

Original Research

Function Evaluation and Optimal Strategies of Three Types of Space in Cross-Provincial Areas from the Perspective of High-Quality Development: A Case Study of Yangtze River Delta, China

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Abstract

Green and high-quality development of China's territorial space is an inevitable requirement for implementing the new vision and building the new development pattern. The paper builds the evaluation model of urban-agriculture-ecology space to scientifically analyze its spatial function characteristics, and makes spatial function optimization zoning to clear priorities and directions for the development of Yangtze River Delta. The results are as follows: (1) the spatial distribution of urban and agricultural functions has a high overlap, which are mainly concentrated in Shanghai, southern Jiangsu and coastal areas of Zhejiang, but the ecological functions are obviously weak, decreasing from southwest to northeast; (2) according to the improved two-dimensional graph theory clustering algorithm, Yangtze River Delta is divided into six function zones, and our study puts forward scientific countermeasures and suggestions for the rational utilization and development of land space based on the actual characteristics of each functional zone; (3) the zoning factor proposed and the zoning method well maintains the continuity of the functional areas and the integrity of the administrative areas. Hence, it has a good application prospect in the functional optimization, providing the scientific basis and reference value for the spatial planning and integrated development of cross-provincial areas with the goals of high-quality development.

Keywords: spatial function, optimal strategies, urban-agriculture-ecology space, cross-provincial areas, Yangtze River Delta

Introduction

The new development pattern is a strategic choice for the new challenges facing the periodic adjustment of globalization to restore China's new advantages in international cooperation and competition and established with the major domestic cycle as the main body and the double domestic and international cycles reinforcing each other. From the perspective of sustainable development and the overall situation, optimizing the spatial layout of cross-provincial areas is a necessary requirement for implementing the new development concept and building a new development pattern [1]. The land space is the carrier of high-quality economic and social development, with multiple functions of production, living, ecology and so on [2, 3], and its development pattern is the distribution state of economic factors formed by a country's long-term production and business activities relying on a certain geographical space. Therefore, the spatial development status is not only affected by the initial state, but also closely related to the national development priorities and policy tendency in a certain period. Under this background, it is urgent to break administrative boundary constraints, improve the utilization efficiency of land space, and further promote spatial connectivity, the integration of neighboring cities and regional integrity in order to form a new pattern of protection and development.

In recent years, China has made remarkable achievements in economic and social development as the pace of territorial space development is accelerating, but many problems have also arisen, such as disordered spatial development, inefficient utilization of resources, and fragile and shrinking ecological space [4, 5]. The contradictions between urban and rural areas, among production, living and ecological space, and between cultivated land protection and construction land expansion at the national level have become more prominent [6]. For this reason, the expression and realization of spatial functions and high-quality land space have received increasing attention [7]. As the basic space function of the human-nature system, urban-agriculture-ecology function can effectively reflect the complexity and vulnerability of man-land relationship, and can fully embody the results and characteristics of spatial resources competition [8]. Therefore, the future research on the formation and effect of the territorial space pattern should focus on the cultural, institutional and human-oriented factors in conflict areas of urban-agriculture-ecology space, so as to adapt to the new development trend and meet the new requirements of high-quality development of national land space [9, 10].

The suitability evaluation of spatial development is an extension of land suitability evaluation [11, 12]. The relevant studies mainly focus on the following four aspects. Firstly, some scholars made suitability evaluation on industrial land and construction land at a medium and macro scale [13, 14]. Secondly, the specific

regions played a supporting role in the development of urbanization and industrialization [15]. Thirdly, the suitability evaluation was judged by comprehensively considering the regional ecological environment and resource conditions, development basis and potential [16, 17]. Fourth, it served the basic work of territorial spatial planning [18]. The establishment of the index system and evaluation model is the key to the suitability analysis of land space. At present, some researchers begin to focus on the suitability analysis of territorial space development based on different scales, such as the suitability evaluation of different types of industrial land [19, 20], control zoning of urban space and the evaluation on specific governance methods [21]. A breakthrough point of the existing research is to build scientific evaluation models by using powerful computer support, mathematical methods and 3S technology, such as ideal point and order average weight, fuzzy mathematical concept model, neural network model and GIS spatial superposition analysis [22]. Also, multi-source data such as remote sensing images, geographical conditions and Internet POI have also been comprehensively used [23, 24]. In addition, some scholars established the index system and determined the evaluation scheme according to the status quo of the research object, such as the land suitability evaluation [25, 26], suitability evaluation of a crop planting area serving agriculture [27], the suitability evaluation of a specific spatial function including ecosystem, agriculture, landscape and other fields [28], and the construction of evaluation index system of comprehensive land development suitability [29, 30]. Because the scientific logic of the suitability evaluation has always been the focus of academic attention and questioning, in the future, the spatial suitability evaluation should not only improve the application of data and methods, but also clarify the evaluation logic problems, meeting the scientific and operational requirements for spatial planning and optimization practice [31].

At present, based on the spatial suitability evaluation, the relevant research analyzes a single spatial function to explore the optimal path of spatial functional zones. Firstly, scholars analyzed urban spatial functions based on urban suitability evaluation, and proposed corresponding improvement countermeasures for conflict zones [32]. Secondly, some researchers proposed a tradeoff framework between the built-up space and green space, and put forward the effective regulation countermeasures for ecological space [33]. Thirdly, a few scholars suggested a regional control model about the spatial functional zones centered on classified protection, the comprehensive control and cluster development [34]. Furthermore, due to the multifunction and dynamic variability of land space utilization, and the conflicts of interests among participants, the territorial space can only be optimized through tradeoff decisions [35]. Based on this, some scholars identified the characteristics and formation mechanism of spatial conflicts through the analysis

of regional land use structure conflicts, land conversion conflicts and landscape pattern conflicts [36, 37], and believed that public participation, spatial equity, rural revitalization and new urbanization are effective ways to resolve land use conflicts [38]. Hence, it is necessary to have forward-looking thinking to study the optimization of land space. In the future, the research on spatial optimization should focus on the combination of macro scale and micro scale, the innovation of spatial optimization ideas and methods, and the establishment of evaluation index system should add some humanistic elements such as the policies, institutions and public interest [39]. More importantly, the administrative boundary constraints should be broken, and the influence and effect on adjacent administrative space units should be emphasized to further promote spatial connectivity and regional integrity.

