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Spatial Pattern Evolution and Driving Mechanism of Rural Settlements in Rapidly Urbanized Areas: A Case Study of Jiangning District in Nanjing City, China

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Abstract: Rural settlement is an important part of studying the relationship between humans and land; it is highly significant in revealing the evolution, driving mechanism and reconstruction scheme of rural settlement pattern. In this paper, Jiangning District, a rapidly urbanized area, was selected as a typical case. Using remote sensing image data, the landscape pattern index, the rank-scale law, the local hot spot-detection model, and the geographical-detector were comprehensively used to analyze the rural settlements pattern evolution and driving mechanism in the rapidly urbanized areas. The results are as follows: (1) From 2010 to 2020, the number of rural settlements showed a trend of large-scale reduction, and the settlements scale system was relatively uniform in Jiangning. The settlements scale had the autocorrelation characteristics of spatial agglomeration, and the local hotspot agglomeration pattern was significant. (2) The spatial distribution of rural settlements in Jiangning showed an "agglomeration" pattern, and the settlements density showed a "multi-core" distribution characteristic. (3) The pattern of rural settlements in Jiangning was shaped by natural environmental factors such as topography, water system and cultivated land resources; economic social factors such as agricultural population, per capita GDP, distance from town, and policy and system were the leading factors that promoted the settlements' pattern evolution in Jiangning, and the interaction between the factors could enhance the interpretation of the settlements' pattern evolution. The research can provide a reference for optimizing the spatial layout of settlements in rapidly urbanized areas.

Keywords: rural settlements; spatial pattern evolution; geographical detector; driving mechanism; Jiangning District

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1. Introduction

Rural settlement refers to population settlements at a certain scale and is closely related to agricultural production, also known as rural residential areas or rural settlements. Rural settlement is a special artificial and semi-artificial landscape on the Earth's surface and a spatial phenomenon with regional characteristics [1]. The spatial characteristics and evolution process of rural settlement are the concentrated embodiment of the human–land relationship in vast rural areas [2]. With the rapid progress of urbanization, rural society has undergone dramatic changes. As the spatial carrier of rural social and economic development, the spatial layout, form, scale, and structure level of rural settlements are also undergoing significant transformation [3,4]. The impact of urbanization on rural settlement space is manifested in two aspects: first, expansion of rural settlement space. Urbanization has brought development opportunities to some villages, causing them to develop by virtue of their own resource advantages and realizing the scale expansion of settlement space. The second aspect is the gradual decline and disappearance of the settlement. Affected by the expansion and development of cities and towns, rural settlement space in the suburbs of cities and towns is gradually being swallowed up by towns, and the nature of the settlement

space has fundamentally changed [5,6]. Therefore, it is of practical significance to explore the evolution and driving mechanism of rural settlements for solving rural diseases caused by excessive urbanization speed.

Rural settlement is the spatial carrier of rural social economy, farmers' production and life, cultural traditions and customs, etc. The study of the evolution process, pattern, effect, and mechanism of rural settlement is the core content of modern rural geography research [7,8]. Kohl [9] systematically expounded the formation of rural settlements for the first time, and analyzed the relationship between the distribution and geographical environment. Demandeon [10], Brunhes [11], and Hoffman [12] provided empirical discussions on the rural settlement spatial evolution characteristics in France, Germany, and Bulgaria. After the 1960s, the study of rural settlements entered the quantitative stage, paying more attention to the impact of human decision-making behavior on formation and development, and emphasizing a combination of qualitative and quantitative research. For example, Cater [13], Palmer [14], and John [15] studied the spatial distribution characteristics from a sociological perspective. In the 1990s, the rural settlement research paradigm began to transform into the socio-humanistic. It has gradually become a trend to explore rural settlements from the perspectives of sociology, ecology, economics, etc. Rural communities, urban–rural relations, rural policies, population and settlements, and rural settlement models have gradually become the main research contents [16–20]. Since the beginning of the 21st century, with the rapid development of urbanization, the settlement spatial structure has undergone significant changes, and study of the evolution has gradually become a hot topic. For example, Ruda [21] explored the morphological structure and scale change characteristics based on the industrialization influence. Matteucci [22] studied the settlement expansion into the outer suburbs of Buenos Aires Province, Argentina, and found the settlement spatial expansion mainly occurred in the high-altitude areas. Njoh [23] analyzed the evolution process of settlements by using the land price fluctuation. Different methods such as Voronoi diagram, CA model, and landscape pattern index were used to quantitatively analyze the evolution of settlements [24–27]. In the early research stage of the influencing mechanism, it was generally believed that the physical geographical environment was the primary one, and the influence of geographical environmental factors on settlement morphology was discussed [28–30]. With the development of productivity, the influence of human factors on settlement layout and form gradually increases, and the influencing factors of the settlements pattern gradually extend to the humanities and social field, involving government policies, land system, population migration, human decision-making behavior, urban–rural interaction, population density, social culture and other aspects [31–33]. On the whole, the research in western countries has gradually diversified, and in-depth study of rural settlements combined with multidisciplinary research has become the main direction.

The research on rural settlements in China was relatively late and mainly focused on rural settlements, agricultural regionalization, and agricultural land use in the initial stage [34–37]. Especially since the 1990s, with the influence of the development of new countryside, domestic scholars have been attracted to the topic, providing different perspectives such as settlement scale [38], settlement system [39], evolution mechanism [40,41], spatial form [42,43], and spatial reconstruction [44,45], and different scales such as province [46,47], city [48,49], county [50,51], and village [52,53]. A systematic and comprehensive study of rural settlements was conducted by using different methods such as "3S" technology [54–56], CA model [57], CLUE-S model [58], and landscape pattern index [59–61]. By reviewing the existing research results, it can be found that: (1) the current research has gradually deepened from the macro scale to the county and village scale; the research scale has been increasingly refined. (2) The research content showed a trend of diversification and integration, among which the evolution mechanism and spatial reconstruction of settlements were the focus of attention, especially in exploring the influencing factors of settlement evolution, in addition to paying attention to the constraints of geographical factors [62], economic factors [63], institutional policies [64], and other factors that have become impor-

tant analysis content. (3) The research method showed a shift from single statistical analysis to integrated analysis of multiple methods. In particular, the application of new technologies and methods made the research process of rural settlements more scientific, which provided support for further revealing the mechanism of settlement evolution. However, most studies have analyzed the spatial distribution of settlements and influencing factors in different periods, and few studies have explored the scale and influencing factors of the overall rural settlements. There was a lack of summary of the rural settlements' evolution rules in typical regions, and the research on the evolution mechanism of rural settlements was insufficient.

