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Spatiotemporal Evolution and Transformation Regulation Strategies of Rural Residential Land on the Grand Canal (China)

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Abstract: Land use is an embodiment of human socio-economic activities and represents a bridge between these activities and natural systems. Rural residential land represents a space for rural residents to reside in and exhibits spatial characteristics that evolve over time, which is proof of rural socio-economic development. As one of the most developed regions in China, cities along the Beijing–Hangzhou Canal experienced significant changes in rural residential land use from 1990 to 2020. This paper analyses the spatial differentiation of rural residential land in 21 cities on the Grand Canal. Then, it explores the driving factors of this land using spatial grid analysis and the geographic detector model. According to the spatial differentiation characteristics and the driving factors of rural residential land, the study proposed an improved potential model for rural residential land improvement. Lastly, it proposes three different forms of rural residential land based on the results. The study found that (1) the change in rural residential land in the northern part of the Grand Canal was more volatile than that in the southern part. The change in rural residential land from 1990 to 2020 conformed to the pattern of cultivated land–rural residential land–urban construction land. (2) Based on the driving factors of rural residential land, the land is divided into one-dimensional cities, two-dimensional cities, and three-dimensional cities. Circular, linear, and scattered cities of different sizes were affected by socio-economic factors, transportation accessibility, and the natural environment, respectively. (3) Based on the potential scale of rural residential land consolidation, different types of development strategies were proposed through research, including constructing large-scale villages, relocating and reconstructing new villages, and constructing high-quality villages, respectively. Enhancing the scientific planning of rural residential land and its efficiency and tapping into the potential of land consolidation can offer the protection of agricultural land and the integration of urban and rural areas in the new era.

Keywords: rural residential land; transformation regulation; potential for rural residential land improvement; the Grand Canal

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1. Introduction

Villages are important rural settlements in which rural residents should live for a long time. They are also the main areas of agricultural production. Due to rapid urbanization and industrialization, the population in China has significantly increased, and many rural residents have moved to urban areas. Nevertheless, the rural population first increased and then decreased. From 1991 to 2022, it decreased from 905 million to 491 million [1]. With the growing demand for urban land, rural residential areas are being converted to urban construction land, while rural residential land[1] is being replaced by agricultural land. In recent years, however, there has been an increase in the number of rural residents migrating to urban areas, resulting in a further increase in the aging population in rural areas [2]. Thus, much rural residential land has been abandoned, resulting in a decrease in land-use efficiency [3,4]. The introduction of policies such as "Merging Villages and

Towns" and "New Urbanization" has led to the demolition of a large number of rural homesteads [5,6], which have been turned into urban construction land or reclaimed as farmland, resulting in significant changes in rural residential land. Nonetheless, the need for rehoming individuals from occupied villages has led to an increase in land use in new rural settlements due to the implementation of adjacent resettlement [7,8]. Thus, rural settlements have undergone dynamic changes in time and space, which have had a significant impact on the socio-economic development of cities. Based on the research on spatial differentiation and change in rural residential land, it is important to explore the driving factors of rural residential land and analyze the potential of rural residential land improvement for improving land-use efficiency in spatial planning.

Domestic and international research on rural residential land has reached a mature stage. It includes research on the spatial differentiation and change in rural residential areas [9,10], the spatiotemporal relationship and transformation of rural and urban construction land [11,12], land structure and transformation of rural residential areas [13–15], and the impact of rural residential areas on the social economy [16]. The methods include remote sensing and spatial analysis technology (ArcGIS), while the research scope involves different villages, towns, counties, cities, provinces, and countries [17–21]. The characteristics of rural residential land change vary significantly among different administrative units due to different driving factors. Relying on the research on the driving factors of urban construction land, scholars have divided the driving factors of rural residential land into socio-economic factors, transportation accessibility factors, and natural environmental factors [22,23]. In particular, the level of socio-economic development has affected the size of rural residential land, especially in the economically developed eastern coastal areas where the growth rate of rural residential land is much higher than that in the western regions [24]. The rapid expansion of rural residential land near the city is more prominent than that in remote mountainous areas. Transportation accessibility mainly includes railways, motorways, and major rivers. These transportation arteries provide convenience for farmers, especially for the development of agricultural production. Thus, most rural residential areas have a linear distribution that relies on main transportation arteries and rivers [25]. Natural environmental factors affect the distribution of rural residential land. This is why areas with flat terrain and relatively low elevation should become rural residential areas and not those with frequent earthquakes, volcanic eruptions, and mudslides. Thus, the density of rural residential land in the plains is much higher than that on plateaus and mountains [26]. The density of rural residential areas and their land-use changes are influenced by various driving factors. Methods to analyze the driving factors of rural residential land include regression analysis, which detects the temporal factors of change in rural residential land, and geographic weighted regression and geographic detectors, which detect the spatial factors of the change in rural residential land [27,28]. The research data of rural residential areas constitute spatial vector points and land grid data. The internal land-use system of rural residential areas consists of homestead land, land for village management institutions, service facilities land, industrial land, and vacant land [29–31]. Different land structures represent different functional forms, including production, ecological, and living functions [32]. To systematically analyze the spatial differentiation of the rural residential land, the rural residential land in different administrative units is converted to grid data with a uniform resolution by means of kernel density analysis or grid-scale conversion. In particular, the GIS spatial analysis method provides reliable technical support for the spatiotemporal analysis of rural residential land [33,34]. Through the mentioned literature, it was determined that there is much research on the use of rural residential land, but there is relatively little research on the development differences between cities due to changes in the use of rural residential land. This study mainly focuses on the analysis of changes in rural residential construction land, exploring their driving factors at different time intervals within the region, revising the potential model for rural residential land improvement based on these driving factors, which has an important reference value for the in-depth analysis of differences in urban development within the region.

As the number of emptied and abandoned rural homesteads rose, the Chinese government began to strictly supervise rural homesteads. The newly revised "Land Management Law of the People's Republic of China" in 2022 stipulates that rural villagers can own one homestead per household and that the villagers should use the abandoned homestead and land in the village for residential construction. This also indicates that most county and district governments will no longer approve the addition of new rural homesteads. Rural residential land can be adjusted only to its original scale. However, over time, the structure and function of rural residential land are constantly changing, from the residential and production functions of the traditional agricultural period to the public service functions of the new era. Rural residential land is constantly being transformed into public service land, commercial land, and park green space [35]. Now, in the hot stage of rural revitalization in China, rural residential land is the core of development and an important carrier of rural revitalization [36]. Rural residential land is a rural asset with potential economic value. In 2023, the Chinese government proposed the withdrawal of the three rights of homestead land, which refers to farmers withdrawing their house ownership, homestead land-use rights, and land contract management rights. By handing over the three rights to the government, farmers can receive corresponding compensation. The government can effectively utilize idle rural homesteads, promote market transactions of homesteads, and turn them into collective land, therefore promoting local economic development. To vigorously develop the rural economy and improve the rural governance level, it is necessary to adjust the structure and function of rural residential land, fully utilize empty and idle rural residential areas, organize and revitalize rural land assets, and unleash the economic value of land [37,38]. Thus, it is important to understand the size and dynamic transformation of abandoned rural homesteads, analyze the spatiotemporal changes in rural residential land, and explore the potential of rural residential land improvement according to its relationship with different factors to optimize the rural residential land layout.

The Grand Canal in China is an important watershed that connects the northern and southern regions through five major river systems. The cities along the Canal are economically and socially developed, with high population density and a developed transportation network. Likewise, it is an important research area because the land use of rural residential areas on the Canal has changed significantly. The purpose of this study is to explore the driving factors that affect rural residential land. It analyses the spatial and temporal changes in rural residential land in 21 cities along the Grand Canal, as well as the natural environment and policies of these cities. The study used spatial remote sensing data from 1990 to 2020 to conduct the analysis. Furthermore, it used a point-axis-region three-dimensional (3D) spatial driving factor system to detect the driving factors of rural residential land in different cities. This paper selects the Grand Canal in China as a key case of economic development, deeply reveals the change in laws of rural residential land use, and analyzes the potential of rural residential land improvement in 21 cities based on the examination of the mechanism of the 3D spatial driving factor system, which offers insight into the necessary means for planning and intensively and economically utilizing rural residential land in the city.

2. Materials and Methods

2.1. The Research Area

The Grand Canal is the oldest and largest canal in the world. With a total length of 1794 km, it is often called the second "Golden Waterway" of China, the first being the Yangtze River. Its value is comparable to the Great Wall. The Grand Canal flows through six provinces (Beijing, Tianjin, Hebei Province, Shandong Province, Jiangsu Province, and Zhejiang Province) and 21 cities from north to south, connecting five major water systems, namely the Hai River, the Yellow River, the Huai River, the Yangtze River, and the Qiantang River (Figure 1). It also possesses one of the richest agricultural regions in China, with developed industries. This region has a high population density, intensive agriculture, and huge production potential. It also impacts the economic and cultural

development of the Canal, exchanges between the northern and southern regions of China, and the development of industrial and agricultural economies along the Canal. Due to the natural environment, development policies, and land development intensity, there are significant differences in socio-economic development between the regions. Likewise, there are significant differences in rural land use. Cities with high levels of urbanization, such as Beijing, Suzhou, and Hangzhou, are driving the transformation of rural land into urban construction land at a significantly faster pace than cities with lower levels of urbanization, such as Cangzhou, Dezhou, and Zaozhuang.

