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Research on the Coupling Coordination and Driving Mechanisms of New-Type Urbanization and the Ecological Environment in China's Yangtze River Delta

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Abstract: For high-quality growth to occur, new-type urbanization and environmental preservation must coexist and advance at the same time. The focus has shifted to maintain a balance between ecological quality and urbanization growth. This study focuses on the Yangtze River Delta (YRD) in China, utilizing panel data from 41 cities in the YRD spanning from 2009 to 2021 to construct evaluation index systems for new (type of) urbanization and ecological environment. To analyze spatial-temporal evolutionary aspects and determine the causes of the degree of coupling coordination between new-type urbanization and the ecological environment, methodologies such as the entropy weight method, coupled coordination degree model, and Tobit regression approach were used. The results show that (1) economic urbanization has experienced the most growth in the level of new-type urbanization in the YRD, which has been steadily increasing. Moreover, the ecological environment evaluation score increased from 0.581 in 2009 to 0.701 in 2021, revealing a cyclical pattern of increase and decrease in its evolutionary trajectory. (2) Within the scope of the study, the overall coupling coordination degree between new-type urbanization and ecological environment has increased, with the average value rising from 0.512 in 2009 to 0.540 in 2021. In comparison to Lishui, Huaibei, Huainan, Ningbo, Chuzhou, and Bozhou saw a greater increase in coupling and coordination degree, with pronounced variations and clustering patterns visible in their spatial distribution. (3) According to the Tobit regression analysis, the level of economic development, technological progress, industrial concentration, global openness, and educational investment had significant positive effects on the degree of coupled coordination between new-type urbanization and the ecological environment in the YRD, whereas the level of information technology did not reach the significance threshold. The findings of the study are crucial for establishing a regional framework for green and sustainable development, as well as for facilitating the coordinated growth of new-type urbanization and ecological environment. These findings hold great potential for driving positive change in both urban development and environmental conservation efforts.

Keywords: new-type urbanization; ecological environment; coupling coordination degree; Tobit model; China's Yangtze River Delta

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1. Introduction

Urbanization, an essential path to modernization and a robust catalyst for sustainable, healthy economic growth, imposes greater demands on urban development in our current era due to the pursuit of high-quality advancement [1]. China has repeatedly adjusted its urbanization strategy, underscoring the human-centric approach of the current new-type urbanization development strategy. As a populous developing country with a substantial economic volume, China has undergone swift urbanization, inevitably leading to massive energy and resource consumption, along with significant pollution emissions, thus placing considerable stress on the ecological environment [2]. The YRD, a frontier in

China's industrialization and urbanization development, ranks among the regions demonstrating the most dynamic economic development, the highest level of openness, and the strongest development foundation in the country. According to the Yangtze River Delta Integration Development Index Report (2022), the region's urbanization rate climbed to 71.45% in 2021, with considerable enhancement in urbanization levels and remarkable progress in industrial upgrading, agricultural modernization, and infrastructure construction. Nonetheless, the continuous urbanization process, marked by urban land expansion, population proliferation, and environmental pollution, has inflicted considerable harm on the natural ecological environment, thereby constraining sustainable urbanization [3–6]. The Yangtze River Delta represents a critical ecological reservoir and a pivotal driver of economic growth in China. YRDs are experiencing heightened human activity, increased natural resource consumption, and diverse energy utilization, leading to increasingly severe discrepancies among resources, the population, and the environment. To address this urbanization–ecology conflict and foster high-quality development in the YRD, it is crucial to establish a coordination mechanism between the two [7]. Therefore, studying the coupling and coordination effects of new-type urbanization and the ecological environment, as well as analyzing the factors influencing their coordinated development, has substantial theoretical and practical importance for promoting sustainable development.

The study of how urbanization and the environment interact has a long history, with theories dating as far back as 1902. At that time, Ebenezer [8] popularized the idea of the 'idyllic city' in urban planning, arguing for a perfect metropolis that expertly combines the advantages of both urban and rural locations. The pressure-state-response (PRR) model was subsequently developed by David J. Rapport and Anthony Marcus Friend as a method for assessing the health of ecosystems while examining the complex interaction between human activity and the natural world. The relationship between economic development and resource use was later defined by the OECD using decoupling theory in environmental economics [9]. Deng et al. [10] utilized the PRR model as a reference and selected indicators from three dimensions—ecological foundation, ecological pressure, and ecological response—to assess the level of the ecological environment in the Yangtze River Economic Belt, with a focus on the interaction between human activities and the ecological environment. Subsequent scholarly efforts studying the relationships between urbanization and the ecological environment have been informed and led by these founding beliefs.

To improve new-type urbanization and the agroecological environment in China, Cai et al. [11] conducted an empirical study on the spatial and temporal differentiation of the coupled and coordinated development of the two in China. They also identified the influencing factors affecting the coupled and coordinated development of the two and, based on their findings, proposed a number of policy recommendations. He et al. [12] developed a novel urbanization and ecological resilience assessment framework grounded in the concept of evolutionary resilience, followed by a rigorous scientific examination of the interplay between these two systems. Yang et al.'s [13] analysis of the correlation, coupling, and coordination degrees between urbanization and the natural environment focused on the Chongqing municipality and used GIS spatial methodologies. Their research offers insightful information on the connections and interdependencies between these two elements. Based on Landsat data and the Tiangong-2 WIS, Ariken et al. [14] developed the Remote Sensing Ecological Index (RSEI). In China's Yanqi Basin, a typical arid region, researchers have thoroughly assessed the coupling and coordination links between urbanization and the ecological environment. A coupling coordination degree model is used to perform this assessment, providing a thorough grasp of the dynamics in this particular area. By combining daytime optical remote sensing and nocturnal light remote sensing data, Zheng et al. [15] analyzed the ecological environment, urbanization intensity, and coupling and coordination characteristics in the YRD urban agglomeration. The study uses the Google Earth Engine platform to shed light on how urbanization and the ecological environment interact in this area. A thorough evaluation index system for urbanization in the Chengdu-Chongqing (Cheng-Yu) urban agglomeration was created by Yang et al. [16]. The index system includes four subsystems that together provide a comprehensive evaluation of the urbanization process: economic, social, ecological, and urban and rural coordination. Together, these investigations shed important light on the intricate interactions and dynamics between urbanization and the natural world. The use of diverse models, remote sensing methods, and assessment index systems paves the way for the creation of sustainable urbanization policies and advances our understanding of this crucial relationship.

The theoretical mechanism underlying new-type urbanization and the ecological environment is first examined in this paper. The coupling coordination degree model was subsequently used to calculate the degree of coupling between new-type urbanization and the ecological environment in the YRD by creating an evaluation index system for these areas. The investigation also looks into the spatiotemporal evolution of this coupling coordination degree. Finally, this paper finds the elements impacting the coupling coordination degree by using the random effects panel Tobit model. The goal is to look into the contemporary state and ecological environment of the YRD. The ultimate objective is to improve people's quality of life, promote peaceful cohabitation between humans and nature, and open the path for the sustainable development of modern urbanization and the ecological environment.

2. Analysis of the Coupling Coordination Mechanism

Amid the evolving urban–rural landscape and the new phase of urbanization development, the Chinese government has presented a novel policy for urbanization development. In contrast to the conventional urbanization model, this new approach places 'people at the core'. It concentrates on the optimal distribution of population and resources, enhances the capabilities of urban services, and upgrades public facilities. The innovative urbanization model departs from the traditional, imprecise, and loosely structured economic development paradigm. Instead, it promotes the cultivation of a sustainable, environmentally-friendly, and low-carbon economy. Furthermore, it integrates the principle of sustainability throughout the entire process of urbanization, thereby facilitating robust economic and social advancement [17].