Rapid urbanization area is a regional concept, which is mainly used to judge the level of urbanization in an area through the urbanization rate (the proportion of urban population in the total population). The urbanization level in a rapid urbanization area exceeds 50%, and the annual growth rate of urbanization exceeds 1%. The process of urbanization in Jiangning District has been accelerating and has entered a stage of rapid development. Rural settlements are undergoing rapid evolution, which is typical of the changes of rural settlements in counties in rapidly urbanized areas. In view of this, this paper took Jiangning District in the Yangtze River Delta, using two remote sensing images (2010, 2020), and comprehensively used landscape pattern index, rank-scale law, and local hotspot detection model to explore the evolution characteristics of rural settlements in Jiangning District; a geographical detector was introduced to reveal the driving mechanism of settlement pattern evolution, in order to provide theoretical support for the spatial reconstruction of settlements in rapidly urbanized areas. The main aims of this paper are as follows:

- What were the evolution characteristics of rural settlements pattern in rapidly urbanized areas? Based on multi-temporal remote sensing images, the characteristics of settlement spatial evolution in rapidly urbanized areas were analyzed from two different dimensions of scale and space distribution, by comprehensive use of landscape pattern index, rank-scale law, and local hotspot detection model.
- What were the evolution-driving mechanisms of rural settlements pattern in rapidly urbanized areas? Natural environment, traffic conditions, and economic social factors were selected; a geographical-detector model was used to quantitatively reveal the leading factors of pattern evolution; and the driving mechanism of the settlement pattern evolution was elaborated.

2. Materials and Methods

2.1. Study Area

Jiangning District is located in the southeast of Nanjing, located in the south bank of the lower Yangtze River (Figure 1). By the end of 2020, Jiangning District had a land area of 1561 square kilometers, a permanent population of 1,954,300, a gross regional product of RMB 250,932 billion, and a per capita disposable income of RMB 60,367. The economic development level of Jiangning District is at the forefront of all the Yangtze River Delta county units. At the same time, the urbanization rate of Jiangning District increased from 68% in 2010 to 78% in 2020, with an average annual growth rate of 1%, which is a significant rapid urbanization area. Under the process of urbanization, the rural settlement pattern underwent reconstruction, representing the basic characteristics of the evolution of rural settlements in rapidly urbanized areas. Therefore, this paper chose Jiangning District as a representative to study the evolution mechanism of rural settlement pattern in rapidly urbanized areas.

2.2. Research Methods

2.2.1. Landscape Pattern Index

The study of landscape pattern focuses on spatiotemporal heterogeneity. Landscape pattern change is usually analyzed and discussed by using landscape pattern index. Pattern index can objectively reflect the overall changes, especially the degree of landscape

fragmentation and diversity, and reveal the landscape structure and spatial configuration characteristics of regional rural settlements [65,66]. In view of this, combined with the regional characteristics of Jiangning and its research needs, this paper selected the number of settlement patches (NP), patch density (PD), total patch area (CA), average patch area (MPA), maximum patch area (LAP), and average nearest neighbor index (ANN) to analyze the evolution of rural settlement pattern (Table 1).

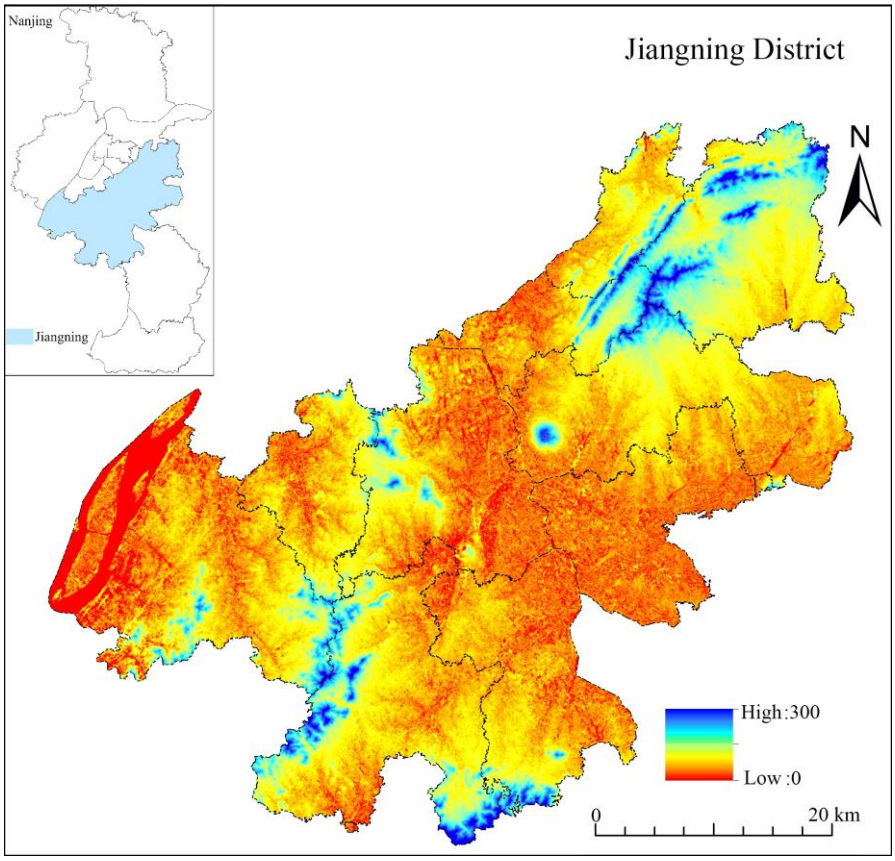

Figure 1. Location of Jiangning District.

Table 1. Calculation method and connotation of pattern index.

