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Dynamic Matching and Spatial Optimization of Land Use and Resource-Environment Constraints in Typical Regions of the Yellow River Basin in China

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Abstract: Accurately identifying the matching relationships between territorial space evolution and the resources and environment carrying capacity will directly guide the sustainable use of territorial space. Based on the evaluation of the territorial space dynamics of the lower Yellow River, this paper evaluates the suitability of territorial space development by focusing on ecological protection, agricultural development, and urban construction. Specifically, the resources and environment carrying capacity is estimated by identifying and mediating potential conflicts in the development of territorial space. The matching relationship between the evolution of territorial space and the resources and environment carrying capacity is identified using the matching degree model. The results demonstrated that: (1) Between 2000 and 2020, the agricultural space of the lower Yellow River was relatively stable, while the ecological space was generally shrinking, and the urban space continued to increase; (2) The characteristics of suitability for the agricultural development and urban construction of the lower Yellow River are characterized by landform and land-sea differentiation. The carrying scale of resources and the environment is based on agricultural space and is increasing yearly, followed by ecological space, which is gradually decreasing, and urban space, which first increased and then decreased; (3) Between 2000 and 2020, the matching index of the ecological and agricultural space evolution and the resource and environmental carrying capacity in the lower Yellow River exhibited a downward trend, while the regional difference increased. Furthermore, the matching index of urban space and the resources and environment carrying capacity indicated an upward trend, while the regional difference decreased.

Keywords: territorial space; potential conflict; resources and environment carrying capacity; matching; regulation; Yellow River

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1. Introduction

At present, China is in the stage of accelerated urbanization and industrialization. The increasing intensity of territorial space development and utilization and the imbalance in social-ecological systems has challenged the sustainable use of territorial space [1]. Several Opinions on Establishing a Land Spatial Planning System and Supervising Its Implementation proposed that "we should scientifically and orderly co-ordinate the layout of ecological, agricultural, urban and other functional spaces based on suitability evaluation and resources and environment carrying capacity of territorial space development (referred to as "dual evaluation")". In practice, "dual evaluation" provides important technical support for the zoning of territorial functions [2] and the optimal regulation of territorial space [3,4], and it also contributes to promoting the compilation of regional territorial space planning and the construction of an ecological civilization [5].

The "dual evaluation" refers to the evaluation of the carrying capacity of the environment and the evaluation of the suitability of the spatial development of territorial space. The suitability evaluation can be traced back to the land ecological suitability evaluation method [6]. The evaluation object is from the initial agricultural land to the construction land, and then to the entire territorial space [7,8]. The carrying capacity has gradually expanded to include the ecological carrying capacity, resource carrying capacity, and environmental carrying capacity [9–11]. The resources and environment carrying capacity is the standard for measuring whether social and economic activities are overloaded. It has multiple attributes, such as objectivity [12], and is an important research topic in the field of international sustainable development [13]. From a theoretical perspective, many theories, such as the Growth Limit Theory [14–16], serve as the theoretical bases for understanding the resources and environment carrying capacity, and finally form a diverse, multi-scale, and multi-objective-oriented research paradigm [17]. From the perspective of research methods, massive methods, such as the Pressure State Response Model, have attracted much attention [18–21], and finally form the framework of the resource and environmental carrying capacity represented by the Driver-Pressure-State-Impact-Response (DPSIR) framework [22]. Furthermore, the process of resource and environmental carrying capacity deduction is centered on building an indicator evaluation system based on the resource carrying capacity, environment carrying capacity, and ecological carrying capacity [23,24]. From the perspective of achievements application, it covers extensive fields, such as spatial layout optimization, industrial layout and planning, and post-disaster reconstruction [25–29]. The achievements application emphasizes the fundamental support of the resource and environmental carrying capacity and its core lies in the interaction between human activities and the resource environment.

The compilation of land spatial planning requires the notion of "dual evaluation". Many scholars have focused on the logical relationship between the resources and environment carrying capacity and the suitability of territorial space development in the "dual evaluation" [30–32]. They have proposed the correlation logic that "suitability determines the space for development and carrying capacity identifies the scale of development" [33]. Specifically, the resources and environment carrying capacity is regarded as having the potential to better guide territorial space planning and sustainable utilization. More importantly, the resources and environment carrying capacity emphasizes the balance and decomposition of the resources and environment carrying capacity among the ecological protection, agricultural production, and urban construction functions in the same administrative unit. In addition, in the current context of increasingly significant territorial space changes, how and whether the matching relationship between the evolution of territorial space and the resources and environment carrying capacity breaks through the bottom line of resource and environment constraints is crucial [34]. Despite exploring resources and environment carrying capacities that possess theoretical and practical implications, limited empirical attention has been paid to it.

This paper selects cities in the Yellow River basin of Shandong Province as the study area for the following reasons. (1) Compared with the entire Yellow River basin, it has complex geomorphological differences. The plateau, hills, and plains are distributed in steps, and the natural conditions are complex. (2) At the same time, the Yellow River basin is one of the regions with the highest level of socio–economic development and urbanization in China. This area covers 77 counties. Therefore, the representativeness of the research area selected in this paper lies in its obvious differentiation characteristics in terms of its natural geographical environment and social economic pattern, which can be regarded as the epitome of the Yellow River basin. Specifically, Shandong Province, the only province located entirely in the lower reaches of the Yellow River, spans across nine cities in western Shandong and covers an area of 83×104 km^2. Thus, there are significant differences in the upper, middle, and lower sections of the region. Specifically, the upper section is an important grain producing area, the middle section is the provincial capital economic circle, and the lower section is an ecologically fragile area that is important for the ecosystem services dominated by the Yellow River Delta. The Yellow River basin in Shandong Province thus conforms to the overall pattern of ecological protection, agricultural production, and urban construction in the Yellow River basin. Therefore, this paper takes the Yellow River basin in Shandong Province as the research object. Firstly, the spatial evolution and the resources and environment carrying capacity are incorporated into the coupling framework of the social economy and the resources and environment to reveal the spatial evolution of the territory. Secondly, this paper establishes an evaluation system for the suitability of territorial space development and identifies the resources and environment carrying capacity through potential conflict mediation. The goal is to uncover the matching relationship between the evolution of territorial space development and the resources and environment carrying capacity. The findings could provide a path for optimizing territorial space.

This paper makes five contributions. Firstly, this paper proposes a framework for determining the alignment between the territorial space and the resource and environmental carrying capacity, as well as realizing the resource and environmental carrying capacity. The framework provides a theoretical basis for understanding the sustainable use of territorial space. Secondly, this paper introduces technical guidelines for assessing the resource and environmental carrying capacity. It emphasizes the importance of identifying and mediating potential conflicts in land and space, thus aiding in the identification of the resource and environmental carrying capacity of regional multi-functional areas. Thirdly, this paper provides a supporting framework for optimizing land structure and pattern reconfiguration. The researchers have conducted an in-depth empirical study in an important ecological region of the Yellow River basin, thus providing a concrete and practical reference for the sustainable development of territorial space. Fourthly, as one of the significant ecological regions in the Yellow River basin, our research area plays a crucial role in supporting the conservation and development of the inlet area and other important ecological regions within the basin. This is achieved through the analysis of the spatial evolution, the matching relationship of resource and environmental carrying capacity, and the ecology-agriculture-urban space. Fifthly, our database on territorial space, resources, and the environment in typical areas of the lower reaches of the Yellow River provides a foundation for the formulation and implementation of the relevant government policies.