The Yangtze River Delta is one of the regions with the most active economic development, the highest degree of openness and the strongest innovation ability in China. It is also an important engine of China's development and an important strategic area for realizing modernization. In recent years, with the continuous expansion of urban and rural construction

land, ecological space and agricultural space have been continuously squeezed and shrinking, leading to the intensification of the contradiction among urban, agricultural and ecological space. Therefore, it is urgent to further clarify the relationship and boundary among urban-agriculture-ecology space, and define the key areas for ecological protection to form a new development and protection pattern with reasonable division of labor, complementary advantages and interconnection, which can provide scientific theoretical guidance and decision-making basis for the implementation of effective geospatial governance.

In view of this, we build the evaluation model of cross-provincial territorial space function to scientifically makes the function division to ensure spatial connectivity and regional integrity by analyzing the evolution of land use type in Yangtze River Delta from 2000 to 2020. More specifically, this study constructs evaluation index system of urban-agriculture-ecology space, then uses the improved two-dimensional graph theory clustering algorithm to determine optimal zoning, and finally puts forward the optimization path and corresponding development suggestions. The purpose of this study is to reveal

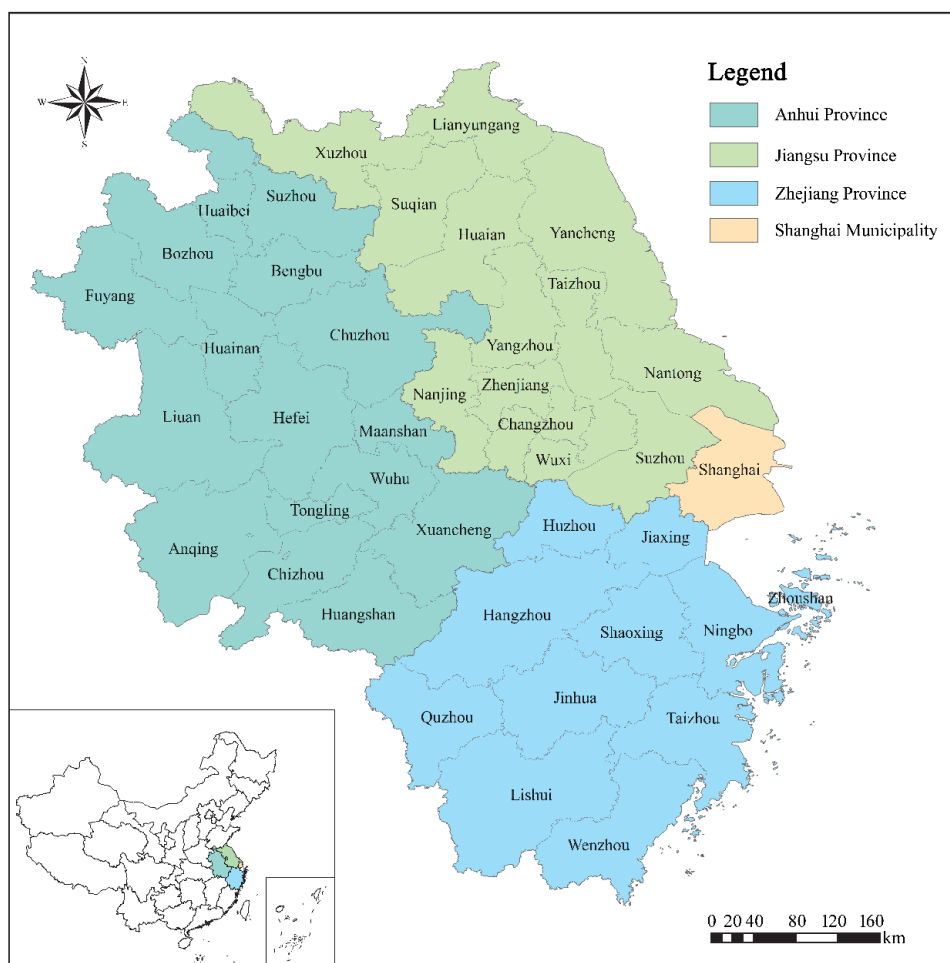


Fig. 1. The location of Yangtze River Delta.

the correlation mechanism between spatial planning and function improvement, and put forward the idea and method of cross-province spatial optimization zoning that can be popularized easily to various jurisdictions beyond China, which is unique from prior relevant empirical studies.

Materials and Methods

Description of Study Area

The study area is in the lower reaches of the Yangtze River, bordering the East China Sea and Yellow Sea, and centering on the Taihu Lake Plain. It includes three provinces of Jiangsu, Anhui, Zhejiang and the City of Shanghai, and 41 city-level units, which covers an area of 358000 km² (Fig. 1). In 2019, the GDP in Yangtze River Delta was 23.72 trillion RMB, accounting for

nearly a quarter of China's total economy, and its total imports and exports accounted for about 30 percent of the country's total. With the rapid development of social economy in recent years, the level of industrialization and urbanization in Yangtze River Delta has been rapidly improved,

However, there still exist some problems. On the one hand, ecological space and agricultural space are continuously squeezed and shrinking. As can be seen from the map of land use change in Yangtze River Delta from 2000 to 2020, the total area of farmland and wetland decreased by 21860.98 km² and 527.72 km² respectively, which directly affected residents' quality of life and increased cross-regional ecological risks. On the other hand, the distribution of high-quality farmland overlaps with that of built-up areas, and the development functions of urban and agricultural space are hard to distinguish. In the past 20 years, the built-up areas have increased by 22172.18 km², the pressure