Index	Formula	Connotation
NP	$NP = n_i$	The index indicates the aggregation degree of landscape types.
PD	$PD = NP/CA$	The index indicates the number of plaques per unit area.
CA	$CA = \sum_{i=1}^{NP} S_i$	The index indicates the sum of each plaque area.
MPA	$MPA = 1/n_i \sum_{j=1}^{n} a_{ij}$	The index indicates the average of plaques and reveals the degree of plaque fragmentation.
LAP	$LAP = max_{i=1}^{NP} S_i$	The index indicates the largest patch area in the landscape patch.
ANN	$ANN = \sum_{s=1}^{n} a_{ijs}/h_{ijs}^2$	The index indicates the proximity degree of spatial distribution between plaques.

2.2.2. Rank-Scale Rule

In this paper, the rank-scale law is used to quantitatively measure the settlement distribution. At present, the rank-scale general relation proposed by Singger is often used [67,68]. The calculation formula is

$$P_i = P_1 \times R_i^{-Z} (R_i = 1, 2, 3 \ldots n) \quad (1)$$

Taking the natural logarithm of the two parts of the equation above, we can obtain

$$lnP_i = lnP_1 - ZlnR_i \quad (2)$$

where P_i is rural settlements area; P_1 is the largest rural settlement land area; R_i is the position order; Z is the Zipf exponent. When $Z < 1$, the distribution of rural settlements is relatively concentrated, and the number of intermediate sequence settlements is large; when $Z > 1$, the difference of settlement distribution is high, and the distribution of settlement scale in the first and last order is scattered.

2.2.3. Local Hotspot Detection Model

Local spatial autocorrelation was used to identify the spatial agglomeration pattern of rural settlements. G_i^* index is [69,70]

$$G_i^*(d) = \sum_{j=1}^{n} W_{ij}(d)X_j / \sum_{j=1}^{n} X_j \quad (3)$$

where W_{ij} is the spatial weight matrix. If G_i^* is positive, the settlement density around the location is concentrated.

2.2.4. Geographical-Detector Model

Geographical detector is a statistical method for analyzing the spatial differentiation of the ground image and its driving factors. The model accepts that factors affecting the development and change of geographical phenomena in different spatial locations are different. If two phenomena show significant consistency in spatial changes, this factor makes a more significant contribution to the geographical spatial distribution [71–73]. In view of this, this paper applies this model to quantitatively explore the driving factors of settlement evolution.

$$P_{D,H} = 1 - \frac{1}{N'\sigma_H^2} \sum_{w=1}^{m} n_{D,W}\sigma_{H_{D,W}}^2 \quad (4)$$

where $P_{D,H}$ is the explanatory power index of the influencing factors of settlement scale differentiation, σ_H^2 is the overall variance of settlement scale, and N' is the number of samples. The value range of $P_{D,H}$ is [0,1]. If the value of $P_{D,H}$ and H is larger, it indicates that the factor influence on the settlement scale evolution is larger (Table 2).

Table 2. The interaction categories of two factors and the interactive relationship.

Judgment Basis	Interaction
$q(X_1 \cap X_2) < \mathrm{Min}(q(X_1), q(X_2))$	Nonlinearity reduction
$\mathrm{Min}(q(X_1), q(X_2)) < q(X_1 \cap X_2) < \mathrm{Max}(q(X_1), q(X_2))$	Single factor nonlinearity decreases
$q(X_1 \cap X_2) > \mathrm{Max}(q(X_1), q(X_2))$	Double factor enhancement
$q(X_1 \cap X_2) = q(X_1) + q(X_2)$	Independence
$q(X_1 \cap X_2) > q(X_1) + q(X_2)$	Nonlinear enhancement

2.3. Data Collection

Research data included: (1) Remote sensing data. The paper mainly used two periods of remote sensing images in 2010 and 2020, which were from the Resource and Environmental Science Data Center of the Chinese Academy of Sciences, and had a resolution of 30 m × 30 m. Based on the ERDAS software platform, the remote sensing images in 2010 and 2020 were pre-processed with image correction and image enhancement; according to the actual situation of the study area, the interpretation marks of different land use types in the study area were established by integrating factors such as hue, brightness, shape, texture, and structure. According to the Supervised Classification function based on the Classification module of ERDAS software, training samples of classification were selected, a template of supervision classification was established, and supervised classification was executed. By using the recoding function, the classification results after cluster statistics

and classification removal were combined accordingly, and finally, they were combined into seven types of land use: cultivated land, garden land, forest land, water body, urban settlement, rural settlement, and unused land. On this basis, ArcGIS10.2 software was used to extract the rural settlement landscape of Jiangning District in 2010 and 2020, and form the spatial distribution map of rural settlements in Jiangning District from 2010 to 2020 (Figure 2).

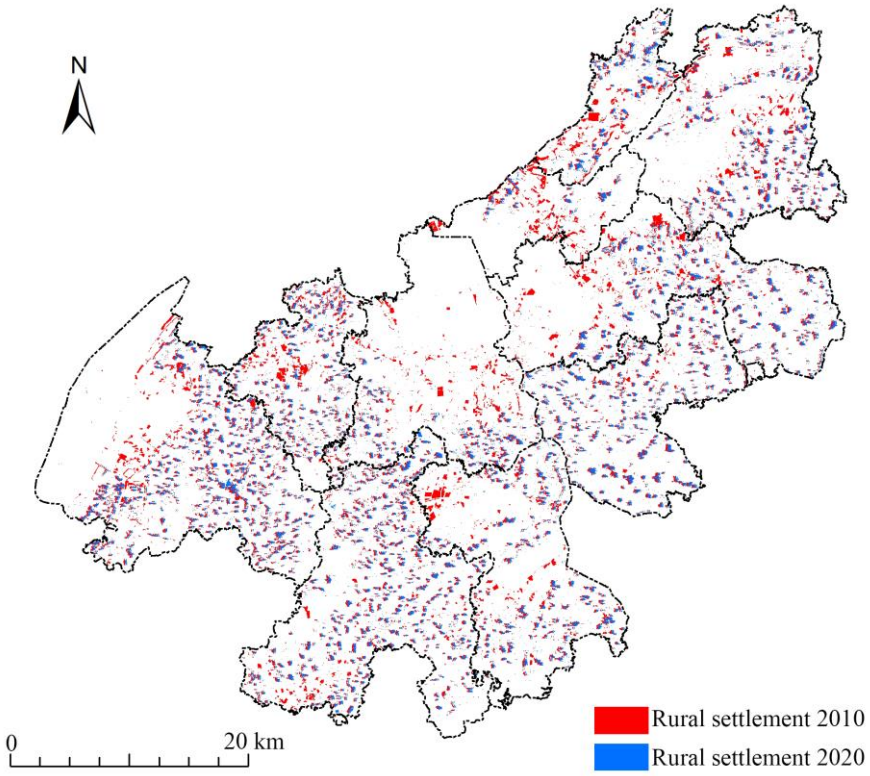

Figure 2. Rural settlements in Jiangning District (2010, 2020).

