

Article

Distribution Characteristics and Influencing Factors of Rural Settlements in Metropolitan Fringe Area: A Case Study of Nanjing, China

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Abstract: Rural settlement is the core content of rural geography research. Exploring the spatial distribution characteristics and influencing factors of rural settlements can provide reference for the optimization of rural settlements. This paper selected Nanjing as a typical case, based on remote sensing image, using R statistics, kernel density analysis, hot spot detection analysis and semi variogram function; the paper analyzed the spatial, scale and morphological distribution characteristics of rural settlements; and preliminarily analyzed the influencing factors of rural settlements distribution in the metropolitan fringe area. The results showed that: (1) The spatial distribution of rural settlements generally presented a “multi-core” center, and a spatial distribution trend of stepwise decline from the core to the periphery, showing a typical “core-edge” structure. (2) There was a significant spatial difference in the scale distribution of rural settlements, which was characterized by a gradual decrease in the scale of rural settlements with the increase in the distance from the central urban area. (3) The morphological distribution of rural settlements showed spatial differentiation, and the morphological types of settlements mainly included strip, arc belt, cluster and scatter. (4) The distribution of rural settlements was affected by such factors as terrain, river system, traffic, economic and social development, cultural and policy. The distribution of rural settlements had the location orientation of “low altitude, water affinity and road affinity”. The increase in agricultural population, rural economic development, cultural and policy factors played an important role in the distribution of rural settlements in the metropolitan fringe area.

Keywords: rural settlement; spatial distribution; scale distribution; morphological distribution; influencing factors; the metropolitan fringe area; Nanjing



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1. Introduction

Rural settlement is the key research field of rural geography. It is a complex system composed of social economy, natural ecology and other subsystems. It has a certain scale, structure, form and function, and has the main characteristics of complexity and dynamics [1,2]. Since the reform and opening up, with the rapid industrialization and urbanization process in China, the interactive flow of urban and rural resource factors has accelerated, the structure of production factors in rural areas is changing, and the development and evolution of rural settlements are undergoing rapid transformation. Rural settlements are also gradually shifting from “homogeneous” to “heterogeneous”, and the transformation and development of rural settlements present a variety of scenarios [3,4]. To promote the implementation of the rural revitalization strategy and build a beautiful countryside suitable for living, working and visiting, the development of rural settlements is an important basis for rural revitalization [5]. Therefore, exploring the spatial characteristics, influence mechanism and reconstruction path of rural settlements in typical regions is a realistic proposition under the background of rural revitalization.

Rural settlement geography is the main branch of rural geography. With the development and transformation of rural geography, the focus of rural settlement geography research is also constantly changing [6]. In the 18th century, geographers began to explore the relationship between people and land in rural areas. In this process, they began to study rural settlements, mainly involving the origin, distribution, type, evolution of rural settlements and their relationship with the environment [7–9]. After the 1950s, research in developed countries began to focus on spatial classification and measurement, research on rural sustainable development and the impact of human decision-making behavior on rural settlements [10–13]; the research content was constantly enriched. By the 1990s, under the influence of many philosophical trends, especially postmodernism, existentialism, idealism, humanistic geography, structuralist geography and critical realism geography, the research paradigm of rural geography in western countries began to transform to the social human direction at this stage [14–16]. With the rapid development of rural industrialization and urbanization, the rural settlement system and spatial structure have been constantly changed. The research on rural transformation and reconstruction has attracted scholars' attention, involving rural economy, society, space and other aspects [17–20]. In terms of distribution characteristics, landscape index, spatial syntax, fractal theory and other research methods are used to study the distribution characteristics of rural settlements from different aspects. For example, Hudson [21] analyzed the distribution system of rural settlements in Iowa on the basis of central place theory and diffusion theory; Weisler [22] studied the settlement space structure of Polynesian bacteria states from the perspective of historical evolution; Conrad [23] used remote sensing technology to measure the expansion of the spatial scale of rural settlements in Uzbekistan; Gallarati [24] combed the context of landscape and environment at various scales and studied the space and type of rural settlements. The research focused on the spatial layout of settlements [25], rural land use [26], settlement scale and form [27], etc. In terms of influencing factors, scholars in western countries started to study the influencing factors of rural settlement layout early. As early as the 1940s, they carried out a discussion on the relationship between rural settlement distribution and geographical environment [28]. With the development of social economy, the focus of research has gradually shifted to the human, economic and social directions, paying more attention to the relationship between population density and rural settlement distribution [29], the relationship between economic transformation and rural settlement distribution [30], the relationship between policy system and rural settlement distribution [31], the relationship between farmers' behavior and rural settlement distribution [30]. The research on influencing factors of rural settlement has experienced a change from focusing on natural factors to comprehensively considering various factors, such as natural, social, economic and cultural factors, and the perspective of research tends to be comprehensive.