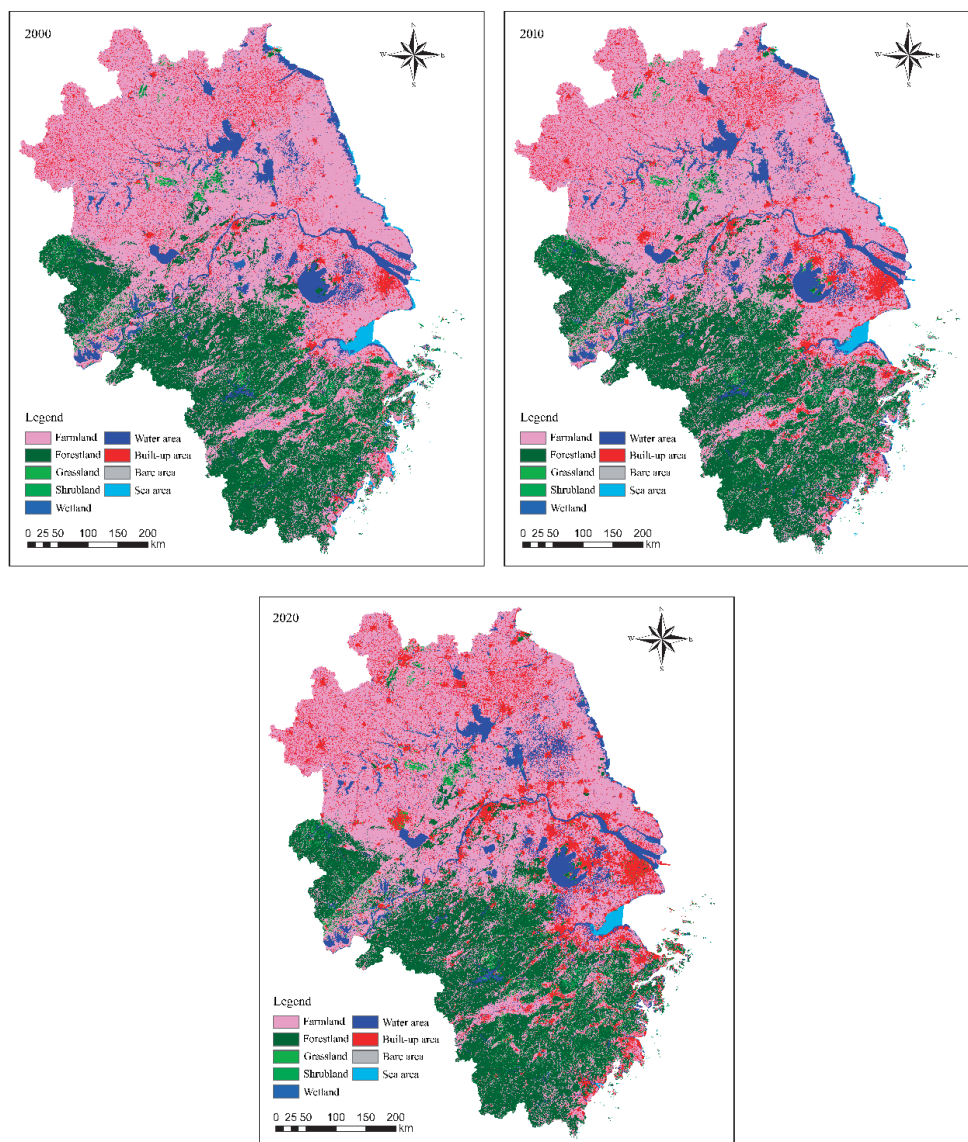


Fig. 2. The land use map of Yangtze River Delta in 2000, 2010 and 2020.

of farmland protection continues to increase, and the contradiction among urban, agricultural and ecological space intensifies, which seriously restricts the high-quality, healthy and sustainable development of Yangtze River Delta (Fig. 2).

The Model of the Spatial Function Evaluation

Firstly, based on the present situation of Yangtze River Delta and the analysis of LUFs (Land Use Functions) index [40], this study establishes a multi-dimensional evaluation index system of urban-agriculture-ecology space function. The second-level evaluation index system includes five aspects: urban life function, urban production function, agricultural production function, ecological regulation function and environmental maintenance function. Considering the data stable, scientific and operable, this paper selects 19 three-level indicators as the evaluation system of spatial function development level. The detailed indicators are listed in Table 1. Secondly, the entropy method is used to confirm the weight of index. Because the method has strong operability, can reflect the implicit information of data, and enhance the discrimination and difference of indicators, it can not only overcome the arbitrariness of subjective assignment, but also effectively solve the overlapping problem of information among multiple indicators. Finally, the spatial single function reflects the single function position in a region compared with the function in other regions, and the size of its function value represents the level of regional function. Therefore, the weighted summation model is used to obtain spatial single function values in this study. The formula is as follows:

$$f_i = \sum_{j=1}^n x_{ij} \times w_j \tag{1}$$

where f_i is the spatial single function value; x_{ij} is the j-th index value of the i-th single function; w_j is the weight of the j-th index, and n is the number of the i-th single function index.

The Improved Two-Dimensional Graph Theory Clustering Algorithm

Due to the differences in spatial location and layout among cities in Yangtze River Delta, it is necessary to consider not only the function value of urban, agricultural and ecological space, but also the geographical position among cities in order to maintain the spatial connectivity and integrity while ensuring the relative consistency of the functional attributes. Therefore, this study uses the improved two-dimensional graph theory clustering method to make functional division scientifically which takes the correlation among the partition units, the spatial adjacency, index similarity and the regional integrity

into account. Specifically, the method introduces a weighted connected network, and on the basis of constructing a weighted connected undirected graph $G = (V, E, D)$ (where V is the set of partition units, E is the set of spatial association relations of each unit, and D is the weight value of the connecting edge between units), the clustering results can be obtained by using the minimum spanning tree in graph theory. Then, according to the principle of small regional difference and large interval difference, the appropriate threshold is selected to divide the minimum spanning tree into N subtrees which will be made appropriate adjustment according to the actual situation of the region, and finally the functional zoning results are obtained (Fig. 3).

The Calculation Method of Connection Edge Weight

The method of two-dimensional graph theory clustering takes the distance between social and economic indicators in different regions as the weight of the undirected graph to make analysis, in which the distance represents the difference between two areas. This study uses Mahalanobis distance function to calculate the weight value of the connecting edges based on the selected index and the actual situation of the study area. Although most relevant scholars adopt Euclidean distance function, in contrast, Mahalanobis distance function is not only not affected by dimension, but also can exclude the correlation interference between variables to judge the distance more accurately. The formula is:

$$D_M(X, Y) = \sqrt{(X - Y)^T \Sigma^{-1} (X - Y)} \tag{2}$$

where $D_M(X, Y)$ represents Mahalanobis distance of the vector between X and Y, Σ is the covariance matrix of the multidimensional random variables.

The Minimum Spanning Tree Method Based on Kruskal Algorithm

There are two kinds of minimum spanning tree algorithms, namely Kruskal algorithm and Prim algorithm, but Kruskal algorithm is more efficient on graphs with sparse edges. Therefore, based on the actual situation of the research area, this study uses Kruskal algorithm to calculate the minimum spanning tree. The specific idea is to sort all the connecting edges in ascending order according to the weight value, and then judge from small to large one by one. If not, the connecting edge will be kicked off until the network with n vertices filters out n-1 edge, and the selected edges and all vertices form the minimum spanning tree of the connected network.

