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Is China's Urbanization Quality and Ecosystem Health Developing Harmoniously? An Empirical Analysis from Jiangsu, China

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Abstract: The relationship between urbanization and ecology environment is a current research hotspot. Most literature to date focuses on the interaction between urbanization and a single component of the ecosystem (e.g., water, forests, and ecosystem services), while little attention has been given to the relationship between urbanization quality and ecosystem health. Accordingly, this paper used the entropy method and vigor—organization–resilience model to measure the urbanization quality and ecosystem health in Jiangsu Province. Based on the results, this paper analyzed the spatial-temporal pattern and evolution characteristics of the coordination degree between urbanization quality and ecosystem health in Jiangsu Province in 2000, 2005, 2010, 2015, and 2017 and then used the geographic detector and Tobit regression model to explore its internal driving forces and external influencing factors. The results show the following: 1. The changing trend of urbanization quality and ecosystem health in the Jiangsu Province share some traits; it first descends and then ascends; 2. The cities in Jiangsu Province are all between primary coordination and high-quality coordination. Central Jiangsu has the best coupling coordination degree, and Northern Jiangsu has the worst coupling coordination degree, but the overall coordination degree is on the rise; 3. The internal and external factors that drive the coordinated development of urbanization and ecosystem health differ based on periodic and regional characteristics. We need to tailor policies to ensure the sustainable development of the region.

Keywords: Jiangsu; urbanization quality; ecosystem health; coordination level; influencing factors

1. Introduction

In the process of urbanization, population agglomeration and land expansion have typically fragmented single, homogeneous, continuous natural habitats, devastated species composition, damaged the stability and interconnectivity of urban structures, and affected urban ecosystem service functions. The increased population and living density trigger problems, such as pollution discharge and resource consumption, which reduce an ecosystem's metabolism and primary productivity. Furthermore, economic urbanization induces changes in the industrial structure, which consumes more resources and energy to improve the overall economy. The pressure thus mounts on the landscape mosaic, which makes the landscape unable to maintain its original structure and function in response to external stress. This especially occurred in China, which has experienced the largest and fastest urbanization process in history [1–3] and accomplished the achievements of urbanization in only a few dozen years, which took the developed countries a century to achieve. While this pattern of rapid development has yielded massive growth in China's economic and social public resources, it has conversely damaged the balance of urban ecosystem health. Presently, "the harmonious coexistence of human beings and nature" is a common goal

pursued by the whole world [4]. Exploring the way of coordination between urban development and ecological protection is a pressing and difficult issue of common concern for academics and government departments alike [5,6].

Existing literature on the relationship between urbanization and the ecological environment mainly focuses on two areas. One is to treat the ecosystem as a static object, using panel data of relevant natural elements of the administrative unit to explore the characteristics of relationship with urbanization [7–9]. Studies have shown that the coupling coordinated degree exhibits an "S"—type curve, with a continuous upward trend over time. Some scholars have also noted instances of decoupling between the two, in which there is a trend of deterioration first then followed by improvement over time. The other one is to concretize the ecological environment in terms of a particular resource (e.g., water, forest, and air), the carrying capacity, or ecosystem services to explore changes during urbanization [10–12]. For example, every 40% expansion of urban land has been found to double increases in the heat index in some areas. Similarly, extreme rainstorm events are more likely to occur in cities. With every 1% increase in built-up land, the ecosystem services decrease by 1.04%. Nonetheless, while previous literature has addressed the relationship between urbanization and ecology from various perspectives, little work has focused on the relationship between urbanization quality and ecosystem health.

Research on urbanization started earlier in Europe and the US than in China, but as that research did not employ a concept that coincides with urbanization quality, there are fewer directly relevant studies. Comparable studies are not uncommon, however, there are studies such as Diener E. and Suh E. (1997) [13], who evaluated the human living quality in three dimensions: economic, social, and subjective; UN-HABITAT (2002), who measured the urban development index and developed the Global Urban Indicator Database [14], and Irene van Kamp et al. (2003), who analyzed urban (quality) development in terms of the conceptual framework of environmental quality and living quality [15]. Despite research on urbanization commencing later in China, investigations on urbanization quality are relatively concentrated [16–18]. Combining the existing academic consensus on the concept of urbanization with China's core requirements for high-quality urban development, a five-dimensional urbanization quality assessment system of "population–economy–society–land–ecology" was constructed for this study.

The concept of ecosystem health was first proposed by Rapport et al. in 1985 [19], who argued that a healthy urban ecosystem should be vibrant, stable, sustainable, and able to maintain organizational structure and self-recovery under external pressure, by incorporating deep research from different disciplinary backgrounds, evaluating ecosystem health by integrating ideas from ecology, the humanities, social economy, and other fields. Therefore, it is much more difficult to assess the intact condition of urban ecosystems. There does not exist an absolute or fixed standard for the urban ecosystem because of the uncertainty caused by the complexity and openness of the urban ecosystem as well as changing human needs, targets, and expectations of the urban ecosystem over time. Different evaluation systems can be constructed based on different indicators and models. Indicators cover economic, social, and ecological attributes such as ecological sustainability, social equity, public health, and effective community management [20,21]. However, the aim of all the indicators is to improve human well-being. Models included the vigor–organization–resilience (VOR) model [22], fuzzy synthetic assessment model [23], set-pair model [24], and press–state–response (PSR) model [25]. The VOR model was chosen for this study. It is universal and suitable for assessing the ecosystem health of any different type and different scale, such as plains [26], plateaus [27], coastal areas [28], etc. [29–31]. Compared with other assessment models, it is measured by microscale patches. Thus, it can better describe the process of ecological environment change, the state of ecosystem service functions, and the effect of spatial adjacency on neighboring ecosystems through landscape spatial patterns. Moreover, this approach can compensate for the general lack of a dynamic microscale perspective in the existing literature.

This research used an urbanization quality evaluation system involving five dimensions (population–economy–society–land–ecology) and the ecosystem health evaluation system involving three aspects (vigor–organization–resilience). The spatiotemporal differentiation characteristic of coordinated development of urbanization quality and ecosystem health during 2000–2017 was studied through the coupling coordination model. The coefficient of elasticity was introduced to analyze coupling types of Jiangsu (overall and in parts). The internal driving forces and external influencing factors affecting the coupling coordinated development between urbanization quality and ecosystem health were also explored by the coefficient of variation method and Tobit regression models. This study explores whether and how the urbanization quality and ecosystem health can develop in harmony. The results can enhance sustainable policymaking.

