[16], and considering the actual development conditions of the study area, this paper adopts a classification standard inspired by physics. It divides the coupling coordination levels between ecological resilience and new urbanization in the Yangtze River Economic Belt into 6 major categories and 18 secondary subtypes.The specific classification criteria and results will be detailed in the following sections.

Table 1: classification criteria for coupling and coordination types of ecological resilience and new-type urbanization

Type	Coupling Coordination Degree (D)	Sub-type	Relative Size of U1 and U2
	$0<D\leq0.4$	Severe Discoordination - Ecological Resilience Lag	U2-U1>0.1

Severe Discoordination		Severe Discoordination - New-Type Urbanization Lag	U1-U2>0.1
Imminent Discoordination	0.4<D≤0.5	Imminent Discoordination - Ecological Resilience Lag	U2-U1>0.1
		Imminent Discoordination - New-Type Urbanization Lag	U1-U2>0.1
Barely Coordinated	0.5<D≤0.6	Barely Coordinated - Ecological Resilience Lag	U2-U1>0.1
		Barely Coordinated - New-Type Urbanization Lag	U1-U2>0.1
Primary Coordination	0.6<D≤0.7	Primary Coordination - Ecological Resilience Lag	U2-U1>0.1
		Primary Coordination - New-Type Urbanization Lag	U1-U2>0.1
Intermediate Coordination	0.7<D≤0.8	Intermediate Coordination - Ecological Resilience Lag	U2-U1>0.1
		Intermediate Coordination - New-Type Urbanization Lag	U1-U2>0.1
Advanced Coordination	0.8<D≤1	Advanced Coordination - Ecological Resilience Lag	U2-U1>0.1
		Advanced Coordination - New-Type Urbanization Lag	U1-U2>0.1

2.2.4 Gray Relational Model

The Gray Relational Model is effective when dealing with systems where the influence factors are unclear or conditions are uncertain. It is particularly useful for analyzing the strength of relationships between one or more indicators and the target indicator, revealing the primary factors influencing changes in the reference series. To explore the influencing factors of ecological resilience and new-type urbanization coupling coordination, this study uses the Gray Relational Model proposed by Professor Deng Julong. The analysis and calculation steps are as follows:

(1) Determine the Reference Sequence

The reference sequence (or parent sequence) reflects the overall behavioral pattern of the system. In this study, the coupling coordination degree (D) between ecological resilience and new urbanization is selected as the dependent variable to form the reference sequence:Y(k) (i=1, 2, …, m) where m represents the number of cities (m=24). The comparison sequences (or child sequences) consist of influencing factors that shape the system's behavioral dynamics. Here, the indicators within each subsystem are chosen as independent variables to form the comparison sequences:X(k) (i=1, 2, …, n) where n denotes the number of influencing factors (n=30).

(2) Calculate Mean Values for Indicators

$$Y(k)=\frac{Y(k)}{\overline{Y}} \tag{11}$$

$$X_i(k)=\frac{X_i(k)}{\overline{X}} \tag{12}$$

(3) Compute Absolute Differences Between Reference and Comparative Sequences

$$|Y(k)-X_i(k)|(k=1,2,...m;i=1,2,...n) \tag{13}$$

(4) Calculate the Correlation Coefficients

$${}_i(k)=\frac{\min\limits_i \min\limits_k |Y(k)-X_i(k)| +\rho \max\limits_i \max\limits_k |Y(k)-X_i(k)|}{|Y(k)-X_i(k)|+\rho \max\limits_i \max\limits_k |Y(k)-X_i(k)|} \tag{14}$$

In the equation: ${}_i(k)$ represents the correlation coefficient; ρ is the distinguishing coefficient, which adjusts the significance of differences. Its value typically ranges between 0 and 1. A smaller ρ reduces the distinction between influencing factors, weakening the ability to differentiate their disparities. When ρ≤0.5463, the distinguishing ability is optimal, and it is commonly set to 0.5 for practical applications.

(5) Calculate the Correlation Coefficients

$$r_i=\frac{1}{m}\sum_{k=1}^{m} {}_i(k) \tag{15}$$

Where r_i represents the correlation degree, with higher values indicating a stronger correlation, meaning a more significant impact on the coupling coordination of the Yangtze River Economic Belt.

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Results And Conclusion

In this paper, 24 cities in the Yangtze River Economic Belt were taken as the research object, and the panel data from 2018 to 2022 were selected as the original data, and the comprehensive weight of each evaluation index was calculated by using the CRITIC method and the entropy method. Then, the coupling coordination model was used to evaluate the development level of coupling coordination between the two, and the spatiotemporal evolution characteristics of each part were analyzed according to the ArcGIS software.

3.1 Temporal and Spatial Evolution Characteristics of Ecological Resilience

3.1.1 Construction of Ecological Resilience Measurement Index System

Resilience is widely used in the study of adaptive strategies in urban systems in response to unpredictable changes in the future, because of its dynamic and co-evolutionary characteristics. The resilience goal of the dynamic balance between urbanization development and ecological environment is reflected in the "pressure-state-response" process of ecological resilience. According to the ecological resilience measurement indicators in the relevant literature in recent years, Guo Haihong established a chain urban ecological resilience system supported by three subsystems: "-".- This statement is based on the logic of "external - - feedback"[12]. Based on the PSR model, Li Yanling proposed an evaluation index system for ecological resilience, which consists of three criterion layers: pressure resilience, state resilience, and response resilience, and includes 12 indicators[11]. Based on the DPSIR model, Lianju Lu constructed an evaluation index system for water ecological resilience from five aspects, namely: driving force, pressure, state, impact, and response[17]. From the four aspects of resistance, adaptability, recovery, and renewal, He Xiaorong constructed 18 index construction systems[13]. Wang Shaojian pointed out that the ecological resilience evaluation system consists of three first-level indicators: "scale resilience", "density resilience", and "morphological resilience"[15]16. Based on existing research, this paper aims to comprehensively evaluate the resilience and recovery status of ecosystems in response to different types of disturbances from three dimensions: resistance, adaptability and resilience, and construct a comprehensive index system for ecological resilience. Resilience is mainly a measure of the ability of ecosystems to resist disturbances. Resilience is concentrated in ecosystems to adapt to changes in the environment; Resilience, on the other hand, focuses on the ability of ecosystems to recover after disturbances. These three are the core elements of ecological resilience, which reflect the overall ability of ecosystems to cope with external disturbances from different perspectives. By establishing this comprehensive index system, the stability, adaptability and resilience of ecosystems under diverse environmental conditions can be more accurately assessed, and ecological protection and management can be scientifically supported.

Table 2: evaluation index system and weights of urban ecological resilience

Target layer	Criterion layer	Indicator layer	Unit & Nature	Weight
Urban ecological resilience	Resistance 0.3960	Industrial sulphur dioxide emissions(X_1)	ton(-)	0.0980
		Water resources per capita(X_2)	cubic metre(+)	0.1100
		Green coverage of built-up areas(X_3)	%(+)	0.0837
		The area of green space in parks per capita(X_4)	square metre(+)	0.1043
	Adaptability 0.2696	Centralized treatment rate of sewage treatment plants(X_5)	%(+)	0.0862
		Harmless treatment rate of domestic waste(X_6)	%(+)	0.0826
		Comprehensive utilization rate of general industrial solid waste(X_7)	%(+)	0.1008
	Resilience 0.3344	R&D (research and development) as a percentage of GDP(X_8)	%(+)	0.1122
		Number of patents granted(X_9)	item(+)	0.0892
		Number of college students per 10,000 people(X_{10})	person(+)	0.1330

3.1.2 Measure of Ecological Resilience Level

According to the regional ecological resilience evaluation index system, combined with the original data and evaluation process, the comprehensive evaluation values of ecological resilience of 24 cities in the three major urban agglomerations of the Yangtze River Economic Belt from 2018 to 2022 were calculated and ranked, and the results are shown in Table 3.

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Table 3: comprehensive evaluation of the ecological resilience of 24 cities in the yangtze river economic belt from 2018 to 2022

City	Urban ecological resilience										Average annual rate of change
	2018	sort	2019	sort	2020	sort	2021	sort	2022	sort	(%)
Shanghai	0.6177	2	0.6000	2	0.5151	4	0.5497	1	0.5340	6	-2.0914
Nantong	0.5397	7	0.5272	12	0.4170	14	0.4612	12	0.4552	10	-2.1121
Taizhou	0.5059	13	0.4995	15	0.4520	9	0.4388	16	0.4397	12	-1.6541
Changzhou	0.4273	21	0.5173	13	0.4602	7	0.5206	6	0.5342	5	2.6740
Yangzhou	0.4535	19	0.4106	20	0.4598	8	0.4886	8	0.4262	14	-0.6833
Zhenjiang	0.5883	4	0.5782	5	0.4436	11	0.4641	10	0.4875	8	-2.5212
Anqing	0.5115	12	0.5302	11	0.4139	15	0.3952	19	0.4308	13	-2.0171
Tongling	0.4725	18	0.3997	21	0.3905	20	0.5145	7	0.5069	7	0.8616
Maanshan	0.5314	8	0.5361	10	0.3833	21	0.3767	21	0.3773	21	-3.8534
Wuhu	0.4785	17	0.4736	17	0.4114	16	0.4547	14	0.4526	11	-0.6484
Hefei	0.5908	3	0.5952	3	0.5202	3	0.5428	4	0.5351	4	-1.3927
Nanjing	0.5842	5	0.6086	1	0.5341	2	0.5288	5	0.5576	1	-0.6654
Chizhou	0.5041	14	0.5405	7	0.4475	10	0.3908	20	0.4017	19	-2.5600
Jiujiang	0.3408	24	0.5556	6	0.4788	6	0.4632	11	0.3796	20	0.9712
Huangshi	0.3772	22	0.3487	23	0.3357	24	0.3581	23	0.3595	23	-0.4426
Ezhou	0.4432	20	0.3904	22	0.4005	18	0.4771	9	0.4050	18	-0.9559
Huanggang	0.3579	23	0.3240	24	0.3952	19	0.3028	24	0.3610	22	0.0782
Wuhan	0.5547	6	0.5370	9	0.4945	5	0.5477	2	0.5392	3	-0.3873
Yibin	0.4922	16	0.5393	8	0.3421	23	0.3637	22	0.3251	24	-4.1788
Luzhou	0.5235	9	0.4346	18	0.4326	12	0.4578	13	0.4769	9	-1.1639
Chongqing	0.6683	1	0.5805	4	0.5359	1	0.5433	3	0.5416	2	-3.1671
Yichang	0.4970	15	0.5051	14	0.3683	22	0.3980	18	0.4060	17	-2.2746
Jingzhou	0.5159	10	0.4190	19	0.4086	17	0.4122	17	0.4189	16	-2.4265
Yueyang	0.5153	11	0.4839	16	0.4297	13	0.4401	15	0.4255	15	-2.2431