2. Theoretical Framework

2.1. A Framework for Matching Territorial Space and Resources and Environment Carrying Capacity

The matching relationship between the evolution of territorial space and the resources and environment carrying capacity is a representation of the interaction between humans and environmental systems. This relationship impacts the optimization and sustainable use of the territorial spatial pattern. Territorial space is the home for people's survival and development and the material basis for the sustainable development of eco-social systems and natural geographic systems [3]. At the same time, territorial space is also an advanced manifestation of the spatialization of land use [35]. According to the Growth Limit Theory, there are limits to both socio–economic development and the resource environment. When this limit is exceeded, it will hinder and curb sustainable development [14]. The two major systems of social economy, represented by territorial space utilization, and natural objects, represented by the resources and environment, constitute the resources and environment carrying capacity; it has to be noted that there is a highly coupled relationship between these two systems [12] (Figure 1). The environmental carrying capacity is a comprehensive and scientifically based evaluation method that serves as a crucial indicator for assessing the long-term sustainability of ecosystems [36]. The impact of socio–economic development on the resources and environment is increasing. In other words, urban space is expanding while ecological space is shrinking, and the utilization of territory reaches the bottom line of resource and environmental constraints. As a result, the matching relationship between the evolution of territorial space and the carrying capacity of the resources and environment has shifted to a mismatched one. To achieve the sustainable utilization of space, differentiated regulation plans should be adopted according to the matching relationship between the evolution of territorial space and the carrying capacity of the resources and environment. Specifically, mismatched areas should be limited to expand the territorial space, near-mismatched areas should be reasonably allocated to ensure that it does not exceed the bottom line of resource and environmental constraints, and well-matched areas should improve the utilization quality of the territorial space. Finally, meeting the resource and environmental constraints in utilizing all types of territorial space would be achieved. Therefore, clarifying the trend of change in the relation between the evolution of territorial space and the carrying capacity of the resources and environment plays an important role in the sustainable use of territorial space.

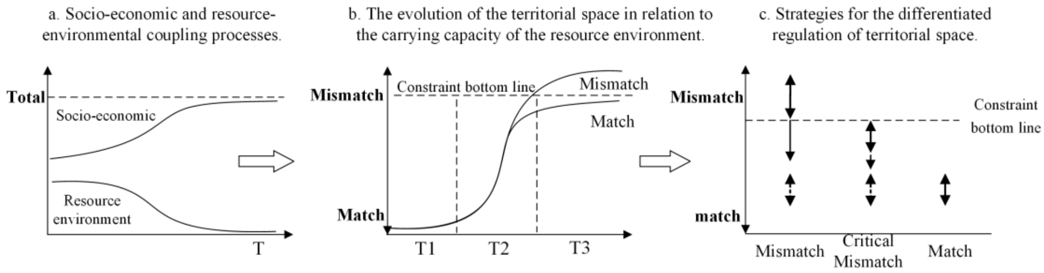

Figure 1. Theoretical basis.

2.2. *The Process of Implementing Resource and Environmental Carrying Capacity*

At present, there are two commonly used methods for evaluating the resources and environment carrying capacity. The first is to select socio–economic and resource environment indicators for evaluation [37,38]. This method is able to uncover the difference in the carrying capacities of different regions. The second method is used to calculate the carrying capacity based on the results of an agricultural production and urban construction suitability evaluation. This method emphasizes the background conditions, in accordance with the "Technical Guidelines for Evaluating the Carrying Capacity of Resources and Environment and the Suitability of Land and Space Development (Trial)". As the territorial spatial planning system was established, the latter approach received increasing attention. However, most existing studies emphasize suitability, while weakening the carrying capacity, thus leading to many problems. For instance, the calculated resource and environmental carrying capacity in the results is too large. Furthermore, there are difficulties in determining the resources and environmental carrying capacity in cases where different areas are considered suitable at the same time. There is also a lack of consideration for the decomposition of territorial space with different functional spatial orientations and the support for the optimization of the territory spatial structure and pattern reconstruction is relatively weak. Identifying and regulating potential conflicts contributes to pinpointing regions with multiple suitabilities and reconstructing the regional spatial pattern. Moreover, this process also has a bridging role as it identifies the resources and environmental carrying capacity. This paper adopts the method of "dual evaluation" to carry out the study, and the specific research process is shown in Figure 2. Firstly, a system of indicators for ecological protection, agricultural production, and urban construction is established around land and water resources, and environment and ecological factors are established in order to conduct a suitability evaluation of the spatial development. Secondly, we construct a territorial spatial potential conflict model that includes no potential conflicts, mild potential conflicts, moderate potential conflicts, and severe potential conflicts. Land use planning requirements act as a binding bottom line to regulate potential conflicts through rigid effects. The remaining areas employ the current status of land use to achieve elastic adjustment. Finally, the paper obtains the scale of the resource and environmental carrying capacity centered around ecology, agriculture, and urban space.