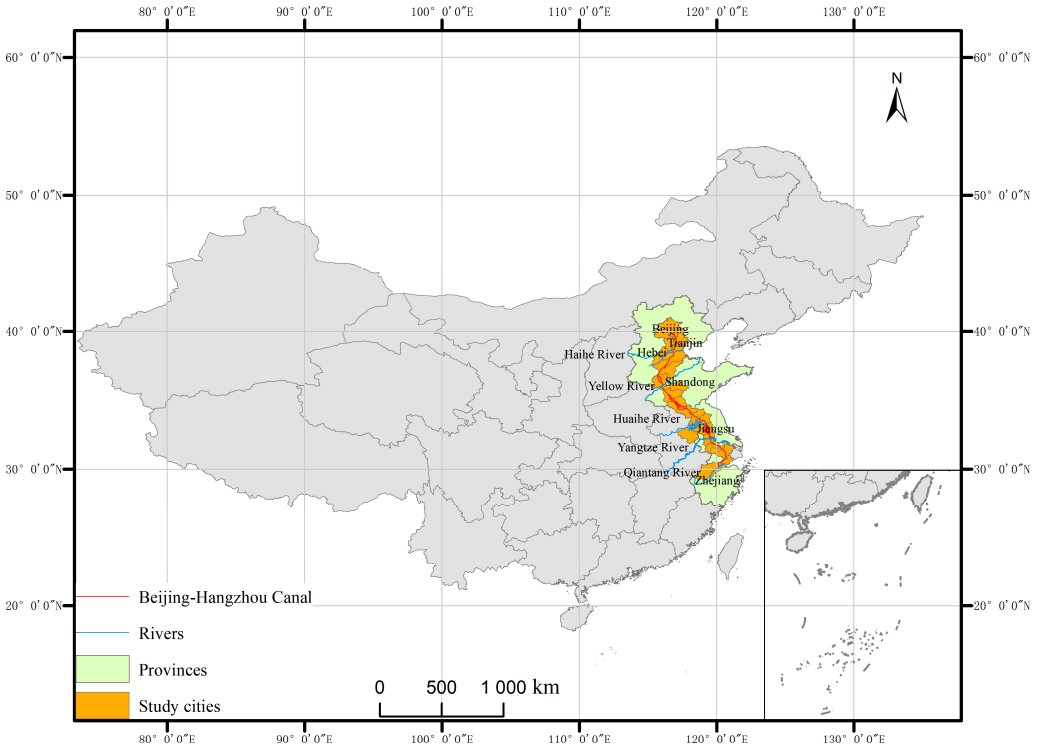

Figure 1. The location of the Grand Canal.

Land is an important factor driving urban development. Rapid land urbanization has transformed a large amount of agricultural land into urban construction land, promoting industrial development and attracting a large population to increase land value. The 21 cities that the Grand Canal flows through are economically developed cities in China, with a rapid increase in urbanization level. A large portion of the rural population flows into cities, and a large portion of rural land is converted into urban construction land. Thus, this study chooses rural residential land in these 21 cities as the research object, which can more deeply analyze the spatiotemporal changes and driving factors of rural residential areas in China's rapid urbanization process. At the same time, it can also reveal the differences in the development of cities in northern and southern China and their impact on changes in rural residential land use. The Grand Canal flows through cities, which is a region of great research value. Currently, different cities are proposing appropriate support policies and practical explorations around the development of the canal. Cities such as Beijing and Zaozhuang have proposed policies to restore the navigation of the Grand Canal, driving economic development along the river and strengthening communication and exchange between cities in the north and south. Thus, this study also has certain enlightening value for the connection and coordinated development of cities along the Grand Canal.

2.2. Data Processing

The theory of agricultural location points out that agricultural areas centered around cities, distributed in a concentric circle from the inside out, have regional differences

in production base and profit income due to different distances from the central city. The theory of industrial location points out that transportation is an important factor affecting the selection of an industrial location and the production site, which could attract enterprises to the location with the lowest production costs and the greatest cost savings. The central place theory suggests that the most important central area may not necessarily be the most populous, but it is the most critical location in the transportation network and can provide a wide range of goods and services. Thus, according to the theories of agricultural location, industrial location, and central place, the distance between the city center and major traffic arteries is an important factor affecting rural development. Furthermore, environmental conditions, such as altitude and slope, are also important factors affecting the location of village construction. This study uses 100 m × 100 m grid data provided by the Resource and Environmental Science Data Centre of the Chinese Academy of Sciences (https://www.resdc.cn/, accessed on 31 January 2021) to analyze the spatiotemporal distribution of rural residential land in 21 cities along the Grand Canal from 1990 to 2020 (The data are for each decade, namely 1990, 2000, 2010, and 2020). All socio-economic data are sourced from the statistical yearbooks of 21 cities (1990–2020). We amassed DEM data from the National Geographic Information Centre in China and analyzed it through image correction and slope analysis to obtain the elevation and slope of the study area, which represent the regional driving factors of the natural environment (NE). Using the spatial neighborhood analysis method in ArcGIS 10.2, the study acquired the distances from each grid to major railways, rivers, motorways, or existing urban, county, and town centers. Major rivers (the watershed area exceeds 100 km^2 and the river length exceeds 50 km), motorways, and railways are typical transportation arteries in each city center. The distance from the spatial grid to each transportation artery represents the spatial axis and the driving factor of transportation accessibility (TA). The distance to the city, county, or town center is measured from the internal grid to the center of the city/county/town, which represents the spatial point and a driving socio-economic factor of market location (ML). The current vector data of urban centers, major highways, railways, and other areas used in the study was from 2020 and was also sourced from the National Geographic Information Centre in China. As a result, this study constructed the point-axis-region three-dimensional (3D) spatial driving factor system of the Grand Canal (Table 1).

Table 1. The point-axis-region 3D spatial driving factor system.

Target Layer	Factor Layer	Element Layer
Point	Market location (ML)	Distance to the city center (x_1) Distance to the county center (x_2) Distance to the town center (x_3)
Axis	Traffic accessibility (TA)	Distance to main railways (x_4) Distance to main motorways (x_5) Distance to main rivers (x_6)
Region	Natural environment (NE)	Elevation (x_7) Slope (x_8)

Using the spatial aggregation function of ArcGIS 10.2, the study converted the land-use data from 100 m to 1000 m grid data. Then, the percentage of the change in rural residential land area of each grid unit was measured using grid operation. This way, it analyzed the spatial differentiation of rural residential land in the cities on the Grand Canal. Converting raster data into point data, the study studied the spatial relationship between rural residential land and the driving factors. Furthermore, it used the Euclidean distance and buffer analysis to obtain the distance distribution of the driving factors, such as the urban centers and major motorways, railways, and rivers. Lastly, the study obtained a data table of rural residential land and point-axis-region 3D driving factors (Table 2)

for geographic detector data analysis using spatial neighborhood analysis and spatial correspondence [39,40].

Table 2. Classification of driving factors of the rural residential land.

Factor Layer	Element Layer	Extremum Distribution	Classification Interval	Number of Categories
Market location (ML)	Distance to the city center (x_1)	(0.15–111.77 km)	5 km	23
	Distance to the county center (x_2)	(0.01–65.88 km)	5 km	14
	Distance to the town center (x_3)	(0.02–19.02 km)	1 km	19
Traffic accessibility (TA)	Distance to main railways (x_4)	(0–92.6 km)	5 km	19
	Distance to main motorways (x_5)	(0–75.51 km)	5 km	15
	Distance to main rivers (x_6)	(0–126.04 km)	5 km	26
Natural environment (NE)	Elevation (x_7)	(−0.12–1881 m)	100 m	19
	Slope (x_8)	(0–49.49°)	5°	10

2.3. The Geographic Detector Model

Jin feng Wang introduced the geographic detector model through the factor force index, combining GIS spatial superposition technology and set theory [41]. They used it to identify the interaction between multiple factors. The theory of spatial differentiation provides a means to obtain the correlation between factor variables and outcome variables. By applying different discrete classification methods to various factors, different types of variables are normalized and analyzed at the same spatial scale. In this study, the dependent variable is the proportion of the change in rural residential land, whereas the independent variables are the driving factors. This study explored and analyzed the impact of point-axis-region 3D driving factors on rural residential land in reference to the decisive force q of spatial differentiation of rural residential land. The formula for q is:

$$q = 1 - \frac{1}{n\sigma^2}\sum_{i=1}^{m} n_i q_i^2 \quad (1)$$

q_i^2 represents the discrete variance of the dependent variable y; i represents the number of the independent variable x_i; n_i represents the number of samples; n represents the total number of samples in the study area; σ^2 is the total variance within the study area.

This paper selected 8 driving factors as independent variables, including elevation, slope, distance to major rivers, distance to major motorways, distance to major railways, distance to urban centers, distance to county centers, and distance to town centers. It analyzed the spatial differentiation of the driving factors of the rural residential land and classified the driving factors based on their data characteristics. The average decision-making power is the average decisive force (q) of all driving factors, which represents the impact of 3D driving factors on rural residential land.

2.4. The Land Improvement Potential Model

The traditional potential model for rural residential land improvement is determined based on the standard of per household land area (the Chinese government's standard for rural residential land area is 150 m^2), and the final determination of rural residential land area is based on the size of the rural population. Study the parameter correction of traditional models based on the changes in the size of rural residential land in different cities and the interaction between different types of driving factors. The results show that the cities with a significant impact on the changes in rural residential land areas of driving factors have severe population loss in rural areas and a great potential for land consolidation. The cities with a small impact of driving factors on rural residential land areas have light population loss and a small potential for land consolidation.

$$K_j = (K_{c_j} - K_t * P_{t_j}) * W_j \quad (2)$$

$$W_j = \frac{q_{sum}}{\sum_{i=1}^{8} q_i} \quad (3)$$

K_j is the potential area of rural residential land consolidation in city j; K_{cj} is the original area of rural residential land in city j; K_t is the per capita rural residential land standard of the government during the t period; P_{tj} is the rural population size of city j in period t; W_j refers to the potential correction coefficient for rural residential land improvement in city j; q_i is the decisive force and q_{sum} refers to the sum of decisive force of core driving factors.