3.1.3 Temporal Evolution Characteristics of Ecological Resilience Level

Overall, the level of regional ecological resilience in the Yangtze River Economic Belt has changed zigzagically in the five years of 2018~2022, and the overall trend is slow, from an average of 0.5038 in 2018 to 2022/b18>0.4490, a decrease of 10.8773%, a relatively small decrease, with an average annual change rate of -1.3689%. There are obvious differences in different regions, and the changes in the ranking of ecological resilience among cities show the evolutionary characteristics of coexistence of time and space. From the perspective of development level, Chongqing, Nanjing and Shanghai have performed well in the development of ecological resilience over the years, ranking among the best. Huangshi, Huanggang and Yibin have been at a low level of ecological resilience development over the years.

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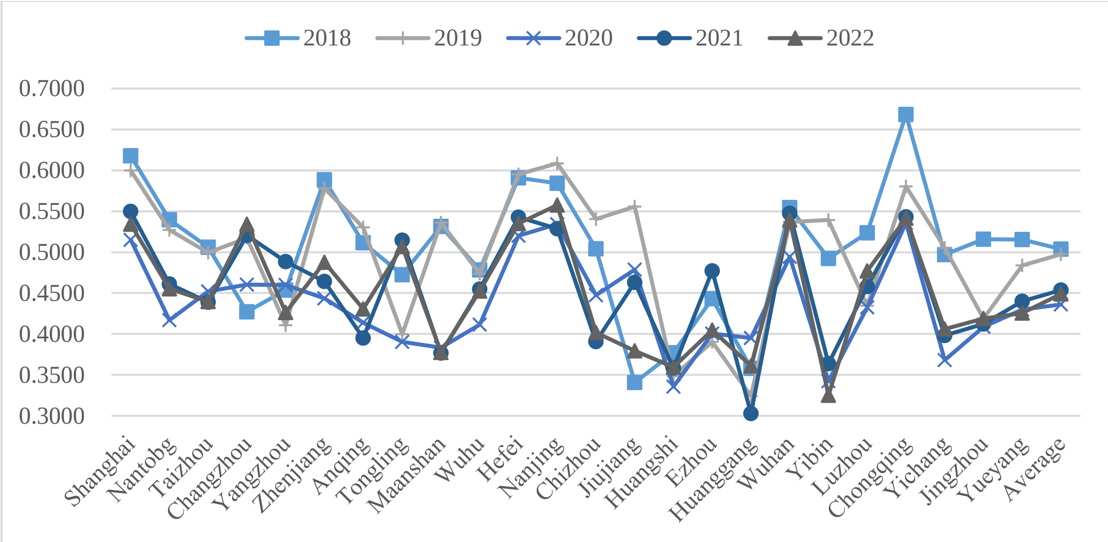
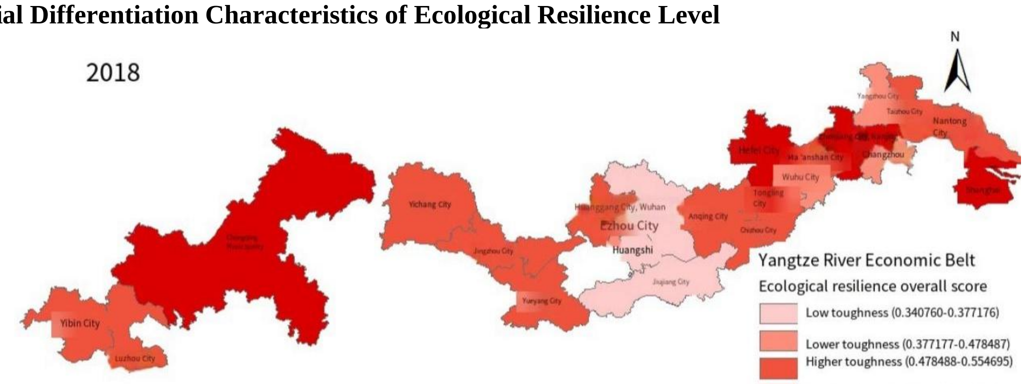


fig. 1 line chart of the changes in the ecological resilience level of 24 cities in the yangtze river economic belt from 2018 to 2022

According to Table 3, the changes in the ecological resilience level of the three major urban agglomerations in the Yangtze River Economic Belt are plotted into a line chart (Fig. 1) to more intuitively reflect the ecological resilience level of each city in the study area from 2018 to 2022Trends and differences over the years.

The level of ecological resilience showed a "W-shaped" trend, and the overall trend was decreasing. As can be seen from Table 3 and Figure 1, the level of regional ecological resilience in the Yangtze River Economic Belt in 2018~2022 has shown a "W-shaped" change state of first decreasing and then declining, with a slight decline as a whole, with an average annual change rate3689%. From 2018 to 2020, the average water value of ecological resilience in the study area decreased from 0.5038 to 0.4363, and increased to 2020-2021.4538, and its average value fell again by 0.4490 in 2021-2022. The level of ecological resilience in most cities continued to change, and the ecological resilience of individual cities changed greatly. Generally, the average annual change rate is 0%-3%, and the change range of individual market sections is large.

3.1.4 Spatial Differentiation Characteristics of Ecological Resilience Level



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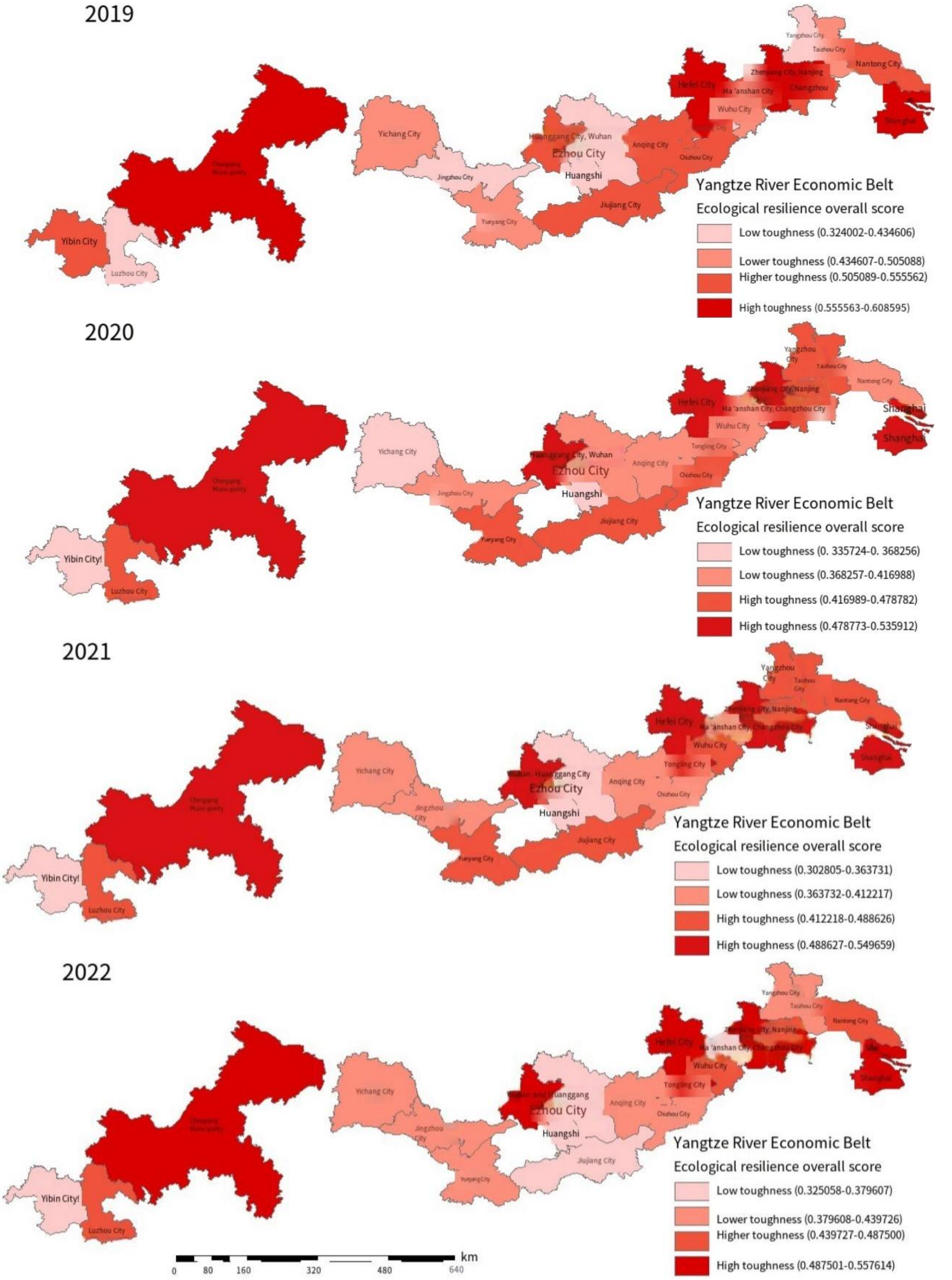

fig. 2 spatial differentiation of ecological resilience levels in 24 cities in the yangtze river economic belt

From the perspective of spatial distribution characteristics (Fig. 2), the level of ecological resilience is spatially distributed in a pattern of "low in the east and west, high in the middle, and low in the middle". /b13> In 2018~2022, the ecological resilience level of cities in the Yangtze River Economic Belt showed the following characteristics: (1) The ecological resilience of each city was significantly different, and the overall spatial pattern was "high in the east and west and low in the middle"; (2) During the period from 2018 to 2022, the level of

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ecological resilience of most cities in the region decreased, but the number of cities in areas with high resilience increased. (3) The number of cities in some areas with high resilience decreased, and many cities changed from high resilience to low resilience, and the spatial distribution gradually shifted from patches to patches and sheets. (4) The number of districts and cities with low resilience has declined, and the cities with low resilience have shown a trend of falling first and then rising, and Huangshi City in central China has also maintained a state of low resilience. On the whole, there are great differences in the level of ecological resilience among cities, and to a certain extent, there is an unbalanced development.