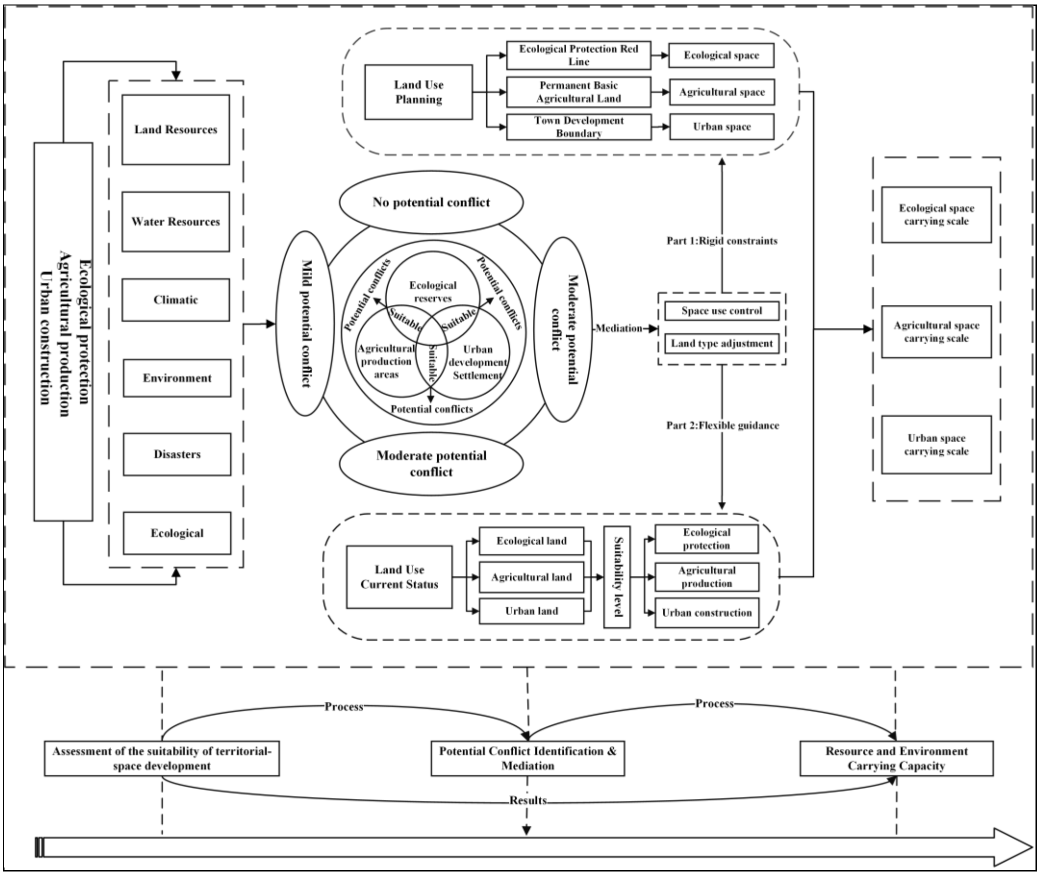

Figure 2. The realization process of resources and environment carrying capacity.

However, there are certain limitations to the current "dual evaluation". Firstly, the "dual evaluation" is based on the simultaneous adaptation of different spaces in the territorial space, and there is still in-depth research to be conducted on the corresponding resource and environmental carrying categories and their capacities. Secondly, there is a clear lack of consideration of the overall planning of multifunctional territorial spaces and the mutual support and constraint relationships between natural background elements and humans, i.e., there is still a lack of corresponding practical research.

3. Research Methods and Data Sources

3.1. Research Methods

3.1.1. Measuring the Spatial Evolution of the Territory

The degree of territorial spatial dynamics is a quantitative evaluation of the rate of change of territorial spatial types. It is divided into a single degree of territorial spatial dynamics and an integrated degree of territorial spatial dynamics.

The degree of spatial dynamics of a country is used to express the degree of evolution of the spatial pattern of the national territory over a period of time. The equation for this, Equation (1), is as follows:

$$K = \frac{U_y - U_x}{U_x \cdot T} \times 100\% \tag{1}$$

where K represents the degree of evolution of the spatial pattern of a country in a certain time period. U_x, U_y denote the area of the initial and final territorial space type, respectively. Moreover, T represents the length of the study period.

The degree of integrated territorial spatial dynamics characterizes the degree of overall territorial spatial evolution over a certain time period. The equation for this, Equation (2), is as follows:

$$C = \left[\frac{\sum_{i=1}^{n} \Delta U_{i-j}}{2\sum_{i=1}^{n} U_i} \right] \times \frac{1}{T} \times 100\% \tag{2}$$

where C represents the extent of the overall spatial evolution of a country over a certain time period, while U_i denotes the area of the initial category i land space type. ΔU_{i-j} represents the absolute value of the area of spatial type i converted to other spatial types during the study period. Lastly, n represents the number of territorial space types.

3.1.2. Identifying the Carrying Capacity of the Resource Environment

1. Assessment of the suitability of territorial spatial development

According to the Technical Guidelines for the Evaluation of the Suitability of Resource and Environmental carrying capacity and Territorial Spatial Development (for Trial Implementation), an ecological protection evaluation is primarily focused on identifying areas with regional ecosystem service functions and a high degree of ecological fragility (shown in Table 1). At the same time, with reference to the relevant research results [39–42], this evaluation accounts for two key aspects: ecosystem service functions and ecological sensitivity. Specifically, it emphasizes the presence of factors related to sanding and salinization sensitivity.

Table 1. Evaluation index system of ecological protection importance.

Target	Aspects	Factors	Formulations
Ecological protection (Fe)	Ecosystem service functions	Biodiversity conservation (e_1)	$e_1 = NPP_{mean} \times F_{pre} \times F_{temp} \times (1 - F_{ait})$
		Water conservation (e_2)	$e_2 = NPP_{mean} \times F_{sic} \times F_{pre} \times \left(1 - F_{slp}\right)$
		Soil and water conservation (e_3)	$e_3 = NPP_{mean} \times (1 - K) \times \left(1 - F_{slp}\right)$
		Windbreak and sand-fixation (e_4)	$e_4 = NPP_{mean} \times K \times F_q \times D$
	Ecological sensitivity	Soil erosion sensitivity (e_5)	$e_5 = \sqrt[4]{R \times K \times LS \times C}$
		Desertification sensitivity (e_6)	$e_6 = \sqrt[4]{I \times W \times K \times C}$
		Salinization sensitivity (e_7)	$e_7 = \sqrt[4]{I \times M \times D \times K}$

Note: NPP_{mean} is net primary productivity of vegetation; F_{pre} is perennial average rainfall; F_{temp} is the perennial average temperature; F_{alt} is the altitude factor; F_{sic} is the soil seepage factor; F_{slp} is the slope factor; K is the soil erodibility factor; F_q is the perennial average climate erodibility factor; D is the surface roughness factor; R is the rainfall erosivity factor; LS is the topographic relief factor; C is the vegetation cover factor; I is the dryness index; W is the number of sand-blowing days greater than 6 m/s in winter and spring; M is the groundwater salinity; and D is the groundwater burial depth. The normalized threshold of each factor is between 0 and 1.

The evaluation of the suitability of agricultural production and urban construction reflects the suitability of the national land space for agricultural production and the needs of urban residents, in terms of land, water, environment, meteorology, and disasters, and is focused on the resources and environment. The suitability of agricultural production emphasizes the influence of factors such as precipitation, light and heat conditions, soil environmental capacity, and meteorological hazards (shown in Table 2). On the other hand, the suitability of urban construction highlights the influence of factors such as climate comfort, water and air environmental capacity, and geological hazards (shown in Table 3). The evaluation system variables and grade classification used in this study are based on *the Guidelines for the Evaluation of the Carrying Capacity and Suitability of the Resource Environment* [43,44].

Table 2. Evaluation index system of agricultural production suitability.

Target	Aspects	Factors	Grade and Scores 0	1	3	5	7	Weight
Agricultural production (Fa)	Land	slope/(°) (a_1)	≥25	15~25	6~15	2~6	<2	0.15
		silt content/% (a_2)	≥80	60~80	40~60	20~40	<20	0.12
	Water	precipitation/mm (a_3)	<200	200~400	400~800	800~1200	≥1200	0.16
		total water resources/10,000 m^3 (a_4)	<3	3~8	8~13	13~25	≥25	0.14
	Climate	light and heat conditions/°C (a_5)	<1500	1500~4000	4000~5800	5800~7600	≥7600	0.15
	Environment	soil environmental capacity (a_6)	Greater than 150% of the risk control value	100~150% of the risk control value	The risk screening value is 70 to 100%	Greater than the risk screening value but less than or equal to 70% of the risk control value	Below or equal to the risk screening value	0.14
	Disaster	frequency of meteorological disasters/%(a_7)	>80	60~80	40~60	20~40	≤20	0.14

Note: The soil environmental capacity classification standard is based on the "Soil Environmental Quality Agricultural Land Soil Pollution Risk Control Standard (Trial) (GB 15618-2018)".