3. Results

3.1. The Characteristics of Overall Changes in Land Use and Changes in Rural Residential Land

3.1.1. The Characteristics of Overall Changes in Land Use

The land-use types of the Grand Canal mainly include agricultural land, forest land, rural residential land, water area land, grassland, and urban construction land. In 1990, the area proportions of the six land-use types were 64.6%, 12.6%, 8.8%, 8.0%, 3.1%, and 1.7%, respectively. In 2020, however, the area proportions of the six land-use types were 56.6%, 12.4%, 11.3%, 8.8%, 2.8%, and 6.5%, respectively. Agricultural land, urban construction land, and rural residential land were evenly distributed. In the north, the main expansion areas of urban construction land were Beijing and Tianjin, while in the south, they were Suzhou and Wuxi. The water area land was found in Tianjin, Huai'an, Yangzhou, and Suzhou, while forest land was found in Beijing, Jining, Zaozhuang, Chuzhou, and Hangzhou (Figure 2).

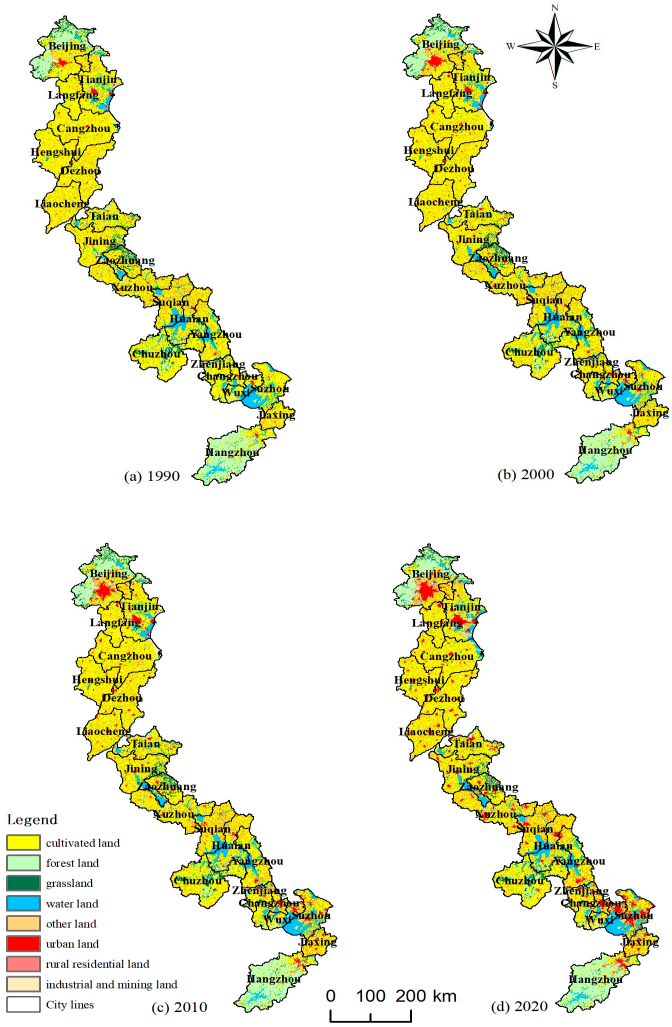

Figure 2. The spatial distribution of land-use types in the Grand Canal (1990–2020).

From 1990 to 2000, agricultural land, grassland, and other land decreased by 6.553 million mu, 353,000 mu, and 909,000 mu, respectively. Forest land, water area land, urban construction land, industrial and mining land, and rural residential land increased by 208,000 mu, 1.672 million mu, 2.663 million mu, 642,000 mu, and 2.649 million mu, respectively. At this stage, agricultural land and unused land were converted to water area land, urban construction land, and rural residential land. From 2000 to 2010, agricultural land, forest land, grassland, and other land decreased by 5.998 million mu, 170,000 mu, 110,000 mu, and 31,000 mu, respectively. In contrast, water area land, urban construction land, industrial and mining land, and rural residential land increased by 259,000 mu, 3.549 million mu, 1.009 million mu, and 1.492 million mu, respectively. This stage was characterized by the conversion of agricultural land to urban land and industrial and mining land. From 2010 to 2020, agricultural land, forest land, and grassland decreased by 10.502 million mu, 636,000 mu, and 544,000 mu, respectively, while water area land, urban construction land, industrial and mining land, and rural residential land increased by 232,000 mu, 7.51 million mu, 883,000 mu, and 3,011,000 mu, respectively. At this stage, agricultural land, forest land, and grassland were converted to urban industrial and mining land. From 1990 to 2020, the main areas that experienced significant changes were agricultural land, urban construction land, and rural residential land. In particular, agricultural land decreased by 23.053 million mu, accounting for 8.1% of the area. Urban construction land increased by 13.722 million mu, accounting for 4.8% of the area, while rural residential land increased by 5.6981 million mu, accounting for 2.5% of the area (Figure 3). It can be seen that the reduced agricultural land, forest land, and grassland on the Grand Canal was converted to urban construction land, rural residential land, or industrial and mining land.

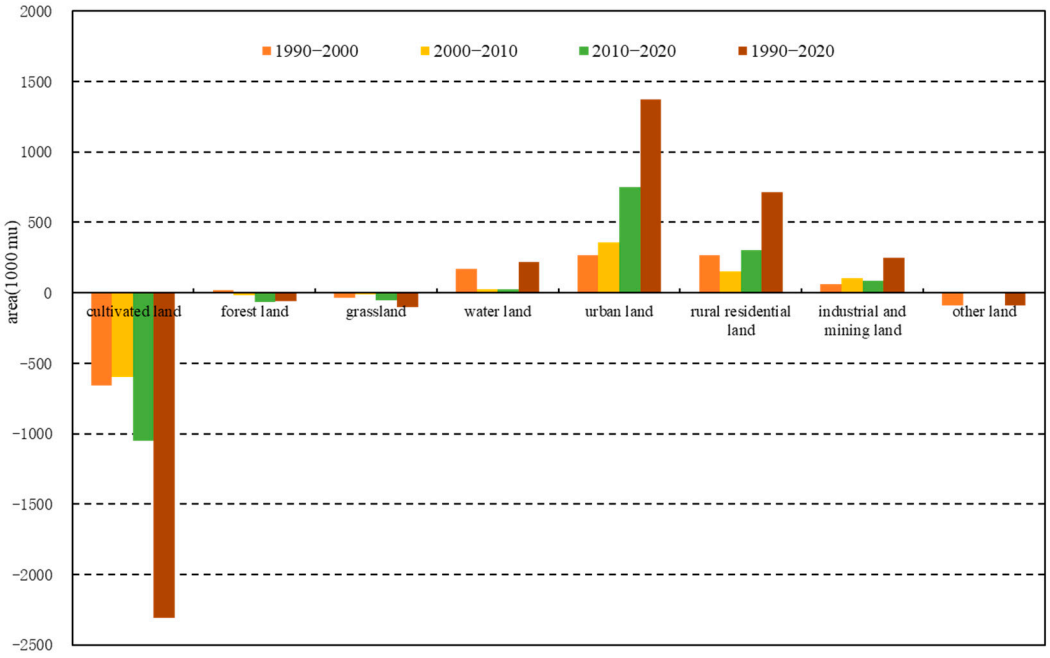

Figure 3. Changes in land-use types and their area size on the Grand Canal during different periods.

3.1.2. Characteristics of Changes in Rural Residential Land

From 1990 to 2020, the distribution of changes in rural residential land was relatively uniform, mainly concentrated in villages around the central urban areas of the cities on the Grand Canal. As time passed and new policies were introduced, there had been significant changes in the spatial layout of rural residential land, with some villages experiencing a decrease or an increase in area size. Within the 1 km × 1 km grid range, the proportion of changes in rural residential land in most cities ranged from −10% to 10%. Based on the spatial distribution of rural residential land, it was found that the extremely dense rural residential land in northern cities was mainly concentrated around Beijing, where rural residential land increased by over 50%. The areas with significantly sparse rural residential land were mainly distributed in Tianjin and Dezhou, where rural residential land decreased

by over 50%. The significant increase in rural residential land in southern cities was mainly found in Suzhou, Wuxi, Changzhou, etc. The proportion of changes in rural residential land was between 20 and 50% (Figure 4).