The study of rural settlements in China started relatively late. Influenced by the academic research trend of geography in western countries, Lin [32] and other geographers of the older generation began to study rural settlements in the 1930s. Summarizing the research results of rural settlements in China, the study can be roughly divided into four stages: embryonic start (before 1949), preliminary development (1949–1978), rapid development (1978–2000), transformation and reconstruction (2000–present) [33–35]. Taking a general view of the research achievements related to rural settlements in China, a summary was made from the three dimensions of research contents, methods and scales. (1) In terms of research contents, the research mainly focused on the spatial pattern [36,37], evolution characteristics [38], influencing factors [39] and optimal regulation [40] of rural settlements. (2) In terms of research methods, multiple methods such as GIS spatial analysis [41], econometric analysis model [42] and field investigation method [43] were applied to the spatial analysis of rural settlements, showing a trend of cross-integration of multidisciplinary research methods. (3) In terms of research area, the current research mainly focused on the Pearl River Delta [44], Yangtze River Delta [45], Beijing-Tianjin-Hebei [46], etc. The research area mainly focused on the developed coastal areas in the east, and the typical areas (hilly area [47], loess area [48]) were also involved. Some scholars have also paid attention to

the spatial pattern of rural settlements in metropolitan areas [49,50]. Through the review, it can be found that the current research focused more on the description of the spatial pattern characteristics of rural settlements. The discussion on the spatial characteristics and formation mechanism of rural settlements in different typical regions was relatively weak.

As a transitional zone between urban and rural areas, the metropolitan fringe is faced with an overall transformation of economic, social and spatial structures. However, the spatial evolution of rural settlements located in the metropolitan fringe was influenced by rural urbanization. Compared with the traditional rural settlements, the rural settlements located in the metropolitan fringe were affected by the radiation and driving effect of the urban core area, and their spatial characteristics were characterized by complexity and diversity [51]. Nanjing is located in the Yangtze River Delta urban agglomeration, which is a metropolis in the coastal development area of eastern China. In the process of rapid urbanization, the rural settlements in the urban fringe are facing transformation and reconstruction, which can better reflect the characteristics of the rural settlements in the metropolitan fringe. In view of this, this paper chose Nanjing as a typical case, based on the interpretation of remote sensing image, using R statistics, kernel density analysis, hot spot detection analysis and semi variogram function, the paper analyzed the distribution characteristics and influencing factors of rural settlements in the metropolitan fringe area. The objective of these analyses is to address the following research goals: (1) What are the distribution characteristics of rural settlements in the metropolitan fringe? (2) What are the factors affecting the distribution of rural settlements in the metropolitan fringe? The research structure of this paper is as follows (Figure 1).