New-type urbanization and the ecological environment represent two interdependent systems comprising multiple elements that interact to form a complex feedback system. The evolution and progression of new-type urbanization inevitably impacts the ecological environment, and vice versa can influence the pace and quality of new-type urbanization [18,19]. Rapid urbanization or an imprudent development pattern, such as extreme population migration in a brief time span, irrational land planning, or rampant exploitation and consumption of resources by businesses, all exert substantial pressure on the environment. When the environmental carrying capacity is breached, this can exacerbate the degradation of the natural environment, leading to issues such as soil, air, and water pollution that significantly impede the sustainability of social systems. Conversely, heightened economic development levels can furnish financial and technological aid for ecological environment management, curb resource consumption rates, and bolster protection and restoration efforts for the ecological environment. Furthermore, transitions in individuals' consumption patterns from material goods to services have the potential to diminish resource utilization and enhance ecological development. Consequently, the ecological environment can exert a beneficial impact on new urbanization by encompassing the climatic environment, biological communities, and natural resources within an integrated ecosystem. This study provides the material foundation for the successful progression of new-type urbanization. An appealing ecological environment can attract an influx of talent, technology, and capital, thereby stimulating the transformation and upgrading of urban industries, bolstering the momentum for the development and construction of new-type urbanization, and contributing to the establishment of a distinguished ecological culture. However, deteriorating ecological health can also impact the establishment of new-type urbanization. Since pollution emissions causing environmental degradation are primarily sourced from the industrial sector, pollution intensity and subsequent mitigation efforts will increase, thereby elevating the cost of environmental management for enterprises. This can potentially result in a decrease in the labor force and skilled personnel, restrict industrial transformation and upgrading, and be detrimental to the enhancement of the stock and quality of regional factor resources. As a result, the sustainable promotion of new-type urbanization may be constrained (Figure 1).

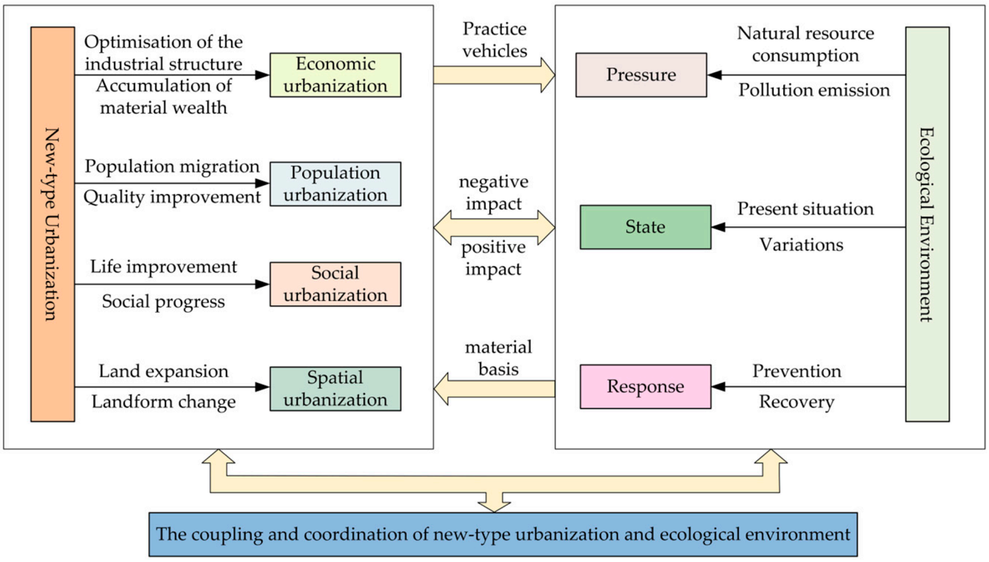

Figure 1. Coupling coordination mechanism.

3. Materials and Methods

3.1. Overview of the Study Area

The YRD, encompassing 358,000 square kilometers and including Shanghai, Jiangsu, Zhejiang, and Anhui, comprises 41 cities. This region is recognized for its dynamic economic development, high level of openness, and robust innovation capacity, placing it at the forefront of China's economic and social development. It also boasts significant advancements in science and technology innovation. In 2022, the regional GDP will reach 29.03 trillion yuan, accounting for roughly a quarter of China's total GDP. Presently, it represents one of the highest urbanization levels in the country [20]. As an example of high-quality and integrated regional development in China, the YRD exhibits a fundamental pattern of coordinated urban–rural development. These cities demonstrate strong linkage effects and have initially established an integrated system of science, technology, and innovative industries, reinforcing their position as essential origins and hubs for technological innovation in China. Furthermore, the region's comprehensive natural ecosystem, distinctive biodiversity, and abundant water and wildlife resources accentuate its richness. However, environmental pollution and ecological imbalances have intensified during urbanization, escalating the conflict between ecological preservation and economic development [21,22]. Currently, as the YRD is undergoing a crucial transformation and development phase, it is vital to elucidate the coordinated developmental relationship between urbanization advancement and the ecological environment to attain the objective of high-quality economic development (Figure 2).