2. Study Area, Data Sources, and Research Methods

2.1. Study Area

Jiangsu, which is in the eastern coastal area of China (Figure 1), is an important part of the Yangtze River Delta and one of the provinces with the highest comprehensive development level in China. By 2019, the urbanization rate of Jiangsu reached 70.61%, ranking fifth in China; its gross domestic product (GDP) (9865.68 billion) ranked second in China [32], which is equivalent to the level designated as "middle and upper class" in developed countries. There are 13 prefecture-level cities in Jiangsu Province, divided into 3 regions: southern, central, and northern. Southern Jiangsu includes five cities (Nanjing, Zhenjiang, Changzhou, Suzhou, and Wuxi). Central Jiangsu has three cities (Nantong, Taizhou, and Yangzhou) and is the least populated of the three regions. Northern Jiangsu has five cities (Xuzhou, Suqian, Huai'an, Lianyungang, and Yancheng). The GDP contribution by southern Jiangsu accounts for more than half of the entire province. While the average population of northern Jiangsu being the same as that of southern Jiangsu, its GDP contribution only accounts for one-fifth of the whole province. The per capita GDP of northern Jiangsu is only one-fourth of the per capita GDP of southern Jiangsu.
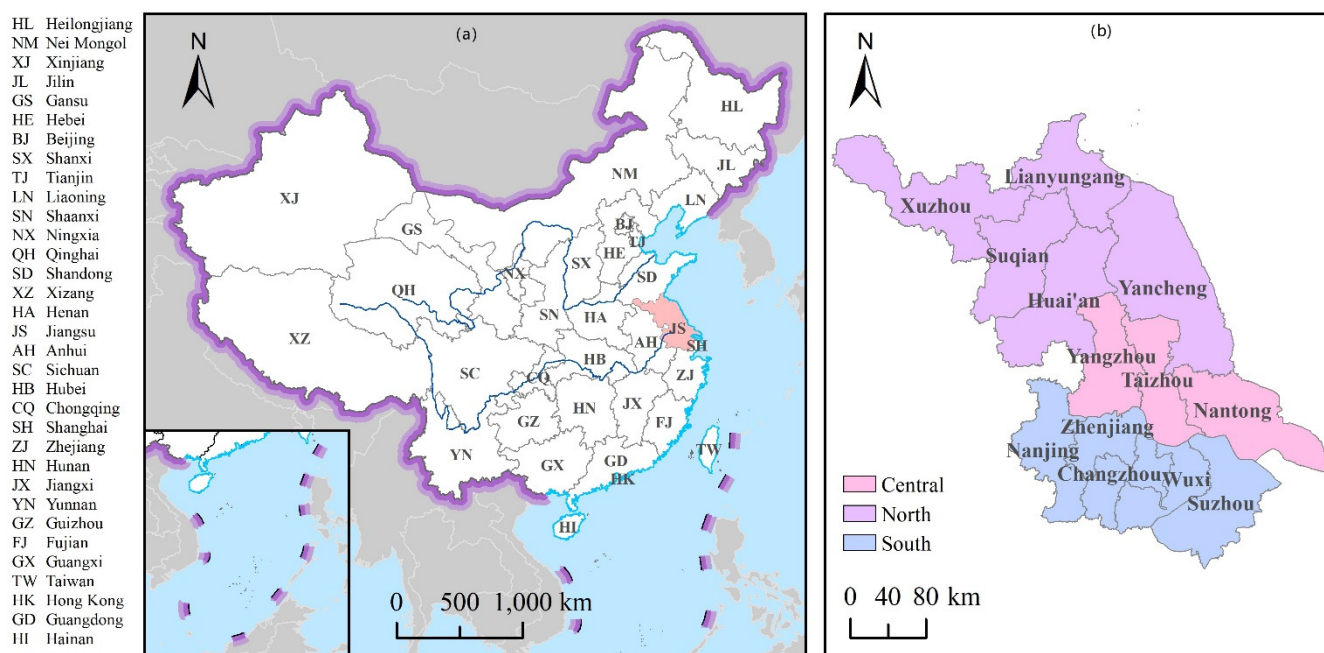

Figure 1. (**a**) Location of the Jiangsu Province; (**b**) three regions in the Jiangsu Province.

2.2. Data Source

The data sources used in this study are listed in Table 1.

Table 1. Data sources.

Data Set	Data Classification	Source	Year	Type	Scale	Purpose
Socio-economic data	Urbanization evaluation factors	"China city Statistical Yearbook", "Jiangsu statistical yearbook", and statistical yearbooks of cities and counties	2000/2005/2010/2015/2017	Form	City	Assess urbanization quality
Land use classification data	Farmland, construction land, forest, grassland, water, unused land	National Earth System Science Data Sharing Platform-Yangtze River Delta Science Data Center, Natural Resources Department of Jiangsu Province Resources and Environment Data Center of Chinese Academy of Sciences, National Earth Science Data Center Google Earth Engine	2000/2005/2010/2015/2017	Vector.shp	1:100,000	Auxiliary statistics of socio-economic data and fine-scale spatial expression of ecosystem health
Remote sensing image data	NDVI		2000/2005/2010/2015/2017	Raster data	30 m × 30 m	Analysis ecosystem health

2.3. Study Methods

2.3.1. Urbanization Quality Evaluation System

Various scholars view urbanization as a process of transformation of the population employment structure, economic industrial structure, and urban-rural spatial community structure [18,33,34]. The core is to achieve harmonious development of the population, economy, society, and ecological environment. Therefore, according to the principles of data comparability, measurability, availability, and feasibility, this research selected 22 indicators to represent the dimensions of urbanization quality from the above ideas and references (Table 2). The entropy method is a weighting method based on the dispersion degree of the evaluation indicators, which has been widely used in many fields due to its objectivity, comprehensiveness, and less complexity. The entropy method was used to evaluate urbanization quality. The formula is as follows [25]:

$$W_q = \frac{d_q}{\sum_{q-1}^{n} d_q} \qquad (1)$$

$$d_q = 1 - e_q \qquad (2)$$

Within

$$e_q = -k \sum_{t=1}^{m} \left(Y_{tq} ln Y_{tq} \right) \qquad (3)$$

where d_q is the information redundancy, e_q is the index information entropy, k is the undetermined constant, $k = 1/\ln m$, m is the number of years of evaluation, n is the number of indicators, and Y_{tq} is the ratio of the index value of the qth index to the t year.

Table 2. The evaluation indicators system of urbanization.