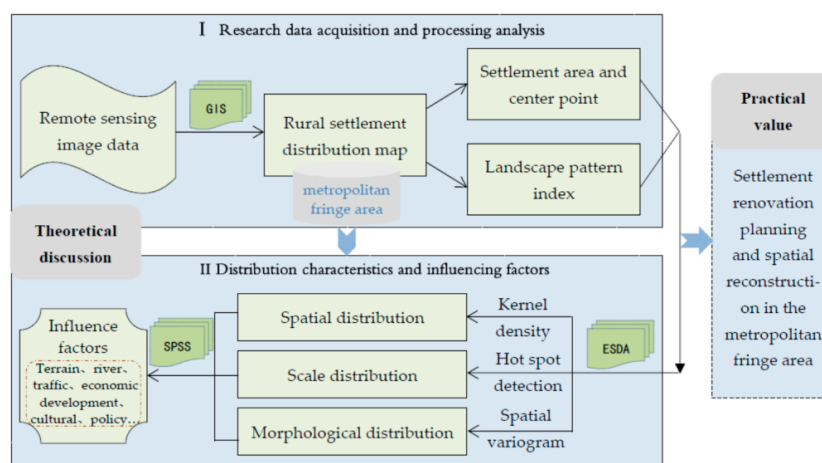


Figure 1. Theoretical analysis framework.

- What are the distribution characteristics of rural settlements in the metropolitan fringe area? Using R statistic, kernel density analysis, hotspot detection analysis and semi-variogram, from three different dimensions: scale distribution, space distribution and morphological distribution, this paper analyzed the spatial distribution characteristics of rural settlements in the metropolitan fringe area.
- What are the factors affecting the distribution of rural settlements in the metropolitan fringe area? On the basis of theoretical analysis of influencing factors, terrain, river system, traffic, economic, social development, cultural and policy factors were adopted to analyze the internal relationship between them and the distribution of rural settlements, and revealed the influencing mechanism of the distribution pattern of rural settlements in the metropolitan fringe area.

2. Materials and Methods

2.1. The Study Area

Nanjing is located in the eastern part of China, the lower reaches of the Yangtze River and the coastal areas near the Yangtze River. It is an important central city in the eastern part of China, an important gateway city for the development of the central and western regions driven by the Yangtze River Delta radiation, and an important node city for the strategic intersection of the eastern coastal economic belt and the Yangtze River Economic Belt. Nanjing covers an area of 6587.02 square kilometers, with a built-up area of 868.28 square kilometers. By 2021, the permanent resident population was 9.4234 million, and the urban population was 8.1889 million, with an urbanization rate of 86.9%. The GDP reached 1635.532 billion. Nanjing as one of the important cities in Yangtze River delta, with the rapid urbanization, rural industrialization, and promote the new rural construction, the dramatic changes in rural landscape, the region characteristics of traditional countryside gradually shift, a shift from rural to urban settlements, space from scattered to gather, lead to the new pattern of rural human settlements faces differentiation restructuring. In addition to its own development, rural settlements in the hinterland of the metropolis are also affected by the radiation of the central city, and their spatial characteristics are characterized by diversity and complexity. In view of this, this paper chose Nanjing as a typical case to analyze the spatial distribution characteristics and influencing factors of rural settlements, which was typical for studying the development of rural settlements in the metropolitan fringe area (Figure 2).