3.2 The Spatiotemporal Evolution Characteristics of the New Urbanization Level

3.2.1 Construction of a New Urbanization Measurement Index System

New urbanization covers a wide range of fields, including population, space, economy and society, and has become a general consensus in the academic world. Its evaluation standard has also developed from the initial single urbanization indicator along with the continuous extension of the connotation of new-type urbanization, and today, it contains a wide range of contents, and is a diversified and comprehensive indicator system with a strong relevance. At present, in terms of dimension design, the comprehensive assessment index system of new urbanization tends to cover as many dimensions as possible. In the urbanization rate of household population, the proportion of added value of high-tech industry in the added value of industry above designated size, the comprehensive social insurance participation rate and the number of telephone numbers (including cell phone numbers) per 100 households, the environmental noise compliance rate, the population civicization, the economic civicization, the social civicization, and the spatial civicization of the four secondary indicator systems, Lv Lianju respectively added the "Population civicization, urbanization, spatial urbanization" indicator system, for the city a total of 39 urbanization work for measurement[18]. Wei Houkai constructed a comprehensive evaluation index system for the quality of urbanization, and comprehensively evaluated the quality of urbanization from three aspects: the quality of the city's own development, the efficiency of urbanization promotion, and the level of urban-rural integration[19]. Zhang Yikun gave relevant reference indicators, which were comprehensively evaluated in four aspects, including the degree of urbanization, basic public services, infrastructure, and resources and environment[20]. On the measurement system of new urbanization influencing factors, Yao Zhi constructed a new urbanization level measurement index system, and in the new urbanization influencing factors are measured as 13 main factors, which include 13 new urbanization influencing factors**Error! Reference source not found.**[21]. Ma Yan has constructed a comprehensive evaluation index system for urbanization and ecological environment of the Yangtze River Economic Zone, covering 2 systems, 8 state layers and 26 basic indexes[22]. On the basis of reference to relevant research results and according to the principle of indicator selection, this paper selects 20 indicators from five dimensions, such as population civicization, economic civicization, social civicization, urban-rural integration, etc., and combines them with the unique development characteristics of urban agglomerations in the Yangtze River Economic Belt to construct a new urbanization assessment indicator system, with the purpose of scientifically assessing the development of new urbanization in the study area.

Table 4:evaluation index system and weights of new urbanization

Target layer	Criterion layer	Indicator layer	Unit & Nature	Weight
New type of urbanization	Urbanization of the population 0.1136	Proportion of urban permanent population in total population(X_{11})	%(+)	0.0627
		The average wage of urban workers(X_{12})	Yuan(+)	0.0509
	Economic urbanization 0.2474	GDP per capita(X_{13})	Yuan(+)	0.0670
		Per capita disposable income in cities(X_{14})	Yuan(+)	0.0480
		Consumption expenditure per capita in cities(X_{15})	Yuan(+)	0.0378
		GDP growth (X_{16})	%(+)	0.0532
		The value-added of the secondary and tertiary industries accounts for the proportion of GDP(X_{17})	%(+)	0.0414
	Urbanization of society 0.1812	Number of beds in healthcare facilities per 10,000 people(X_{18})	sheet(+)	0.0396
		There are public libraries per capita(X_{19})	root(+)	0.0594
		Number of public trams per 10,000 people(X_{20})	vehicle(+)	0.0400
		Registered urban unemployment rate(X_{21})	%(-)	0.0422

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Ecological urbanization 0.1319	Number of public toilets per 10,000 people(X_{22})	seat(+)	0.0372
	Density of urban road network(X_{23})	km/km^2(+)	0.0533
	Proportion of expenditure on energy conservation and environmental protection(X_{24})	%(+)	0.0414
Urban-rural integration 0.2012	Ratio of per capita income of urban and rural residents(X_{25})	(-)	0.0811
	Per capita consumption ratio of urban and rural residents(X_{26})	(-)	0.0662
	Urban-rural Engel coefficient ratio(X_{27})	(+)	0.0539
Spatial urbanization 0.1247	Population density(X_{28})	people/km^2(+)	0.0331
	Road area per capita(X_{29})	m^2(+)	0.0463
	Built-up area per capita(X_{30})	m^2 (+)	0.0453

3.2.2 Measurement of the Level of New Urbanization

According to the new urbanization evaluation index system, combined with the original data and evaluation process, the comprehensive evaluation values of new urbanization in 24 cities in the three major urban agglomerations of the Yangtze River Economic Belt from 2018 to 2022 were calculated and ranked, and the results are shown in Table 5/b16>show.

Table 5:comprehensive evaluation of new urbanization in 24 cities in the yangtze river economic belt from 2018 to 2022

City	New urbanization of cities										Average annual rate of change
	2018	sort	2019	sort	2020	sort	2021	sort	2022	sort	(%)
Shanghai	0.5938	1	0.5798	1	0.5239	1	0.5331	1	0.4661	1	-3.1912
Nantong	0.3642	13	0.3189	15	0.3290	14	0.2992	15	0.2663	15	-2.4486
Taizhou	0.3686	11	0.3142	16	0.3282	15	0.3134	14	0.3428	11	-0.6440
Changzhou	0.4602	4	0.4145	5	0.4157	6	0.4496	2	0.4165	2	-1.0917
Yangzhou	0.3966	9	0.3773	11	0.3722	11	0.3269	13	0.3228	12	-1.8449
Zhenjiang	0.4050	8	0.4012	8	0.4071	8	0.3930	5	0.3761	4	-0.7234
Anqing	0.2876	20	0.2586	20	0.2997	18	0.2620	21	0.2545	18	-0.8274
Tongling	0.2280	22	0.2491	21	0.3178	16	0.2693	20	0.2402	21	0.3055
Maanshan	0.3766	10	0.3449	13	0.3594	12	0.3317	12	0.3494	8	-0.6806
Wuhu	0.3651	12	0.3792	10	0.3822	9	0.3806	7	0.3696	6	0.1118
Hefei	0.4136	7	0.4379	4	0.3517	13	0.3343	11	0.3173	13	-2.4075
Nanjing	0.4849	2	0.4780	2	0.4946	2	0.4266	3	0.3714	5	-2.8355
Chizhou	0.2782	21	0.3081	17	0.2990	19	0.2969	16	0.2645	17	-0.3415
Jiujiang	0.2245	23	0.2177	23	0.2241	22	0.2176	23	0.1993	23	-0.6297
Huangshi	0.2921	19	0.2927	18	0.2524	21	0.2716	19	0.2498	19	-1.0584
Ezhou	0.3533	15	0.3347	14	0.2184	23	0.2806	18	0.2488	20	-2.6102
Huanggang	0.2105	24	0.2005	24	0.1392	24	0.1443	24	0.0871	24	-3.0846
Wuhan	0.4594	5	0.3963	9	0.4089	7	0.4144	4	0.3857	3	-1.8426
Yibin	0.3001	17	0.2402	22	0.2837	20	0.2593	22	0.2373	22	-1.5685
Luzhou	0.3452	16	0.3543	12	0.3806	10	0.3379	10	0.3077	14	-0.9359
Chongqing	0.4393	6	0.4051	6	0.4217	4	0.3712	8	0.3452	9	-2.3524
Yichang	0.4668	3	0.4477	3	0.4275	3	0.3826	6	0.3602	7	-2.6646
Jingzhou	0.2996	18	0.2870	19	0.3092	17	0.2845	17	0.2652	16	-0.8603
Yueyang	0.3637	14	0.4026	7	0.4214	5	0.3564	9	0.3438	10	-0.4965

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3.2.3 Temporal Evolution Characteristics of New Urbanization Level

Overall, the level of new urbanization in the Yangtze River Economic Belt has changed tortuously in the five years from 2018 to 2022, and the average value has decreased from 0.3657 in 2018 to 0.36570.3078 in 2022-2022, with a decrease of 15.8326%, a small decrease, with an average annual change rate of -1.4468. There are obvious differences in different regions, and the ranking of the level of new urbanization among cities is also constantly changing, showing the characteristics of spatio-temporal evolution. From the perspective of development level, Shanghai, Nanjing and Changzhou have been at the forefront of the development level of new urbanization over the years, while Huanggang, Jiujiang and Yibin have low average levels of new urbanization. In terms of development speed, Shanghai, Nanjing and Yichang are the three cities with the fastest decline in the level of new urbanization. The overall downward trend is the tortuous trend of the level of new urbanization.