(2) Social economic data. These were from Nanjing Statistical Yearbook, Jiangning District Statistical Yearbook (2011–2021), Nanjing and Jiangning District Statistical Bulletin on National Economic and Social Development, and China County Statistical Yearbook (2011–2021).

(3) DEM data. These were obtained from the geospatial data cloud platform (http://www.gscloud.cn, accessed on 10 December 2022.), and river and traffic data were obtained from the National Geographic Information Resources Directory Service system.

3. Results

3.1. Evolution Characteristics of Rural Settlement

3.1.1. Scale Evolution Characteristics of Rural Settlement

(1) The number of rural settlements showed a significant decrease. Based on ArcGIS10.2 software, the data of rural settlement patches in 2010 and 2020 were processed, and spatial superposition analysis was conducted on the distribution of settlement patches in the two years to obtain the characteristics of rural settlement scale changes in Jiangning District from 2010 to 2020 (Table 3). According to Table 2, the rural settlement number patches in Jiangning decreased from 18,800 in 2010 to 16,553 in 2020, and the area of rural settlement patches decreased from 135,464,111 hm^2 in 2010 to 70,050,296 hm^2 in 2020. In 10 years, the area decreased by 48.29%, nearly by half. This indicates that the settlement number has shown a sharp decline trend since 2010. In addition, the average patch area and maximum patch area decreased from 6673 hm^2 and 479,309 hm^2 in 2010 to 4231 hm^2

and 142,750 hm^2 in 2020, respectively, indicating that the rural settlement scale showed a decreasing trend.

Table 3. Settlement landscape index in Jiangning District (2010, 2020).

Year	NP	CA	MPA	LAP
2010	18,800	135,464,111	6673	479,309
2020	16,553	70,050,296	4231	142,750

(2) The scale system of rural settlements was relatively uniform. The scale of rural settlements was selected as a dependent variable; the location order of settlement was selected as an independent variable. The location order scale curve of rural settlements in 2010 and 2020 (Figure 3) was drawn to analyze the hierarchical structure characteristics of settlement scale. Figure 3 shows that the goodness of fit R^2 of the model was greater than 0.8, and the overall estimation effect was good. In 2010, large-scale rural settlements were slightly lower than the fitted curve, while small and medium-sized rural settlements were mostly on the fitted curve, indicating that there was little difference in the scale of rural settlements of different grades. By 2020, the distance of large-scale settlements below the fitted curve and the small and medium-sized rural settlements above the fitted curve had increased, indicating that the settlement scale of different grades had a certain polarization trend. The Zipf index of 2010 and 2020 was 0.593 and 0.629, respectively, both less than 1, indicating that the settlement scale was generally well developed, and the scale system of rural settlements was evenly distributed.

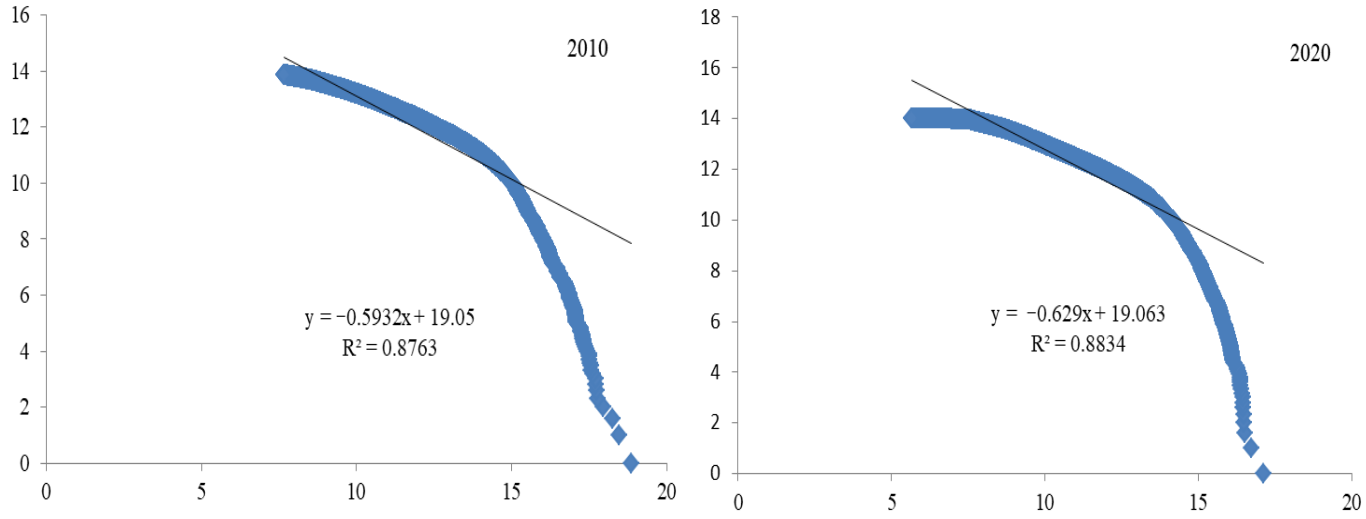

Figure 3. Rank−scale curve of rural settlements from 2010 to 2020.

(3) The scale of rural settlements had a significant concentration of local hotspots. Moran's I index in 2010 and 2020 was 0.355 and 0.423, respectively, which were both greater than 0. It shows that the scale of rural settlements in Jiangning District has experienced significant spatial agglomeration globally since 2010. At the same time, the hotspot detection tool was used to further analyze the local differentiation of rural settlement scale in Jiangning District (Figure 4). According to Figure 4, the local hotspot agglomeration of rural settlement scale in Jiangning District was significant from 2010 to 2020, and the hotspot areas were mainly distributed in Jiangning Street and Hengxi Street in 2010. By 2020, the hotspot areas were distributed in Jiangning Street, while the hotspot distribution in Hengxi Street had decreased. This was mainly due to the flat terrain of Jiangning Street, the radiation and driving role of the Nanjing–Maanshan expressway, the Nanjing–Wuhu railway, and National Highway 205, as well as the increase in rural population and economic development, resulting in the

formation of a "hot spot" distribution pattern with Jiangning Street as the center. The hot-spot distribution of rural settlement scale changed little, forming a stable hot-spot distribution pattern.