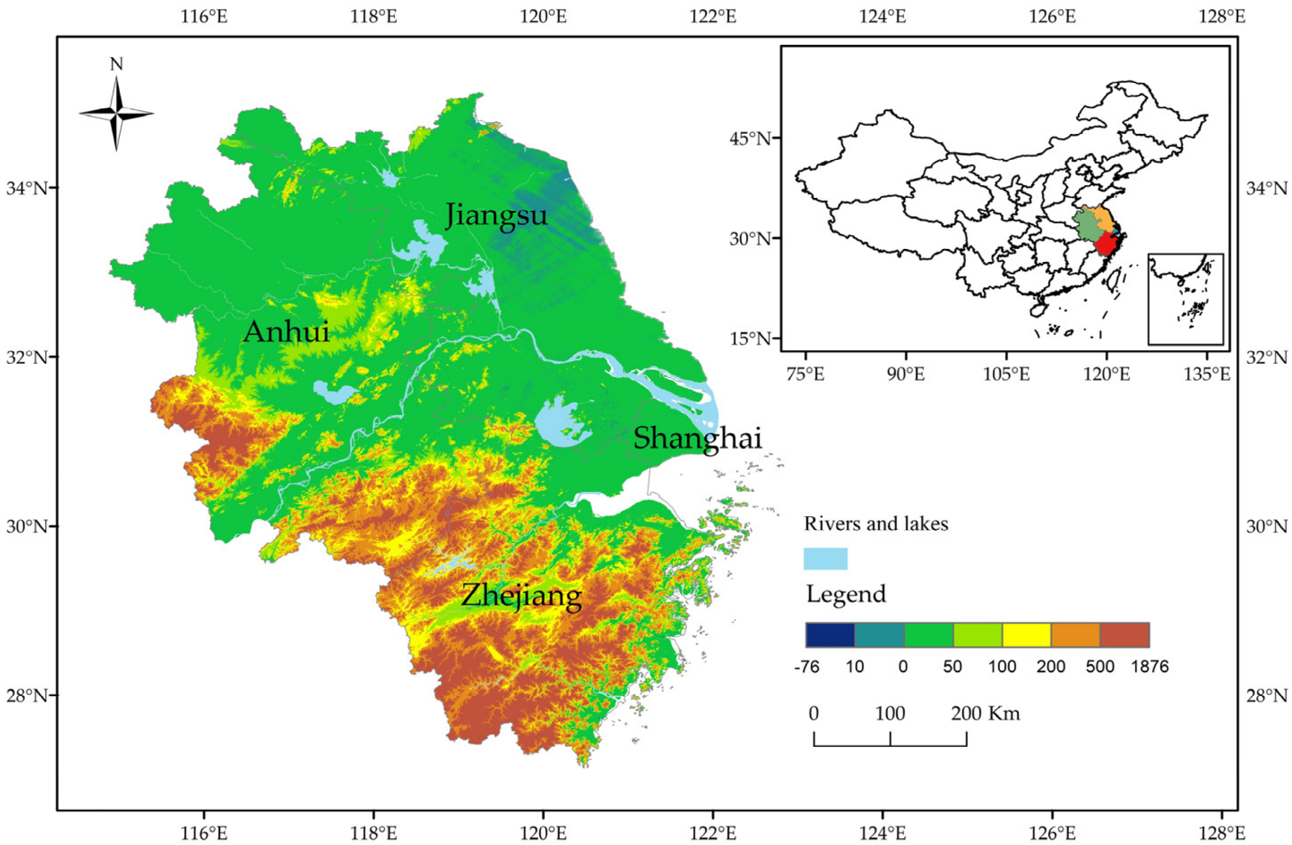

Figure 2. Map of the study area location.

3.2. Indicator System Construction

3.2.1. New-Type Urbanization Evaluation Indicator System

The formulation of an appropriate evaluation index system serves as the foundational basis for quantitatively assessing the degree of coordination between new-type urbanization and ecological environment coupling. This study builds an evaluation index system for the YRD's new-type urbanization and ecological environment. Guided by the principles of scientific rigor, representativeness, and data accessibility, the construction of this system relies on previous research findings [23–25].

Given the connotations and characteristics of new-type urbanization, economic development serves as a direct representation of new-type urbanization's high-quality development and functions as a material foundation for its consistent progression. This is a crucial aspect of quantifying the urbanization development level. Central to the notion of new-type urbanization is a 'people-oriented' approach, whereby strategic population expansion and the enhancement of population quality are vital to fostering healthy progression of this new-type urbanization type. The social benefits of new-type urbanization mainly manifest in the gradually decreasing income and consumption expenditure disparities between urban and rural areas. This evolution accelerated equal access to basic public services, enabling urban and rural residents to equally benefit from reform and developmental progress. Spatial urbanization represents the geographical manifestation of the urbanization process and encompasses the creation of urban entities that reflect modern civilization's characteristics and the enhancement of infrastructure such as transportation. The academic community generally agrees that new urbanization is a complex system involving population, economy, society, and spatial environment [26]. This study develops an evaluation system for new-type urbanization indicators across four dimensions—economic, population, social, and spatial—considering the above analyses. As shown in Table 1, each size was further subdivided according to specific secondary indicators. In the development of an indicator system for river delta urbanization and ecological environment, certain scholars have taken into consideration the influence of water resources management [27,28] and legal governance [29] on urbanization. However, due to constraints in data collection and processing, as well as the research focus of this discipline not encompassing these two aspects, they are not factored into the construction of indicators.

Table 1. New-type urbanization evaluation index system and weights.

	Standard Layer	Index Layer	Unit	Indicator Efficacy	Weight	
New urbanization	Economic urbanization	Per capita GDP	CNY	+	0.045	0.343
		The proportion of added value of the second and third industries to GDP	%	+	0.009	
		Total retail sales of social consumer goods	CNY	+	0.114	
		Average wage of employees	CNY	+	0.036	
	Population urbanization	Proportion of urban population	%	+	0.017	0.153
		Urban population density	person/km^2	+	0.038	
		Proportion of employees in the secondary and tertiary industries	%	+	0.005	
		Number of urban employees	people	+	0.092	
	Social urbanization	Proportion of education expenditure to fiscal expenditure	%	+	0.006	0.204
		Public library collections per 100 people	number	+	0.094	
		Number of hospital and health center beds per capita	number	+	0.072	
		Number of internet broadband access users	number	+	0.129	
	Spatial urbanization	Proportion of built-up area	%	+	0.116	0.300
		Green area per capita	m^2	+	0.069	
		Number of public toilets per 10,000 people in urban areas	number	+	0.133	
		Road area per capita	m^2	+	0.025	

'+' indicates that the indicator is positive.

3.2.2. Ecological Environment Evaluation Indicator System

The pressure-state-response (PSR) model, commonly employed in environmental quality assessment, has evolved into a comprehensive framework for examining environmental issues over time. This model elucidates the interplay between human productive activities and the ecological environment through a logical schema of 'pressure-state-response' [30–32]. Essentially, the PSR model addresses foundational queries pertaining to sustainable development. Pressure indicators reveal the environmental effects triggered by human economic and social activities. State indicators signify the condition of the environment and its evolution, while response indicators illustrate how society and individuals can undertake tangible actions to prevent, mitigate, and reverse the negative impacts human activities have on the environment. The specific indicators are presented in Table 2.

The statistical data utilized in this paper are sourced primarily from provincial and city statistical yearbooks, along with the China City Statistical Yearbook and the China City Construction Statistical Yearbook. Certain data sets involving the average land value and per capita average were computed from the raw data. Missing data points for certain variables were estimated by employing interpolation techniques from the data of adjacent years.

Table 2. Eco-environmental evaluation index system and weights.

	Standard Layer	Index Layer	Unit	Indicator Efficacy	Weight	
Ecological environment	Pressure	Industrial wastewater discharge	ton	–	0.056	0.328
		Industrial SO_2 emissions	ton	–	0.078	
		Industrial dust emissions	ton.	–	0.089	
		Proportion of environmental protection expenditure to fiscal expenditure	%	+	0.105	
	State	Green coverage rate in built-up areas	%	+	0.087	0.442
		Per capita land area	m^2		0.102	
		Expenditure on urban maintenance and construction funds	CNY	+	0.116	
		Water ownership per capita	m^3	+	0.137	
	Response	Industrial fumes removal	ton	+	0.161	0.230
		Integrated utilization rate of industrial waste	%	+	0.025	
		Domestic sewage treatment rate	%	+	0.018	
		decontamination rate of urban refuse	%	+	0.026	

'+' indicates that the indicator is positive. '−' indicates that the indicator is negative.

3.3. Research Methods

3.3.1. Entropy Weighting Method

The entropy weighting method is an objective weighting technique that facilitates balanced relations among evaluation indicators. This method leverages the dispersion within the data to assign weights to indicators, thereby effectively managing the intrinsic conflicts among the integrated criteria [33,34]. This approach circumvents the subjectivity inherent in the expert scoring method and mitigates the drawbacks of the principal component analysis method, such as outlier interference. Consequently, the entropy method yields objective and reasonable evaluation outcomes. The procedure involves the following steps:

(i) Standardize the indicators based on their respective characteristics using the extreme difference method.