System	Indicator	Status	Weight
Population urbanization	The proportion of urban population (%)	+	0.042
	The proportion of employed population in secondary and tertiary industries (%)	+	0.044
Economic urbanization	Secondary, Tertiary Industry as Percentage to GRP (%)	+	0.043
	Per capita GDP (CNY)	+	0.045
	Income ratio of urban and rural residents (%)	-	0.048
	Land output per unit area (10,000 CNY/square kilometer)	+	0.042
Social urbanization	Number of doctors per 10,000 population	+	0.035
	Books in public libraries per 10,000 people	+	0.044
	Number of primary education teachers per 10,000 people	+	0.046
	Urban gasification rate (%)	+	0.087
	Daily domestic water consumption per capita (liter)	+	0.038
	Education expenditure (10,000 CNY)	+	0.051
Land urbanization	Area of city paved roads per capita (m^2)	+	0.046
	Land used for urban construction as percentage to urban area (%)	+	0.046
	Green area per capita (m^2)	+	0.044
Ecological urbanization	Volume of industrial wastewater discharged (10,000 tons)	−	0.043
	Volume of industrial sulphur dioxide emission (ton)	−	0.044
	Volume of industrial soot (dust) emission (ton)	−	0.040
	Centralized treatment rate of urban domestic sewage (%)	+	0.043
	Utilization rate of industrial solid waste (%)	+	0.044
	Harmless treatment rate of domestic garbage (%)	+	0.041
	Green covered area as % of built-up area (%)	+	0.043

2.3.2. Ecosystem Health Evaluation System

This study uses the Vigor-Organization-Resilience (VOR) model to measure ecosystem health. Vigor characterizes the metabolism of an ecosystem and its ability to produce material. The higher the energy input, the faster the material cycle and the higher the vitality will be. Organization refers to the structure of an ecosystem and the interrelationships between its species. It reflects the structure and function of the ecosystem. Resilience refers to the ability of the ecosystem to maintain its original function and structure under the interference of natural and human factors. The formula is as follows:

$$EH = V \times O \times R \tag{4}$$

This paper selected the normalized difference vegetation index (NDVI) as the vigor index. NDVI is an effective indicator of vegetation growth, vegetation productivity, and regional ecological change. It is therefore widely used to identify vigor indicators in ecosystems [35–37].

The organization reflects the effectiveness and stability of the links between the various components of the ecosystem. Generally speaking, ecosystem organization is mainly

determined by Land Heterogeneity (LH), Landscape Connectivity (LC), and Landscape Shape (LS) [38–40]. Concerning the relevant literature, the following indicators were selected and weighed [35,41,42]. The Shannon Diversity Index (SHDI) and Shannon Evenness Index (SHEI) were used to measure LH. LS is quantified by the Landscape Division Index (DIVISION), Interspersion Juxtaposition Index (IJI), and Contagion index (CONTAG). LH and LC are dominant in the organization, so they are both set to a weight of 0.4. The weights of SHDI and SHEI are both set to 0.2. The IJI and CONTAG, are set to 0.15, and DIVISION is set to 0.1, mainly because the IJI and CONTAG can determine the degree of landscape aggregation. The LS was set to 0.2 and characterized by PARFIC. The formula is as follows:

$$\text{O} = 0.4 \times \text{LH} + 0.4 \times \text{LC} + 0.2 \times \text{LS} = (0.2 \times \text{SHDI} + 0.2 \times \text{SHEI}) + (0.1 \times \text{DIVISION} + 0.15 \times \text{IJI} + 0.15 \times \text{CONTAG}) + 0.2 \times \text{PAFRAC} \tag{5}$$

Resilience has mainly reflected the resistance and adaptability of landscape patches to external disturbances [43]. The closer the land use type is to the natural ecosystem, the easier it is to recover from external disturbances [44]. In particular, unused land usually turns into a waste grassland, which has strong resistance to natural disasters and can quickly renew itself after external disturbances disappear, thus it has the greatest potential for restoration. Referring to the studies of relevant scholars [22,38,39], the resilience coefficients of different land-use types are set according to their restoration difficulty, as shown in Table 3.

Table 3. The ecosystem resilience coefficient of each landscape type.

Land Type	Grassland	Farmland	Unused Land	Forest	Construction Land	Water
0.6 × Resil	0.8	0.3	0.4	0.6	0.2	0.7
0.4 × Resist	0.6	0.5	0.6	1.0	0.3	0.8

The resilience index was finally defined as follows:

$$\text{R} = 0.6 \times \sum P_i \times \text{Resisl}_i + 0.4 \times \sum P_i \times \text{Resist}_i \tag{6}$$

Finally, the ecosystem's health is divided into five grades [22,44,45], as shown in Table 4.

Table 4. The ecosystem health scores and grades.

Score	Grade	Score	Grade
0–0.2	Weak	0.6–0.8	Good
0.2–0.4	Relatively weak	0.8–1.0	Well
0.4–0.6	Moderate		

2.3.3. Coupling Coordination Degree Model

Coupling refers to the phenomenon of two (or more than two) systems or motion forms affecting each other [46]. In this paper, the coupling coordination degree model proposed by Wang et al. [47] is used:

$$\text{D} = (C \times T)^{\frac{1}{2}}, T = na + mb \tag{7}$$

within

$$\text{C} = \sqrt{[1 - (U_j - U_i)] \times \frac{U_i}{U_j}} \tag{8}$$

where C is the coupling degree; U_j represents the subsystem with a higher score; U_i represents the subsystem with a lower score, D is the coordination degree; T is the index of the coupled and coordinated development level; n and m are weights of urbanization quality and the ecosystem health, and both are set to 0.5. According to D, the coupling

coordination degree between urbanization quality and ecosystem health can be divided into 10 classes, as shown in Table 5.

Table 5. Criteria for coupling coordination degree.

Score	0–0.1	0.1–0.2	0.2–0.3	0.3–0.4	0.4–0.5	0.5–0.6	0.6–0.7	0.7–0.8	0.8–0.9	0.9–1
C	Extreme disorder	Serious disorder	Moderate Disorder	Mild disorders	On the verge of disorder	Barely coordination	Primary coordination	Moderate Coordination	Well-coordinated	High quality coordination
D	Recession	Recession	Recession	Recession	Recession	Development	Development	Development	Development	Development

2.3.4. Elastic Coefficient Method

The elastic-coefficient method can explain the spatiotemporal coupling coordination characteristics of urbanization quality and ecosystem health. It can reflect the direction and speed of how the system has changed. Therefore, it was used to analyze the changes in the urbanization quality and ecosystem health. The formula is as follows:

$$\beta = \frac{EHR}{UQR} = \frac{(EH_i - EH_0)/EH_0}{(UQ_i - UQ_0)/EH_0} \tag{9}$$

where β is the elastic coefficient of ecosystem health and urbanization quality; *EHR* and *UQR* represent the change rate of ecosystem health and urbanization quality; EH_i and EH_0 are the ecosystem-health of year *i* and the base year; and UQ_i and UQ_0 are the urbanization quality of year *i* and the base year.

According to the changes of EHR and UQR and their comparison, regarding related literature [48], the coupling relationship between ecosystem health and urbanization quality can be divided into six types (Table 6).

Table 6. Coupling types of ecosystem health and urbanization quality.