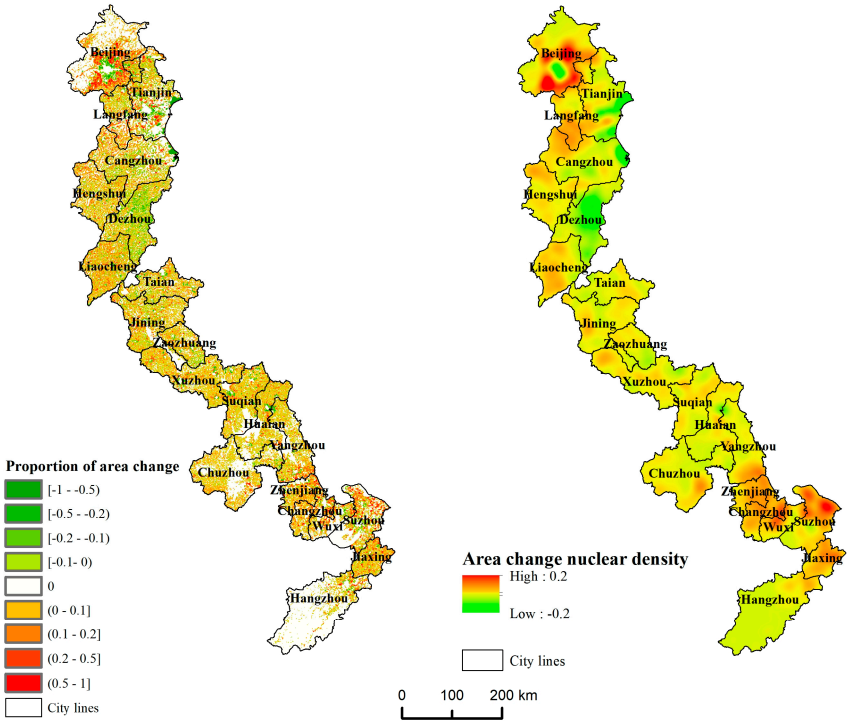

Figure 4. The change in density of rural residential land (1990–2020).

According to the changes in rural residential land area on the Grand Canal from 1990 to 2020, the total area increased by 16.6521 million mu and decreased by 10.954 million mu, resulting in an actual increase of 5.6981 million mu. Cities that have added over 1 million mu include Beijing, Cangzhou, Liaocheng, Tianjin, and Jining. Cities with an area of less than 500,000 mu include Changzhou, Hangzhou, Zhenjiang, Zaozhuang, and Wuxi. In contrast, cities with a decrease in rural residential land area of over 1 million mu include Dezhou, Cangzhou, and Tianjin, while cities with less than 300,000 mu include Chuzhou, Suzhou, Hangzhou, Zhenjiang, Changzhou, and Wuxi. Thus, it was found that the spatial changes in rural residential land in the northern cities of the Grand Canal were significant, while those in the southern cities were relatively small.

Based on the actual changes in rural residential land, it was found that only Beijing's rural residential land increased by over 1 million mu, followed by Suzhou, with a rural residential land area of 629,000 mu. The size of rural residential land in Dezhou and Tianjin significantly decreased, with 449,500 mu and 85,100 mu, respectively. The change in the size of rural residential land in 12 cities ranges from 200,000 to 400,000 mu, while that in Huai'an, Tai'an, Hangzhou, Cangzhou, and Zaozhuang was less than 200,000 mu. Cities with per capita rural residential land exceeding 5 mu include Chuzhou, Yangzhou, Zhenjiang, and Hangzhou. However, cities with less than 2 mu include Liaocheng, Langfang, Zaozhuang, and Jiaxing (Figure 5). Due to the impact of the rural population in different regions, the per capita rural residential land area in each region varied to some extent. For example, the per capita rural residential land area in the southern region of the Grand Canal was higher than that in the northern region. Thus, it can be inferred that Beijing and Suzhou, as the central cities of the northern and southern regions, respectively, had significantly higher levels of socio-economic development and urbanization compared to other regions. This had a strong effect on the changes in the size of rural residential land. However, as the main cities in Shandong Province began implementing the "Merging Villages and Towns" policy, Dezhou significantly reduced the size of rural residential land.

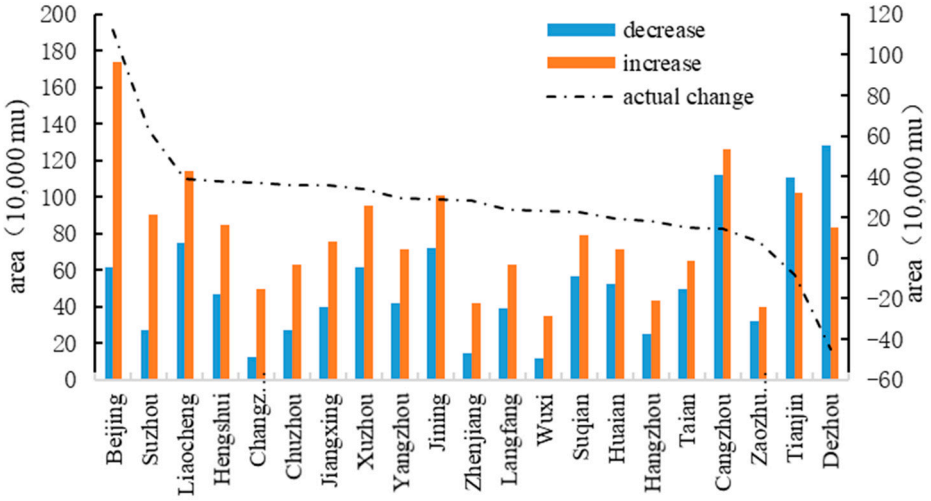

Figure 5. The change in area size of rural residential land on the Grand Canal (1990–2020).

3.2. Driving Factors and Mechanism of the Change in Rural Residential Land

3.2.1. Driving Factors of Rural Residential Land

According to the distribution characteristics of the driving factors that influence the spatial differentiation of rural residential land, it was found that the distance to the market location, such as city centers, county centers, and town centers, was distributed in a clear concentric circle. The maximum distance to city or county centers was distributed in the peripheral areas of the Grand Canal, while the maximum distance to town centers was distributed around cities such as Cangzhou, Hengshui, and Suzhou. Furthermore, the spatial distribution of the distance to major motorways, railways, and rivers was zonal. The maximum distance to major railways was distributed in a line from Suqian, then to Huai'an, and finally to Yangzhou. The maximum distance to major motorways was found west of Liaocheng, while the maximum distance to rivers was located east of Tai'an. Lastly, the distribution of the factors of the natural environment, such as elevation and slope, were similar, with their maximum values distributed in the northern and southern peripheral areas of the study area (Figure 6).

Using geographic detectors, this study found that all 21 cities were influenced by socio-economic driving factors. Except for Xuzhou City, 20 cities were affected by the driving factors of transportation accessibility. Only five cities, including Beijing, Tai'an, Zaozhuang, Zhenjiang, and Hangzhou, were affected by the driving factors of the natural environment. The distance to the city center had the greatest impact on the differentiation of rural residential land, with 20 cities being affected and an average decision-making power of 2.9. Next is the distance to the main rivers, which affected 19 cities with an average decision-making power of 1.9. The impact of elevation and slope was minimal. Elevation affected 4 cities, while slope affected 3 cities, with an average decision-making power of only 0.3 and 0.29, respectively (Table 3).

Table 3. Results of driving factor detection for rural residential land on the Grand Canal.

City	X1	X2	X3	X4	X5	X6	X7	X8	Driver Dimension
Beijing	2.03	0.34	0.52	0.51	0.42	1.33	0.97	0.90	three-dimensional
Tianjin	3.34	5.31	1.56	0.58	0.54	1.99	0.34	0.13	two-dimensional
Langfang	1.47	1.21	0.21	0.22	0.29	2.68	0.12	0.24	two-dimensional
Cangzhou	19.12	9.94	0.77	0.79	0.65	4.40	0.13	0.00	two-dimensional
Hengshui	1.19	0.16	0.65	0.15	0.07	0.75	0.00	0.00	two-dimensional
Dezhou	4.16	0.25	0.51	1.34	0.72	3.15	0.00	0.00	two-dimensional
Liaocheng	1.69	1.12	0.35	1.23	0.99	1.14	0.00	0.00	two-dimensional
Tai'an	1.11	0.40	0.29	1.20	0.70	2.98	1.33	0.11	three-dimensional
Jining	0.97	0.60	0.40	0.20	0.55	0.37	0.09	0.06	two-dimensional

Table 3. *Cont.*

City	X1	X2	X3	X4	X5	X6	X7	X8	Driver Dimension
Zaozhuang	1.83	3.12	0.52	1.26	0.18	1.12	0.77	0.08	three-dimensional
Xuzhou	0.73	0.60	0.30	0.40	0.29	0.29	0.02	0.11	one-dimensional
Suqian	0.48	0.80	0.22	1.87	0.06	1.12	0.00	0.24	two-dimensional
Huai'an	0.89	0.37	0.30	2.43	1.71	0.99	0.00	0.01	two-dimensional
Chuzhou	1.89	0.55	0.79	2.13	2.53	5.66	0.06	0.10	two-dimensional
Yangzhou	3.00	0.40	0.05	1.28	0.31	0.80	0.09	0.00	two-dimensional
Zhenjiang	1.63	1.27	1.34	0.25	0.72	1.76	0.42	1.40	three-dimensional
Changzhou	3.67	1.06	1.16	1.58	1.21	2.30	0.27	0.33	two-dimensional
Wuxi	4.54	3.25	1.52	0.65	0.38	1.70	0.30	0.30	two-dimensional
Suzhou	3.93	0.50	0.25	1.41	0.73	2.09	0.07	0.24	two-dimensional
Jiaxing	1.60	0.18	0.80	0.57	0.18	3.14	0.07	0.28	two-dimensional
Hangzhou	1.78	1.32	0.57	1.46	0.39	1.19	1.32	1.62	three-dimensional