Table 1. The multi-dimensional evaluation index system of urban-agriculture-ecology space function.

The first-level index	The second-level index	The third-level index	The calculation method
Urban space function (X1)	Urban life function	Land urbanization rate (+)	Urban area/Total administrative area
		Urban-rural income ratio (-)	The urban incomes/farmer's incomes
		Population density (+)	The permanent residents/Total administrative area
		Number of medical beds per area (+)	Number of medical beds/Total administrative area
		School number per area (+)	The number of schools/Total administrative area
	Urban production function	Proportion of employed population in second and third industries (+)	Number of jobs in second and third industries/total number of employees
		density of highway (+)	Highway mileage/Total administrative area
		Energy consumption per capita (+)	Total energy consumption/Permanent resident population
Working population density (+)		Total working population/Total administrative area	
Agricultural space function (X2)	Agricultural production function	Grain guarantee rate (+)	Grain output per capita /400*100%
		Land reclamation rate (+)	Arable land/Total administrative area
		arable land per capita (+)	Arable land/Permanent resident population
		Proportion of output value in first industry (+)	Output value of primary industry/Regional gross output
Ecological space function (X3)	Ecological regulation function	NDVI (+)	NDVI / Total administrative area
		The drainage density (+)	Water area/Total administrative area
	Environmental maintenance function	Habitat quality index (+)	$Abio*(0.35*Woodland+0.21*Grassland+0.28*Wetland+0.11*Arableland+0.04*Constructionland+0.01*Unusedland)/Total\ area$
		Biological abundance index (+)	$Abio*(0.5*Woodland+0.3*Waterarea+0.15*Grassland+0.05*Others)/Total\ area$
		The industrial waste water discharge (-)	
		Sulfur dioxide and nitrogen oxide emissions (-)	

Note: The „+” and „-” symbols in parentheses and their combination are used to express the index attribute, which respectively represent the positive index and negative index.

Results

The Spatial Function Evaluation

By using the entropy weight method, the weight of the second-level index is calculated to reflect the position and role of each single function in the area (Table 2). Then, in order to further explore the characteristics of interval differences of spatial functions in Yangtze River Delta, this paper uses the Natural Breaks (Jenks) based on the ArcGIS platform to divide the calculated

functional values of urban space, agricultural space and ecological space into four levels: low, medium, medium-high and high, and draws the corresponding spatial function distribution map (Figs 4-6).

The Evaluation of Urban Space Function

Fig. 4 show that there is a high overlap between urban production function and urban life function in Yangtze River Delta, mainly concentrated in Shanghai, southern Jiangsu and the coastal areas of Zhejiang.

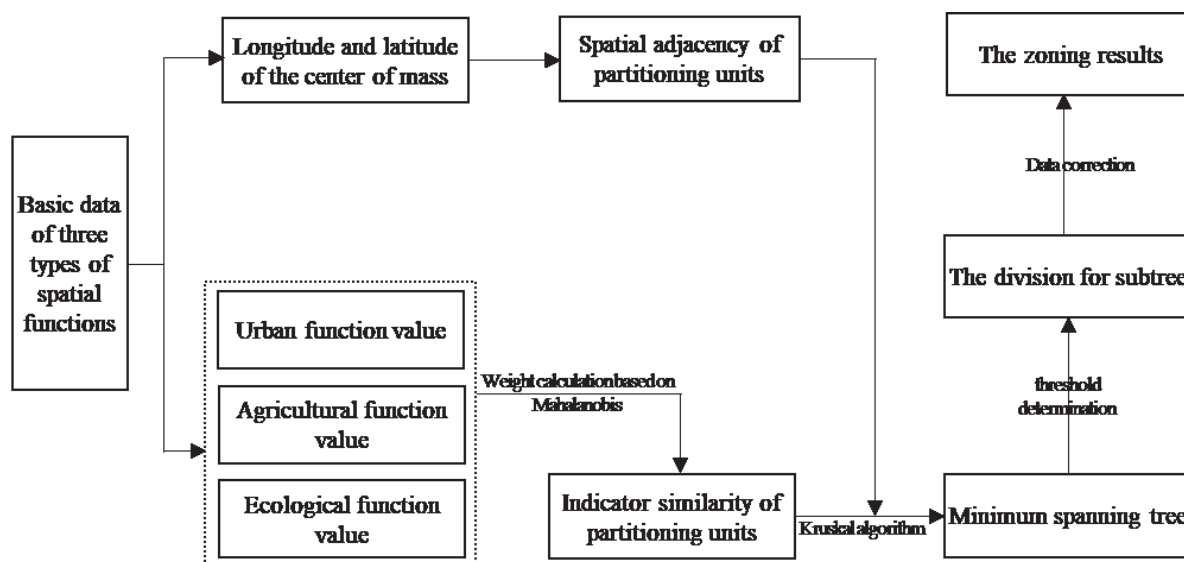


Fig. 3. The flow chart of land use multifunctional zoning.

The urban space function is at relatively higher level, but the spatial difference is significant. The distribution pattern of high-level, medium-high level and low-level cities changes greatly with obvious spatial agglomeration trend. The high-value areas ($X1 > 0.203$) are concentrated in the eastern and central parts of the Yangtze River Delta, including Shanghai, Wuxi, Suzhou

and Nanjing. Among them, due to the high urbanization rate, population density, medical level and convenient transportation facilities, the urban space function value (0.368) of Shanghai is the highest in Yangtze River Delta. The medium-high value areas ($0.140 < X1 < 0.203$) include Changzhou, Zhenjiang, Taizhou, Ningbo, Huaibei and Jiaxing, where the proportion of population

Table 2. The weight of the second-level index based on entropy weight method.

Cities	Agricultural production function	Urban life function	Urban production function	Ecological regulation function	Environmental maintenance function
Shanghai	0.012	0.255	0.113	0.046	0.028
Nanjing	0.036	0.146	0.090	0.026	0.033
Wuxi	0.023	0.151	0.108	0.050	0.042
Xuzhou	0.089	0.087	0.050	0.015	0.015
Changzhou	0.038	0.109	0.092	0.027	0.028
Suzhou	0.017	0.134	0.116	0.088	0.051
Nantong	0.102	0.057	0.074	0.026	0.027
Lianyungang	0.168	0.060	0.055	0.029	0.032
Huaian	0.116	0.040	0.036	0.041	0.044
Yancheng	0.123	0.037	0.046	0.029	0.030
Yangzhou	0.078	0.065	0.067	0.034	0.033
Zhenjiang	0.056	0.073	0.093	0.025	0.035
Taizhou	0.079	0.072	0.078	0.022	0.024
Suqian	0.098	0.062	0.029	0.040	0.040
Hangzhou	0.016	0.061	0.055	0.025	0.175
Ningbo	0.025	0.088	0.078	0.029	0.104
Wenzhou	0.020	0.068	0.044	0.019	0.156
Jiaxing	0.039	0.090	0.084	0.058	0.044

Table 2. Continued.