X_{ij} is a positive indicator:

$$x_{ij} = \frac{a_{ij} - \min(a_{ij})}{\max(a_{ij}) - \min(a_{ij})}(i = 1, 2, \cdots, n; j = 1, 2, \cdots, m) \tag{1}$$

X_{ij} is a negative indicator:

$$x_{ij} = \frac{\max(a_{ij}) - a_{ij}}{\max(a_{ij}) - \min(a_{ij})}(i = 1, 2, \cdots, n; j = 1, 2, \cdots, m) \tag{2}$$

In the given expression, 'i' signifies the year, 'j' represents the indicator under consideration, 'X_{ij}' and 'x_{ij}' are the initial and standardized indicator values, respectively, 'max(a_{ij})' and 'min(a_{ij})' denote the maximum and minimum values of indicator 'j', respectively, 'n' is the number of years and 'm' is the total count of indicators.

(ii) Calculate the information entropy H_j of indicator j:

$$f_{ij} = \frac{x_{ij}}{\sum\limits_{i=1}^{n} x_{ij}} \tag{3}$$

$$H_j = -\frac{1}{\ln n}\sum_{i=1}^{n} f_{ij} \ln f_{ij} \tag{4}$$

The variable 'f_{ij}' represents the weight of year 'i' under indicator 'j', which is specific to that indicator. Additionally, 'H_{ij}' denotes the information entropy.

(iii) Calculate the weight of each indicator and the comprehensive evaluation index of each subsystem.

$$w_j = \frac{1 - H_j}{m - \sum\limits_{j=1}^{n} H_j} \tag{5}$$

$$I = \sum_{j=1}^{n} \left(w_j \times x_{ij} \right) \tag{6}$$

'w_j' signifies the weight of indicator 'j', and 'I' represents the composite evaluation index across different systems.

3.3.2. Coupling Coordination Model

This model facilitates the analysis of coordinated development levels among systems. Herein, the 'coupling degree' represents the dynamic correlation among two or more systems during interactive processes, while the 'coordination degree' signifies the harmony and consistency degree among systems during mutual development. This model encapsulates the mutuality and constrictions relationships between systems [35,36]. The specific coupled coordination model employed in this paper, pertaining to new-type urbanization and the ecological environment, is defined as follows:

$$C = \sqrt{\frac{U_1 \times U_2}{\left(\frac{U_1 + U_2}{2} \right)^2}} \tag{7}$$

$$T = a \times U_1 + b \times U_2 \tag{8}$$

$$D = \sqrt{C \times T} \tag{9}$$

In this framework, 'C' denotes the coupling degree, while 'U_1' and 'U_2' symbolize the comprehensive evaluation indices for the two systems. The coordination degree is represented by 'T', and the contribution coefficients are designated 'a' and 'b'. Given that new-type urbanization and the ecological environment hold equal importance for societal development, we have set $a = b = 0.5$. Additionally, 'D' is used to represent the coupling coordination degree. Informed by pertinent research findings [37,38], the coupling coordination degree is categorized into seven types, as outlined in Table 3.

Table 3. Classification of coupling coordination levels.

Coupling coordination	[0,0.3)	[0.3,0.4)	[0.4,0.5)	[0.5,0.6)	[0.6,0.7)	[0.7,1)
Type	Moderate disorder	Mild disorders	On the verge of disorder	Primary coordination	Moderate coordination	Advanced coordination

3.3.3. The Tobit Model

Given that the value of the coupling coordination degree is constrained within the (0,1) interval, constituting a restricted dependent variable, the Tobit model is frequently employed for estimation to circumvent the bias associated with ordinary least squares (OLS) estimation [39,40]. Consequently, to examine the influencing elements of the combined degree of new-type urbanization and the ecological environment, this study used a panel Tobit regression model, as outlined below:

$$y_{it} = \begin{cases} y_{it}^* = a_0 + \sum\limits_{t=1}^{n} b_k x_{it} + c_{it} & y_{it}^* > 0 \\ y_{it}^* = 0 & y_{it}^* \leq 0 \end{cases} \tag{10}$$

In Equation (10), 'i' and 't' symbolize the city and year, respectively, 'y_{it}' represents the dependent variable, and 'x_{it}' is the independent variable. The term 'b_k' denotes the regression coefficient of the independent variable, 'a_0' signifies the constant term, and 'c_{it}' corresponds to the random disturbance term.

4. Results and Discussion

4.1. Temporal Evolutionary Trends of New-Type Urbanization and the Ecological Environment

4.1.1. Temporal Evolutionary Trends of New-Type Urbanization

Table 1 reveals that economic urbanization has the highest weight (0.343) in the evaluation model, thereby contributing most significantly to new-type urbanization development. Spatial urbanization follows next with a weight of 0.300. These findings suggest that economic advancements and spatial expansion serve as the primary drivers of growth in the YRD, a region characterized by rapid economic development. Such growth provides robust material conditions for the construction of new-type urbanization areas, with spatial development and construction processes supporting the advancement of urban infrastructure. Conversely, population urbanization and social urbanization rank third and fourth, respectively, with corresponding weights of 0.204 and 0.153. Their less substantial roles in promoting new-type urbanization in the YRD suggest that population and social urbanization lag behind their economic and spatial counterparts. Hence, government agencies and related departments should enhance their focus on population mobility and social benefits. In formulating regional and urban development policies, the government is obliged to orchestrate balanced development among the economic, spatial, population, and social sectors.

Figure 3 illustrates that the comprehensive evaluation results range from 0.374 to 0.486, indicating a discernible upward trend in the level of new urbanization, consistent with the research findings of Xu Xue [41]. From 2009 to 2021, all four urbanization indicators, economic, population, social, and spatial, exhibited concurrent growth. This growth suggests an intensive, efficient shift in economic development during the promotion of new-type urbanization in the region. Concurrently, the rural population is increasingly concentrating in cities and towns, the industrial structure is optimizing progressively, the employment structure is urbanizing, and both the quality of public service construction and urban planning and management are experiencing parallel improvements. Among these, economic urbanization witnessed the most substantial development, escalating from 0.082 to 0.306, which underscores YRD's economic vibrancy within China, thereby setting the stage for higher quality urbanization. Conversely, spatial urbanization progressed at the slowest pace, advancing only from 0.098 to 0.127, likely due to the advanced development of most cities in the region, characterized by a high rate of spatial exploitation and a slower rate of urban spatial expansion.

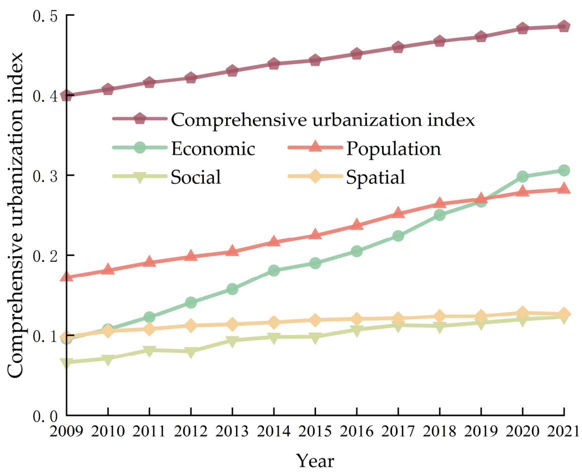

Figure 3. Temporal evolution of new-type urbanization in the YRD from 2009 to 2021.