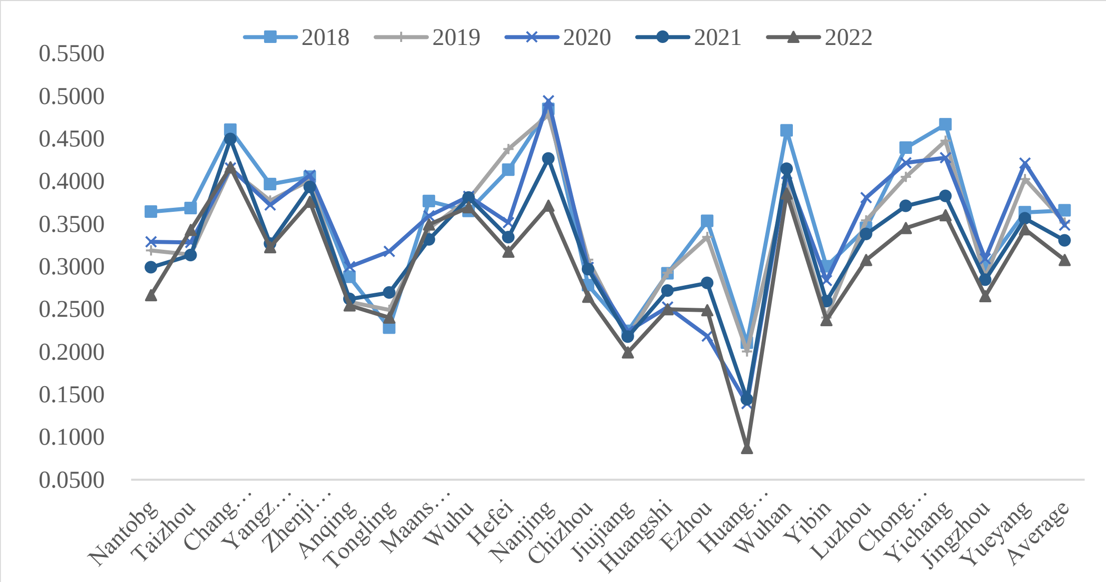

fig. 3 line chart of changes in the level of new urbanization in 24 cities in the yangtze river economic belt from 2018 to 2022

According to Table 5, the changes in the level of new urbanization in the three major urban agglomerations of the Yangtze River Economic Belt are plotted as a line chart (Fig. 3) to more intuitively reflect the level of new urbanization in each city in the study area from 2018 to 2022Trends and differences over the years.

The level of new urbanization shows a tortuous trend, and the overall trend is declining. According to Tables 5 and 3, from 2018 to 2022, the level of new urbanization in the Yangtze River Economic Belt is in a state of zigzag decline, with an average annual change rate of -1.4468%. The overall ranking shows that most cities have not changed, and a few cities have changed significantly.

3.2.4 Spatial Differentiation Characteristics of New Urbanization Levels

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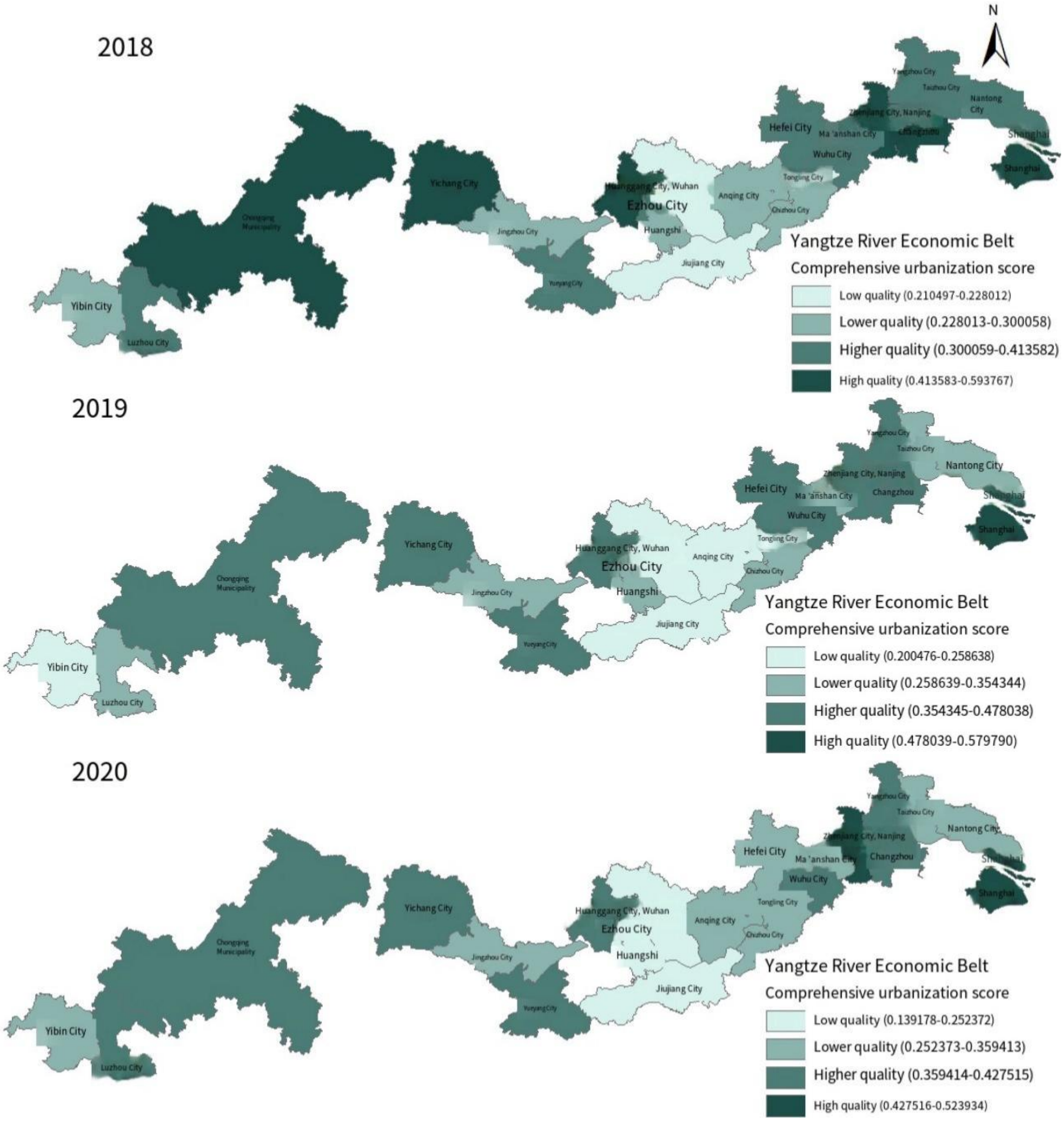

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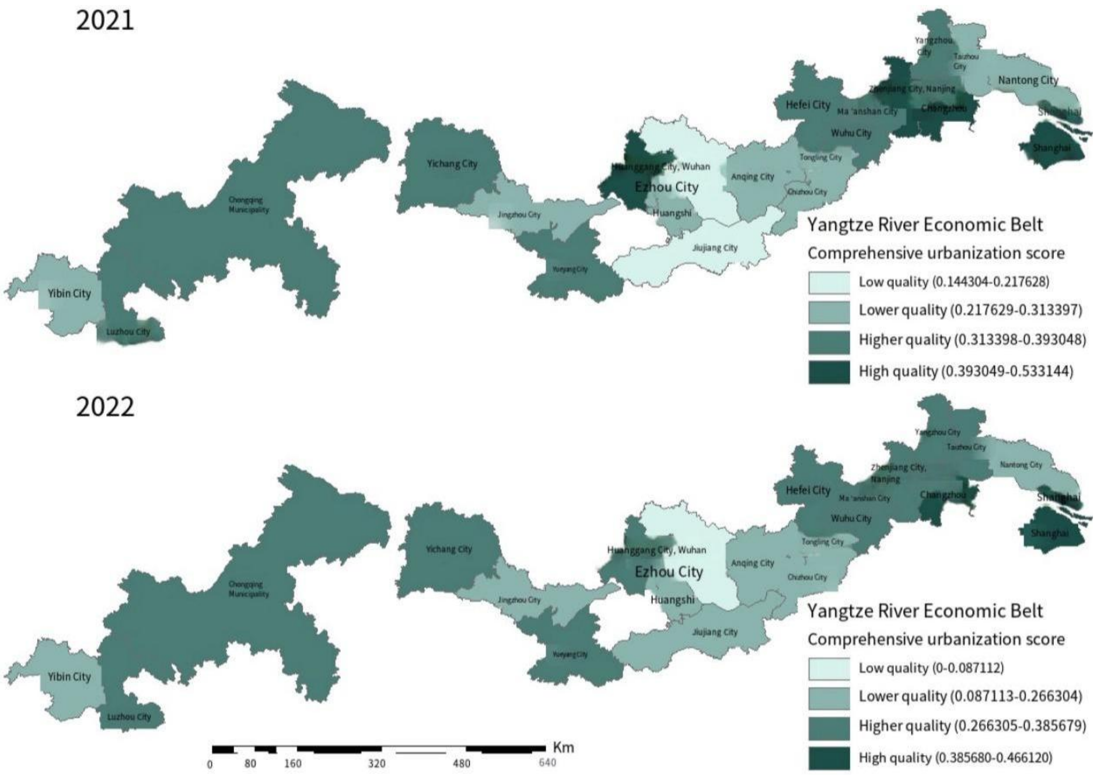

fig. 4 spatial differentiation of new urbanization levels in 24 cities in the yangtze river economic belt

On the whole (Fig. 4), the spatial distribution of the comprehensive score of new urbanization shows a gradient distribution in the east, middle and west, and the overall trend is decreasing. In terms of spatial distribution, the level of new urbanization in the central region has increased year by year, the east-west gradient region has decreased, the differences between cities have gradually narrowed, and the overall development tends to be balanced.