Table 3. Evaluation index system of urban construction suitability.

Target	Aspects	Factors	Grade and Scores 0	1	3	5	7	Weight
Urban construction (*Fc*)	Land	slope/(°) (c_1)	>25	15~25	8~15	3~8	≤3	0.17
		altitude/m (c_2)	>50	30~50	20~30	10~20	≤10	0.13
	Water	total water resources/ (m^3/km^2) (c_3)	<50,000	50,000~ 100,000	100,000~ 200,000	200,000~ 500,000	≥500,000	0.17
	Climate	Thermal Comfort/(THI) (c_4)	<32 or >90	32~41 or 82~90	41~51 or 73~82	51~60 or 65~73	60~65	0.12
	Environment	atmospheric environmental capacity index (c_5)	≤0.2	0.2~0.4	0.4~0.6	0.6~0.8	>0.8	0.09
		water environmental capacity/(t/km^2) (c_6)	<0.04 <0.8	0.04~0.14 0.8~2.9	0.14~0.39 2.9~7.8	0.39~0.96 7.8~19.2	≥0.96 ≥19.6	0.10
	Disaster	distance from fault zone/m (c_7)	<30	30~100	100~200	200~400	>400	0.08
		peak ground acceleration/g (c_8)	≥0.30	0.20	0.15	0.10	≤0.05	0.07
		cumulative land subsidence/mm (c_9)	>2400	1600~2400	800~1600	200~800	<200	0.06

Note:①The comfort degree is represented by the temperature and humidity index, $THI = T - 0.55 \times (1 - f) \times (T - 58)$. THI is the temperature-humidity index; T is the monthly average temperature (in Fahrenheit); and f is the monthly average relative humidity of the air. ② the water environmental capacity is controlled by COD and NH_3-N.

The ecological protection importance is categorized into three levels using the natural breakpoint method and the stepwise correction method (Equation (3)). The three levels are classified as extremely important, important, and generally important.

$$Fe = max(E_1, E_2, E_3, E_4, E_5, E_6, E_7) \quad (3)$$

where *Fe* represents the ecological protection importance level. E_1, E_2, E_3, E_4, E_5, E_6, and E_7 denote biodiversity maintenance, water conservation, soil conservation, wind and sand control, erosion sensitivity, sand sensitivity, and salinity sensitivity, respectively.

The evaluation of the suitability of agricultural production and town construction is conducted using the factor assignment-restrictive integrated evaluation method. This builds upon the deductions made for ecological protection. The weights of the factors are determined using the expert assessment method, and are assigned in a hierarchical manner using the corresponding specifications:

$$F_i = \begin{cases} 0\ (f_{ij} = 0) \\ \sum_{i=1}^{n} w_{ij} \times f_{ij}\ (f_{ij} \neq 0) \end{cases} \tag{4}$$

where F_i denotes the suitability level of the i evaluation unit, while w_{ij} represents the index weight of factor j in the *i-th* evaluation unit. Furthermore, f_{ij} denotes the index score of factor j in the *i-th* evaluation unit. When $F_i = 0$, it is considered unsuitable. Conversely, when $F_i \neq 0$, it is classified as generally suitable and suitable according to the natural breakpoint method.

2. Identification of the resources and environment carrying capacity based on potential conflict mediation.

The three-step process of identifying potential conflicts in land and space, reconciling them, and identifying the resource and environmental carrying capacity is used to establish the scale of the resource and environmental carrying capacity for ecological, agricultural, and urban spaces.

Step 1: Ecologically critical areas are potentially conflict-free. Mild potential conflict is present when at least two of the three suitability evaluations result in the lowest rating. Furthermore, a potential conflict is considered moderate when the assessment of the ecological importance is generally important and the assessment of the suitability for agricultural production and urban construction is generally suitable or higher. It is also moderate when the assessment of the ecological importance is important and at least one of the assessments of the suitability for agricultural production and urban construction is generally suitable or higher. Finally, a potential conflict is considered heavy when the assessment of the ecological importance is categorized as important, and the suitability for agricultural production and urban construction is considered suitable [45,46].

Step 2: The "three red lines" (the ecological protection red line, permanent basic agricultural land protection red line, and urban development boundary) are adopted as a constraint and guidance mechanism for potential conflict mediation. Firstly, the "three red lines" are divided into three categories of national land space. Then, the existing land types are maintained for areas without potential conflicts. According to the current land use status, identify and reconcile land classes with mismatched suitability classes in mild and severe potential conflict areas. The current ecological land is not subject to mediation. According to the highest level of suitability, achieve potential conflict mediation by achieving one-way or two-way conversion between ecological land, agricultural land, and construction land for moderate potential conflict areas. While ecological land is maintained in its current state, construction land and agricultural land in ecologically important areas are adjusted to ecological space. Moreover, construction land in areas suitable for agricultural production is adjusted to agricultural space, while agricultural land in areas suitable for urban construction is adjusted to urban space.

Step 3: In order to co-ordinate the decomposition and balance of the resource and environmental carrying capacity within different administrative regions, it is measured according to the ecological, agricultural, and urban space scales. It is based on the results of the reconciliation of potential conflicts within the national territory.

3.1.3. Matching Relationship between Spatial Evolution of Territories and Resource and Environmental Carrying Capacity and Optimal Zoning

Based on the matching relationship between the evolution of territorial space and the resources and environmental carrying capacity, this paper explores whether the evolution of territorial space exceeded the threshold of the resources and environment, as well as the degree of stress borne by the resources and environment (Equation (5)).

$$D = \begin{cases} D_z/D_x \\ D_y/D_z \end{cases} \quad (5)$$

where D represents the matching index between the evolution of territorial space and the carrying capacity of the resources and environment. D_Z denotes the resource and environmental carrying capacity, while D_x represents the current scale of ecological space, and D_y denotes the scale of agriculture and urban space. In short, the existing scale is compared with the carrying scale. As ecological conservation is given priority, the more scales other than the carrying scale for ecological space exist, the better; therefore, for ecological space accounting, use D_z/D_x. For agricultural and urban spaces, the fewer scales other than the carrying scale exist, the better; therefore, use D_y/D_z. When $D < 1$, the spatial evolution of territory does not exceed the threshold of the resources and environment and there is a matching relationship between the two. Conversely, when $D > 1$, the spatial evolution of territory exceeds the threshold of the resources and environment, and there is a mismatch. According to the existing studies [47], this paper classifies the matching relationships into seven distinct categories (Table 4).

Table 4. Matching relationship between territorial space evolution and resources and environment.