4.1.2. Time-Series Evolution Trend of the Ecological Environment Index

Table 2 reveals that within the ecosystem evaluation system, the state of the ecological environment carries the greatest substantial weight at 0.442, followed by ecological pressure, at 0.328. Therefore, state and pressure are the predominant factors influencing the ecological environment in the YRD. Amid economic growth and urbanization, maintaining a dynamic equilibrium of the ecological environment is vital. If industrial production's resource consumption and pollutants, such as wastewater and exhaust gases, severely impact the ecological environment beyond the ecosystem's self-regulating capacity, the original stability cannot be regained. Consequently, urbanization threatens the health of the environment, impairing its structure and function. Among the indicators measuring the ecological environment's state, per capita water possession is paramount, accounting for 0.137%. With an increase in environmental pressure, this indicator necessitates heightened attention to enhancing the town's green environment. While the ecological response indicator ranks third within the system, its weight is very close to that of the state indicator.

Figure 4 shows that the comprehensive ecological environment development index of the YRD fluctuated between 0.581 and 0.701 from 2009 to 2021. Overall, despite the cyclic pattern, there is a discernible upward trend in the ecological environment quality within this region, which corroborates the findings of Liu et al. [42]. From 2009 to 2010, an upward trajectory was observed, while 2011 to 2016 featured a period of decline followed by improvement, and the 2017 to 2021 interval showed an initial increase and subsequent slight decrease. When considering the three eco-environmental effect indicators, they mirror the comprehensive eco-environmental development index, which displays an overall increase by the end of the study period compared to its beginning. Specifically, the YRD experienced a notable surge in urban environmental pressure and resource and energy consumption during the study. However, the ecological and environmental quality improved due to factors such as heightened expenditures on environmental protection, increased pollutant treatment efficiency, and intensified efforts in environmental treatment and ecological protection.

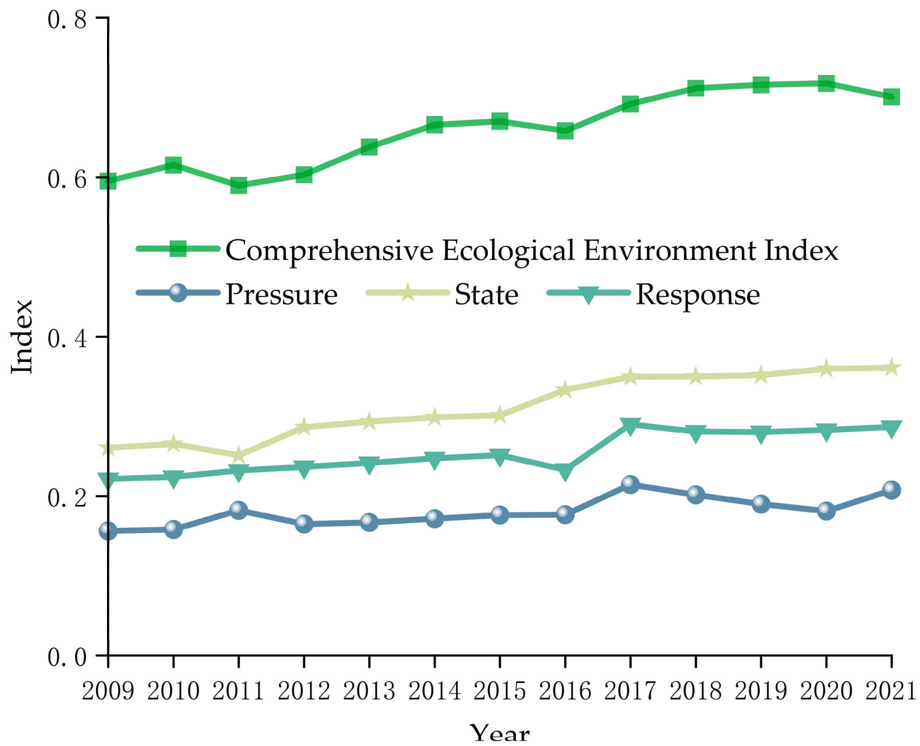

Figure 4. Temporal development of the ecological environment of the YRD from 2009 to 2021.

4.2. Analysis of the Coupling Coordination Degree between New-Type Urbanization and the Ecological Environment

4.2.1. Time-Series Analysis

Table 4 reveals that the fluctuating coupling coordination degree ranges between 0.4 and 0.7. From 2009 to 2013, the mean coupling coordination value increased from 0.521 to 0.542. Notably, several cities, including Jiaxing, Lianyungang, Suqian, Anqing, Huangshan, Xuancheng, and Bozhou, transitioned from near-disorder to primary coordination. Additionally, Chuzhou and Chizhou bypassed near-disorder to primary coordination, attaining intermediate coordination. Conversely, Jinhua, Lishui, and Luan declined from primary coordination to a near-dissonance stage. Between 2013 and 2017, the average coupling coordination level fell from 0.542 to 0.514. During this period, 16 cities underwent changes in their coupling coordination levels within the neighboring coordination interval, without any abrupt shifts. Notably, Zhenjiang advanced from near-dissonance to primary coordination. According to the 2021 data, compared to that in 2017, the average coupling coordination degree increased from 0.514 to 0.540. Twenty-five cities exhibited a shift in their coupling coordination levels. Among these, Ningbo experienced the most significant increase, moving from 0.421 to 0.623 and reaching intermediate coordination. Similarly, several cities, including Shanghai, Zhoushan, Hangzhou, Jiaxing, and Jinhua, elevated their coupling coordination levels. However, in cities such as Shaoxing, Zhenjiang, Huainan, Quzhou, and Suqian, the coupling coordination levels decreased. Comparing the study endpoint to the initial value, the coupling coordination degree in the YRD increased from 0.521 in 2009 to 0.540 in 2021. This shift is intimately associated with the pace of new-type urbanization and the intensity of ecological environmental protection. Notably, the increase in the coupling coordination degree in Ningbo, Chuzhou, Bozhou, Shanghai, and Huangshan was greater than 0.1. Shanghai, renowned as China's most developed city, demonstrated increased coupling coordination. The city's extensive ecological space capacity, robust ecological advantages, and high-quality new-type urbanization development facilitated this increase. Similarly, Ningbo's eco-economic development model results in less pressure on the ecological environment. With their lower levels of new-type urbanization and comparatively lower consumption of resources and the environment, cities such as Chuzhou, Bozhou, and Huangshan exhibited a rapid increase in coupling coordination. On the other hand, Lishui, Huabei, Huainan, Shaoxing, and Xuzhou showed notable decreases in their coupling coordination degrees. This was due to accelerated urban expansion and the indiscriminate pursuit of higher urbanization rates, which caused significant damage to the ecosystem and a reduction in urban green spaces [43].

Figure 5 highlights the trends in the number of cities with varying degrees of coupling and coordination between new-type urbanization and the ecological environment in the YRD. Generally, the trend suggests an encouraging pattern. Specifically, the number of cities on the brink of disorder in terms of coupling and coordination first experienced a decline, then returned to the initial 2009 level in 2017, and subsequently experienced a reduction of half from 2017 to 2018. In 2009, 25 cities had a coupling coordination degree surpassing 0.5, indicating a state of primary or superior coupling coordination and constituting 61.0% of all the cities in the YRD. By 2021, the number of cities exhibiting a primary or higher state of coupling coordination increased to 29, representing 70.7% of the total cities in the study area. Overall, the coupling and coordination between new-type urbanization and the ecological environment in the YRD have steadily improved. The overarching developmental trajectory leans toward an escalation in the degree of coupling and coordination.

Table 4. Coupling coordination degree in YRD cities from 2009 to 2021.