A new horizontal distribution pattern of urbanization of high-quality core cluster area, high-quality cluster area and low-quality core cluster area was formed, showing the spatial characteristics of the transformation from "decentralized" distribution to "cluster" distribution. The high-quality cluster area is mainly in the eastern part of the study area, the eastern high-quality cluster area centered on Nanjing and Shanghai, and the adjacent cities such as Changzhou, Zhenjiang and Hefei are all high-quality areas or relatively high-quality areas, among which the Yangtze River Delta region is dominated by the high-quality cluster area centered on Chongqing. The low-quality cluster areas are mainly Huanggang City and Jiujiang City, and the central cities of the study area are the main cities, and the adjacent Huangshi City and Anqing City are in the low-quality area or low-quality area, and the number of cities in the low-quality area is decreasing year by year At present, the low-quality cluster areas of Huangshi City mainly take Huanggang City as the central city of the study area, Jiujiang City as the central city of the study area as the research object, Huanggang City as the central city of the study area, and the central part of the study area as the focus. The number of cities in the random distribution area decreased, and its spatial distribution gradually changed from point to sheet distribution in 2018.

Although the quality of new urbanization development in different cities is gradually narrowing, there are still obvious imbalances and uncoordinated phenomena in regional development. /b12> In 2022, the number of high-quality cities is small and all of them are located in the east, the eastern part of the country is rapidly leading the urbanization development, and the development of new urbanization in the central and western cities is increasing year by year, but the uneven development is still significant. There are obvious regional differences in the quality of new urbanization development in different cities, with few high-quality cities and a "bimodal distribution" as a whole, with rapid development in the east and west and relatively backward in the central part.

3.3 The Spatiotemporal Evolution Characteristics of the Coupling Coordination Degree Between Ecological

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Resilience and New Urbanization

3.3.1 Coupling and Coordination Measurement of Ecological Resilience and new urbanization

According to the above comprehensive evaluation score data of ecological resilience and new urbanization, the values of coupling degree C and coupling coordination degree D between comprehensive resilience and new urbanization of each study city were calculated and ranked by formula, and the results are shown in Table 6/b20>, 7.

Table 6 Coupling degree of ecological resilience and new urbanization in 24 cities in the Yangtze River Economic Belt

City	Degree of coupling										Average annual rate of change
	2018	sort	2019	sort	2020	sort	2021	sort	2022	sort	(%)
Shanghai	0.9966	4	0.9999	3	0.9985	4	1.0000	1	0.9986	4	0.0509
Nantong	0.9797	13	0.9234	19	0.9955	9	0.9734	19	0.9966	8	0.4230
Taizhou	0.9952	6	0.9411	18	0.9966	7	0.9933	13	0.9882	13	-0.1745
Changzhou	0.9104	19	0.9959	7	0.9975	6	0.9984	7	0.9999	2	2.2375
Yangzhou	0.9861	10	0.9788	13	0.9999	1	0.9737	17	0.9848	16	-0.0316
Zhenjiang	0.9811	12	0.9676	15	0.9921	10	0.9999	5	0.9991	3	0.4488
Anqing	0.9024	20	0.7716	22	0.9995	2	0.9947	10	0.9999	1	2.4377
Tongling	0.6483	24	0.9431	17	0.9679	18	0.8946	23	0.9496	19	7.5335
Maanshan	0.9896	8	0.9481	16	0.9152	19	0.9737	18	0.8666	22	-3.0762
Wuhu	0.9998	3	0.9986	6	0.9692	16	1.0000	3	0.9887	12	-0.2773
Hefei	0.9841	11	0.9789	12	0.9690	17	0.9452	21	0.9812	17	-0.0731
Nanjing	0.9998	2	0.9882	8	0.9994	3	0.9935	12	0.9900	11	-0.2459
Chizhou	0.8864	21	0.8940	21	0.9896	12	0.9989	6	0.9855	15	2.4778
Jiujiang	0.7671	22	0.4865	24	0.8560	20	0.8435	24	0.9937	10	5.6658
Huangshi	0.9554	16	0.8949	20	0.3543	23	0.9835	15	0.8823	21	-1.8275
Ezhou	0.9964	5	0.9801	11	0.9768	14	0.9440	22	0.9945	9	-0.0479
Huanggang	0.6950	23	1.0000	1	0.3527	24	1.0000	1	0.4689	23	-5.6537
Wuhan	1.0000	1	0.9835	9	0.9981	5	0.9847	14	0.9970	7	-0.0740
Yibin	0.9478	17	0.6733	23	0.5961	22	0.9962	8	0.3091	24	-15.9663
Luzhou	0.9750	14	0.9998	4	0.9919	11	0.9936	11	0.9984	5	0.5843
Chongqing	0.9684	15	0.9688	14	0.9885	13	0.9689	20	0.9882	14	0.4936
Yichang	0.9864	9	0.9999	2	0.7775	21	0.9748	16	0.9396	20	-1.1690
Jingzhou	0.9234	18	0.9834	10	0.9956	8	0.9950	9	0.9972	6	1.8447
Yueyang	0.9902	7	0.9997	5	0.9764	15	1.0000	4	0.9761	18	-0.3523

table 7 coupling coordination level of ecological resilience and new urbanization in 24 cities in the yangtze river economic belt

city	Coupling coordination										Average annual rate of change
	2018	sort	2019	sort	2020	sort	2021	sort	2022	sort	(%)
Shanghai	0.9545	1	0.9875	1	0.9684	2	0.9950	1	0.9690	1	0.3612
Nantong	0.7027	9	0.6881	12	0.6699	14	0.7112	13	0.7170	14	0.3572
Taizhou	0.6760	11	0.6573	14	0.7305	11	0.6998	15	0.7585	10	2.0623
Changzhou	0.6462	13	0.7853	8	0.8156	6	0.9087	2	0.9362	2	7.2506

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Yangzhou	0.6409	15	0.6159	16	0.7813	7	0.7700	9	0.7210	13	2.0021
Zhenjiang	0.7855	6	0.8271	5	0.7813	8	0.8022	7	0.8516	7	1.6516
Anqing	0.5731	19	0.5827	17	0.6369	15	0.5830	21	0.6702	16	2.4273
Tongling	0.3857	22	0.4377	22	0.5997	19	0.7251	12	0.7492	11	9.0889
Maanshan	0.7087	8	0.7298	10	0.6103	18	0.6185	18	0.6308	18	-1.9480
Wuhu	0.6431	14	0.7055	11	0.6995	12	0.7805	8	0.7979	8	3.8705
Hefei	0.7959	5	0.8758	3	0.8423	5	0.8283	6	0.8579	6	1.5514
Nanjing	0.8514	3	0.9211	2	0.9735	1	0.8994	4	0.9268	3	1.8847
Chizhou	0.5497	20	0.6830	13	0.6943	13	0.6136	19	0.6285	19	1.9700
Jiujiang	0.1463	24	0.4579	21	0.6332	17	0.5957	20	0.5179	21	9.2905
Huangshi	0.4016	21	0.3919	23	0.2337	24	0.5249	22	0.5083	22	2.6688
Ezhou	0.5870	17	0.5402	18	0.5131	21	0.7058	14	0.6207	20	0.8445
Huanggang	0.1573	23	0.1000	24	0.2343	23	0.1000	24	0.2004	24	1.0786
Wuhan	0.8051	4	0.7870	7	0.8607	4	0.9076	3	0.9191	4	2.8498
Yibin	0.5768	18	0.5393	19	0.3536	22	0.5242	23	0.2512	23	-8.1398
Luzhou	0.6665	12	0.6317	15	0.7417	10	0.7470	10	0.7837	9	2.9303
Chongqing	0.8761	2	0.8328	4	0.9219	3	0.8656	5	0.8891	5	0.3263
Yichang	0.7507	7	0.8007	6	0.5961	20	0.6976	16	0.7081	15	-1.0660
Jingzhou	0.5969	16	0.5297	20	0.6350	16	0.6339	17	0.6609	17	1.5979
Yueyang	0.6800	10	0.7391	9	0.7651	9	0.7415	11	0.7350	12	1.3763

3.3.2 coupling and coordination time series differences between ecological resilience and new urbanization
According to Table 7, the changes of coupling degree and coupling coordination degree between ecological resilience and new urbanization in each study city are plotted into a line chart, which intuitively reflects the change trend and difference from 2018 to 2022.

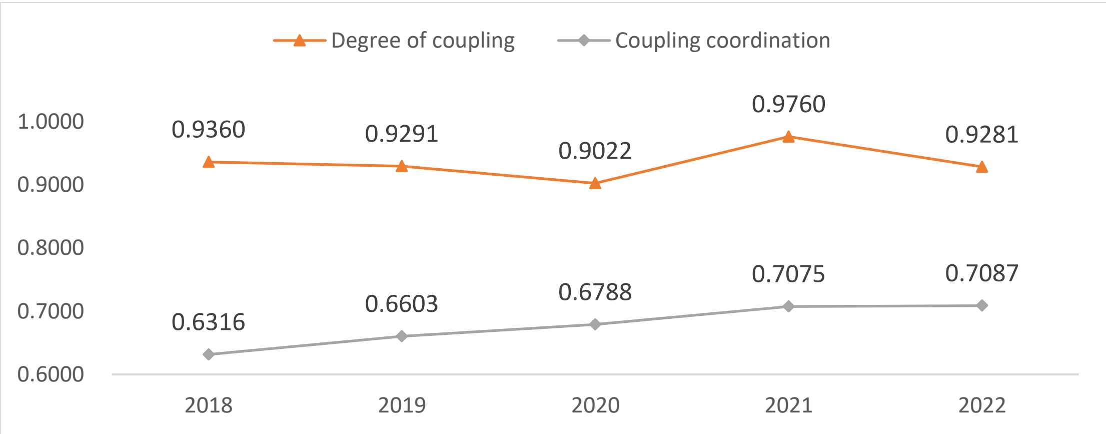

fig. 5 horizontal line chart of the coupling degree and coupling coordination degree between ecological resilience and new urbanization