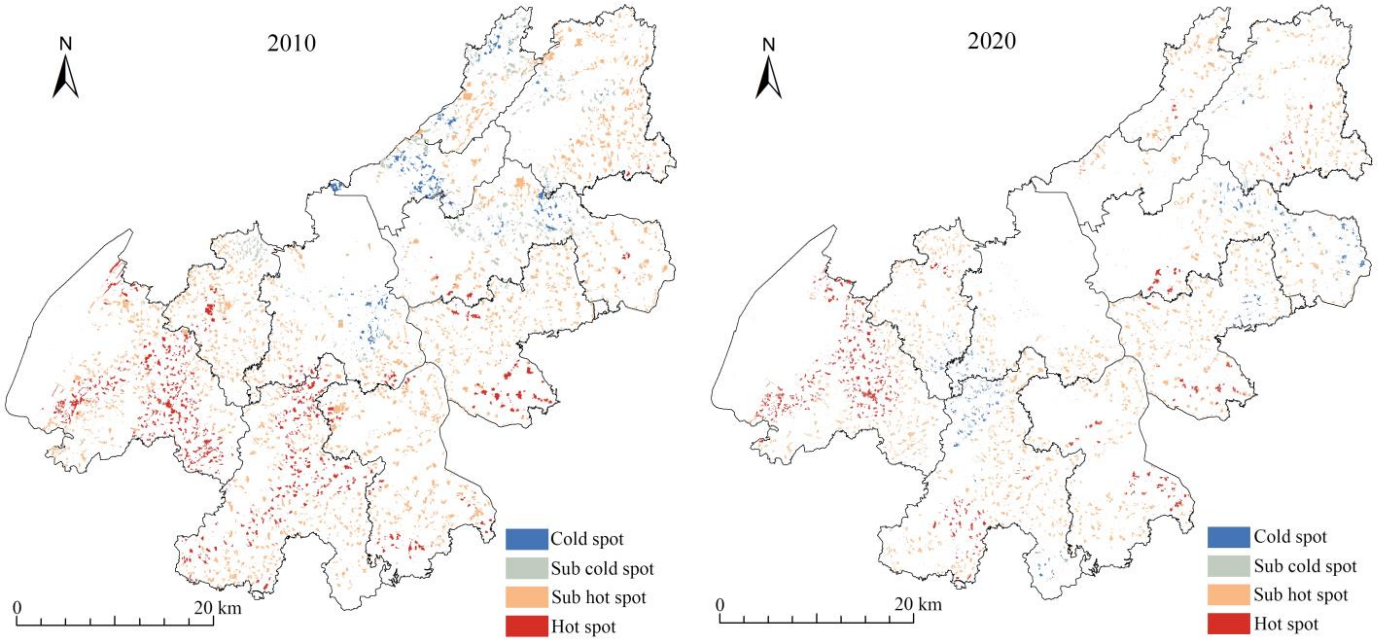

Figure 4. Hotspot agglomeration pattern of rural settlements scale from 2010 to 2020.

3.1.2. Spatial Distribution Evolution of Rural Settlements

(1) The spatial distribution of rural settlements showed an agglomeration pattern. ANN (Table 4) was calculated by using the analysis method of average nearest neighbor factors in ArcGIS10.2. According to Table 3, the nearest neighbor index of rural settlements in Jiangning District in 2010 and 2020 was 0.5851 and 0.5042 respectively, both less than 1. It was preliminarily concluded that the spatial distribution of rural settlements in Jiangning District showed an agglomeration pattern, and the ANN index showed a downward trend. The results indicate that the spatial distribution of rural settlements has become more concentrated since 2010.

Table 4. ANN index in Jiangning District (2010, 2020).

Year	ANN	Z Value	*p* Value
2010	0.5851	−120.7652	0.0001
2020	0.5042	−123.0836	0.0001

(2) The spatial distribution of rural settlements showed a multi-core structure. Based on the Kernel density analysis tool, we used the kernel density analysis method to generate a distribution map of rural settlement density in Jiangning District, and the rural settlement density was divided into five hierarchical areas: low density area, sub-low density area, medium density area, sub-high density area, and high density area. We also output the Kernel density maps of rural settlements in Jiangning District (Figure 5). As shown in Figure 5: ① From 2010 to 2020, the spatial distribution of rural settlements in Jiangning District showed a "multi-core" center; ② The areas with high settlement density were located in Jiangning Street, Moling Street, Hengxi Street, and Chunhua Street, and the settlement density was above 18.87/km^2.