Huzhou	0.053	0.049	0.062	0.012	0.080
Shaoxing	0.036	0.062	0.058	0.018	0.118
Jinhua	0.027	0.052	0.043	0.014	0.161
Quzhou	0.053	0.024	0.033	0.015	0.176
Zhoushan	0.053	0.075	0.059	0.036	0.069
Taizhou	0.034	0.061	0.050	0.020	0.143
Lishui	0.045	0.008	0.016	0.015	0.237
Hefei	0.062	0.065	0.061	0.032	0.039
Huzhou	0.065	0.058	0.060	0.022	0.044
Bengbu	0.103	0.064	0.030	0.025	0.032
Huainan	0.107	0.060	0.055	0.026	0.031
Maanshan	0.073	0.050	0.089	0.026	0.043
Huaibei	0.088	0.083	0.121	0.012	0.020
Tongling	0.062	0.049	0.070	0.042	0.073
Anqing	0.089	0.029	0.034	0.032	0.101
Huangshan	0.049	0.010	0.015	0.017	0.237
Chuzhou	0.143	0.020	0.046	0.021	0.036
Fuyang	0.109	0.081	0.046	0.012	0.020
Suzhou	0.116	0.049	0.036	0.012	0.019
Liuan	0.127	0.022	0.026	0.019	0.123
Bozhou	0.138	0.061	0.036	0.012	0.020
Chizhou	0.083	0.014	0.025	0.023	0.179
Xuancheng	0.095	0.012	0.029	0.017	0.138

employed in secondary and tertiary industries is relatively large and the per capita energy consumption function value is very high. The medium-value areas ($0.076 < X_1 < 0.140$) are mainly distributed in the north, east and south of the Yangtze River Delta, including Xuzhou, Nantong, Lianyungang, Yancheng etc., which account for a relatively large proportion. The low-value areas ($X_1 < 0.076$) include 9 cities of Huaian, Quzhou, Lishui, Anqing, etc., and the urban space function value of Lishui is the lowest (0.024) in Yangtze River Delta because of the low population density and the low level of its infrastructure such as education and medical care.

The Evaluation of Agricultural Space Function

From the perspective of spatial distribution, the value of agriculture space function in Yangtze River Delta decreased gradually from northwest to southeast, and the agricultural production function in the central and southern regions was relatively insufficient. As shown in Fig. 5, the high-value areas of agricultural

space function ($X_2 > 0.109$) are mainly concentrated in the north of Jiangsu and Anhui, including Lianyungang, Huaian, Yancheng, Chuzhou, etc. They are the important agricultural area and main grain-producing area, with multiple modern agricultural science and technology demonstration garden and strong agricultural production service capacity. Among them, the agricultural function value of Lianyungang is the highest (0.168). The medium-high value areas ($0.073 < X_2 < 0.109$) are mainly distributed in the western and northern regions with the advantage of agricultural multifunctional development. The medium-value areas ($0.039 < X_2 < 0.073$) include 10 cities of Zhenjaing, Huzhou, Zhoushan, etc., and the average value is 0.057. The low-value areas ($X_2 < 0.039$) including Shanghai, Nanjing, Wuxi, etc., mainly distributed in the central and southeastern regions, where the proportion of ecological land is large, the average grain yield per unit area of cultivated land is low, and the reserve resources for development are limited. what's more, the land utilization rate is relatively low due to insufficient land use.

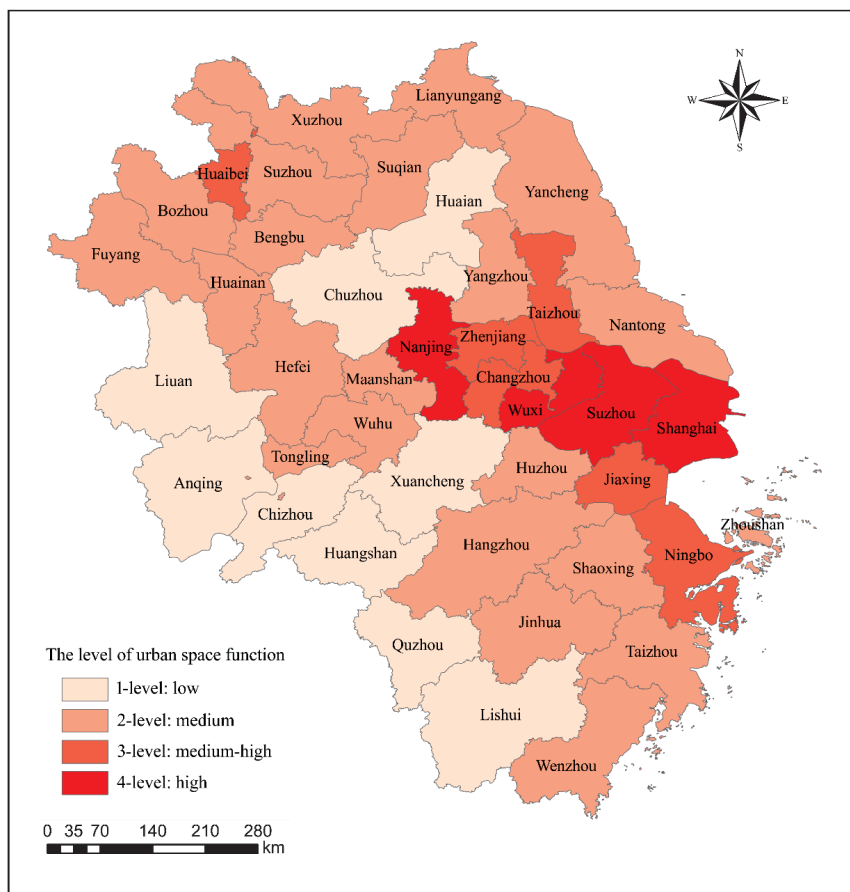


Fig. 4. The evaluation results of urban space function.