City	2009	2013	2017	2021	City	2009	2013	2017	2021
Shanghai	0.556	0.587	0.569	0.656	Yangzhou	0.565	0.576	0.501	0.594
Hangzhou	0.510	0.527	0.460	0.530	Zhenjiang	0.484	0.496	0.524	0.497
Ningbo	0.464	0.467	0.421	0.623	Taizhou	0.593	0.582	0.530	0.604
Wenzhou	0.564	0.575	0.503	0.521	Suqian	0.479	0.571	0.623	0.506
Huzhou	0.478	0.483	0.440	0.489	Hefei	0.546	0.530	0.515	0.626
Jiaxing	0.496	0.517	0.448	0.506	Wuhu	0.444	0.432	0.403	0.453
Shaoxing	0.558	0.563	0.525	0.476	Bengbu	0.494	0.490	0.491	0.540
Jinhua	0.534	0.419	0.488	0.542	Huainan	0.578	0.566	0.536	0.496
Quzhou	0.593	0.563	0.636	0.588	Maanshan	0.553	0.524	0.516	0.565
Zhoushan	0.635	0.633	0.590	0.664	Huaibei	0.552	0.533	0.521	0.472
Taizhou	0.530	0.529	0.489	0.549	Tongling	0.522	0.506	0.470	0.553
Lishui	0.512	0.494	0.436	0.466	Anqing	0.477	0.586	0.535	0.463
Nanjing	0.507	0.519	0.480	0.545	Huangshan	0.488	0.592	0.596	0.578
Wuxi	0.542	0.508	0.538	0.557	Fuyang	0.437	0.475	0.421	0.491
Xuzhou	0.641	0.628	0.578	0.533	Suzhou	0.532	0.542	0.618	0.566
Changzhou	0.544	0.557	0.469	0.566	Chuzhou	0.436	0.610	0.576	0.569
Suzhou	0.573	0.615	0.568	0.599	Luan	0.513	0.496	0.474	0.520
Nantong	0.459	0.469	0.416	0.481	Xuancheng	0.489	0.591	0.565	0.458
Lianyungang	0.495	0.511	0.448	0.511	Chizhou	0.478	0.652	0.542	0.477
Huaian	0.536	0.550	0.506	0.563	Bozhou	0.448	0.596	0.577	0.548
Yancheng	0.521	0.579	0.526	0.587	Average	0.521	0.542	0.514	0.540

Note: [light orange] Indicates an enhancement in the coupling coordination relative to the preceding research year. [light blue] Indicates a reduction in the coupling coordination relative to the preceding research year.

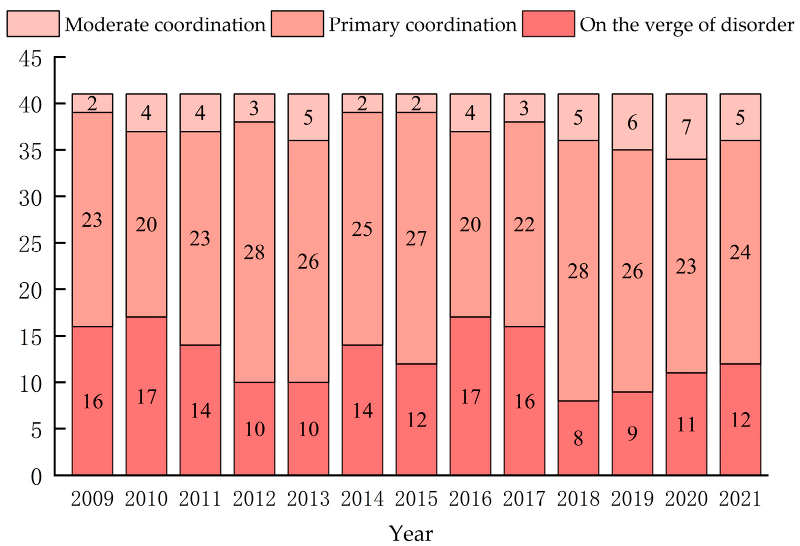

Figure 5. Trends in the coupling and coordination of new-type urbanization and the ecological environment in the YRD from 2009 to 2021.

4.2.2. Spatial Analysis of the Coupling Coordination Degree

Figure 6, based on a time-series analysis, illustrates the spatial distribution pattern of the coupled and coordinated development between new-type urbanization and the ecological environment across 41 cities in the YRD throughout the study period, as depicted through ArcGIS 10.2 software. This graphic representation delineates distinct spatial distribution features in the coupled coordination of new-type urbanization and the ecological environment within the YRD. Specifically, Wenzhou, Wuxi, Huai'an, Yancheng, Yangzhou, and Maanshan consistently exhibited primary coupling coordination in 2009, 2013, 2017, and 2021. Conversely, Huzhou, Nantong, and Fuyang hovered on the brink of dislocation between 0.4 and 0.5 throughout the selected years, necessitating careful developmental scrutiny during new-type urbanization promotion. In 2009, only Zhoushan and Xuzhou attained intermediate coordination, with cities reaching primary coordination primarily clustered in the northern and southern regions of Anqing, Chizhou, Xuancheng, Chaozhou, and Jiaxing and proximal to the provincial capital. By 2013, most cities had achieved primary coordination or above, leaving only 10 cities on the verge of dislocation. This showcases the radiant influence of cities, with those achieving primary coordination initially prompting neighboring cities toward similar states through the export of skilled individuals and advanced technology. The number of cities attaining intermediate coordination increased to five, exhibiting a scattered distribution predominantly across the northern and central areas of the YRD. However, as new-type urbanization progressed, the number of cities achieving intermediate coordination decreased to three by 2017: Suzhou, Suqian, and Quzhou. Furthermore, the coupling coordination level in Zhoushan, Xuzhou, Suzhou, Chuzhou, and Chizhou decreased, transitioning from intermediate to primary coupling coordination. This might be attributed to an unregulated pursuit of urban expansion during new-type urbanization construction. By 2021, the aforementioned cities failed to maintain their intermediate coordination level, which was superseded by Hefei, Taizhou, Shanghai, Ningbo, and Zhoushan. As urban development models become increasingly scientific and rational and the concept of sustainable development permeates the urbanization process, the number of cities on the brink of dislocation decreases to 12. In conclusion, the increase in the coupling and coordination level between new-type urbanization and the ecological environment in the YRD commenced, signifying the emergence of a trend toward coordinated regional development. However, it is crucial to consider the relationships between urban development and the carrying capacity of resources and the environment to prevent escalation of atmospheric, water, and soil pollution induced by the pursuit of higher urbanization rates.