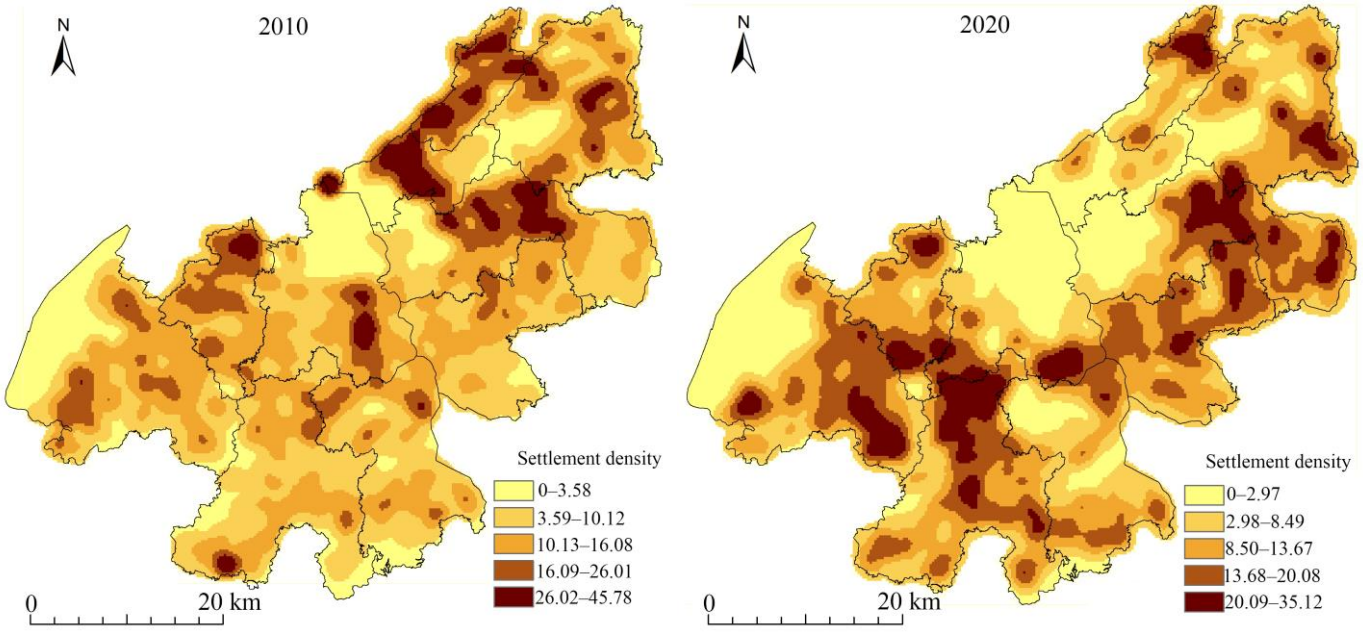

Figure 5. Density distribution of rural settlements in Jiangning from 2010 to 2020.

3.2. Driving Mechanism Analysis

3.2.1. Selection of Influencing Factors

In theory, rural settlement is the product of the interaction and evolution of the two subsystems of "human" and "land" in the regional system of the human–land relationship in a specific region. Its formation and distribution are jointly affected by the geographical environment (topography, climate, soil, vegetation, etc.), location conditions, and human and social factors (population, economy, traditional culture, etc.), and there are differences in the main factors in different development stages and regions. For example, Zhou [74] believed that the village's distribution pattern in China was the result of the interaction and coupling of geographical and socio-economic factors; Yang [75] believed that elevation and slope were two important basic influencing factors that affect the rural settlement distribution, and the background attribute of physical geography was the first factor considered in the village reconstruction. To summarize, the spatial distribution of rural settlements was mainly affected by natural environment, economic development, traffic location, and cultural system factors.

This paper fully considered the actual situation of Jiangning, and selected the factors from the natural environment, traffic location, and social economy. The elevation X_1, slope X_2, and cultivated land resource X_3 were selected as the natural environment indicators; distance from river X_4 and distance from town X_5 were selected as the traffic location indicators; per capita disposable income of farmers X_6, per capita GDP X_7, and agricultural population X_8 were selected as socio-economic indicators; the proportion of financial support to agriculture X_9 was selected as an indicator of policy and system. Empirically, the scale of rural settlements in 2010 and 2020 was taken as the explained variable, and nine influencing factors were taken from four aspects, namely, physical geography, traffic location, social economy, and policy system, as explanatory variables. The main controlling factors and driving mechanism of the rural settlement pattern evolution in Jiangning District were quantitatively revealed by geographical-detector model.

3.2.2. Factor Detection Analysis

The degree of influence of different factors on the rural settlement distribution in Jiangning District was measured by the factor detector in the geographical detector (Table 5). According to the factor detection results, agricultural population X_8, per capita GDP X_7, the proportion of financial support to agriculture X_9, and distance from towns X_5 had a

significant impact on the distribution of rural settlements in Jiangning District. The per capita disposable income of farmers X_6 also had important effects on the scale distribution of rural settlements in Jiangning District. However, elevation X_1, slope X_2, and cultivated land resource X_3 had no significant influence on the scale distribution of rural settlements in Jiangning District, and showed a certain weakening trend. Therefore, the main influencing factors of the distribution of rural settlements in Jiangning District from 2010 to 2020 were as follows: socio-economic factors > traffic location factors > physical geography factors.

Table 5. Detection results of factors influencing the distribution of rural settlements.

Indicator	2010		2020	
	***q* Value**	**Rank**	***q* Value**	**Rank**
elevation X_1	0.323	8	0.315	8
slope X_2	0.295	9	0.287	9
cultivated land resource X_3	0.358	7	0.343	7
distance from river X_4	0.393	6	0.385	6
distance from town X_5	0.487	4	0.492	4
per capita disposable income of farmers X_6	0.456	5	0.473	5
per capita GDP X_7	0.517	2	0.526	2
agricultural population X_8	0.523	1	0.535	1
proportion of financial support to agriculture X_9	0.506	3	0.515	3

In addition, we deeply explored the interactive relationship between the factors influencing settlement scale distribution in Jiangning District (Table 6). ① In general. The interaction of pairwise factors on the distribution of rural settlements in Jiangning District showed an enhanced relationship, indicating that the interaction of pairwise factors would enhance the explanatory power of the settlement distribution and evolution. ② The difference. The q values of the interaction between agricultural population X_8, per capita GDP X_7, the proportion of financial support to agriculture X_9, and distance from towns X_5 were all more than 0.5, which further indicated that X_8, X_7, X_9, and X_5 were the dominant factors affecting the evolution of rural settlement pattern in Jiangning District.

Table 6. Interactive detection values of factors influencing rural settlements.

Interaction Factor	***q*(A∩B)**	***q*(A)**	***q*(B)**	Interaction Result
$X_1 \cap X_2$	0.062	0.018	0.027	NE
$X_1 \cap X_3$	0.083	0.026	0.031	NE
$X_1 \cap X_4$	0.085	0.032	0.028	NE
$X_1 \cap X_5$	0.503	0.038	0.032	DE
$X_1 \cap X_6$	0.238	0.021	0.028	NE
$X_1 \cap X_7$	0.516	0.038	0.037	DE
$X_1 \cap X_8$	0.546	0.046	0.045	DE
$X_1 \cap X_9$	0.532	0.037	0.041	DE
$X_2 \cap X_3$	0.077	0.019	0.025	NE
$X_2 \cap X_4$	0.123	0.027	0.029	NE
$X_2 \cap X_5$	0.508	0.037	0.024	DE
$X_2 \cap X_6$	0.263	0.042	0.031	NE
$X_2 \cap X_7$	0.521	0.046	0.043	DE
$X_2 \cap X_8$	0.555	0.052	0.048	DE
$X_2 \cap X_9$	0.536	0.045	0.047	DE
$X_3 \cap X_4$	0.203	0.031	0.028	NE
$X_3 \cap X_5$	0.512	0.042	0.035	DE
$X_3 \cap X_6$	0.256	0.033	0.037	NE
$X_3 \cap X_7$	0.512	0.038	0.042	DE
$X_3 \cap X_8$	0.575	0.069	0.059	DE
$X_3 \cap X_9$	0.561	0.062	0.052	DE