Matching index interval	[0, 0.2)	[0.2, 0.4)	[0.4, 0.6)	[0.6, 0.8)	[0.8, 1)	[1, 1.2)	[1.2, +∞)
Matching degree	Severe match	High match	Mild match	Low match	Critical match	Mild mismatch	Severe mismatch

To identify single and combined types of territorial space in different regulatory areas and propose regulatory strategies, this paper complies with the following requirements: (1) It refers to the matching index of ecological, agricultural, and urban space and the carrying capacity of the resources and environment of each administrative unit in 2022; (2) Following the principle of "Mismatch first, low degree matching second, and high degree matching third", this paper identifies severe mismatch and mild mismatch units as priority regulation areas. Critical match and low degree match units are identified as key regulatory areas, while moderate and above match units are considered as moderate regulatory areas.

3.2. Data Source and Processing

The land use status and planning data in this paper are taken from the Resource and Environmental Science and Data Center of the Chinese Academy of Sciences and the General Land Use Planning of Shandong Province (2006–2020), respectively. The digital elevation product SRTMDEMUTM is derived from the Geospatial Data Cloud (http://gscloud.cn/) with a resolution of 90 m. The water resource data from long time series precipitation observations of meteorological stations in and adjacent to the study area in 2020 are obtained from the Resource and Environment Science and Data Centre of the Chinese Academy of Sciences (http://www.resdc.cn). The soil data are taken from the investigation of soil pollution status in and around the research area in 2020. The climate data are sourced from the accumulated temperature and wind speed of the annual average daily temperature ≥ 0 °C at the meteorological stations within the research area in 2020. Finally, the Normalized Difference Vegetation Index (NDVI) is obtained from the resource and environment data cloud platform of the Chinese Academy of Sciences (https://www.resdc.cn/), with a resolution of 1 km. Using the ArcGIS operation platform, the resource, environment, and spatial zoning data were extracted to construct a database of the land space and resource environment in typical areas of the lower reaches of the

Yellow River, in which precipitation, temperature, and other meteorological data were processed using the Kriging interpolation method of the ArcGIS software (ArcGIS 10.8.2). The types of land space were classified into ecological space, agricultural space, and urban space based on the existing literature [45].

4. Results

4.1. Spatial Evolutionary Characteristics of the Territory

The degree of territorial spatial dynamics exhibited a slight decrease, followed by a sharp increase, resulting in significant changes in the spatial structure, as shown in Figure 3. The percentages for the periods of 2000–2005, 2005–2010, 2010–2015, and 2015–2020 were 0.167%, 0.091%, 0.079%, and 1.707%, respectively. Specifically, the expansion of ecological space is centered in the outer-side of the Yellow River Delta, the mountainous parts of Central Lu, and around the South Four Lakes. Conversely, the reduction areas are concentrated in the landward extension of the Yellow River Delta. The extension regions of agricultural space are located in the Yellow River Delta, while a decrease is observed around the towns of the administrative regions. Finally, regarding the urban space, the majority of the increments are distributed in the periphery of the central city, with a minimal reduction.

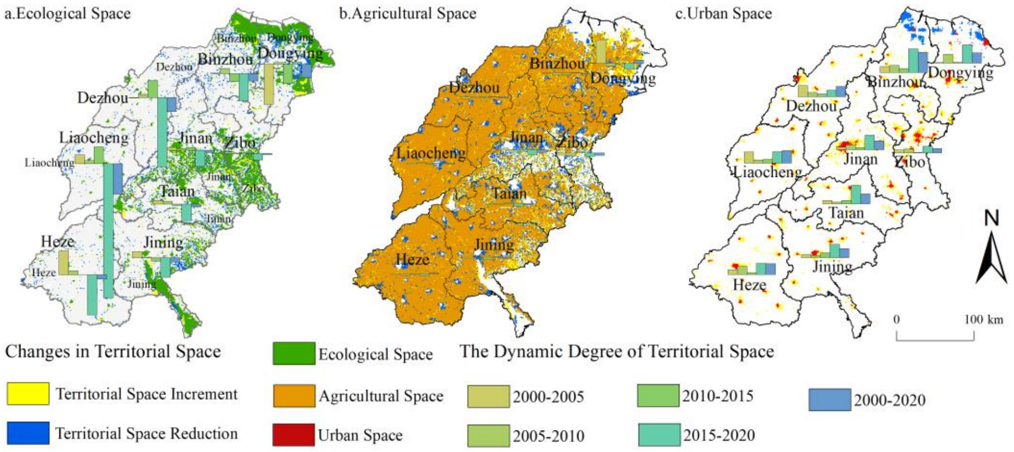

Figure 3. Evolution of territorial space in the Shandong section of the Yellow River basin from 2000 to 2020.

The extent to which the ecological spatial dynamics are affected is characterized by fluctuations between 2000 and 2020. Except for a small number of areas that experienced increases between 2000 and 2005 and between 2010 and 2015, the research period is dominated by a reduction in ecological space. The spatial dynamics of agriculture remained stable between 2000 and 2020, with a trend of shrinking agricultural space in each administrative region. However, the rate of shrinkage was relatively low. The spatial dynamics of towns and cities in all boroughs exhibited growth between 2000 and 2020.

4.2. Resource and Environmental Carrying Capacity Status

4.2.1. Suitability of Land for Spatial Development

The importance of ecological protection (Figure 4a) exhibits a gradient distribution along the rivers, coast, and mountains, and extends inland. Approximately 12.82% of the extremely important ecological protection areas are primarily concentrated in the mountainous areas of central Lu and in ecological reserves along the rivers, lakes, and coastline. The suitability of agricultural production (Figure 4b) demonstrates an overall decrease from inland to coastal and mountainous areas. Nearly 86.96% of the agricultural production areas are suitable or above, and these areas are mainly restricted by the slope of the central terrain and the soil texture. The overall spatial characteristics of the urban construction suitability (Figure 4c) exhibit a decrease from the periphery to the center.

Nearly 86.06% of the urban construction areas are suitable or above, and these areas are mainly constrained by the slope of the terrain and the risk of geological hazards.

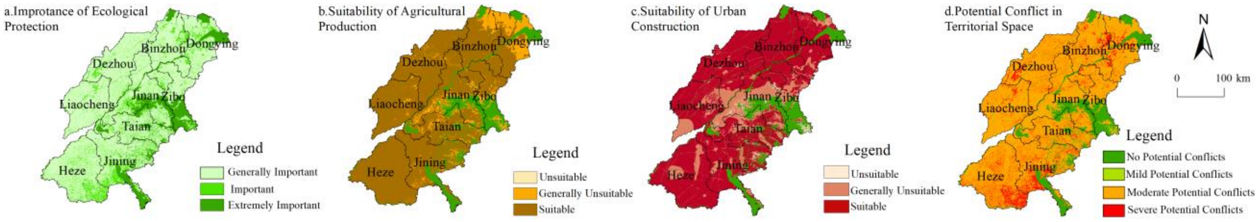

Figure 4. Suitability and potential conflict of territorial space development.

4.2.2. Potential Conflicts in Territorial Space

The intensity of potential conflicts in typical areas of the lower Yellow River is characterized by moderate potential conflicts (Figure 4d). The area share of each potential conflict intensity, in descending order, is as follows: light potential conflict (0.58%), heavy potential conflict (9.13%), no potential conflict area (13.08%), and moderate potential conflict (77.21%). The potential conflict intensity decreases from the plains to the mountains, with some regional variations.