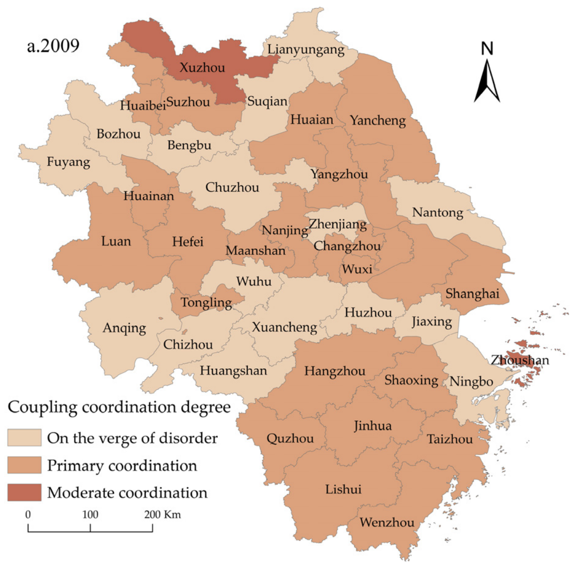

Figure 6. *Cont.*

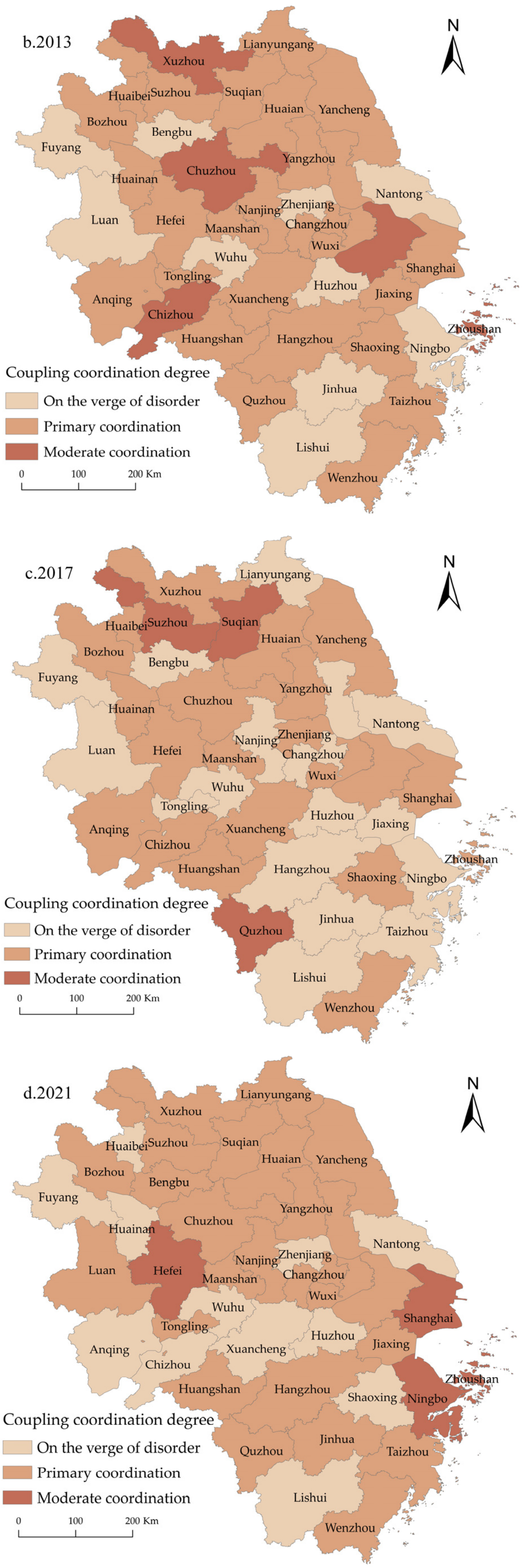

Figure 6. Spatial distribution of the coupling coordination degree in the YRD from 2009 to 2021. (**a**–**d**) represent the years 2009, 2013, 2017, and 2021, respectively.

4.3. Factors Influencing the Change in Coupling Coordination

4.3.1. Selection of Indicators of Influencing Factors

We chose particular variables to explore the influences of coupling and coordination between new-type urbanization and the natural environment, considering the specific development context of the YRD, building on prior studies and analyses of influencing mechanisms [44–47]. ① Economic development level (eco): Economic growth has a considerable impact on infrastructure construction, pollution emissions, and treatment. It is the critical factor impacting new-type urbanization and the ecological environment. The urban GDP per capita serves as a proxy for this. ② Technological progress (tech): Scientific and technological developments directly related to regional R&D expenditures can help reduce pollution and increase treatment standards. The ratio of spending on research and technology to overall public spending is used to express this. ③ Industrial agglomeration (indu): Increasing industrial agglomeration increases the effectiveness of resource allocation and production. This is determined using location entropy. First, the ratio of employment in secondary and tertiary industries to all work in each city and the balance of jobs in secondary and tertiary sectors to engagement in the YRD are determined. To determine the degree of industrial agglomeration in the YRD, the former is divided by the latter. ④ Openness to the outside world (openness): A higher level of transparency encourages the flow of production elements, increases the caliber of public services, and modifies the spatial arrangement of industries. The number of actual foreign investment cities in a given year is used as a proxy for this variable. ⑤ Investment in education (edu): Promoting modern urbanization requires educated and skilled high-quality talent because workers are carriers of innovative technology. The percentage of education spending in total spending is a proxy for this. ⑥ Level of information (info) The number of people who use internet broadband access suggests that as informatization grows, it can enhance the effectiveness of information flow and encourage interconnection.

4.3.2. Tobit Model Regression Results

To further investigate the factors affecting new-type urbanization and the ecological environment in the YRD, we employed a random effects panel Tobit regression model estimated using Stata 16.0 software. The outcomes of this analysis are presented in Table 5.

Table 5. Tobit model regression results.

Variable	Coefficient	Standard Error	Z Value	*p* Value
constant	0.657	0.068	9.681	0.000 ***
eco	0.105	0.011	9.104	0.000 ***
tech	0.338	0.078	4.353	0.000 ***
indu	5.862	2.079	2.820	0.005 **
open	0.144	0.056	2.571	0.010 **
edu	0.227	0.042	5.414	0.000 ***
info	0.342	0.212	1.613	0.107

Note: The symbols '*', '**', and '***' denote significant variables at the 10%, 5%, and 1% levels, respectively.

With a value of 0.105, the economic development level coefficient was significant at the 1% level, indicating a favorable effect on the coupling coordination degree. This shows that as economic development levels rise, additional resources are being made available in the form of money and other materials to promote new-type urbanization and ecological and environmental protection simultaneously [48–50]. This development steers the latest state of urbanization toward high-quality development, where the needs of production, lifestyle, and ecology are harmoniously addressed. It also helps to reduce the friction between new-type urbanization and the ecological environment.

Technology's regression coefficient was 0.338, which was significant at the 1% level. A logical flow of production factors between various industries is encouraged by technological advancement, which also enhances resource use efficiency and reduces ecological and environmental losses. On the one hand, this helps the manufacturing industry transform and upgrade, phasing out high-energy-consuming and low-tech industries and reducing environmental impact. As a result, new-type urbanization and the ecological environment are increasingly coupled and coordinated due to technological advancement.

With a significant coefficient of 5.862 at the 5% level, industrial agglomeration positively impacts the coupling and coordination between new-type urbanization and the ecological environment in the YRD. This shows that when the industrial layout consolidates, the advantages of aggregation become more apparent. The spread of environmentally friendly and energy-efficient technologies across regions is bolstered by industrial agglomeration, which lowers pollutant emissions and promotes factor movement among local businesses. As a result, there is a tendency for harmony in the interplay between modern urbanization and the natural world.

At the 10% level, external openness produced a significant coefficient of 0.144, indicating a favorable influence on the status of connection and coordination. The YRD is a crucial entry point for China's relationships with the outside world. By stimulating the transformation and modernization of the industrial structure, fostering emerging industries, and diversifying the development of new-type urbanization, the cutting-edge technology and knowledge generated by foreign capital can increase labor productivity and promote the coexistence of new-type urbanization with the natural environment.