Table 6. *Cont.*

Interaction Factor	q(A∩B)	q(A)	q(B)	Interaction Result
$X_4 \cap X_5$	0.511	0.053	0.038	DE
$X_4 \cap X_6$	0.324	0.032	0.041	NE
$X_4 \cap X_7$	0.521	0.042	0.044	DE
$X_4 \cap X_8$	0.588	0.067	0.066	DE
$X_4 \cap X_9$	0.563	0.061	0.059	DE
$X_5 \cap X_6$	0.528	0.056	0.055	DE
$X_5 \cap X_7$	0.602	0.057	0.052	DE
$X_5 \cap X_8$	0.616	0.068	0.062	DE
$X_5 \cap X_9$	0.585	0.055	0.052	DE
$X_6 \cap X_7$	0.578	0.049	0.053	DE
$X_6 \cap X_8$	0.552	0.052	0.055	DE
$X_6 \cap X_9$	0.571	0.061	0.059	DE
$X_7 \cap X_8$	0.598	0.065	0.064	DE
$X_7 \cap X_9$	0.585	0.062	0.059	DE
$X_8 \cap X_9$	0.625	0.073	0.065	DE

Note: NE is nonlinear enhancement; DE is double-factor enhancement.

3.2.3. Analysis of Driving Mechanism

The main influencing factors and interactive relationships affecting the evolution of rural settlements were identified quantitatively through geographical detectors; on this basis, the paper further analyzed the driving mechanism of leading factors such as agricultural population, economic, traffic accessibility, and policy system behind the evolution of rural settlement pattern.

(1) Agricultural population driven. The results showed that the q value of agricultural population factor ranked first, and the growth of agricultural population had the most significant impact on the evolution of rural settlements in Jiangning District. Rural settlement is the carrier of the spatial distribution of population, and population factors are the most important factors affecting the spatial distribution of rural settlements. The change in agricultural population will directly affect the pattern formation and evolution of rural settlements. The agricultural population in Jiangning District has changed rapidly. The change in agricultural population has had an important impact on the evolution of rural settlement pattern in Jiangning District. In particular, the agricultural population around the urban built-up areas was transformed into non-agricultural population, and a large number of settlements were transformed into urban settlements, which led to significant changes in the spatial structure and scale distribution of rural settlements. Therefore, agricultural population was the dominant factor affecting the evolution of rural settlement pattern in rapidly urbanized areas.

(2) Economic development driven. The results show that the q value of per capita GDP ranks second, which fully reflected the fact that the economic development level had a significant impact on the evolution of rural settlement pattern in Jiangning District. The level of economic development was the basis of the formation and development, which determined the settlement landscape type and distribution. With the continuous development of economy, the farmers' comprehensive income rises, and the rural residents' requirements for their own living environment rise, so as to build houses with more perfect functions, which also leads to the continuous expansion of the rural settlement scale. The per capita GDP of Jiangning increased from RMB 137.82 million in 2010 to RMB 639.82 million in 2020. With the support of economic foundation, farmers' willingness to improve housing was implemented, and new houses were built in places with better locational conditions, and the rural settlements gradually formed an extended expansion pattern. This not only affected the scale of rural settlements but also changed the settlement spatial structure. Therefore, economic development was the dominant factor affecting the distribution of rural settlements in rapidly urbanized areas.

(3) Traffic accessibility driven. The detection results showed that the q value of distance from town was third. Traffic accessibility is a basic factor affecting the evolution of rural settlements pattern; good traffic accessibility is conducive to rural settlement expansion. With the general road lines in 2010 and 2020 as the center and 250 m as the buffer radius, 10 buffer zones will be established to explore the rural settlement distribution as the road buffer zone extends to the periphery. When the road buffer zone was 500 m, the number of settlements in the buffer zone was 8204 and 6934 for 2010 and 2020, respectively, accounting for 43.64% and 41.89%. With the increase in buffer distance, the number distribution of the rural settlements continued to decrease. When the buffer distance was 2500 m, the number of settlements was 1289 and 1025 for 2010 and 2020, respectively, which only accounted for 6.86% and 6.19%. This showed that the distribution characteristics of rural settlements along the road were significant. The closer to the road, the denser the rural settlement distribution. The farther away from the road, the fewer the number of rural settlements, and the lower the settlement distribution density. Therefore, traffic accessibility was also a leading factor affecting the evolution of rural settlement pattern.

(4) Policy and system driven. The influence of government regulation on the evolution of rural settlement pattern is reflected in the aspects of policy guidance, planning regulation, and administrative division adjustment. Since 2010, Jiangning District has optimized the settlement space by implementing a series of spatial renovation policies, such as village withdrawal and town consolidation, central village construction, and characteristic village retention. In recent years, Jiangning has continued to promote the construction of beautiful villages. The construction of a series of scenic spots has driven the transformation of the surrounding rural settlement space from traditional residence to complex business forms such as farmhouse, public services, and the combination of commercial and residential areas, and further affected micro forms such as the exterior facade and surface pattern of the rural settlements. The adjustment of administrative divisions has greatly changed the administrative territory of rural settlements, which further promoted the changes in population and social economy, and had a significant impact on the evolution of rural settlement pattern. Therefore, policy and system factors were the dominant factors affecting the evolution of rural settlement pattern in rapidly urbanized areas.

In conclusion, the spatial evolution of rural settlement pattern was influenced by dominant factors such as agricultural population, economic development, traffic accessibility, and policy system. In the future, the interaction of these leading factors will increasingly influence the evolution of rural settlement pattern in rapidly urbanized areas (Figure 6).