4.2.3. Resource and Environmental Carrying Capacity

The ecological, agricultural, and urban space orientation of the carrying capacity of the resources and environment reflects the dynamic evolution of human activities and resources towards sustainable development. In quantitative terms, the scale of the resource and environmental carrying capacity in the lower reaches of the Yellow River between 2000 and 2020 is dominated by agricultural space, followed by ecological space, and finally urban space, which has the lowest proportion. Specifically, the ecological space decreased from 15,344.82 km^2 to 10,498.27 km^2, showing a decreasing trend year by year. Conversely, the agricultural space increased from 60,316.11 km^2 to 65,959.59 km^2, showing an increasing trend year by year. The spatial scale of the urban areas changed from 8144.92 km^2 to 7345.11 km^2, showing an upward and then downward trend. The ecological spaces are mainly distributed in the Yellow River Delta, the Luzhong mountainous area, and the Weishan Lake area, with ecosystem service functions such as water connotation and soil conservation (Figure 5). Lastly, the agricultural spaces are distributed over the majority of western and southwestern Lu. The towns are distributed in patches within the administrative districts.

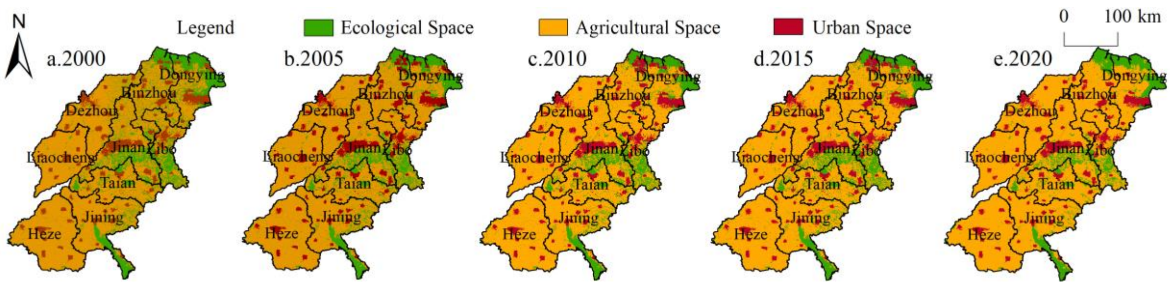

Figure 5. The carrying scale of resources and environment directed by ecological-agriculture-urban space.

4.3. Matching Relationship Analysis

4.3.1. Overall Matching Relationship

Between 2000 and 2020, the index reflecting the alignment between the evolution of ecological space and the carrying capacity of the resources and environment had a decreasing trend. Even though the stress level on ecological space caused by human activities significantly decreased, the coefficient of variation has slightly increased. Furthermore, despite this overall improvement, local areas still faced threats to their ecological space.

Between 2000 and 2020, the match index between the spatial evolution of agriculture and the carrying capacity of the resources and environment exhibited a decreasing trend. This indicates a decrease in the degree of stress that agricultural space imposes on environmental resources. However, the regional disparities in the match relationship have widened over time. Namely, the spatial evolution of towns and cities, as well as the matching index of the carrying capacity of the resources and environment, exhibited an upward trend from 2000 to 2020. The coefficient of variation consistently decreased, thus indicating a reduction in the variability of the matching index across different regions. In addition, the spatial impact of towns and cities on the resources and environment gradually increased, as shown in Table 5.

Table 5. Mathematical statistics on the matching relationship between the evolution of territorial space and the carrying capacity of resources and environment.

Year	Ecological Space			Agricultural Space			Urban Space		
	Mean	SD	COV	Mean	SD	COV	Mean	SD	COV
2000	1.09	0.36	0.33	1.15	0.15	0.13	0.20	0.13	0.65
2005	0.92	0.32	0.34	1.11	0.14	0.13	0.26	0.15	0.58
2010	0.91	0.32	0.35	1.10	0.14	0.13	0.32	0.16	0.49
2015	0.90	0.32	0.36	1.09	0.14	0.13	0.37	0.17	0.47
2020	0.73	0.32	0.43	1.01	0.16	0.15	0.77	0.34	0.44

4.3.2. Partial Matching Relationship

Between 2000 and 2020, the relationship between the evolution of the ecological spatial patterns and the matching of the resource and environmental carrying capacity exhibited a spatial divergence. Namely, it transitioned from a south–north pattern to a center-periphery ring (Figure 6a–e). At the early research stage, Binzhou and Dezhou exhibited a severe mismatch in their respective resource and environmental carrying capacities. Furthermore, Liaocheng, as well as the eastern parts of Tai'an and Jinan, were predominantly characterized by low and critical matches. In the final research stage, a low match area formed around the provincial capital of Jinan, while a mismatch was observed in the Yellow River Delta and in localized areas of Heze and Liaocheng. The main reason for these changes is attributed to the influence of topography. In the early research stage, the unused plains in the north and northwest were reclaimed as arable land, resulting in the shrinkage of ecological space. In contrast, the southeastern region, which is part of the TaiShan Mountains, has a relatively intact ecological base. Additionally, ecological space in the provincial capital increased in later years due to the construction of the forest city of Jinan in 2010. However, ecological protection source areas, such as the Yellow River Delta, have still been significantly disturbed by human activities.

During the research period, the relationship between the spatial evolution of agriculture and the matching of the resource and environmental carrying capacity exhibited a spatial divergence characterized by a northwest–southeast gradient (Figure 6f–j). At the beginning of the study—with the exception of Tai'an and Zibo, which exhibited a locally critical matching relationship—all of the other areas demonstrated a mismatching relationship. In particular, Dongying experienced a severe mismatching relationship. The mismatch improved towards the end of the research period, even though northwestern areas, such as Dezhou, still exhibited a more pronounced mismatch. The main reason for this is that the northwestern region features a plain terrain with abundant resources that are favorable for agricultural production, leading to over-exploitation. In contrast, the southeastern region has a more undulating terrain, which is not conducive to agricultural farming.

The relationship between the spatial evolution of towns and cities and the matching of the carrying capacity of the resources and environment between 2000 and 2020 is characterized by a spatial divergence in the form of a center-periphery ring (Figure 6k–o). At the beginning of the research period, the entire region exhibited a matching relationship, with the exception of Jinan, which had a critical matching relationship. Towards the end of the study, the non-municipal areas showed a serious mismatch, while the remaining parts were predominantly characterized by a matching relationship. The main reason for this is the slow pace of urbanization in the early years. In later years, even though industrialization and urbanization motivated the expansion of urban space, the scale of the resource and environmental carrying capacity was insufficient to support the intensified human activities. This was particularly evident in the pressure exerted on the resources and environment due to the construction of small towns.