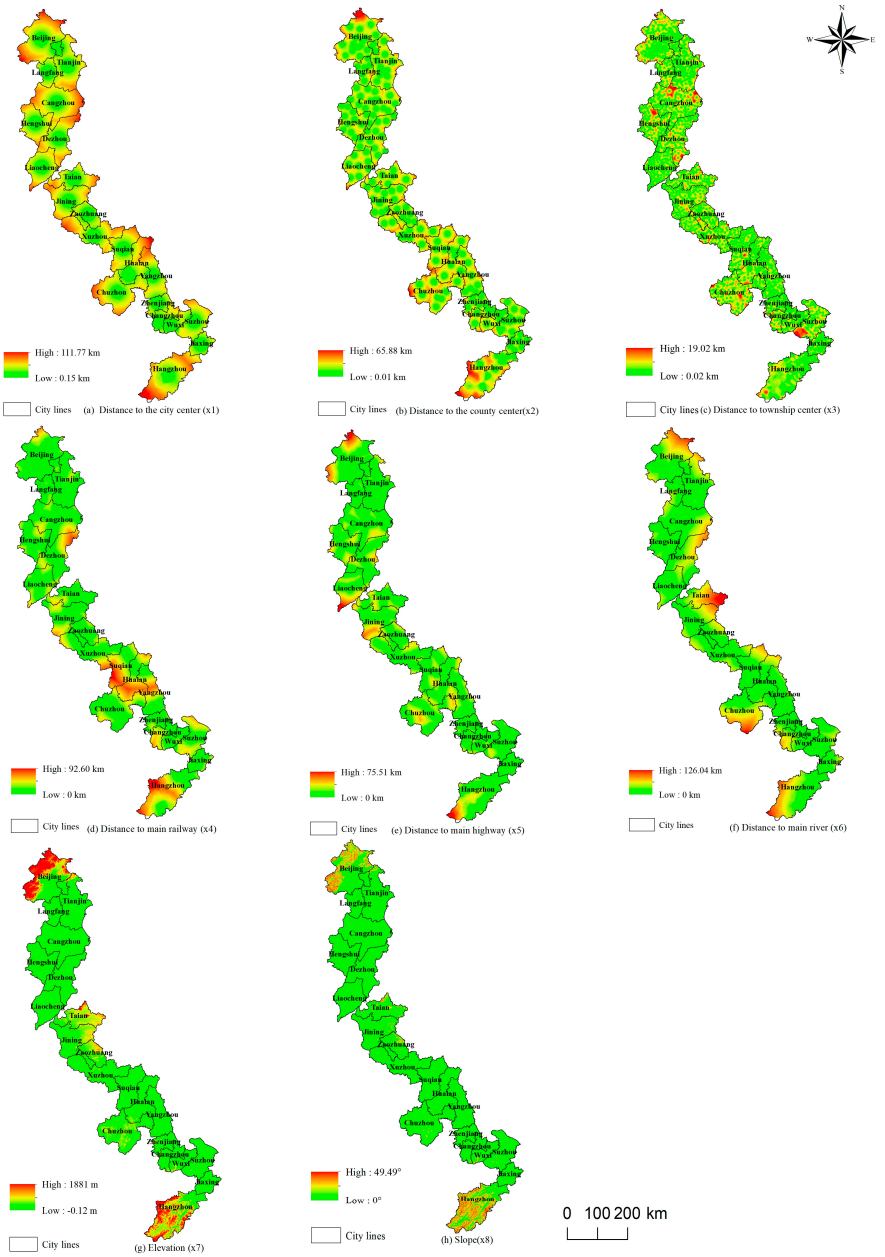

Figure 6. The distribution of driving factors that influence the spatial differentiation of rural residential land on the Grand Canal.

To further explore the differentiation types of rural residential land in 21 cities, the study divided all cities into three categories based on the dimensions of the driving factors. Xuzhou, the only one-dimensional city, was influenced by the distance to the city and the county center. Thus, it represents a point-driven development city. Next, two-dimensional cities, including 15 cities, among which are Tianjin, Langfang, and Cangzhou, were influenced by the distance to the city, county, or town center and the distance to the main railways, motorways, or rivers. These cities represent the main types of rural residential land, which can be termed point-axis-driven development cities. Finally, three-dimensional cities, including Beijing, Tai'an, Zaozhuang, Zhenjiang, and Hangzhou, were driven by a combination of socio-economic factors, transportation accessibility, and the natural environment. These cities represent the "point-axis-region-driven development cities".

3.2.2. Driving Mechanism of the Change in Rural Residential Land

Based on the distribution characteristics of rural residential land in the cities and the influence of their point-axis-region 3D driving factors, this study further analyzed the driving factors of the change in rural residential land on the Grand Canal by combining the sources of increase and decrease in rural residential land in the cities. This has important implications for accelerating the high-quality development of the rural social economy and improving the land-use efficiency of rural residential land. Compared with previous research, this article attempts to construct a three-dimensional driving force model composed of market, environment, and transportation location factors [42,43]. By detecting the location factors of rural residential areas, the spatial differentiation mechanism of rural residential land in different cities is analyzed. The three-dimensional driving force model eliminates the inaccurate influence of the original administrative regional factors rasterization [44]. Based on the location theory, it makes full use of the spatial driving factor distribution law to explore the driving mechanism of rural residential land, which can better understand the spatial distribution and change law of rural residential land and has important reference value for promoting the spatial planning and development of rural residential land.

(1) Socio-economic driving factors

The socio-economic driving factors include the distance to the city center, county center, or town center. Among the 21 cities on the Grand Canal, 8 cities were affected by these driving factors, while Suzhou, Yangzhou, and Tai'an were affected only by the distance to the city center. Due to rapid urbanization, urban centers, densely populated industrial areas, and central areas of regional socio-economic development have increased their demand for land and the size of urban land, leading to the occupation of surrounding rural residential land and agricultural land. Therefore, the rural residential land close to the urban area was reduced. To meet the demands of rural residents, a large amount of agricultural land was converted to rural residential land to establish new communities and build new residential areas in the suburbs. It was found that rural residential land around the urban center exhibited a block-like change, radiating to the surrounding area in a concentric circular shape. This result is most observable in the increase or decrease in rural residential areas in Beijing and Suzhou.

(2) Driving factors of transportation accessibility

The driving factors of transportation accessibility include the distance to main railways, motorways, and rivers. Among the 21 cities on the Grand Canal, 9 cities were affected by these factors. Langfang, Hengshui, and Jining were affected only by the distance to the main rivers. In these places, rapid industrialization and urbanization have led to the large-scale development of transportation arteries and primary roads, which have contributed to the socio-economic development of urban and rural areas. At the same time, the efficient and smooth operation of transportation arteries caused changes in land use along their routes, especially at crucial transportation hubs. To ensure the transportation of industrial and agricultural produce, most industrial parks were built along the main transportation

arteries, occupying a large amount of agricultural and rural residential land. Thus, the rural residential land moved to the periphery of the transportation arteries and the surrounding areas. This study found that rural residential land surrounding the transportation arteries exhibited a linear change, i.e., it was distributed in a line toward the surrounding areas. Examples of these can be seen in the rural residential land in Suqian, where the increase or decrease of rural residential land was shown in a linear pattern.

(3) Driving factors of the natural environment

The driving factors of the natural environment include elevation and slope. Among the 21 cities on the Grand Canal, Beijing, and Hangzhou were affected by these factors. However, Tai'an and Zaozhuang were mainly affected by elevation, while Zhenjiang was affected by slope. The driving factors of the natural environment are relatively stable and have a significant impact on the spatial distribution and location of rural residential land, especially in the early stages of rural residential construction in which residential land was built on flat terrain and low elevation. As urban construction land expanded, rural residential land was continually being occupied, and some flat and low-lying areas in cities were converted to urban land. Nevertheless, rural residential land can only expand in three-dimensional spaces. The mountainous regions and ecological protection areas in the northern part of Beijing and the southern part of Hangzhou are unsuitable for the development of rural residential land due to high altitudes and rugged terrain. Thus, rural residential land in Beijing and Hangzhou established new high-quality communities to improve land-use efficiency in rural residential areas.

3.3. The Conversion Mechanism of Rural Residential Land

Through spatial correction and matching analysis, it was found that agricultural land was the main source of increase in rural residential land from 1990 to 2020, accounting for 93.09%, followed by forest land, accounting for 2.17%. The main sources of decrease in rural residential land were farmland, urban construction land, water area land, and industrial and mining land, with a proportion of 68.11%, 19.0%, 5.41%, and 5.03%, respectively. To further analyze the driving factors of the change in rural residential land in various cities, this study chose Beijing, Cangzhou, Dezhou, Chuzhou, Huai'an, Suzhou, Jiaxing, and Hangzhou cities as cases where the change in rural residential land was most prominent. It based the analysis on the driving factors and change in area size using an equal proportion amplification method.

3.3.1. The Conversion of Rural Residential Land in the One-Dimensional City

The only one-dimensional city in this study was Xuzhou. From 1990 to 2020, the area of rural residential land increased by 949,000 mu and decreased by 612,000 mu, thus actually increasing by 337,000 mu. The main sources of increase in rural residential land were agricultural land and forest land, with an area of 884,100 mu and 32,100 mu, respectively, accounting for 93.2% and 3.39%. However, the main source of decrease was also agricultural land, followed by urban construction land, with an area of 407,500 mu and 174,900 mu, respectively, accounting for 66.58% and 28.59%. This indicates that the source of changes in rural residential land in Xuzhou was agricultural land (Figure 7). The change was mainly influenced by socio-economic driving factors, such as the distance to the city and county center, with a decision-making power of 0.73 and 0.60, respectively. Since Xuzhou is in the North China Plain and is flat, it was less affected by the driving factors of the natural environment. Moreover, Xuzhou is an important transportation hub that connects the Grand Canal to the eastern and western regions of China. Its main motorway and railway network density were relatively high, so it had little impact on the spatial differentiation of rural residential land.