The regression coefficient of education investment is 0.227, demonstrating a positive effect on the enhancement of coupling coordination at the 1% significance level. An increase in education investment enhances the synergy between new-type urbanization and the ecological environment. Such investment can foster high-quality talent, which is crucial for new-type urbanization, maximizing human resource advantages and elevating the efficiency and quality of urbanization operations [51]. Moreover, higher education investment can improve the quality of life of people, facilitating their adoption of new technologies and methods and helping them boost their environmental awareness and motivation via informal environmental regulations, thereby furthering the synergy between new-type urbanization and the ecological environment.

The informatization level coefficient is positive, albeit insignificant. Although higher informatization levels can foster industrial structure upgrading, enhance public service levels, advocate rational urban spatial planning through contemporary information technology, and amplify the ability to monitor ecological and environmental information, the coupling and coordination degree of new-type urbanization and the ecological environment are potentially insensitive to alterations in the informatization level. This could be attributed to the advanced state of informatization in the YRD.

4.4. Discussion

The present study investigates the spatiotemporal distribution and influencing factors of the coupling and coordination between new urbanization and natural environment in the urban agglomerations of the Yangtze River Delta. Building upon prior research, this paper conducts a more precise and focused analysis of the coupling and coordination effects of urbanization on the natural environment. An understanding of the economic and ecological challenges facing the region, coupled with tailored policy recommendations, can secure its enduring leadership in national development. Due to limitations in the acquisition and processing of data, this paper selects four primary dimensions for measuring new urbanization indicators, but it is not as comprehensive as existing research. Therefore, future studies could consider expanding the construction of the assessment index system to encompass five to six aspects in order to provide a comprehensive description of the development status of new urbanization. Numerous factors influence the coupling and coordination of new urbanization and ecological environment, with certain potential influencing factors posing challenges in identification and quantification, leading to deviations in the analysis results. Subsequent studies will further refine these influencing factors, proposing more targeted optimization strategies for the coupling and coordination of new urbanization and ecological environment from diverse perspectives. Finally, in future research, economic geography theory and spatial econometrics models can be utilized to explore the correlation and spatial impact of the coupling coordination between new urbanization and ecological environment across cities. This will provide a broader perspective on the spatial disparities in the level of coupling and coordination between these two factors.

5. Conclusions

5.1. Conclusions

This article employs data from 41 cities in China's YRD to construct and evaluate a new-type urbanization and ecological environment index system. We used the entropy weight method, coupling coordination degree model, and panel Tobit model to analyze the coupling coordination degree of the two variables and their influencing factors. The primary findings of the study are as follows:

(1) Between 0.374 and 0.486 are used to evaluate the new-type urbanization level in the YRD, which shows an overall increase during the study period. Among the subindicators, economic, population, social, and spatial urbanization experienced concurrent expansion, with economic urbanization showing the most significant increase. In the evaluation model, economic urbanization is given the most weight, and, along with spatial urbanization, it makes a considerable contribution to new-type urbanization. These results imply that the new-type urbanization in the YRD is primarily driven by a rapid increase in economic status and a constant increase in geographic area. The overall development index for the ecological environment evaluation varied from 0.581 to 0.701, revealing a cyclical development pattern in flux. Calculations of indicator weights show that state and pressure have the most significant effects on the region's ecological environment.

(2) The spatiotemporal analysis of the coupling coordination degree indicated a general improvement across the study period, with the average value increasing from 0.521 in 2009 to 0.540 in 2021. Three stages make up the urban coupling coordination level: near chaos, primary coordination, and intermediate coordination. Cities such as Lishui, Huaibei, and Huainan have experienced relative reductions in coupling and coordination, whereas cities such as Ningbo, Chuzhou, and Bozhou have seen considerable improvements. In light of recent urbanization, these cities must prioritize their relationships with the ecological environment. According to the study period's regional distribution, there are noticeable high and low zoning and clustering features in the YRD, as well as strong spatial nonequilibrium characteristics. High coupling coordination areas exhibit an 'increasing-decreasing-increasing' trend, whereas low coupling coordination areas exhibit the opposite trend. Overall, even though it is anticipated that most cities will achieve primary coordination by 2021, there is still a need to strengthen environmental and ecological protection as part of the process of new-type urbanization to prevent relapse into an impending state of disorder.

(3) Regarding influencing elements, the degrees of economic development, technological advancement, industrial agglomeration, external openness, and education investment all passed the significance test. According to the regression analysis, these five parameters and the degree of connectivity between new-type urbanization and the ecological environment were positively correlated. These findings imply that these factors promote the coordinated and interconnected development of urbanization and the environment. Therefore, these elements should be the main focus of governments' new-type urbanization initiatives. However, the correlation test was unsuccessful for the level of information technology. At all levels, governments should identify the key influencing factors on the degree of coupling and coordination to determine the proper policy emphasis to further improve the coupling and coordination of new-type urbanization and the natural environment.

5.2. Policy Implications

To foster the coordinated development of YRD cities and to actualize the integrated construction of the YRD city cluster, this study considers the above analysis and conclusions in addition to the specific circumstances of the cities within this region and proposes the following policy recommendations:

(1) The emergence of new-type urbanization represents a turn toward sustainable development and is strongly related to China's quest for high-quality growth. In the future, our efforts should focus on achieving high-quality development in this new-type urbanization area along with strong ecological and environmental protection. YRD should support a green development trajectory that involves passionately advancing green products and technology while promoting industries that are resource-, energy-, and environmentally friendly. For the purpose of facilitating industrial upgrading and transformation and creating contemporary governance, regions should also support the growth of emerging industries and strengthen the influence of the digital economy on conventional sectors. An effective strategy for ecological conservation in the YRD involves making the best use of ecological space to increase the carrying capacity of resources and the environment. Integrated ecological system innovation should be strengthened, urban defense and pollution control should be coordinated, and a complete green transformation of the economy and society should be promoted as additions to this plan.

(2) Cities that are now in the primary and intermediate levels of coupling and coordination must integrate their achievements in green development into the new urban environment and ecological context. Strict adherence to ecological red lines, strict regulation of urban development land, growth in the percentage of ecological land, and optimization of spatial land patterns are all required for this process. Along with the establishment of organizations and processes for cross-city watershed cooperation and coordination, a platform for the cooperative exchange of river, air, and soil monitoring data must be created. By leveraging the influence of areas with high coupling and coordination, this project will encourage information collaboration across regions, industries, and businesses. Government dynamics should be actively used in cities that are on the verge of collapse, embracing the idea of people-centric urbanization. The standards for public services and infrastructure development should increase, the rate of application and transformation of scientific and technological advancements should increase, and innovation should be used as a catalyst for high-level new-type urbanization. It is crucial to strengthen ecological compensatory mechanisms, increase resource and environmental utilization effectiveness, and accelerate the development of cities' and towns' spatial carrying capacities.

(3) It is essential to improve public support infrastructure, commerce and distribution networks and the synergistic effects of other driving variables. This strategy should promote the growth of industrial clusters and the smooth movement of factors. To encourage the population to congregate, it is advised to actively build a modern industrial system, support pillar industries, and use industrial clustering. Cities are urged to increase education spending; increase the effectiveness of basic and higher education input and output; deepen the integration of R&D, production, and learning; and improve the caliber of their labor forces. The knowledge creation and factor distribution capabilities of YRD cities such as Shanghai and Hangzhou should simultaneously increase the capacity to transform original innovation and scientific and technological achievements and maximize the use of resources and energy through innovative technologies. Along with the active development of foreign power, a larger area and a higher level of openness should be promoted. This strategy addresses issues such as inadequate information exchange between cities and the ineffective movement of resources and forces.

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