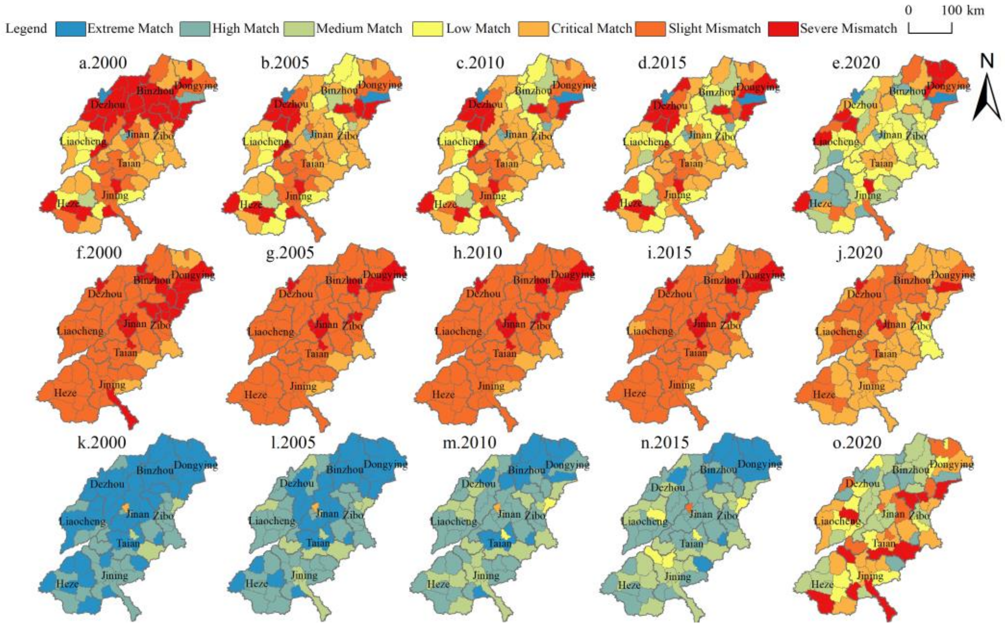

Figure 6. The matching relationship between territorial space evolution and resources and environment.

5. Discussion

5.1. Research Contribution

Our paper found that the urban space in the lower reaches of the Yellow River continued to expand and the ecological space shrank during the specific study period. In this paper, we concluded that the expansion of urban space squeezes the ecological space and leads to the shrinkage of ecological space. Tang et al. concluded that urban expansion is increasingly interfering with the ecological environment, which is in line with our study [42]. Global urban spatial expansion has the same effect on agricultural space, which is the same as the research result of Talema and Nigusie [43]. After that, the resource and environmental carrying scale derived from the evaluation of the national land space suitability and the conflict and regulation of space use in this study has been confirmed to be reasonable by Qu et al. and Wang et al. [35,44]. There is already a foundation of related research on which we developed the framework used in this study. The inherent factors in the construction of the framework have a co-ordinated relationship, and our aim is to change the disordered pattern to establish an orderly and sustainable pattern. Moreover, the results of this research can be applied to the practice of territorial spatial planning, and similar studies are as follows [48,49]. The effectiveness of spatial planning strategies in curbing urban sprawl and environmental protection has been proven in countries and regions [50]. The research pattern helps to provide a basis for decision-making.

This paper proposes a framework for determining the alignment between territorial space and the resource and environmental carrying capacity, as well as realizing the resource and environmental carrying capacity. The framework provides a theoretical basis for understanding the sustainable use of territorial space. Specifically, the matching relationship between the spatial evolution of national land and the carrying capacity of the resources and environment serves as a representation of the interaction between human-environment systems, with implications for the optimization and sustainable management of spatial patterns. By elucidating the changing trends in the relationship between the spatial evolution and carrying capacity of the resources and the environment, differentiated control paths can be developed. In areas with a mismatch relationship, restrictions should be placed on the expansion of territorial space. Furthermore, in areas with a small mismatch, territorial space should be reasonably allocated to ensure that the bottom line of resource and environmental constraints is not breached. Finally, in matched areas, the quality of territorial space use should be improved, aligning the use of various types of territorial space with the resource and environmental constraints.

This paper introduces technical guidelines for assessing the resource and environmental carrying capacity. It emphasizes the importance of identifying and mediating potential conflicts in land and space, thus aiding in the identification of the resource and environmental carrying capacity of regional multi-functional areas. The paper provides a supporting framework for optimizing land structure and pattern reconfiguration.

The authors of this research have conducted an in-depth empirical study in an important ecological region of the Yellow River basin, thus providing a concrete and practical reference for the sustainable development of territorial space. Lastly, as one of the significant ecological regions in the Yellow River basin, our research area plays a crucial role in supporting the conservation and development of the inlet area and other important ecological regions within the basin. This is achieved through the analysis of the spatial evolution, the matching relationship of the resource and environmental carrying capacity, and the ecology-agriculture-urban space. Moreover, our database on territorial space, resources, and the environment in typical areas of the lower reaches of the Yellow River provides a foundation for the formulation and implementation of the relevant government policies.

5.2. Territorial Spatial Optimization and Regulation Strategies

The spatial optimization zoning of typical areas in the lower reaches of the Yellow River is determined by the alignment of the regional control objectives and the variations in the control targets over a specific period. A "three zones and seven categories" spatial optimization pattern facilitates the implementation of tailored control measures, highlighting the urgency of distinct regional control strategies (Figure 7).

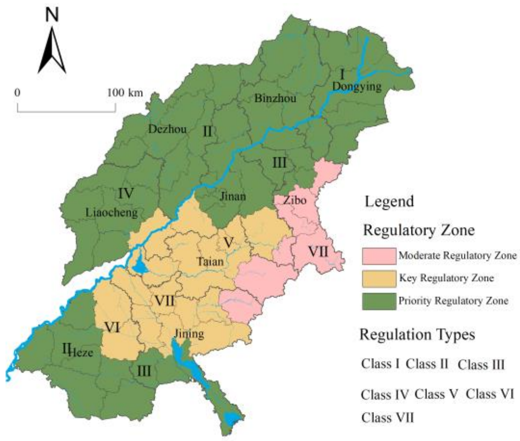

Figure 7. Territorial spatial optimization pattern in typical areas of the lower Yellow River.

The priority control zone encompasses four types of control: ecology-led (I), agriculture-led (II), urban-led (III), and ecology-agriculture synergy (IV). The objective is to address the mismatch between territorial space, on one hand, and the resources and environment, on the other, in order to ensure that the land use aligns with the resource and environmental constraints. This category comprises six administrative regions, primarily located in the Yellow River Delta. This paper recommends establishing an interconnected ecological security pattern of "source-sink-corridor" based on the ecological protection red line. Category II comprises 25 administrative districts, primarily located in northwest and southwest Lu.

Although these regions have a rich agricultural history, they are faced with challenges in terms of water resources availability. We recommend actively implementing fallow rotations on arable land to maintain soil fertility and alleviate water pressure. Category III encompasses 12 administrative districts, all characterized by the expansion of urban construction land. This paper suggests strict control over the expansion of urban land, based on the delineation of urban development boundaries. Emphasis should be placed on pursuing a path of intensive urbanization development by using the potential of existing urban stock. Category IV comprises nine administrative districts, primarily situated in western Lu, where the ecological and agricultural space faces significant challenges. To address them, this paper suggests prioritizing the establishment of ecological corridors. In addition, it is crucial to promote agricultural intensification and large-scale operations through the utilization of modern agricultural machinery. This approach will contribute to the development of a synergistic mechanism for the co-ordinated development of both ecological and agricultural space.