State	EHR	UQR	β	Features
Type I	EHR > 0	UQR > 0	β > 1	The growth of ecosystem health is faster than that of urbanization quality
Type II	EHR > 0	UQR > 0	0 < β < 1	The growth of ecosystem health is slower than that of urbanization quality
Type III	EHR > 0	UQR < 0	β < 0	Ecosystem health improved, urbanization quality declined
Type IV	EHR < 0	UQR > 0	β < 0	Ecosystem health reduced, urbanization quality improved
Type V	EHR < 0	UQR < 0	0 < β < 1	The decline of ecosystem health is slower than that of urbanization quality
Type VI	EHR < 0	UQR < 0	β > 1	The decline of ecosystem health is faster than that of urbanization quality

2.3.5. The Coefficient of the Variation Method

An indicator's coefficient of variation represents its ability to discriminate information. The higher the coefficient of variation is, the greater the indicator's variability and recognition ability is. The method of coefficient variation can thus help identify the most important index of each subsystem in the whole system. It can also help avoid the subjectivity of

experts deciding weights, and weaken the influence of the extreme value index on the evaluation result. The formula is as follows [49]:

$$V_i = \frac{\delta i}{\overline{x_l}}$$ (10)

where V_i is the coefficient of variation of i-th index; δi is the standard deviation of the *i*-th index; $\overline{x_l}$ is the average of the *i*-th index.

The coefficient of variation method was used to explore the most important index in the urbanization quality subsystem. The indexes with the largest coefficient of variation in each subsystem were selected: the proportion of urban population in the population urbanization subsystem, the per capita GDP in the economic urbanization subsystem, the education expenditure in the social urbanization subsystem, land used for urban construction as a percentage of urban area in the land urbanization subsystem, and volume of industrial sulfur dioxide emissions in the green urbanization subsystem.

2.3.6. Geodetector

The Geodetector is a quantitative technique to determine whether the spatial distribution of a geostatistical variable resembles that of an independent variable [50]. The key idea behind Geodetector is that if factor X is associated with Y, then X and Y would exhibit similar spatial distributions. In other words, if the spatial variability of coupling coordination degree is caused by a specific factor, there should be some similarity between the spatial distributions of the factor and the coupling coordination degree. The Geodetector method uses the power of determinant to reflect the spatial correlation of factor X and Y. The formula is as follows [51]:

$$q_x = 1 - \frac{\sum_{h=1}^{L} N_h \sigma_h^2}{N\sigma^2}$$ (11)

where N is the number of samples in the study area; N_h is the number of samples in zone (category) h of factor X; σ^2 is the total variance of Y in the study area; σ_h^2 is the variance of Y within zone (category) h of factor X; and L is the number of zones (categories) of factor X. $\sum_{h=1}^{L} N_h \sigma_h^2$ is within the sum of variances, and $N\sigma^2$ is the total sum of variances. The greater the value of q_x is, the more factor X explains Y, and vice versa.

2.3.7. Panel Tobit Regression Model

The coupling coordinated degree of urbanization quality and ecosystem health is not only driven by internal factors but is also affected by external factors. Referencing prior-published research [52–54], we selected the independent variables, which are the per capita actual use of foreign capital to represent the degree of opening up (x1), the proportion of regional fiscal expenditure as GDP to represent government capacity (x2), the proportion of fiscal expenditure representing science and technology investment (x3), the expenditure for urban construction and maintenance to represent the intensity of urban construction (x4), and the proportion of fixed-assets investment as GDP to represent the level of economic development (x5). The coupling coordination degree between urbanization quality and ecosystem health was applied as the dependent variable. The Tobit regression model is a limited dependent variable regression model that describes the association between a non-negative dependent variable (latent variable) and the independent variables when data are censored or truncated. As the scores of the coupling coordination degree are censored from both the lower and upper bounds and range from 0.0 to 1.0, the explained variable was truncated. Rhus, the panel Tobit model was used for analysis:

$$D = \text{cons} + \beta_1 x1 + \beta_2 x2 + \beta_3 x3 + \beta_4 x4 + \beta_5 x5 + \varepsilon$$ (12)

where D is the coupling coordination degree; cons is a constant; β_i is the regression coefficient of the influencing factor; and ε is a random-disturbance term. Regression was performed by applying Stata v.15.1 (https://www.stata.com/, accessed on 27 March 2022).

3. Results

3.1. Urbanization Quality

The urbanization quality of Jiangsu first decreased and then increased, showing a "V" shape. According to the process, the urbanization of Jiangsu can be divided into two stages. The first stage was 2000–2005, during which the average value dropped from 0.544 to 0.505; the second stage was 2005–2017, during which the average value returned to 0.544.

The overall urbanization quality of Southern Jiangsu is higher than central than Northern Jiangsu (Figure 2). Although the latitudinal spatial difference is notable, the spatial pattern is relatively stable. In the five research periods, the ratios of the highest to the lowest scores were 2.10, 1.94, 2.21, 2.11, and 2.12, respectively, which indicates that the urbanization quality of cities in Jiangsu was relatively well-coordinated with no obvious gap. During the study period, the urbanization quality in Southern Jiangsu, except for Zhenjiang and Changzhou in 2005, was at a medium-to-high level. Only Nanjing and Suzhou reached high-level urbanization quality twice, showing a "dual-core" mode. The development of the three cities in central Jiangsu was also stable. Nantong was at the medium level during 2000–2010, but rose to a high level after 2015; Yangzhou has always been at a medium level; Taizhou has been hovering in the middle and low class since its weak development due to its unclear positioning. The urbanization quality of Northern Jiangsu is not good; it first showed the structural characteristics of "high periphery and low center" and then gradually transformed into the spatial characteristics of "high west and low east."
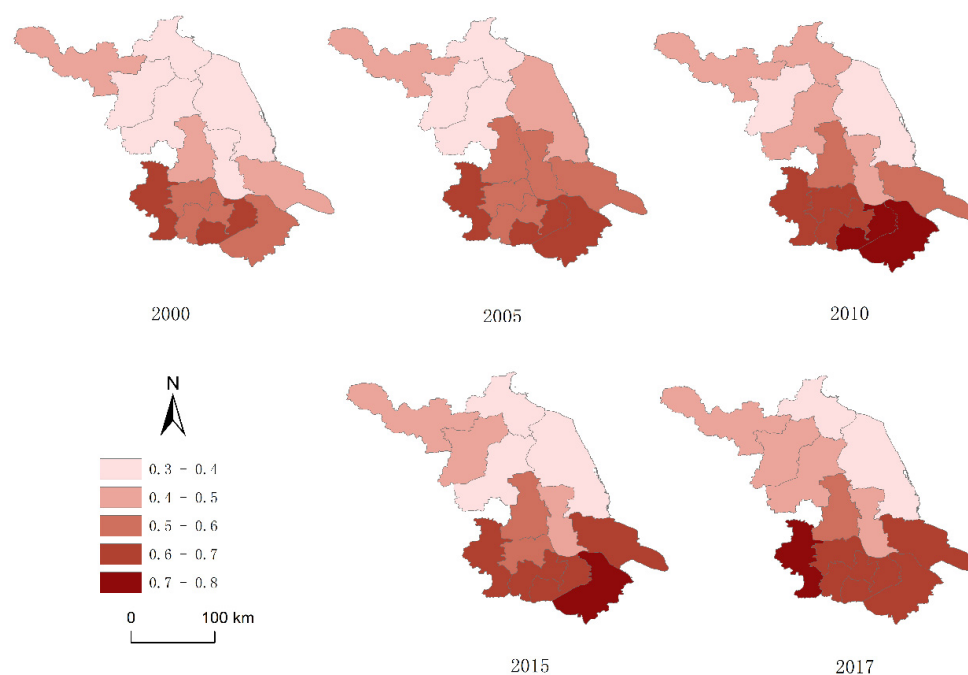

Figure 2. Spatial and temporal changes of urbanization quality in Jiangsu Province from 2000 to 2017.