The Evaluation of Ecological Space Function

The evaluation value of the ecological space function in Yangtze River Delta is relatively low, with an average value of 0.102. Fig. 6 shows that the spatial heterogeneity of ecological function is obvious, with a higher distribution of functional level in the southwest than the northeast. The areas with higher ecological function value are mainly distributed along the Yangtze River and the regions dominated by forestland. Among them, the ecological function value of Huangshan is the highest with the better environmental maintenance function and the higher habitat quality and water conservation index. However, the ecological function value of Xuzhou is the lowest in the whole region because of its low habitat quality index and biological abundance index, poor maintenance and protection of resources and landscape. Specifically, the high-value areas ($X_3 > 0.163$) are mainly located in the key ecological function zones in the southwest of the Yangtze River Delta; the medium-high areas ($0.093 < X_3 < 0.163$) include Suzhou, Ningbo, Jiaxing, Shaoxing, etc., which is in high forest coverage rate, strong function of regulating and mitigating pollution emission, and better habitat quality and water conservation capacity; the medium-value areas ($0.046 < X_3 < 0.093$) are mainly distributed in the northeast region with low vegetation coverage rate

and need to be strengthened in resource and landscape maintenance; the low-value areas ($X_3 < 0.046$) include six cities of Xuzhou, Huaibei, Fuyang and Suzhou, etc., where the forest and water acreage is low and the quality of habitat is poor.

The Optimized Zoning Results of Spatial Functions

Combined with the centroid longitude and latitude data, this paper makes analysis of graph-theoretic clustering for urban-agriculture-ecology space function by using PYTHON, and finally obtains the diagram of two-dimensional graph theory cluster tree, in which the weights of the connection edge ranged from 2.904 to 7.682, and the larger the weights, the lower the similarity between the partition elements. The results show that connection edges with higher weight include Shanghai-Jiaxing, Zhoushan-Ningbo and Haozhou-Huaibei and the weight value of Zhenjiang-Taizhou is the smallest. To ensure the centralized contiguity of functional zoning results, such differences can be ignored and the branches on the same trunk can be directly grouped into the same functional zone. Therefore, based on the principle of internal consistency and functional difference, combined with the spatial utilization characteristics of Yangtze River Delta, this

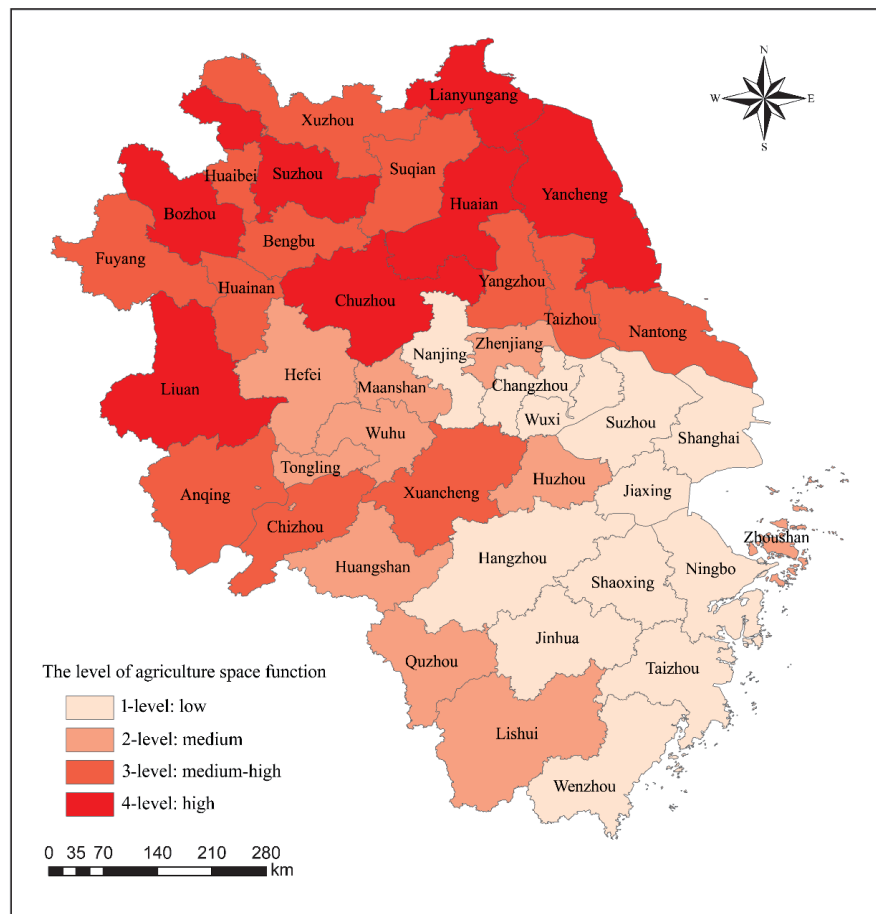


Fig. 5. The evaluation results of agricultural space function.

study divides Yangtze River Delta into six functional zones, which are named as agricultural production core zone, agricultural potential development zone, urban optimized development zone, urban expansion and promotion zone, urban and ecological function complex zone and key ecological function guide zone (Fig. 7).

The agricultural production core zone includes 7 cities in north Jiangsu and northeast Anhui, with a total area of 66769.29 km², and the agricultural production function value is the highest. It is the main agricultural production area in Yangtze River Delta, which is suitable for the development of ecological agriculture. The agricultural potential development zone is in the northwest of Yangtze River Delta, including five cities with a gross area of 38620.44 km². This area is rich in agricultural resources and has great potential for agricultural development, which is suitable for developing the specialized agricultural products brand and promoting the development of characteristic industries. The urban optimized development zone covers a total area of 48272.4 km² and is near the estuary of the Yangtze River, which is the most economically developed region in Yangtze River Delta, and the function values of urban production and living are both high. The urban expansion and promotion zone is on the central and western part, and its future

development direction is to integrate resources, expand space, improve industry, and transform and upgrade the region. The total area of urban and ecological function complex zone is 20694.6 km², of which the ecological land accounts for more than 20%. Duo to the infrastructure construction in this region is relatively perfect, urban production, living and ecological functions coexist, making it an ecologically livable and employable region. The key ecological function guide zone is in the southwest Yangtze River Delta, covering an area of 19553.67 km², in which the ecological function is more prominent based on the favorable ecological conditions. Therefore, the method of two-dimensional graph theory clustering can not only achieve the goal of the consistency and similarity of functional zones, but also maintain the adjacency and the integrity of the regions.