The key control zone encompasses three types of control: ecological town synergy (V), agricultural town synergy (VI), and ecological-agricultural town synergy (VII). The objective is to ensure the rational allocation and use of national space, while also ensuring that it remains within the limits of the resource and environmental carrying capacity. Category V comprises four administrative districts, located in the central part of Lu. All of these districts are influenced by topographical conditions. In urban planning, this paper suggests prioritizing the shaping of ecological space within built-up areas. In addition, there should be a strong emphasis on promoting the construction of landscape and forest cities. Category VI comprises two administrative regions situated in southwest Lu. These regions exhibit high suitability levels for agricultural production and town construction. This paper recommends undertaking a rational planning of the spatial layout and scale of the agriculture and towns. Furthermore, it is important to establish a spatial symbiosis of agriculture and towns based on urban development. Finally, category VII encompasses 12 administrative districts, located in the Dawen River basin. The focus in this category is on the sustainable use of territorial space. This is accomplished by emphasizing the strategic leadership of territorial space planning and recognizing the role of resources and the environment in controlling the use of territorial space.

The moderate control zone comprises the ecological-agricultural-town synergy type (VII), which aims to ensure the stability of spatial utilization. Firstly, it is essential to ensure ecological spatial integrity and connectivity, as this enhances the quality of the living environment and facilitates industrial transformation. Secondly, it is recommended to actively use agricultural development models, such as special agriculture, sightseeing agriculture and picking agriculture, while focusing on exploring the mechanisms required to achieve agricultural ecology. Finally, it is important to prioritize ecological security while focusing on utilizing the existing stock of construction land. This can be achieved by promoting the intensive use of construction land and striving for the co-ordinated development of national land.

5.3. Limitations and Future Research Direction

There are certain shortcomings to this paper, which need to be addressed. Firstly, the research area is rather limited as it is restricted to the typical areas in the lower reaches of the Yellow River. It thus fails to cover the entire Yellow River basin. To provide more comprehensive coverage, future studies should expand the research scope and cover the entire Yellow River basin, thus exploring the spatial evolution patterns of ecology, agriculture, and towns in different areas, as well as the matching relationship between the carrying capacity of the resources and environment.

Furthermore, due to the limitations of data availability and precision, this paper requires further refinement with regards to the relationship of ecological-agricultural-urban space. The delineation criteria can be further improved by drawing on other relevant theories and experiences. In addition, this paper only considers the bearing scale from the perspective of resource background and natural endowment, thus failing to account for the socio–economic factors related to the spatial development and use of territory. This limitation impacts the accurate identification of the carrying scale. In order to assess the carrying capacity in a more comprehensive manner, future studies should incorporate socio–economic indicators, such as population density, the economic development level, and infrastructure development. Such a comprehensive analysis will help to better guide the sustainable development and rational use of territorial space.

Finally, the territorial spatial planning system contains five levels of planning: national, provincial, city, county, and township level. Therefore, exploring the multi-dimensional decomposition and transmission of the territorial spatial pattern from the perspective of multi-scale correlation will aid in understanding and planning the sustainable development of territorial space.

6. Conclusions

This paper structures the role of potential conflict identification and mediation between the suitability of territorial space development and the carrying capacity of the resources and environment. It further identifies the problems of territorial space utilization in typical areas of the lower reaches of the Yellow River by investigating the matching relationship between the evolution of territorial space and the carrying capacity of the resources and environment.

Firstly, the rate of change to the territorial space in 2000–2005, 2005–2010, 2010–2015, and 2015–2020 period is 0.167%, 0.091%, 0.079%, and 1.707%, respectively. These data show the fluctuating shrinkage of ecological space, a relatively stable agricultural space, a continuous increase in urban space, and significant changes in the territorial space structure.

Secondly, the spatial development suitability of the land in typical areas of the lower reaches of the Yellow River exhibits topographic and land-sea divisions. Namely, the intensity of potential conflicts is dominated by moderate potential conflicts. Furthermore, the spatially directed resource and environmental carrying capacity of the ecology, agriculture, and towns reflects the dynamic evolutionary processes of human activities and the resources and environment, which tend towards sustainable development.

Thirdly, between 2000 and 2020, the index of matching the ecological and agricultural spatial evolution with the resource and environmental carrying capacity experienced a decreasing trend, with expanding regional differences. Conversely, the index of matching urban space and the resource and environmental carrying capacity showed an increasing trend, leading to smaller regional differences. The development of "three zones and seven categories" of national spatial optimization and the control strategy to achieve them can help in the sustainable use of national spatial areas by adopting differentiated control paths.

Finally, this paper proposes strategies for the optimal regulation and control of the use of sustainable territories. This paper only explores the matching relationship between the territorial spatial evolution and the bearing capacity of resources and the environment from the perspective of scale. The research on matching human activities and the resources and environment under the perspective of multi-dimensional coupling requires further corroboration. In addition, it is important to note that this paper solely focuses on the matching analysis between the spatial evolution of national land and the carrying capacity of the resources and environment at the present stage. However, the typical areas in the lower reaches of the Yellow River are currently undergoing a critical period of transition. Therefore, the spatial evolution of national land in this area is of significant importance and requires further investigation.

The priority control zone encompasses four types of control: ecology-led (I), agriculture-led (II), urban-led (III), and ecology-agriculture synergy (IV). This paper suggests prioritizing the establishment of ecological corridors. In addition, it is crucial to promote agricultural intensification and large-scale operations through the utilization of modern agricultural machinery. The key control zone encompasses three types of control: ecological town synergy (V), agricultural town synergy (VI), and ecological-agricultural town synergy (VII). In urban planning, this paper suggests prioritizing the shaping of ecological space within built-up areas. In addition, there should be a strong emphasis on promoting the construction of landscape and forest cities. The moderate control zone comprises the ecological-agricultural-town synergy type (VII). Firstly, it is essential to ensure ecological spatial integrity and connectivity, as this enhances the quality of the living environment and facilitates industrial transformation. Secondly, it is recommended to actively use agricultural development models, such as special agriculture, sightseeing agriculture, and picking agriculture.

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Data Availability Statement: The land use status and planning data in this paper are taken from the Resource and Environmental Science and Data Center of the Chinese Academy of Sciences and the General Land Use Planning of Shandong Province (2006–2020), respectively. The digital elevation product SRTMDEMUTM is derived from the Geospatial Data Cloud (http://gscloud.cn/). The water resource data from the long time series precipitation observations of meteorological stations in and adjacent to the study area in 2020 are obtained from the Resource and Environment Science and Data Centre of the Chinese Academy of Sciences (http://www.resdc.cn). The soil data are taken from the investigation of soil pollution status in and around the research area in 2020. The climate data are sourced from the accumulated temperature and wind speed of the annual average daily temperature ≥ 0 °C at the meteorological stations within the research area in 2020. Finally, the Normalized Difference Vegetation Index (NDVI) is obtained from the resource and environment data cloud platform of the Chinese Academy of Sciences (https://www.resdc.cn/).

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