3.2. Ecosystem Health

Changes in ecosystem health in Jiangsu have not been very significant (Figure 3). All scores were distributed in the range 0.52–0.64. The overall trend has been consistent with the progressive movement of urbanization, and also at its lowest point in 2005. During the study period, the ecosystem health of 10 cities (Changzhou, Huai'an, Lianyungang, Nanjing, Nantong, Suqian, Suzhou, Xuzhou, Yancheng, and Yangzhou) increased to varying degrees,

with Lianyungang and Suqian experiencing the greatest increase. Wuxi and Zhenjiang stayed at a high level throughout the period. Of the 13 cities in Jiangsu Province, only Taizhou's ecosystem health declined slightly.
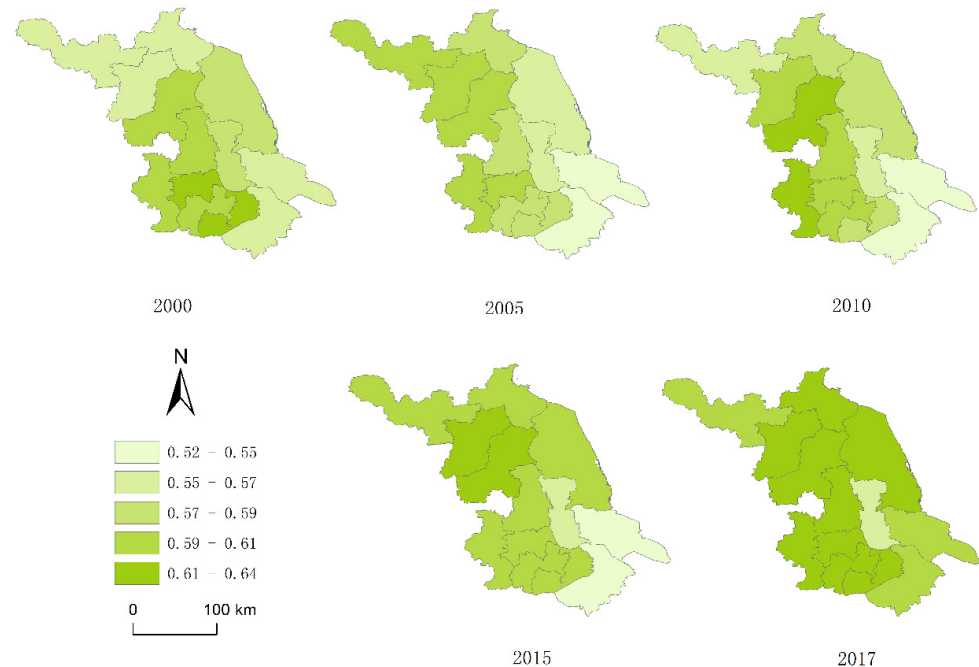

Figure 3. Spatiotemporal changes of ecosystem health in Jiangsu Province from 2000 to 2017.

In 2000, Southern Jiangsu had the best ecosystem health, but by 2017, Northern Jiangsu had the best and central Jiangsu had the worst.

Figure 4 shows the vigor-organization-resilience of 13 cities in Jiangsu Province from 2000 to 2017. The vigor layer shows that Suzhou had the lowest and Wuxi had the second-lowest vigor in the whole province. This suggests that Suzhou and Wuxi had poor vegetation coverage, apparently owing to the least cultivated land area in Jiangsu, as farmland is the main form of vegetation. The data from 2000 and 2017 indicated that the vigor of Changzhou, Suzhou, Wuxi, Nantong, and Taizhou was declining, which to a certain extent was caused by their farmland not getting a balance between occupation and compensation. Taizhou's vigor was the highest in the whole province in 2000, but it was in the middle in 2017. From the organization layer, data in 2017 showed that only Huai'an and Suqian had been on a decline since 2000. This is mainly because of the decrease of PAFRAC, SHEI, and SHDI in Huai'an and Suqian, which means that their LS and LC were decreasing. From the resilience layer, only Wuxi's and Taizhou's resilience declined, while the resilience of other cities increased. The decline in resilience is evident, primarily in the expansion of construction land. As the expansion of construction land in Wuxi and Taizhou is bigger than the expansion of ecological land such as forests, their resilience has therefore been in decline.
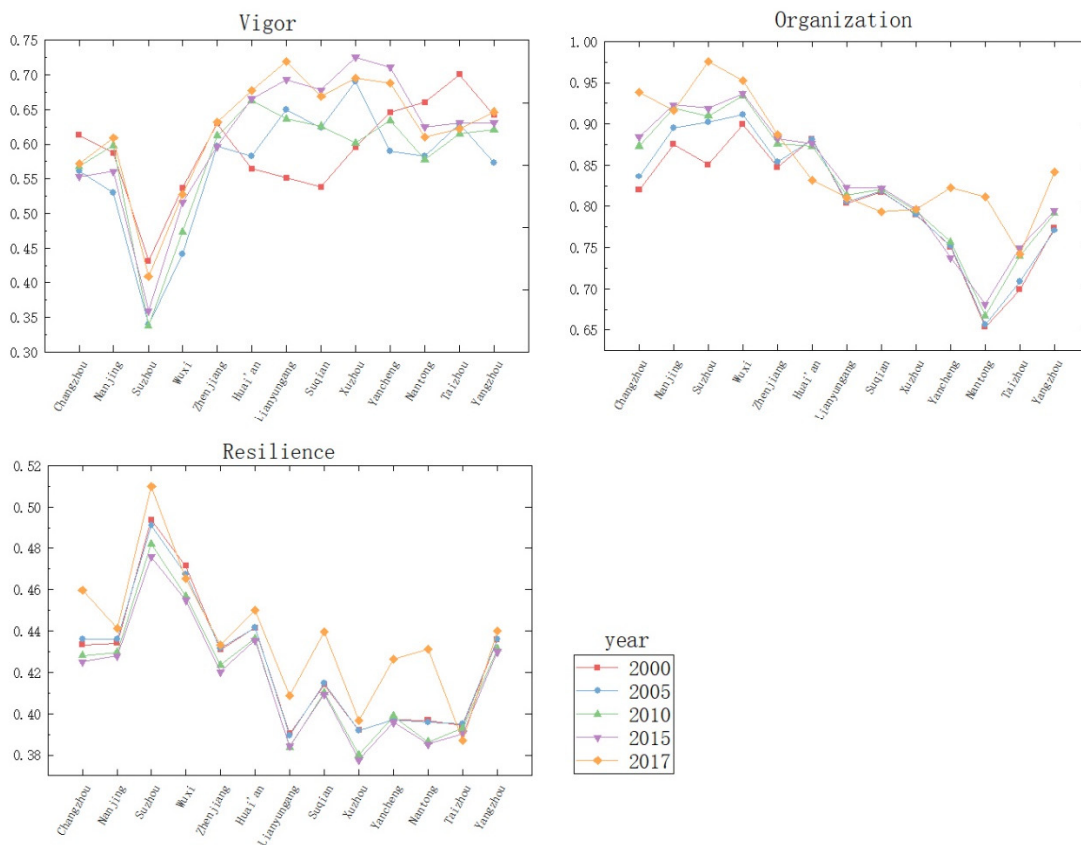
Figure 4. Vigor-organization-resilience of 13 cities in the Jiangsu Province from 2000 to 2017.