It can be inferred from Figure 5 that the interaction between ecological resilience and new urbanization has increased, and it is in a state of orderly development. It is not difficult to see that from 2018 to 2022, the coupling degree of ecological resilience and new urbanization in the Yangtze River Economic Belt is in the range of 0.9-1.0, indicating that there is a strong interdependence between the two and is in a high-level coupling stage. The mean coupling coordination degree increased from 0.6316 to 0.7087, indicating that the ecological resilience and new urbanization in the study area were in a benign state of resonance coupling and orderly development. Although the coupling coordination level between regional ecological resilience and new urbanization studied in this paper was always lower than that of the coupling degree from 2018 to 2022, the gap is gradually narrowing. This indicates that although the relationship between the ecological resilience of the studied cities and the new

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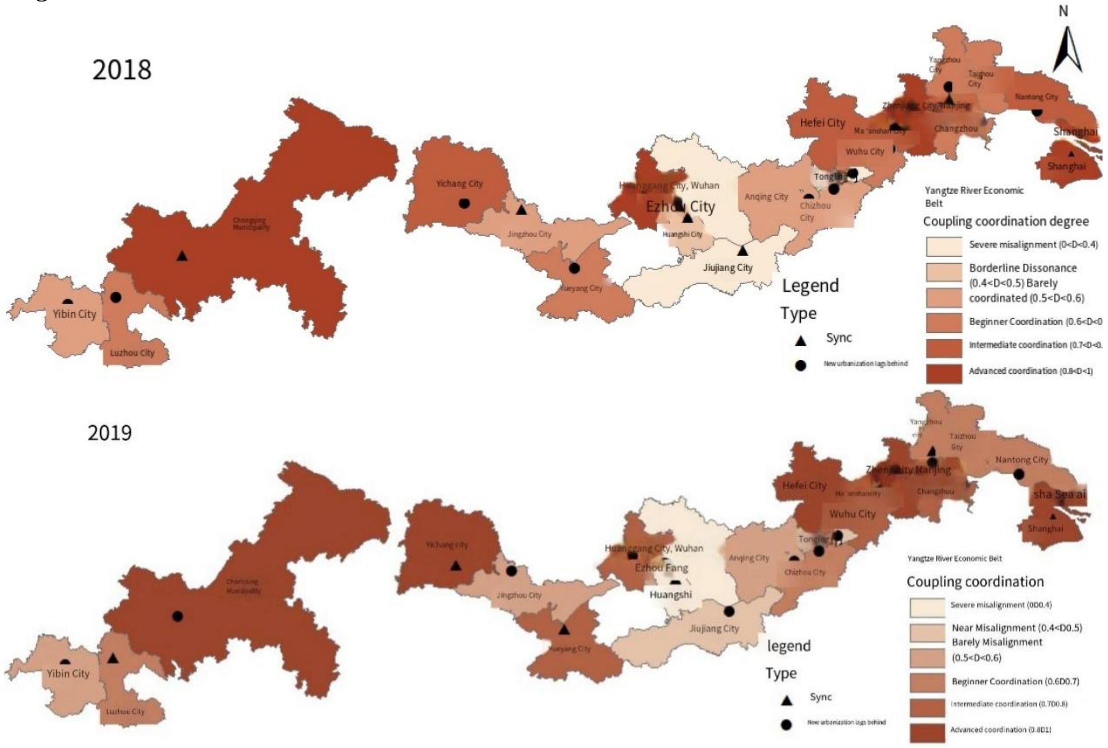
urbanization is relatively stable, it is still in the run-in period of "ecological resilience - new urbanization", that is, "high coupling". /b121>- Low coordination" status.

3.3.3 Spatial Differentiation Characteristics of Coupling and Coordination Between Ecological Resilience and New Urbanization

According to the classification criteria of coupling coordination degree types and subtypes in Table 1 and the actual measurement results of coupling coordination degree, this paper uses ArcGIS10.2 software to draw a spatial differentiation map of coupling coordination degree to further analyze the Yangtze River Economic Belt from 2018 to 202224. Spatial differentiation characteristics of the coupling coordination degree and coordination type of ecological resilience and new urbanization in 24 cities.



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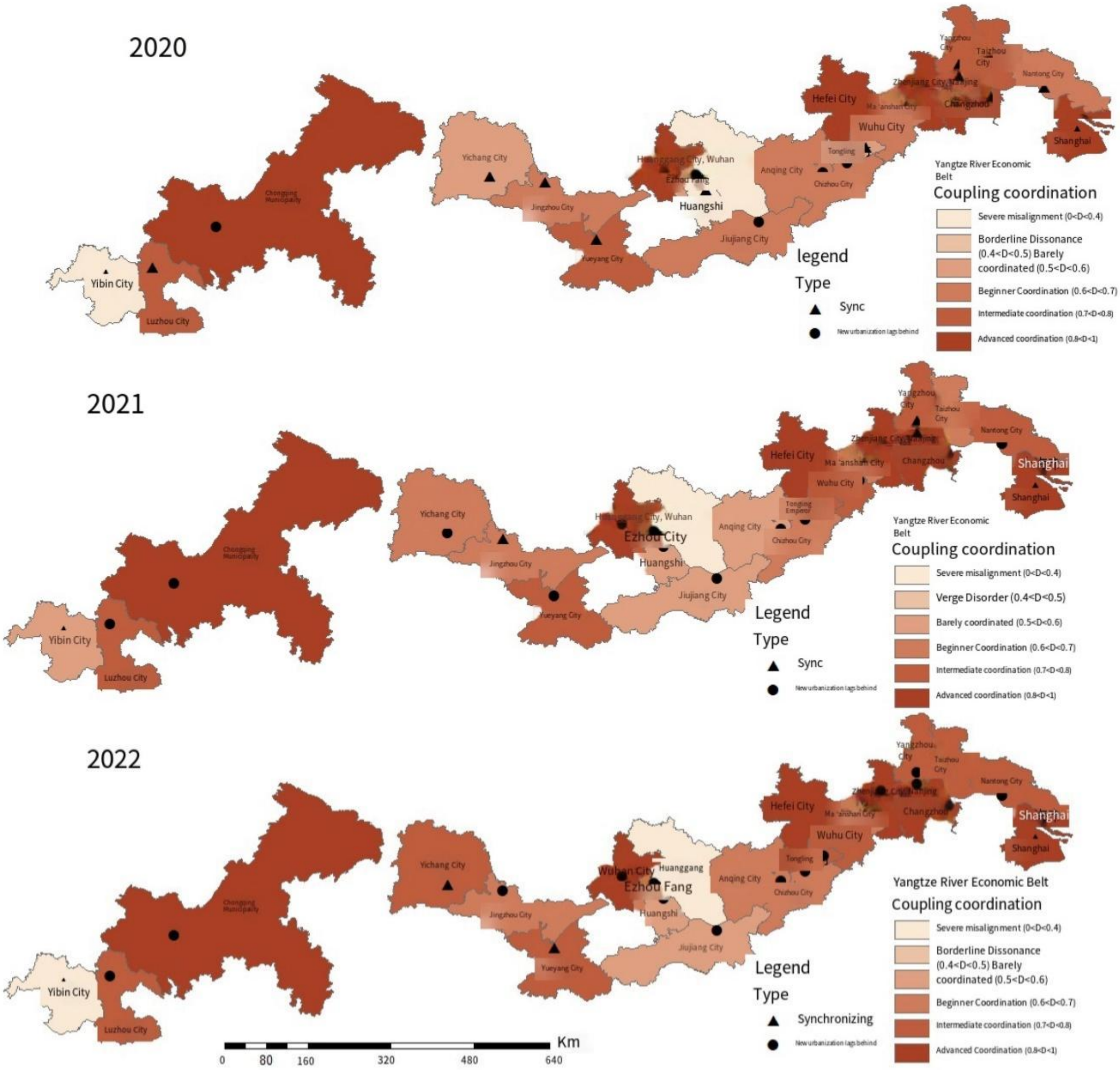

fig. 6 spatial differentiation of coupling coordination between ecological resilience and new urbanization

It can be concluded that the spatial distribution pattern of coupling coordination degree is "high on both sides and low in the middle", and the number of primary and intermediate coordination cities increases. At the same time, the spatial differentiation pattern of ecological resilience and new urbanization coupling coordination degree in the Yangtze River Economic Belt from 2018 to 2022 has the following characteristics:

(1) There is little difference between the ecological resilience and the coupling coordination degree of new urbanization among cities in the region, but it still shows the spatial distribution characteristics of "high on both sides and low in the middle".

(2) During the study period, the coupling coordination type of the Yangtze River Economic Belt as a whole has undergone a change process from primary coordination to intermediate coordination, and the number of cities with intermediate coordination and primary coordination has increased significantly.

(3) The subtype of coordinated development of cities has gradually changed from synchronous development to lagging new urbanization.