3.3.2. The Conversion of Rural Residential Land in Two-Dimensional Cities

To examine the changes in rural residential land in two-dimensional cities, the study selected Cangzhou, Dezhou, Suqian, and Suzhou as representatives (Figure 7). It found

differences in the number of driving factors affecting each city. There were also differences in the changes in rural residential land. Due to the large number of two-dimensional cities, they were mainly influenced by the distance to the city, county, or town center and the distance to major railways, motorways, or rivers. In contrast, they were less affected by the driving factors of the natural environment.

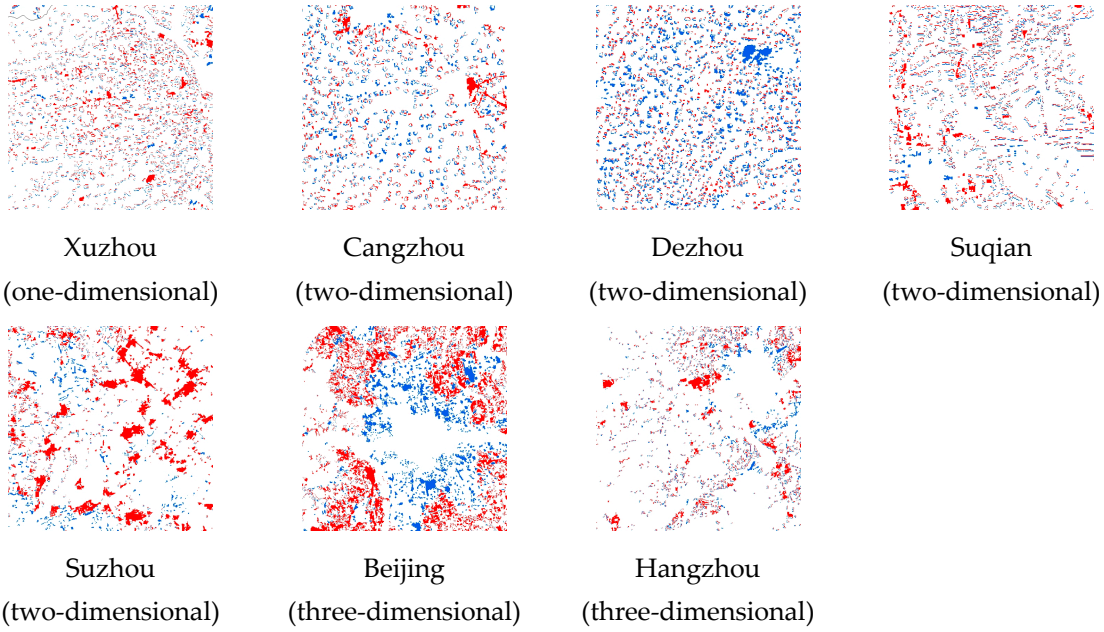

Figure 7. Main types of changes in rural residential land in the Grand Canal. Note: Blue indicates a decrease, while red indicates an increase.

The actual changes in rural residential land from 1990 to 2020 were 141,000 mu in Cangzhou, −449,500 mu in Dezhou, 222,400 mu in Suqian, and 629,000 mu in Suzhou (Figure 7). Suzhou is the economic center of the southern part of the Grand Canal. In Suzhou, the actual increase in rural residential land area was second only to Beijing. The main sources of increase in rural residential land were agricultural land, water area land, and urban construction land, with an area proportion of 92.14%, 3.27%, and 2.66%, respectively. The main sources of decrease in rural residential land were urban construction land, agricultural land, and water area land, with an area proportion of 59.29%, 33.83%, and 4.07%, respectively. This city was mainly influenced by four driving factors, including the distance to the city center, the distance to main railways, the distance to main motorways, and the distance to main rivers, with a decision-making power of 3.93, 1.41, 0.73, and 2.09, respectively. Furthermore, Dezhou is one of the central cities of the Grand Canal. It experienced a negative growth in rural residential land from 1990 to 2020. The main sources of increase in rural residential land were agricultural land and other land, with an area proportion of 93.84% and 3.73%, respectively. However, the main source of decrease in rural residential land was also agricultural land, followed by urban construction land, with an area proportion of 89.0% and 8.97%, respectively. This city was influenced by five driving factors, including the distance to the city center, the distance to the town center, the distance to the main railways, the distance to the main motorways, and the distance to the main rivers. Each of these factors had a decision-making power of 4.16, 0.51, 1.34, 0.74, and 3.15, respectively. Next, Cangzhou is a city in the northern part of the Grand Canal. From 1990 to 2020, the increase and decrease in rural residential land exceeded 1 million mu. The main source of increase in rural residential land was agricultural land, accounting for 97.01% of the total area. The main sources of decrease in rural residential land were agricultural land, water area land, industrial and mining land, and urban construction land, with an area proportion of 65.06%, 18.31%, 12.46%, and 3.62%, respectively. This city was

influenced by six driving factors, including the distance to the city center, the distance to the county center, the distance to the town center, the distance to the main railways, the distance to the main motorway, and the distance to the main rivers. These factors had a decision-making power of 19.12, 9.94, 0.77, 0.79, 0.65, and 4.40, respectively. Like Dezhou, Suqian is also one of the medial cities of the Grand Canal. It experienced a change in rural residential land area of less than 300,000 mu. The main source of increase in rural residential land was agricultural land, accounting for 96.98% of the total area. The main sources of decrease in rural residential land were agricultural land and urban construction land, with an area proportion of 72.43% and 25.34%, respectively. This city was mainly influenced by the distance to the county center, the distance to the main railways, and the distance to the main rivers, each of which had a decision-making power of 0.80, 1.87, and 1.12, respectively.

3.3.3. The Conversion of Rural Residential Land in Three-Dimensional Cities

To show the change in rural residential land in three-dimensional cities, this study selected Beijing and Hangzhou as representatives. From 1990 to 2020, the area of rural residential land increased by 1.736 million mu in Beijing and 430,000 mu in Hangzhou. It decreased by 616,000 mu and 248,000 mu, respectively. The actual increase in Beijing was 1.12 million mu and 182,000 mu in Hangzhou. The main sources of increase in rural residential land in Beijing were agricultural land, forest land, and grassland, with an area proportion of 85.46%, 7.57%, and 2.6%, respectively. The main sources of decrease in rural residential land were urban construction land, agricultural land, industrial and mining land, and forest land, with an area proportion of 51.83%, 23.59%, 13.35%, and 5.67%, respectively. The driving factors of rural residential land in Beijing were the distance to the city center, the distance to the town center, the distance to the main railways, the distance to main rivers, elevation, and slope. Their decision-making power was 2.03, 0.52, 0.51, 1.33, 0.97, and 0.90, respectively. In Hangzhou, the main sources of increase in rural residential land were agricultural land and forest land, with an area proportion of 86.76% and 10.39%, respectively. The main sources of decrease in rural residential land were agricultural land, urban construction land, industrial and mining land, and forest land, with an area proportion of 49.52%, 23.21%, 11.42%, and 11.27%, respectively. Similar to Beijing, the driving factors for rural residential land in Hangzhou include the distance to the city center, the distance to the county center, the distance to the town center, the distance to main railways, the distance to main rivers, elevation, and slope. Their decision-making power was 1.78, 1.32, 0.57, 1.46, 1.19, 1.32, and 1.62, respectively.

Beijing and Hangzhou are both economically developed cities in the northern and southern parts of the Grand Canal, respectively. As the capital of China, Beijing is a political, economic, and cultural center, with the largest area size in rural residential land and the greatest scale of converting rural residential land to urban construction land. Due to socio-economic development, the central urban area represents the main area where people live and work. Urban construction land continues to expand to the periphery, occupying a large amount of rural residential land and agricultural land. To meet the production and living demands of rural residents, a large amount of agricultural land has been transformed into new rural communities. The transportation network and various terrain types in Beijing have a significant impact on the selection of the space where rural residential land can be built, especially in the northern mountainous areas of Beijing, where the density of rural residential land is low and the proportion of its change is small.

As the capital of Zhejiang Province, Hangzhou is an important city in the Yangtze River Delta Economic Zone. The density of transportation arteries, such as railways and motorways, is high. Likewise, the speed at which urban construction land is expanding is high. Due to the influence of urban terrain and landforms, especially in the mountainous areas in the southern part of the city, the proportion of rural residential land converted to urban construction land is relatively low, and the proportion of the increase in rural residential land is relatively small.

3.4. The Potential for Rural Residential Land Improvement

According to the calculation results, there are significant differences in the potential for rural residential land improvement among 21 cities. The total potential for rural residential land improvement in 21 cities is 19.7431 million mu. There are 10 cities with a remediation potential exceeding 1 million mu, among which Beijing has the largest remediation potential at 1.7593 million mu, followed by Suqian at 1.7267 million mu. There are 5 cities with a remediation potential of less than 0.5 million mu, with Wuxi having the lowest at 159,700 mu, followed by Hangzhou at 171,700 mu (Figure 8). Meanwhile, from the perspective of overall spatial distribution, cities in the north have greater potential for land improvement in rural residential areas compared to cities in the south.