3.3. Coupling Coordination Degree of Ecosystem Health and Urbanization Quality

According to Section 2.3.3, the result shows that Jiangsu has been in a state of primary to high-quality coupling coordination during 2000–2017 (Table 7), with little difference in the average but with a slight decline. Central Jiangsu was the highest coupling coordination degree and northern Jiangsu was the lowest. Among the cities, the average coordination degree of Zhenjiang was the highest (0.974), followed by Changzhou (0.956), and Nantong (0.948); Yancheng, Lianyungang, and Huai'an were the lowest. The average of Huai'an was only 0.718, at a medium coordination state, while Zhenjiang, Changzhou, Nantong, and Yangzhou were in the high-quality coordination. Compared with the base period and the end of the period, the coordination states of Wuxi, Taizhou, and Suqian were rising, whereas Lianyungang, Xuzhou, and Yancheng were falling.

Because the coupling-coordination degree model could not clearly distinguish the internal imbalance of the system, the elastic model was introduced. The coupling state of ecosystem health and urbanization quality in Jiangsu during 2000–2017 can be described in terms of six forms or types (Figure 5). During the period 2000–2005, the "contrary" (Types III and IV), and the "all decrease" (Types V and VI) coupling states were the most common. During 2005–2010, Type I was newly added, and Type VI disappeared, while the "all increase" (Types I and II), and the "contrary" (Types III and IV) coupling states were most prevalent. During 2010–2015, Types II and III were dominant. During 2015–2017, the "all decrease" (Types V and VI) coupling states completely disappeared. The proportions of Types I–IV were 15.38%, 23.08%, 46.15%, and 25.38%, respectively. The proportions of the "all increase" and "contrary" coupling states were 38.46% and 61.54%, respectively. Thus, because ecosystem health and urbanization quality were in asynchronous decoupling in most cities during this period, the development keystone needed to be adjusted.

Table 7. Coupling coordination degree of ecosystem health and urbanization quality in Jiangsu Province.

| Region.	City	2000	2005	2010	2015	2017	Mean
Southern Jiangsu	Changzhou	0.956	0.946	0.959	0.939	0.980	0.956
	Nanjing	0.880	0.901	0.931	0.946	0.893	0.910
	Suzhou	0.868	0.867	0.746	0.732	0.873	0.817
	Wuxi	0.856	0.907	0.807	0.916	0.964	0.890
	Zhenjiang	0.972	0.922	0.995	0.984	0.997	0.974
Central Jiangsu	Nantong	0.924	0.954	0.990	0.923	0.949	0.948
	Taizhou	0.845	0.960	0.881	0.837	0.911	0.887
	Yangzhou	0.960	0.916	0.953	0.961	0.921	0.942
Northern Jiangsu	Huaian	0.743	0.709	0.701	0.676	0.763	0.718
	Lianyungang	0.831	0.667	0.776	0.718	0.625	0.723
	Suqian	0.693	0.713	0.675	0.811	0.747	0.728
	Xuzhou	0.954	0.765	0.857	0.751	0.834	0.832
	Yancheng	0.791	0.816	0.671	0.691	0.656	0.725
	Mean	0.867	0.849	0.842	0.837	0.855	
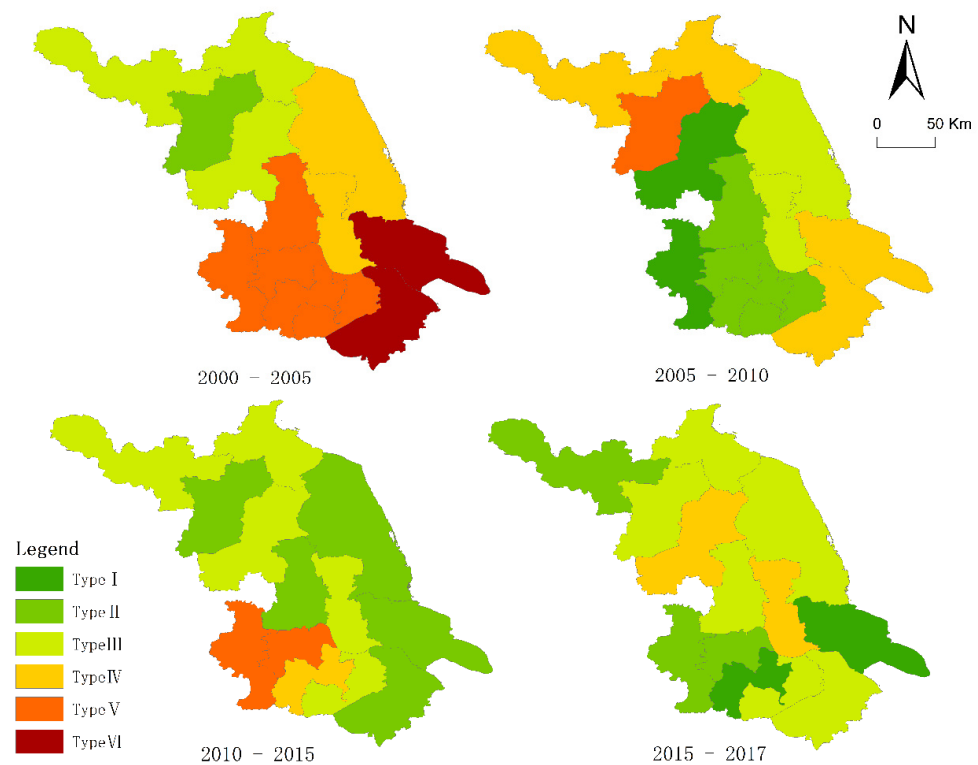
Figure 5. Spatiotemporal changes of coupling coordination types between urbanization quality and ecosystem health in the Jiangsu Province.

The southern Jiangsu area was undergoing fluctuating change during the study period. Ecosystem health and urbanization quality all descended early on, and then all cities showed an upward trend. Among them, Nanjing had the fastest growing trend, transitioning from Type V to Type I. However, except for Suzhou, this upward momentum was not maintained during 2010–2015 in other cities, which experienced various decoupling situations. As of 2017, Nanjing, Zhenjiang, and Changzhou had re-coordinated development. Suzhou and Wuxi were in a state of increasing ecosystem health but declining urbanization quality.