Discussion

The Urban Function Space

In urban space, it mainly focuses on optimizing development, expansion and upgrading of spatial function. Specifically, for urban optimized development

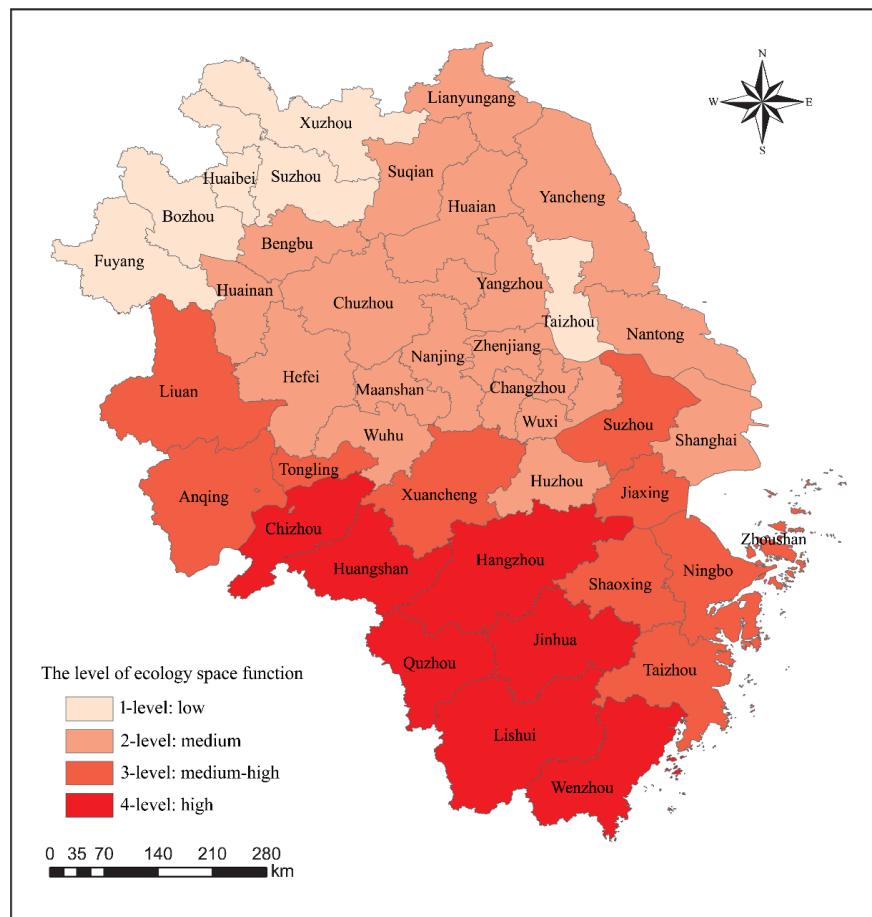


Fig. 6. The evaluation results of ecological space function.

zone, cities such as Shanghai, Nanjing, Wuxi and Suzhou should play a leading role in high-quality development, and Nantong, Zhenjiang, Taizhou and Jiaying should enhance the socio-economic development level and potential by optimizing the industrial structure, raising industrial efficiency, investment efficiency and the level of science and technology industries. In addition, by accelerating the supply-side structural reform, Nantong, Zhenjiang, Taizhou and Jiaying should increase the public facilities such as education, health care, etc., and take effective steps to control non-point source pollution of water, soil and air, improving the quality of the ecological environment and fostering a green, low-carbon and circular way of life, in order to attract the population and industries of Shanghai, Nanjing and Suzhou, which can balance the regional pressure on the resources and promote the construction of ecology civilization. For urban expansion and promotion zone, it should strive to enhance the status of Hefei as a central city in the future and speed up the construction of a famous lake city. On the one hand, give full play to the innovation-driven effect of the comprehensive national science demonstration zone in Hefei-Wuhu-Bengbu, promoting the cooperation and co-construction with Huainan, Luan, Chuzhou, Tongcheng and Dingyuan.

On the other hand, it is necessary to lead industrial transformation and upgrading, realizing seamless connection with Nanjing metropolitan area, become an influential metropolitan area in China and an important growth pole rising in central China, and actively build a world-class electronic information industrial cluster to accelerate the integrated development of industry and city.

The Agricultural Function Space

The regional space dominated by agricultural functions includes agricultural production core zone and agricultural potential development zone. Therefore, the first place is to fully explore the multi-functionality of agriculture and cultivate new forms with the new idea of “agriculture plus” to form a new growth point of rural revitalization in Yangtze River Delta, and then promote the deep integration of agriculture, tourism and the internet. Secondly, it is necessary to deepen the supply-side structural reform of agriculture in this functional zone and focus on developing ecological and smart agriculture with high-quality, high-added-value. Finally, it should promote green agricultural production by reducing the use of chemical fertilizers and pesticides to achieve zero growth, improving the comprehensive