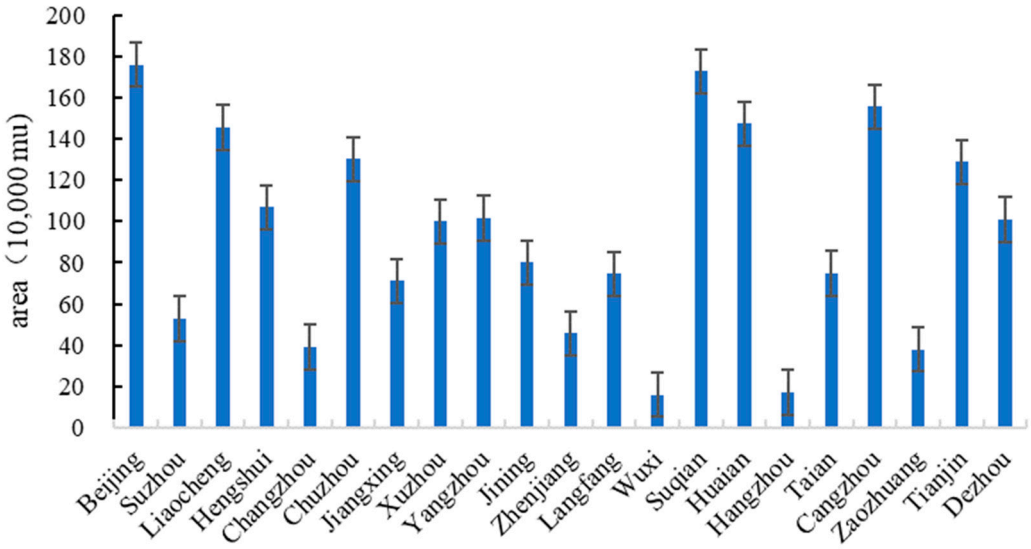

Figure 8. Potential for rural residential land improvement in the Grand Canal.

Why is there such a huge gap in the potential for rural residential improvement? The cities along the Grand Canal selected in this article are socioeconomically developed cities in the eastern region of China, with frequent rural population mobility and high urbanization rates. From 1990 to 2020, while urban boundaries continued to expand, the area of rural residential land also continued to increase. The rural residential areas in northern cities have flat terrain, and most farmers live in bungalows. Along with the construction of living courtyards, the area of rural residential land far exceeds national standards. The rural settlements in southern cities are mainly mountainous and hilly areas, with rural residential buildings as the main type, and the difference in land area between rural settlements and national standards is relatively small. At the same time, influenced by driving factors based on the spatiotemporal variation of rural residential land in various cities, cities such as Beijing, Cangzhou, and Liaocheng have a larger area of original rural residential land but a smaller rural population and are greatly affected by the market, transportation, and other driving factors, resulting in a greater weight of remediation potential and a higher potential for rural residential land improvement. However, cities such as Wuxi, Suzhou, and Hangzhou have a high level of urbanization, and a large amount of rural residential land has been occupied. The impact of driving factors is relatively small, resulting in a smaller weight of remediation potential and a lower potential for rural residential land improvement. Thus, compared to two-dimensional cities, three-dimensional cities have greater development potential for rural residential land. With the rapid socio-economic development of eastern coastal cities and the continuous migration of rural populations to cities, the problem of empty rural homesteads is becoming increasingly serious. How to fully utilize rural residential land and explore the transformation strategies of rural residential land use based on local conditions has important reference significance for the social and economic development of different regions.

4. Discussion

4.1. The Necessity of Optimizing Allocation of Rural Residential Land

The cities along the Beijing–Hangzhou Canal are one of the most developed regions in China, connecting the northern Beijing Tianjin Hebei Economic Zone with the southern Yangtze River Delta Economic Zone. According to the changing patterns of rural residential land in various cities, it can be found that due to the impact of rapid urbanization and industrialization, rural residential land is mainly converted into urban construction land. As in the early stages of urban development in developed countries in Europe and America, as the population in the central urban area increases, the demand for land carrying space continues to increase, and rural residential land in the suburbs of cities is constantly occupied [45,46]. For example, the boundaries of cities such as Beijing, Tianjin, Suzhou, and Hangzhou are constantly expanding outward, occupying rural residential land in the suburbs. Residents who have been occupied with residential land have to choose new residential land in the form of relocation and resettlement compensation. There are two main ways: one is to convert new urban residents on site and live in newly built buildings; another way is to relocate to distant rural residential areas and build new housing, therefore increasing the land area of rural residential areas. Another main destination for the reduction of rural residential land is the conversion to arable land (Figure 9). With a large portion of the rural population flowing to cities, the utilization rate of rural residential land gradually decreases, and the hollowing rate of some villages in remote suburbs has significantly increased [29]. As time goes by, rural houses are gradually damaged, and some cities choose to carry out engineering renovations on villages with a high proportion of severe damage and a high rate of hollowing out, such as Dezhou and Tianjin. Multiple small village settlements are merged into a new rural settlement, and the original rural settlement land is reclaimed into farmland. Therefore, the main direction for the transformation of rural residential land is urban construction land and arable land.

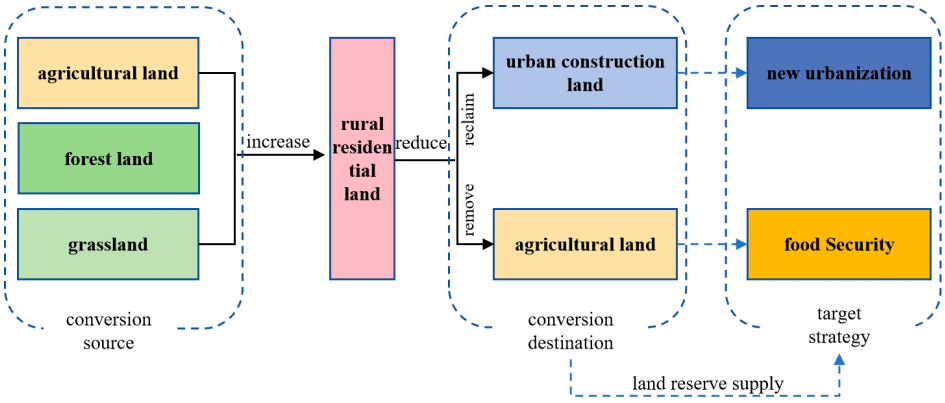

Figure 9. Rural residential land conversion mechanism.

However, we found that among the cities along the Beijing–Hangzhou Canal, the total rural residential land area increased in 19 cities, except for Dezhou and Tianjin, from 1990 to 2020. This is mainly because the cities along the Beijing–Hangzhou Canal are important economically developed areas in eastern China. In addition to increasing the number of local residents, cities such as Beijing, Suzhou, and Hangzhou can attract a large number of migrant workers. Therefore, the demand for urban land in the research area is much higher than in other regions. On the other hand, after 2010, China adopted a large number of policies that attach importance to rural economic development, such as targeted poverty alleviation, new rural construction, rural revitalization, and harmonious villages, promoting the construction of new rural settlements in some areas, such as Zhenjiang, Wuxi, and Suzhou. Rural labor enters the cities to work, but due to the remaining rural household registration, they still retain homesteads in rural areas, which makes it difficult to demolish some old rural settlements, increasing the scale of rural residential land use in some

cities. Therefore, although the rural population in China has decreased, the scale of rural residential land has not decreased accordingly, which is different from the development law of rural land reduction in developed countries such as South Korea and Japan [47,48]. In the context of the strategic development of farmland protection and urbanization, the scale of rural residential land must be strictly controlled, and the potential of rural residential land must be fully explored to improve the efficiency of rural residential land use. In 2023, the Chinese government formulated a policy to no longer approve new rural homesteads and new housing for rural residents can only be built on existing homesteads. Therefore, in the context of the lack of demand for urban land along the Beijing–Hangzhou Canal, how to fully utilize the potential of rural residential land use and provide backup land resources for urbanization and food security is an important research topic.

In this study, we found that there were significant differences in the distribution of rural residential land due to different driving factors that affected the northern and southern cities on the Grand Canal. Although China has already introduced policies on rural residential land, the rural population is constantly decreasing. Due to practices such as the construction of new buildings without demolishing old ones, the migration of rural residents to urban areas, and the conversion of rural residential land for non-agricultural uses, the size of rural residential land in the city expanded from 1990 to 2020, posing a serious threat to farmland protection and rapid urbanization in the new era. However, due to the continuous reduction of the rural population, scholars have begun to pay attention to how to improve the efficiency of rural construction land. Reclamation can turn empty and abandoned homesteads into arable land, and some scattered and hollowed-out villages can be demolished by merging villages or towns [49,50]. New villages, towns, or communities can be built to reduce the area occupied by rural residential areas and improve land-use efficiency [6,51]. The cities along the Grand Canal, as important economic development zones, have experienced a significant loss of rural population and a large surplus in rural residential land, which would represent important guarantees of land supply to promote the protection of arable land and new urbanization strategies in the region.

4.2. Optimization Allocation Strategies of Rural Residential Land

In the process of implementing various policies, there are issues such as dissatisfaction with the demolition compensation and the new living environment and difficulties in building new communities in the process of rural residential land demolition [52]. Thus, based on the driving factors and distribution of rural residential land, to fully utilize rural residential land and tap into the potential of homestead land, the following suggestions are proposed regarding the planning of rural land use and clarifying the direction of rural residential land use, which provide a reference for further promoting the intensive use of rural residential land.