In 2000–2015, central Jiangsu exhibited rising trends, but different change characters in the three cities during 2015–2017. Nantong was in a negative state of overall shrinking ecosystem health and urbanization quality during 2000–2005. After adjustment from the first five-year plan issued by China, the urbanization quality increased, but ecosystem

health was still in decline. In 2010–2015, the development core was adjusted to raise and develop the ecosystem health. Then, in 2017, ecosystem-health growth exceeded urbanization-quality growth and reached an optimal state. The evolutionary path of Yangzhou is somewhat similar to that of Nantong. During 2000–2005, it was an "all decrease" coupling state. In the following 10 years, Yangzhou established and maintained the "all increase" state, but its urbanization quality declined in the last period, in contrast to Nantong. Taizhou was at first Type IV, with descending ecosystem health and increasing urbanization quality; it was then transformed into Type III and eventually returned to Type IV. In the study period, ecosystem health and urbanization quality were continuously resistant, thereby making it necessary to balance the development mode of the two.

The evolution of coupling relationships is generally both complex and different across the five cities in northern Jiangsu. Although the coupling paths differ, the leading coupling state is "contrary" (specified 14 times and accounting for 70%). As of 2017, only Xuzhou's ecosystem health and urbanization quality had changed to the "all increase" state.

3.4. Factors Influencing the Coupling Coordination Degree between Ecosystem Health and Urbanization Quality

3.4.1. Internal Driving Forces of the Coupling Coordination Degree between Ecosystem Health and Urbanization Quality

Using the coefficient of the variation method, we selected indicators representative of the urbanization quality system (Section 2.3.5). We calculated them together with three indicators (vigor, organization, resilience) representing ecosystem health using the geodetector. The final results are shown in Table 8.

Table 8. Driving forces of coupling coordination degree between urbanization quality and ecosystem health in the Jiangsu Province.

Year	The Proportion of Urban Population	Per Capita GDP	Education Expenditure	Land Used for Urban Construction as Percentage to Urban Area	Volume of Industrial Sulphur Dioxide Emission	Vigor	Organization	Resilience
2000	0.468	0.414	0.310	0.488	0.384	0.235	0.351	0.713 *
2005	0.505 *	0.476	0.540 *	0.433	0.529 *	0.675 *	0.576 *	0.613 *
2010	0.544 *	0.504 *	0.344	0.798 *	0.558 *	0.451	0.698 *	0.756 *
2015	0.535 *	0.606 *	0.412	0.429	0.454	0.847 *	0.578 *	0.616 *
2017	0.629 *	0.493	0.290	0.461	0.436	0.778 *	0.614 *	0.416
Mean	0.536 *	0.499	0.379	0.522 *	0.472	0.597 *	0.563 *	0.623 *

Notes: A higher value indicates that it plays a greater role in the coupling degree of urbanization quality and ecosystem health. p * denotes the value is higher than 0.5.

The main driving factor in 2000 was resilience. In 2005, driving forces involved the proportion of urban population, education expenditure, volume of industrial sulfur dioxide emissions, and VOR index (among which vigor had the most impact). The main driving factor in 2010 was land used for urban construction as a percentage to urban area; other driving factors in 2010 were the proportion of urban population, per capita GDP, volume of industrial sulfur dioxide emissions, and organization, and resilience. The main driving force in 2015 was vigor; others included resilience, per capita GDP, organization, and the proportion of urban population. The driving factors in 2017 were vigor, the proportion of urban population, and organization.

To sum up, resilience is the most important driving factor, followed by vigor, organization, and the proportion of urban population; the weakest factor was land used for urban construction as a percentage to urban area. Thus, we can see that the three indexes of ecosystem health occupy important positions in the coordinated development of urbanization and ecosystem health.

3.4.2. External Factors Influencing the Coupling Coordination Degree between Ecosystem Health and Urbanization Quality

The external influencing factors of the coupling coordination degree are calculated by the panel tobit regression model, and the results are shown in Table 9.

Table 9. Influencing factors of coupling coordination between ecosystem health and new urbanization quality in the Jiangsu Province.

Index	Jiangsu	Southern Jiangsu	Central Jiangsu	Northern Jiangsu
x1	0.02 ***	0.0029	−0.0145 *	0.0084 *
x2	0.0004	0.0002	0.0012	−0.0001
x3	0.0009 *	0.0057 **	0.0109 *	−0.0064
x4	0.0007	−0.0001	0.0006	−0.00054
x5	−0.0082 **	−0.0074 ***	0.001	−0.00143

Notes: significance levels: $p * < 0.1$; $p ** < 0.05$; $p *** < 0.001$. "+" and "−" stand for the positive and negative correlation between the influencing factor and coupling degree of urbanization quality and ecosystem health in Jiangsu, Southern Jiangsu, Central Jiangsu, and Northern Jiangsu.

The x1 (the degree of opening up) has a significant positive impact on the entire Jiangsu Province and Northern Jiangsu in particular, indicating that increasing foreign investment and expanding the degree of opening to the outside have a particular catalytic effect on the coordinated degree between urbanization quality and ecosystem health for the whole province and especially the northern part. However, it negatively impacts central Jiangsu and has no apparent effect in Southern Jiangsu.

The x3 (Science and technology innovation) has a positive impact on Jiangsu Province and southern and central Jiangsu in particular.

Negative regression coefficients of x5 (the level of economic development) indicate that although economic development has been at the forefront in the entire province and the southern part, in particular, excessive economic growth greatly hinders coordination between urbanization and ecosystem health.

The x2 (government capacity) and x4 (urban-construction intensity) were found to have no significant impact in the Jiangsu Province as a whole or by region within the province.

4. Discussion

4.1. Urbanization Quality

Urbanization quality in Jiangsu Province between 2000 and 2017 underwent two distinct phases. The year 2005 was a turning point that coincided with the Eleventh Five-Year Plan, in which China began to prioritize environmental protection, accelerate the optimization and upgradation of industrial infrastructure, and encourage the establishment of a resource-saving, environmentally friendly society. Thus, urbanization quality is influenced by ecological factors [55], which once again validates the environmental Kuznets inverted U curve: high economic development leads to pollution, which reduces the quality of urban development; then, the decline in urbanization quality and the living environment necessitates high-tech green technological innovation to improve urbanization quality. The spatial pattern of urbanization quality in Jiangsu suggests that economic development has been a determining factor, which is consistent with views advanced by Sun et al. (2019) and Wang et al. (2010) [56,57]. Conversely, the experiences of Suzhou and Xuzhou demonstrate that location is also a key factor in improving the quality of urbanization [58]. Nanjing is the provincial capital of Jiangsu and benefits from advantages such as preferential policies. By contrast, Suzhou has taken advantage of its geographical location and vigorously developed itself by relying on the radiation effect of Shanghai, thus surpassing Nanjing. Meanwhile, Xuzhou is a crucial regional city in China that acts as a major transportation hub, which has cemented its position as the leading city of northern Jiangsu.