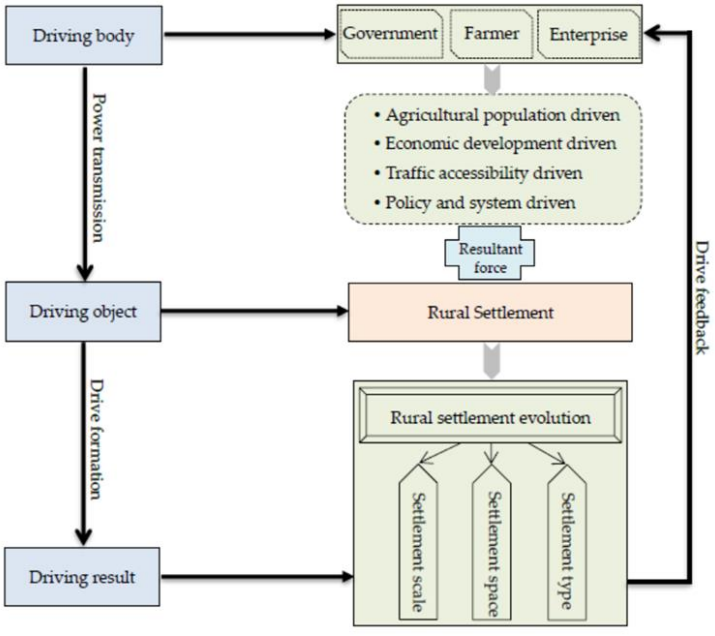

Figure 6. Theoretical framework of settlement evolution driving mechanism.

4. Discussion

With the significant transformation from the planned economy to the market economy system and the rapid progress of urbanization and industrialization, the space of rural settlements has changed from the past "homogeneous and homogeneous" to "heterogeneous and heterogeneous", and gradually tends to differential development paths and diversified development goals. In particular, in regions with high economic development level and rapid urbanization, the spatial elements, structure, and organizational relationship of rural settlements are changing rapidly. Rural settlements are also undergoing the transformation stage of optimizing the regional spatial pattern, restructuring the socio-economic form, and improving the functional layout. Taking Jiangning District as a typical case, this paper found that the patches area of rural settlement decreased by nearly half from 2010 to 2020, showing a trend of massive reduction, which indicated that rapid urbanization had an important impact on the evolution of rural settlement pattern, and caused a serious "squeeze" on rural space. The analysis conclusion was basically consistent with the research conclusions of Liu [76], Li [77], Lin [78], and other scholars.

On the research of the mechanism of rural settlement pattern evolution, the current research [79–81] has shown that the evolution process of rural settlements was comprehensively driven by multiple factors, and different factors show different characteristics as time and regional environment change. At present, many scholars [82–84] believe that natural environmental factors played a fundamental role in the pattern formation of rural settlements in the early stage, and the natural environmental factors lasted for a long time due to less interference from other sources; socio-economic factors played an increasingly prominent role in the process of urbanization, and gradually became an important factor affecting the pattern of rural settlements. Using the geographical-detector model, this study confirmed that economic and social factors played a leading role in the evolution of rural settlement pattern in rapidly urbanized areas, and the role was becoming stronger, and the impact of natural environmental factors was diminishing.

Against the background of rapid urbanization, how to optimize and reconstruct the spatial pattern of rural settlements is a realistic proposition. Combined with the future evolution trend of rural settlements, and according to the implementation goals and requirements of rural vitalization, this paper tried to put forward the typical models of rural settlement spatial reconstruction in rapidly urbanized areas, namely, suburban integration type, agglomeration promotion type, characteristic protection type, and relocation and withdrawal type [85–88]. ① Suburban integration type refers to the suburbs near the city and the villages where the county seat Chengguan town is located, which have the advantages of becoming the back garden of the city, but also have the conditions of becoming part of the city. We will accelerate the integrated development of urban and rural industries, infrastructure connectivity, and joint contribution and sharing of public services, and gradually strengthen our capacity to serve urban development and carry out spillover of urban functions. ② Agglomeration promotion type refers to the existing large central villages and other general villages that will continue to exist, and orderly promote transformation and upgrading on the basis of the original scale, by activating the industry, optimizing the environment, protecting and preserving the rural style, and building a beautiful village suitable for living and business. ③ Characteristic protection type refers to villages with rich natural, historical, and cultural characteristics, such as famous historical and cultural villages, traditional villages, minority villages with characteristics, and famous landscape tourism villages. We should make reasonable use of characteristic village resources, develop rural tourism and characteristic industries, and form a benign mutual promotion mechanism between characteristic resource protection and village development. ④ Relocation and withdrawal type refers to villages located in areas with poor living conditions and a fragile ecological environment, villages that need to be relocated due to major construction projects, and villages with particularly severe population loss. The government has adopted such measures as poverty alleviation relocation, ecological livable relocation, and rural agglomeration and development relocation, and implemented village

relocation and consolidation, so as to coordinate solutions to problems related to villagers' livelihoods and ecological protection.

5. Conclusions

The paper took Jiangning District as a case study, comprehensively using the landscape pattern index, the rank-scale law, the local hot spot-detection model, and the geographical-detector model, and revealed the pattern evolution and driving mechanism of rural settlements in rapidly urbanized areas from 2010 to 2020. The following conclusions were obtained:

(1) The number of rural settlements showed a trend of large-scale reduction in Jiangning District, with the area of rural settlements reduced by 44.18% in recent 10 years. This shows that the pattern of rural settlements has undergone significant changes in the rapidly urbanized areas. The Zipf index of the settlements scale was less than 1 in Jiangning District in 2010 and 2020, indicating that the scale of rural settlements was generally well developed and the scale system of rural settlements was evenly distributed in the rapidly urbanized areas.

(2) The spatial distribution of rural settlements showed an "agglomeration" pattern in Jiangning District from 2010 to 2020, and the agglomeration trend was increasing. This showed that the distribution of rural settlements was closely related to human activities in the rapidly urbanized areas. The density distribution of rural settlements showed a "multi-core" center, and the distribution pattern gradually decreased from the center to the periphery in the rapidly urbanized areas.

(3) The evolution of rural settlement pattern was the result of the effects of geographical, traffic-accessibility, and socio-economic factors in the rapidly urbanized areas. Natural environmental factors such as terrain, water system, and cultivated land resources have shaped the spatial pattern of rural settlements, and their role has gradually weakened. Economic development, agricultural population, traffic conditions, and other socio-economic factors have played a leading role in the evolution of rural settlement pattern, and the interaction could enhance the impact on the evolution of rural settlement pattern.

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