4.2.1. The Construction of Large-Scale Villages through Relocation and Consolidation

Due to abandoned homesteads, especially in the central plain areas of the Grand Canal, including Dezhou, Liaocheng, and Cangzhou, the scales of rural residential land have increased, and the potential for rural residential land improvement exceeds 1 million mu. However, the rural population has decreased significantly. This study proposes that old residential sites with high levels of point-axis-region 3D driving factors should be transformed into the central village. The abandoned surrounding villages with poor waste management should be relocated to the central village, which would be equipped with high-level service facilities and infrastructure. By reconstructing the spatial layout of the village, rural grassroots, and industrial parks, it is possible to build a large type of village with high social and economic development capabilities. The reconstructed central village would serve as a center for industrial and agricultural production and living, encouraging the old and new residents to achieve social and economic development in the large village (Figure 10a). After the demolition, the village would adopt engineering measures, such as land remediation and reclamation, to develop a large and connected land for agricultural

use. According to the Chinese government's policy of linking increase and decrease, rural residential land has been converted into arable land, which can be converted into construction land and sold to cities. This land would then provide a more stable channel for collective economic income through subleasing, transfer, and collective management, providing financial support for the development of new village industries and facilities.

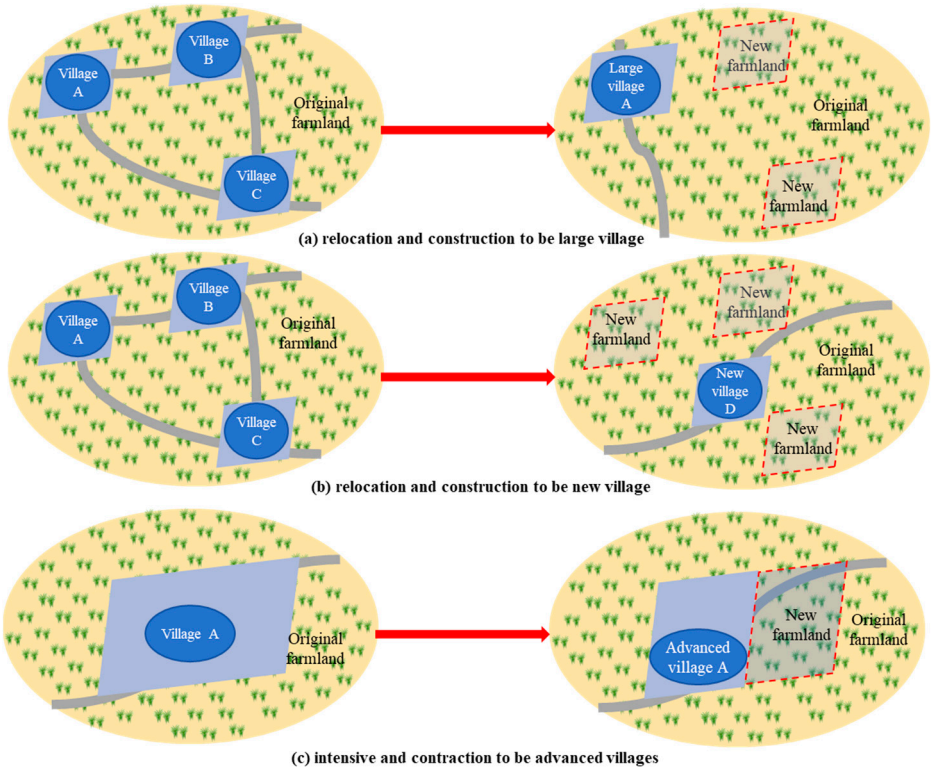

Figure 10. Optimization allocation models of rural residential land.

4.2.2. The Construction of New Villages through Relocation and Reconstruction

Relatively small and scattered villages are in the northern and southern remote mountainous regions of the Grand Canal. These villages are situated at high altitudes and slopes, far from major cities and transportation arteries. The potential for rural residential land improvement in these cities is 500,000 to 1 million mu, and their rural residential land is relatively scattered. In these villages, residential land is also located in ecologically fragile areas or areas prone to natural disasters. This land has unfavorable conditions for industrial and agricultural production and cannot support social and economic development. By relocating scattered villages, small villages would be transformed into new ones (Figure 10b). This would, in turn, group the population of the villages in one place, enable the reclamation of farmland and homesteads and convert land in ecological protection areas to forests and grassland. The construction of new rural areas requires local investment from the state, local governments, social enterprises, and village collectives, leveraging the power of diverse entities and conducting careful layout planning. The collective economic development of new villages would need to rely on multiple factors for their development, especially government financial support. By introducing new technologies to develop characteristic industries in the new villages, sustainable development can be ensured.

4.2.3. The Construction of Advanced Villages through Intensive Expansion and Contraction

Some rural residential land has a large land area and a relatively low level of waste management. It also has villages with abandoned residential buildings. These villages are concentrated in the suburbs of Wuxi, Changzhou, and Hangzhou in the southern

part of the Grand Canal, and their potential for rural residential land improvement is less than 500,000 mu. Considering the current state of the rural residential land, which includes abandoned villages, roadside villages, and ribbon villages, with a large area for settlement and a favorable location, the land near the main transportation arteries would be transformed into commercial housing and shop houses in the process of intensive expansion and contraction (Figure 10c). Residents on this land would be relocated to residential land of the same size as in their former village. This could be achieved through spatial replacement, intra-village rectification, and spatial layout planning. The village committee should purchase, decorate, and renovate empty residential buildings, transform them into village collective assets, and use them as channels for increasing the collective rural economic income through subleasing and other forms to provide financial support for improving the construction of village facilities and the appearance of houses.

5. Conclusions

Due to urbanization, the rural population has migrated to urban areas, resulting in a decrease in the efficiency of rural residential land use and an increase in the number of abandoned rural homesteads. In the context of integrating urban and rural areas and protecting farmlands, one key issue requires immediate attention. This issue deals with the scientific analysis of the remaining rural residential land to ensure the improvement of its land-use efficiency. This study analyzed the spatiotemporal differentiation of rural residential land in 21 cities on the Grand Canal under various driving factors using geographic detectors. It offered suggestions for scientific planning of rural residential land according to local conditions and provided a reference for the conservation and intensive use of that land. This study drew the following conclusions.

(1) The cities with a significant increase in rural residential land (over 1 million mu) in the Grand Canal were concentrated in the north, including Beijing, Tianjin, Cangzhou, etc. The cities with a smaller decrease (less than 300,000 mu) were mainly concentrated in the south, including Suzhou, Hangzhou, Zhenjiang, etc. It was found that the changes in rural residential land in the northern cities were significant. In contrast, the changes in rural residential land in the southern cities were relatively stable. The main sources of increase in the rural residential land include agricultural land and forest land, while the main sources of decrease include urban industrial and mining land and agricultural land. From 1990 to 2020, rural residential land experienced a cycle of changes in agricultural land, rural residential land, and urban construction land.

(2) The driving factors that affected the spatiotemporal differentiation of rural residential land were mainly manifested as socio-economic factors (points), transportation accessibility (axes), and the natural environment (regions). According to the number of driving factors and their decision-making power (greater than 0.5), the 21 cities were divided into three types: one-dimensional, two-dimensional, and three-dimensional cities. The one-dimensional city, Xuzhou, was mainly influenced by socio-economic factors. In this city, significant differences in the change in rural residential land could be spotted around urban centers. Moreover, the two-dimensional cities were mainly influenced by socio-economic factors and factors of transportation accessibility. This city type included 15 cities, such as Tianjin, Langfang, and Yangzhou. In these cities, rural residential land was found in circular and linear patterns around the urban center and main transportation arteries. Finally, the three-dimensional cities were influenced by all driving factors. This city type included five cities, such as Beijing, Hangzhou, and Tai'an. Apart from the rural residential land exhibiting a linear and circular pattern, the distribution of rural residential land in these cities was relatively scattered due to the rugged terrain.

(3) Based on the spatial differentiation characteristics, driving factors of rural residential land, and the potential for land improvement in rural residential areas of different cities, this study proposed three types of villages to ensure the intensive use and careful planning of rural residential land and the protection of agricultural land and improve the efficiency of rural residential land use. These villages would be developed based on the following

strategies: the construction of large-scale villages through relocation and consolidation, the construction of new villages through relocation and reconstruction, and the construction of advanced villages through intensive expansion and contraction. The relocation and consolidation of rural areas implies using old residential areas as the central village, merging multiple scattered villages in the surrounding area, and freeing up excess rural residential land and transforming it into agricultural land. Relocation and reconstruction-oriented rural areas imply building new villages in other suitable locations, relocating multiple existing villages, and constructing new larger villages. The original rural residential land would be converted to farmland, forests, or grasslands. These areas would then focus on ecological restoration. Intensive expansion and contraction of rural areas implies that they retain the original villages, improve the level of rural housing through renovation, move scattered rural homesteads to central villages through spatial replacement, transform the remaining rural homesteads into collective assets, and build commercial housing or shop houses to increase the collective economic income.

This study takes rural residential land in different cities as the research object, detects the spatial driving factors of spatial and temporal differences of rural residential land, and proposes a 3D spatial driving system to eliminate the impact of administrative factors rasterization through location grid data. The study focuses on the rural development laws of different cities in the Grand Canal area and on the potential estimation of rural residential land use. At the same time, this article attempts to construct a strip research method, selecting cities along the Grand Canal for comparison, which can better highlight the differences in the distribution of rural residential land along the linear terrain. However, due to the large scale of our research, we were not able to consider the actual development of specific villages, and there is a lack of comparison with similar studies in other regions. In the future, we will take specific villages as examples and conduct a detailed analysis of changes in rural residential land use and driving factors according to local conditions.

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Notes

[1] Rural residential land refers to the settlement places where people gather for production and life. This article specifically refers to the land used by rural villagers for the construction of housing, buildings, and facilities related to residential life.

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