3.4 Analysis of the Influencing Factors of the Coupling and Coordination Degree of Ecological Resilience and New Urbanization

3.4.1Contact Values

Based on the comprehensive scores and index data of the coupling coordination of ecological resilience and new urbanization in cities in the Yangtze River Economic Belt from 2018 to 2022, the correlation coefficients between

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each influencing factor and the coupling coordination degree of each city at different times were calculated, and the correlation coefficients were sorted out to form a single value at different times, as shown in the following table.

table 8 detection results of the correlation coefficient of influencing factors in 24 cities in the yangtze river economic belt

Nuberin	correlation coefficient											
	Shanghai	Nantobg	Taizhou	Changzhou	Yangzhou	Zhenjiang	Anqing	Tongling	Maanshan	Wuhu	Hefei	Nanjing
X1	0.9049	0.8696	0.9386	0.9308	0.9449	0.9203	0.9346	0.9372	0.9823	0.9579	0.9169	0.9341
X2	0.8795	0.9272	0.9171	0.9132	0.9194	0.9087	0.9108	0.8472	0.9703	0.9581	0.9378	0.9102
X3	0.9420	0.9947	0.9939	0.9730	0.9910	0.9792	0.9911	0.9802	0.9886	0.9944	0.9745	0.9670
X4	0.9226	0.9461	0.9652	0.9884	0.8969	0.9697	0.9563	0.9645	0.9737	0.9906	0.9792	0.9903
X5	0.9563	0.9958	0.9961	0.9743	0.9908	0.9811	0.9867	0.9826	0.9881	0.9929	0.9762	0.9673
X6	0.9548	0.9949	0.9963	0.9804	0.9942	0.9812	0.9869	0.9818	0.9868	0.9928	0.9763	0.9648
X7	0.9608	0.9899	0.9950	0.9884	0.9935	0.9896	0.9740	0.9872	0.9860	0.9832	0.9639	0.9713
X8	0.9213	0.9573	0.9566	0.9510	0.9794	0.9852	0.9344	0.9611	0.9444	0.9760	0.9373	0.9013
X9	0.6818	0.9649	0.9804	0.9466	0.9869	0.9591	0.9313	0.9177	0.9339	0.9502	0.9354	0.8371
X10	0.9354	0.9362	0.9295	0.9669	0.9472	0.9765	0.9368	0.9473	0.9775	0.9882	0.9582	0.9121
X11	0.9773	0.9924	0.9889	0.9841	0.9916	0.9863	0.9858	0.9830	0.9869	0.9897	0.9898	0.9842
X12	0.9567	0.9902	0.9836	0.9851	0.9899	0.9855	0.9907	0.9857	0.9795	0.9830	0.9026	0.9810
X13	0.9767	0.9672	0.9777	0.9612	0.9624	0.9778	0.9680	0.9822	0.9860	0.9965	0.9887	0.9684
X14	0.9782	0.9820	0.9966	0.9869	0.9928	0.9953	0.9866	0.9835	0.9866	0.9883	0.9786	0.9884
X15	0.9862	0.9944	0.9895	0.9871	0.9822	0.9850	0.9721	0.9826	0.9881	0.9764	0.9685	0.9879
X16	0.9338	0.9784	0.9879	0.9783	0.9863	0.9575	0.9826	0.9814	0.9914	0.9794	0.9802	0.9599
X17	0.9608	0.9955	0.9959	0.9834	0.9941	0.9838	0.9914	0.9823	0.9869	0.9938	0.9791	0.9694
X18	0.9634	0.9892	0.9883	0.9817	0.9875	0.9793	0.9887	0.9632	0.9757	0.9796	0.9912	0.9740
X19	0.7746	0.9734	0.9596	0.9811	0.9846	0.9847	0.9722	0.9313	0.9858	0.9500	0.9473	0.9246
X20	0.9527	0.9600	0.9447	0.9749	0.9820	0.9725	0.9304	0.9898	0.9533	0.9605	0.9770	0.9745
X21	0.9644	0.9908	0.9841	0.9703	0.9701	0.9674	0.9641	0.9581	0.9689	0.9759	0.9766	0.9499
X22	0.8210	0.9533	0.9725	0.8830	0.9855	0.9578	0.9653	0.9029	0.9568	0.9439	0.9033	0.9622
X23	0.8994	0.9811	0.9900	0.9484	0.9853	0.9732	0.9624	0.9776	0.9523	0.9693	0.9399	0.9179
X24	0.9483	0.9581	0.9559	0.9423	0.9669	0.9793	0.9828	0.9675	0.8980	0.9462	0.9532	0.9559
X25	0.9587	0.9924	0.9893	0.9693	0.9879	0.9727	0.9738	0.9688	0.9768	0.9806	0.9716	0.9748
X26	0.9693	0.9937	0.9844	0.9666	0.9786	0.9605	0.9876	0.9600	0.9858	0.9895	0.9849	0.9645
X27	0.8719	0.9143	0.9124	0.8971	0.9143	0.8998	0.3345	0.9273	0.9186	0.9106	0.8936	0.8841
X28	0.7402	0.9836	0.9915	0.9763	0.9789	0.9811	0.9469	0.9629	0.9658	0.9665	0.9698	0.9445
X29	0.8739	0.9304	0.9307	0.9078	0.9237	0.9127	0.9144	0.9210	0.9115	0.9069	0.8895	0.8886
X30	0.9557	0.9812	0.9665	0.9592	0.9896	0.9941	0.9857	0.9346	0.9839	0.9606	0.9925	0.9170

table 8 (cont'd) results of correlation coefficients of impact factors for 24 cities in the yangtze river economic belt

Numbering	correlation coefficient											
	Chizhou	Jiujiang	Huangshi	Ezhou	Huanggang	Wuhan	Yibin	Luzhou	Chongqing	Yichang	Jingzhou	Yueyang
X1	0.9590	0.9535	0.9651	0.9503	0.9839	0.9519	0.9178	0.9641	0.6115	0.9694	0.9760	0.9568
X2	0.7982	0.8834	0.9826	0.9643	0.9313	0.9032	0.9671	0.9675	0.9665	0.9051	0.9613	0.9725
X3	0.9872	0.9541	0.9740	0.9883	0.9217	0.9673	0.9727	0.9924	0.9875	0.9877	0.9952	0.9943
X4	0.9346	0.9494	0.9620	0.9464	0.9830	0.9732	0.9413	0.9248	0.9809	0.9828	0.9696	0.9763
X5	0.9898	0.9641	0.9642	0.9872	0.9303	0.9748	0.9679	0.9948	0.9701	0.9886	0.9868	0.9892
X6	0.9901	0.9652	0.9647	0.9889	0.9204	0.9732	0.9700	0.9940	0.9705	0.9870	0.9871	0.9934
X7	0.9905	0.9645	0.9852	0.9802	0.9305	0.9862	0.9492	0.9895	0.9628	0.9360	0.9890	0.9914
X8	0.9783	0.9507	0.9436	0.9609	0.9639	0.9443	0.9806	0.9698	0.9393	0.9560	0.9618	0.9544
X9	0.9199	0.9616	0.9569	0.9190	0.9911	0.8672	0.9653	0.9031	0.9396	0.9486	0.9232	0.9028
X10	0.9604	0.9825	0.9800	0.9447	0.9925	0.9116	0.8861	0.9740	0.9234	0.9236	0.9859	0.9683
X11	0.9859	0.9827	0.9757	0.9937	0.9270	0.9871	0.9735	0.9926	0.9860	0.9826	0.9897	0.9922
X12	0.9871	0.9813	0.9903	0.9830	0.9494	0.9673	0.9737	0.9734	0.9581	0.9635	0.9792	0.9730
X13	0.9702	0.9848	0.9907	0.9818	0.9794	0.9784	0.9744	0.9477	0.9492	0.9856	0.9594	0.9511
X14	0.9818	0.9791	0.9809	0.9859	0.9492	0.9788	0.9732	0.9822	0.9482	0.9893	0.9893	0.9427
X15	0.9692	0.9807	0.9827	0.9809	0.9424	0.9779	0.9805	0.9758	0.9851	0.9819	0.9697	0.9057
X16	0.9832	0.9590	0.9386	0.9649	0.9047	0.9568	0.9732	0.9480	0.9742	0.9625	0.9780	0.9571
X17	0.9932	0.9664	0.9653	0.9911	0.9327	0.9770	0.9683	0.9934	0.9699	0.9863	0.9952	0.9958
X18	0.9811	0.9734	0.8975	0.9723	0.9599	0.9708	0.9743	0.9864	0.9592	0.9739	0.9684	0.9857
X19	0.9492	0.9747	0.9898	0.9753	0.9763	0.9856	0.9803	0.9692	0.9702	0.9629	0.9563	0.9628
X20	0.9315	0.9527	0.9881	0.9698	0.9867	0.9270	0.9174	0.9946	0.9670	0.9470	0.9412	0.9213
X21	0.9669	0.9044	0.9081	0.9689	0.9051	0.9834	0.9560	0.9099	0.9050	0.9329	0.9416	0.9792
X22	0.9933	0.9775	0.9785	0.9541	0.9885	0.9400	0.9805	0.9636	0.9426	0.9709	0.9795	0.9531
X23	0.9858	0.9844	0.9620	0.9749	0.9374	0.9318	0.9796	0.8733	0.8918	0.8599	0.8801	0.9412
X24	0.8968	0.9559	0.9525	0.9447	0.9444	0.9492	0.9699	0.9666	0.9452	0.9702	0.9812	0.9667
X25	0.9889	0.9516	0.9555	0.9948	0.9183	0.9417	0.9595	0.9934	0.9664	0.9838	0.9894	0.9870
X26	0.9839	0.9685	0.9689	0.9935	0.9148	0.9540	0.9639	0.9923	0.9800	0.9802	0.9767	0.9923
X27	0.9253	0.9478	0.9524	0.9279	0.9939	0.9183	0.9500	0.9124	0.8902	0.9127	0.9264	0.9096
X28	0.9279	0.9562	0.9951	0.9891	0.9768	0.9470	0.9702	0.9585	0.9487	0.9615	0.9727	0.9168
X29	0.9119	0.9343	0.9401	0.9167	0.9791	0.8916	0.9678	0.9143	0.8915	0.9265	0.9321	0.3376
X30	0.9717	0.9815	0.9799	0.9618	0.9936	0.9655	0.9771	0.9728	0.9751	0.9872	0.9380	0.9359

3.4.2 Analysis of correlation values and influencing factors

On the basis of the previous calculation results, the correlation coefficients of the indicators in the comparison series are averaged to reflect the correlation between the factors, i.e. the degree of correlation. According to the results of the correlation degree calculation, it can be seen that the correlation degree between each influence factor and the coupling coordination degree of ecological resilience and new urbanization is overwhelmingly above 0.9, indicating that there is a strong correlation between each influence factor and the coupling coordination degree of the two.