4.2. Ecosystem Health

Consistent with trends in urbanization quality, 2005 remains a turning point in the ecosystem health of Jiangsu Province, suggesting that the Eleventh Five-Year Plan has indeed played a guiding role in ecological protection. Many other studies concur that national policy guidance has played a significant role [59–61]. However, the spatial pattern of ecosystem health differs from that of the urbanization quality. As can be seen in Figure 3, the spatial pattern of ecosystem health in Jiangsu Province in 2000 exhibited some commonality with the pattern of urbanization quality; both were the highest in Southern Jiangsu and lowest in Northern Jiangsu. By 2017, the spatial pattern had changed, with Northern Jiangsu having the best ecosystem health. This suggests that population concentration and economic development can negatively affect ecosystem health [62,63].

4.3. Implications

As shown in Section 3.3, cities in Northern Jiangsu have the lowest coupling coordination degree, which is mainly due to their poor urbanization quality [44,46]. The results of the elasticity coefficient method show that the relationship between urbanization quality and ecosystem health typically exhibits a fluctuating 'S' curve, indicating that the coordinated development of cities should be a current focus of development.

The results of Section 3.4.2. demonstrate that the urbanization quality of Northern Jiangsu could be improved by introducing foreign capital. This would stimulate the relatively disadvantaged economic situation of the region, thus improving urbanization quality and achieving healthy and harmonious development with ecosystem health. In central Jiangsu, where economic development is relatively better, expanded foreign investment is likely to result in increased pollution, deepening the contrast between urbanization and the ecological environment. The technological investment could catalyze coordinated development between urbanization quality and ecosystem health in Southern and central Jiangsu. Urbanization quality is better than ecosystem health in Southern and central Jiangsu. Consequently, these areas need science and technology investment to encourage enterprises to shift their methods away from high-pollution and high-energy methods to green, low-carbon, and environmentally friendly alternatives, thereby promoting ecosystem health.

The above analysis encompasses the whole of Jiangsu. The driving forces of the coupling coordination degree of urbanization quality and ecosystem health are the most apparent in the negotiation between built-up land and the green space to achieve a sustainable balance between occupation and compensation in the urbanization process. Some scholars have previously argued that human factors have a more significant impact than natural elements on the relationship of man and land [22,64]. However, the findings of Section 3.4.1. clearly show that the three elements of ecosystem health also play an important role. The urban ecosystem is unable to be self-purifying, self-repairing, and self-regulating to maintain a dynamic balance [65,66]. It requires humans to guide the construction and rational planning of production space, living space, and ecological space. Thus, the expansion of ecological land and reforestation should be pursued in the insufficient vigor area, and the expansion of built-up areas should be rationally guided to guarantee a balance with areas with less resilience. In addition, care must be taken not to over-develop the economy in rapidly growing areas but instead to adjust relevant development plans. Similarly, although foreign investment can stimulate economic development, caution is needed to avoid triggering the adverse effects of "pollution refuges." Simultaneously, scientific and technological innovation should be stimulated to give full play to the spillover effects of cleaner production technology, to adjust industrial infrastructure, to change development modes, and to accelerate the coordinated development of urbanization quality and the ecosystem.

4.4. Limitations and Future Research Direction

According to different criteria, the evaluation indicators are also different. This paper selected the evaluation indicators from a system perspective and refers to relevant liter-

ature, but the relationship between urbanization and ecological environment is an open and complex giant system involving many elements [4]. The urbanization system includes many subsystems like population, economy, society, information, infrastructure, etc. The ecological environment system includes subsystems such as water, land, atmosphere, biology, energy, and minerals. Each subsystem contains many elements. Therefore, many literatures have selected relevant indicators to refer to these elements, such as population density [44], urban and rural poverty headcount [67], access to public transport [68], water quality [69], etc. These selected indicators are representative, operable, and policy applicability [68]. Although the greatest effort has been made, there are still some unavoidable limitations in the evaluation of urbanization quality and ecosystem health. Owing to the complex interaction between the socio-economic system and the natural ecosystem, it is still the direction for scholars to find an integrated evaluation model covering the two aspects. In the future research, instead of staying in the static conditions, more observation will focus on the dynamic processes of various factors and their inherent causality when exploring the relationship between urbanization quality and ecosystem health.

5. Conclusions

In this study, the urbanization quality and ecosystem health of Jiangsu Province was calculated for 2000, 2005, 2010, 2015, and 2017, and the current status and evolution mode of their coordinated development were analyzed. The internal driving forces and external factors influencing coordinated development were also explored.

The main conclusions are as follows:

During the study period, the urbanization quality of Jiangsu Province generally first decreased and then increased. From a regional perspective, Southern Jiangsu's urbanization quality is higher than central Jiangsu and Northern Jiangsu. The urbanization quality is strongly influenced by the level of economic development; the overall trend of ecosystem health has much in common with the urbanization quality. The ecosystem health of each region changed with time, and the initial order was consistent with the urbanization quality. Thus, ecosystem health and urbanization quality in Southern Jiangsu were initially higher than central and Northern Jiangsu, but later, they were higher in Northern Jiangsu than in Southern and central Jiangsu. Ecosystem health is also affected by economic development. Economically developed areas usually have more population clusters, and the expansion of built-up areas can impair ecosystem vitality and reduce resilience.

The coupling coordination degree of all the cities in Jiangsu Province ranges from primary to high-quality coordination. The coupling coordination degree of central Jiangsu is best and Northern Jiangsu ranks last. During the study period, there were six coordination types in the Jiangsu Province. The dominant types differed through time, but the overall coordination state had an upward trend. It is therefore necessary for the government to identify the focus of development according to the actual situation and guarantee a harmonious development of the urbanization quality and the ecosystem health.

The internal factors that drove the coordinated development between urbanization quality and ecosystem health in Jiangsu Province differed across periods, but are mainly composed of three elements of ecosystem health. Although the impacts on Northern, Southern, and central Jiangsu differ, the external factors affecting Jiangsu Province and regions within it are primarily the degree of opening up, scientific and technological innovation, and the extent of economic development. Development measures should therefore be tailored to the particular regional characteristics.

This research established a system to evaluate urbanization quality and ecosystem health. By combining data on human-social and natural attributes, the relationship between urbanization and the ecological environment can be better explored. The research can better balance regional development and maintain ecosystem health. The evaluation method and framework established in the research can also be applied in the other study area, after clarifying the situation of the study area and adjusting the specific indicators and weights. Although many indicators were selected to evaluate the urbanization quality and ecosystem

health, the complexity of human-earth systems and the limitations in data availability prevented a complete interpretation of urbanization quality and ecosystem health, and we will consider more factors to improve our evaluation framework in the future.

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