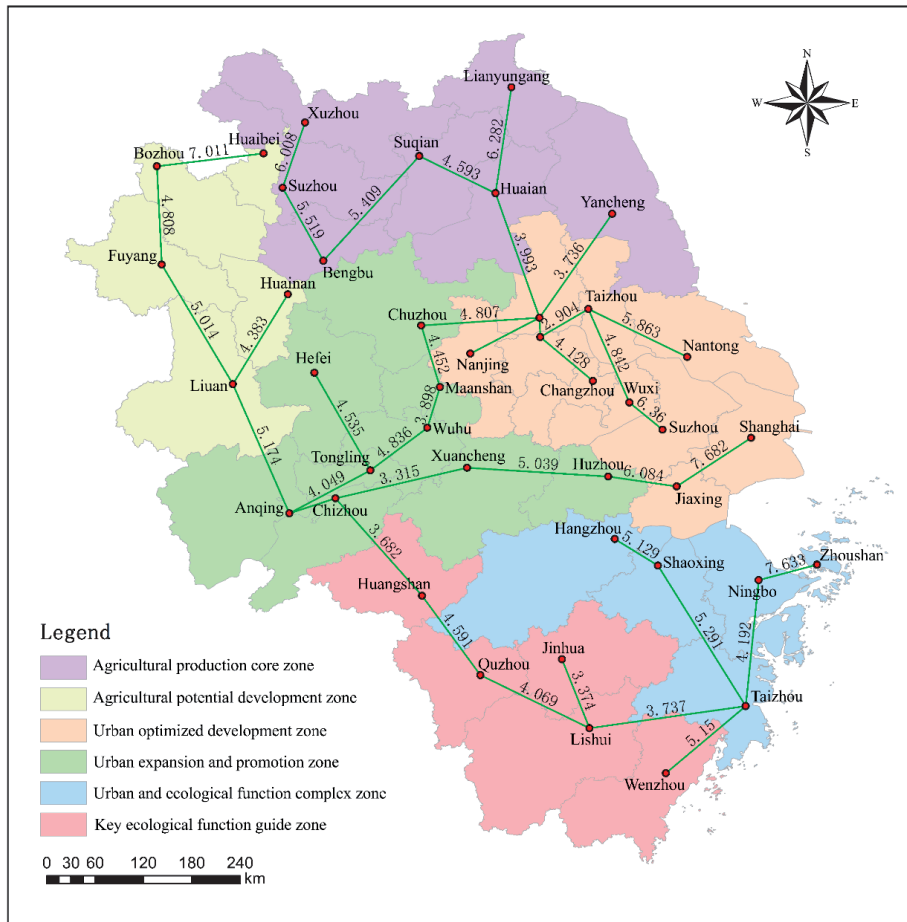


Fig. 7. The optimized zoning results of spatial functions in Yangtze River Delta.

Note: The value represents the weight of the connection edge. Among them, the weight of Yangzhou-Zhenjiang is 3.681, the weight of Yangzhou-Nanjing is 6.246, and the weight of Anqing-Chizhou is 3.583.

utilization of waste, and popularizing the cultivation techniques of symbiosis and co-cultivation of ecological agriculture, and form a new development pattern of symbiosis of ecological agriculture. For agricultural potential development zone, based on local agricultural resources, regional industries should be positioned in a green, differentiated and specialized way, and promoted from scattered, low-yielding and small-scale to intensive, high-quality and specialized direction. In addition, this area should remodel traditional agriculture, vigorously develop facilities agriculture and export-oriented agriculture, and speed up the development of the large-scale and high-efficiency agricultural bases to form ecological supply areas for high-quality agricultural products. Meanwhile it is necessary to develop tourism agriculture, experience agriculture and creative agriculture by expanding its versatility and adapt to the four metropolitan circles of Shanghai, Nanjing, Hangzhou and Anhui.

The Ecological Function Space

In ecological space, urban and ecological function complex zone belong to comprehensive exploitation

and utilization of spatial function in Yangtze River Delta, which has both the green ecological conservation function, and the better functions of production and life, and is suitable for ecological living, green production and leisure tourism. Therefore, on the premise of protecting the ecological environment, it should establish the green ecological barrier and complement the shortcomings of ecological livable construction in some regions. Furthermore, taking metropolitan circle and large and medium-sized cities as the fulcrum, integrating the green industrial projects and investments attract people to the fulcrum cities and satellite towns for employment, building them into an ecologically livable and workable cluster center for coordinated development in Yangtze River Delta. Based on the rich vegetation and tourism resources, the key ecological function guide zone bears the ecological security of the region and even the country, so it is necessary to comprehensively strengthen the protection of forest parks and natural forests, and improve the function of water and soil conservation to ensure that forest coverage and the proportion of nature reserves only increase. Moreover, guided by ecological functions, the speed of development in ecological industrialization

and industrial ecology should be accelerated, vigorously developing ecological agriculture, cultural tourism, green and health industry, and other characteristic industries by giving full play to the advantages of natural and cultural landscapes, which can promote rational and efficient utilization of the ecological function space.

Conclusions

(1) In this study, the evaluation index system of urban-agriculture-ecology space function in Yangtze River Delta is constructed from five aspects of urban life function, urban production function, agricultural production function, ecological regulation function and environmental maintenance function, which can better analyze the interval difference characteristics of the spatial function. The results show that the urban and agricultural space function values are relatively high, and the ecological space function is obviously weak. Spatially, there is a significant difference in urban function level, but its agglomeration trend is obvious. The high value areas of urban production function and urban life function have a high overlap, mainly concentrated in Shanghai, southern Jiangsu and the coastal areas of Zhejiang; agricultural spatial function value decreases gradually from north to south, mainly concentrated in Jiangsu and northern Anhui. The agricultural production function in the central and southern regions is relatively insufficient. The ecological space function value is low, the spatial heterogeneity is obvious, and gradually decreases from southwest to northeast; the agricultural spatial function value decreases gradually from north to south, mainly concentrated in Jiangsu and northern Anhui, while the agricultural production function in the central and southern regions is relatively insufficient; the ecological space function value is low with the obvious spatial heterogeneity which gradually decreases from southwest to northeast.

(2) According to the evaluation results and location conditions and development direction of the functional areas, this paper puts forward scientific countermeasures and suggestions for the rational utilization and development of the land space in the Yangtze River Delta. The northern areas including agricultural production core zone and agricultural potential development zone should fully explore the multi-functionality of agriculture, promoting the development of ecological agriculture, characteristic agriculture, facility agriculture and intelligent agriculture, and pay more attention to improving the quality of the urban ecological and life. For the central areas urban optimized development zone and urban expansion and promotion zone, it should lead the transformation and upgrading of the population and industry, and balance the pressure of resources and environment in the region, promoting the construction of ecological civilization,

to realize the seamless connection with the Nanjing metropolitan area and strive to become an influential metropolitan area in China and the rising and important growth pole in the central region. Furthermore, the southern region will give full play to the advantages of natural and cultural landscapes, and accelerate the speed of the pace of development in ecological industrialization and industrial ecology to release the ecological bonus and promote the rational and efficient utilization of land space, which can vigorously develop characteristic industries such as ecological agriculture, cultural tourism and green health.

(3) Under the current new situation, the governance of territorial space follows the management mechanism from top to bottom (national, provincial, municipal, county, township) and from whole area to the plot (whole area, subdivision, community, plot), and problems such as complex data types, inconsistent indicators and complicated methods are common in the existing spatial functional subdivision. Thus, this study uses the improved two-dimensional graph clustering method to optimize the spatial functional division, which can solve the problem that traditional zoning is difficult to ensure spatial adjacency and administrative integrity. At the same time, the zoning factor proposed and the zoning method is brief and clear, and is easy to be popularized. Therefore, it has a good application prospect in the functional zoning to promote spatial connectivity and regional integrity of the cross-provincial areas, which theoretically enriches the empirical research on the optimization of land space development and utilization, and practically not only provides scientific guidance for the green and high-quality development of the Yangtze River Delta, but also has reference value for inter-provincial spatial planning and integrated development.

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Conflict of Interest

The authors declare no conflict of interest.

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