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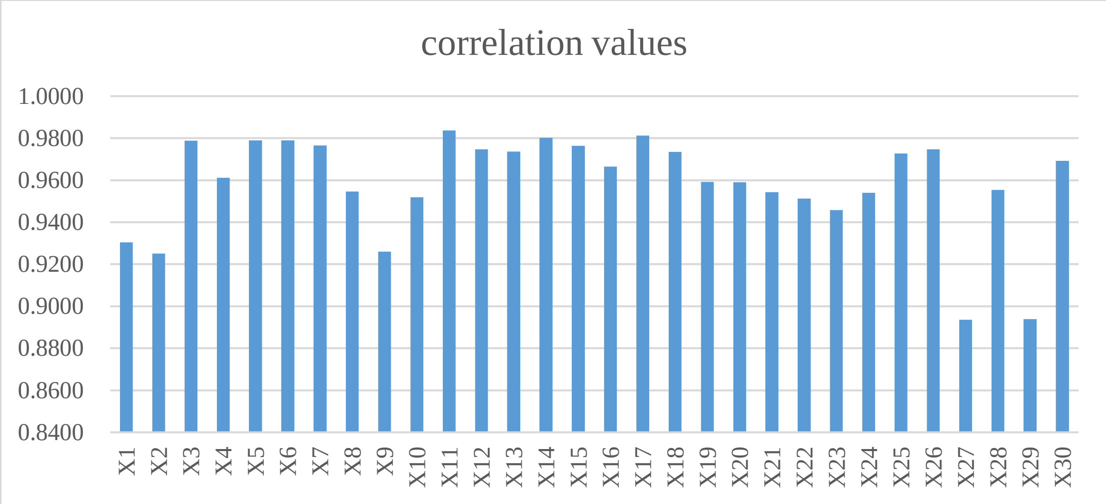

fig. 7 correlation of each influencing factor with coupling harmonization degree

The influencing factors were divided into nine dimensions according to the resistance, adaptability and recovery capacity of ecological resilience, demographic urbanization, economic urbanization, social urbanization, ecological urbanization, urban-rural integration and spatial urbanization of new urbanization, and were classified into three levels according to the value of the correlation degree, namely, high correlation ($0.96<r<=1$), medium correlation ($0.9<r<=0.96$) and low association ($0.84<r<=0.9$) levels, which are analyzed in combination with the previous chart. It is not difficult to find that the influencing factors of the coupled and coordinated development of ecological resilience and new urbanization vary from city to city due to the different development processes of each city. The factor that has the greatest influence on the coupled and coordinated development of ecological resilience and new urbanization is the proportion of urban resident population to total population in population urbanization (0.9837), and the factor that has the least influence is the ratio of urban and rural Engel coefficients in urban-rural integration (0.8936).

3.5 Conclusion and Discussion

3.5.1Main Research Conclusions

This article focuses on 24 cities in the Yangtze River Economic Belt. The concepts of ecological resilience, new urbanization, and their coupling coordination are clearly defined, by analyzing existing research results at home and abroad. Further in-depth exploration is conducted to explore the degree of coupling coordination between ecological resilience and new urbanization. This article uses CRITIC weighting method and entropy method to select data on various indicators of cities in the Yangtze River Economic Belt from 2018 to 2022, and determines the comprehensive weight of each evaluation indicator. On this basis, it further evaluates the development status of the coupling coordination between the two using the coupling coordination model, reveals its spatiotemporal evolution law using ArcGIS software, and finally introduces the grey correlation model to analyze the correlation between various factors, in order to understand the problems faced by urban development and provide direction for future urban development paths.

This research draws the following conclusions:

Firstly, the ecological resilience level of the Yangtze River Economic Belt region experienced a "W-shaped" change state of first decreasing, then increasing, and then decreasing again, during the five-year period from 2018 to 2022. Overall, there was a slight decline, with an average annual change rate of -1.3689%. The overall annual average change rate of ecological resilience level remains between 0% and 3%, with only a few cities experiencing significant changes. Looking at the ranking of ecological resilience levels, the rankings between cities are relatively stable, with only a few cities experiencing fluctuations in their rankings. At the same time, the development differences between cities, whether absolute or relative, have been reduced to some extent, but there is still uneven development within the region. In terms of space, the ecological resilience level of the study area shows a distribution characteristic of "high in the east and west, low in the middle". The number of cities in high resilience zones is increasing, while the number of cities in lower resilience zones is decreasing. The number of cities in low resilience zones first decreases and then increases, and the spatial distribution gradually changes from

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patchy to point like. The ecological resilience levels vary significantly among cities, and there is an overall imbalance in development.

Secondly, in terms of temporal evolution, the process of new urbanization in the Yangtze River Economic Belt region has been tortuous, with an average annual change rate of -1.4468%, and the level of new urbanization is slowly declining. From the comprehensive ranking of the level of new urbanization in various cities, the ranking of most cities has not changed much, while some cities have shown significant changes in their ranking, demonstrating temporal and spatial evolution characteristics. Shanghai, Nanjing, and Changzhou have held a leading position in the development of new urbanization over the years. The absolute and relative differences in development between cities have narrowed in recent years, and the phenomenon of uneven development still exists. In terms of space, the level of new urbanization in the Yangtze River Economic Belt presents a stepped distribution that decreases from east to west. The level of new urbanization in the central region has been increasing year by year, while it has decreased in the eastern and western regions. The differences between cities are gradually narrowing, and the overall trend is towards balanced development. The spatial distribution has shifted from a "dispersed" distribution to a "clustered" distribution, forming high-quality core agglomeration zones, high-quality core agglomeration zones, and low-quality core agglomeration zones. The high-quality core agglomeration zone is mainly concentrated in the eastern part of the research city, with Shanghai and Nanjing as the core, forming a "dual center" distribution. The low-quality core agglomeration areas are concentrated in the central part of the research cities, with Huanggang and Jiujiang as the core. The number of cities in low-quality areas is continuously decreasing, and most cities are moving towards higher quality levels, achieving cross level improvement. However, while the differences in the development quality of new urbanization in various towns are gradually narrowing, the phenomenon of uneven and uncoordinated development within the region is still prominent.

Furthermore, the coupling coordination degree between ecological resilience and new urbanization fluctuates within the range of 0.9-1.0, indicating a close interdependence between the two and a high-level coupling. Although the coupling coordination between ecological resilience and new urbanization remained lower than the coupling degree between 2018 and 2022, the gap between the two is gradually narrowing. This indicates that although the relationship between ecological resilience and new urbanization in the current research area is relatively stable, the two are still in the process of adjustment, showing the characteristics of "high coupling low coordination". In terms of space, the distribution of coupling coordination degree is" high on both sides and low on the other side", and the number of primary and intermediate coordination cities has increased. During the research period, the overall coupling and coordination type of the Yangtze River Economic Belt underwent a transition from primary to intermediate. In terms of coupling types, there is little change between the new urbanization lagging type and synchronous type cities. Synchronous type cities are mainly concentrated in the eastern and western regions, while the new urbanization lagging type cities are mainly located in the central region of the study area.

The coupling coordination degree between ecological resilience and new urbanization is also influenced by multiple factors such as per capita GDP, per capita urban consumption expenditure, urban road network density, and per capita built-up area. The correlation degree of the vast majority of influencing factors exceeds 0.9, indicating strong correlation, according to the grey relational model.

3.5.2Discussion and Inspiration

Overall, the ecological resilience of the Yangtze River Economic Belt urban agglomeration and the coupling and coordination of new urbanization are still in a stage of continuous adjustment and adaptation amidst fluctuations. Based on its spatiotemporal evolution characteristics and influencing factors, there are the following two strategic suggestions:

It is necessary to simultaneously strengthen the level of ecological resilience and the coupling coordination between the two, while improving the level of new urbanization. In response to the shortcomings of the new urbanization, especially the lagging level of social urbanization, efforts should be made to improve the level of urban infrastructure, including public transportation, medical and health services, to stimulate the advantages of cities in human resources and industrial agglomeration, and drive the overall level of urbanization. In terms of ecological resilience, it is necessary to accelerate the green transformation of traditional industries and gradually eliminate outdated production capacity with high energy consumption, high pollution, and high emissions. In the aspect of improving coupling degree, attention should be paid to spatial and economic urbanization, especially

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assisting cities with lower levels of new urbanization to accelerate development; Pay attention to ecological pressure, adhere to the "red line", accurately control pollution, use dialectics to deeply analyze the main contradictions and aspects of ecological pressure, reduce industrial waste emissions, and promote regional sustainable development.

Adapt measures to local conditions and promote the improvement of coupling and coordination through classification. Each central city, based on its own level of new urbanization, gradually promotes the high-quality development stage of new urbanization. Eastern cities such as Shanghai, Nanjing, and Changzhou need to improve resource intensive utilization, optimize construction land, set resource red lines, and enhance ecological resilience; Central cities such as Yichang, Huanggang, and Chizhou need to promote industrial structure optimization and support clean energy and green industries. Other cities should learn from experience, steadily promote new initiatives, scientifically plan green spaces, enhance self purification capabilities, and achieve a win-win situation between new urbanization and ecological resilience.

In the current context of the deepening implementation of the new urbanization strategy, the research results provide a new theoretical perspective and practical basis for the high-quality and sustainable development of cities. However, as an exploratory study on the coupling and coordination of ecological resilience and new urbanization, this article still has many shortcomings and needs further improvement in the future. In terms of time scale, this study focuses on the five-year period from 2018 to 2022, which is relatively short and difficult to fully reveal the dynamic evolution characteristics of both. At the same time, it takes the entire Yangtze River Economic Belt as the research area and evaluates various cities within the region. The large differences between cities are not conducive to the accuracy of the study. Future research can be refined to the county level to improve research accuracy. In addition, this article only analyzes the existing indicators in the two indicator systems of ecological resilience and new urbanization, ignoring the diversity of influencing factors. In the future, we will consider selecting more diverse indicators to conduct more comprehensive and multidimensional analysis of influencing factors, enrich research perspectives, and enhance the comprehensiveness of research conclusions.

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