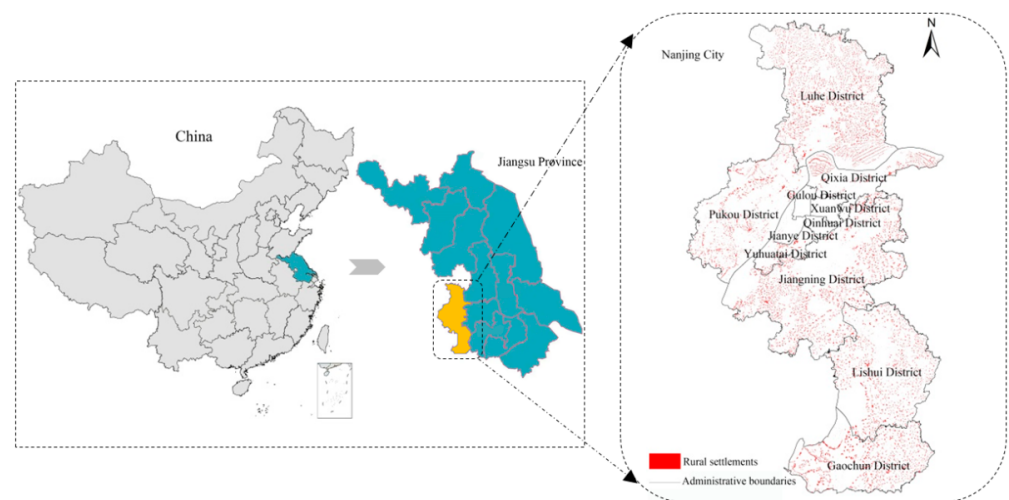


Figure 2. Location map of Nanjing.

2.2. Research Methods

2.2.1. R Statistics

The R statistic was first proposed by Clark and introduced into geographical research by Dacey in 1960 [52]. The core idea is to compare the minimum distance between each point and the distance between its nearest neighbors to obtain the spatial distribution characteristics of points, which can effectively reveal the basic characteristics of aggregation or dispersion of observation patterns and random patterns [53]. The theoretical formula is as follows:

$$R = \frac{r_{obs}}{r_{exp}}; r_{obs} = \frac{\sum_{i=1}^n d_i}{n}; r_{exp} = 0.5\sqrt{\frac{A}{n}}$$

where r_{obs} is the average distance observation value of the nearest neighbor; r_{exp} is the expected average distance of the nearest neighbor; d_i is the nearest neighbor distance of rural residential area i ; n is the total number of rural residential areas; A is the area of the study area. If $R > 1$, it indicates that the observation mode is more dispersive than the

random mode; If $R < 1$, it indicates that the observation mode is more concentrated than the random mode.

2.2.2. Kernel Density Analysis

Kernel Density Estimation (KDE) is a nonparametric method for estimating probability density function and a spatial analysis method for studying the distribution characteristics of certain elements in a region. The basic principle is to estimate the density function of the research object first, and then calculate the density value from the density function. In theory, the higher the density value is, the higher the distribution density of the geographic object is. The calculation formula is as follows [54,55]:

$$f(x, y) = \frac{1}{nh^2} \sum_{i=1}^n K(d_i/h)$$

where $f(x, y)$ is the density estimation of (x, y) position; n is the observed value; h is the smoothing parameter; K is the kernel function; d_i is the distance between (x, y) position and the i th observed position. Kernel density estimation is calculated by running ArcGIS10.2 software.

2.2.3. Hot Spot Detection Analysis

The local spatial autocorrelation analysis method is used to identify the possible agglomeration pattern in the local space, judge the spatial correlation between the rural settlement density and the settlement density in the surrounding areas, so as to show its spatial agglomeration or discrete characteristics. The theoretical model of G_i^* index is as follows [56,57]:

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

where W_{ij} is the spatial weight matrix, spatial adjacency is 1, and non adjacency is 0. If G_i^* is positive and significant, it indicates that the rural settlement density around the location is concentrated in high value space. On the contrary, if G_i^* is negative and significant, it indicates that the rural settlement density around the location is low.

2.2.4. Semi Variant Function

The rural settlement forms are different with different location directions of villages, and show certain spatial differentiation rules, which belong to regionalized variables. Semi variogram is an effective tool to describe the spatial variation rules and spatial structure of regionalized variables. In this paper, semi variogram method based on landscape shape index (LSI) is used to explore the distribution characteristics of rural settlement morphology. The theoretical formula is as follows [58,59]:

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^n [Z(x_i) - Z(x_i + h)]^2$$

The spatial variation function is generally represented by the variance graph (Figure 3), which is the corresponding graph between the variation function value $\gamma(h)$ of a certain lag variable H and this H . It is defined under the condition that the regionalized variable satisfies the stationary and eigenassumptions. When the semi variogram increases, the spatial autocorrelation decreases. The distance h is the most important characteristic of variance graph. Another important characteristic quantity is the direction, that is, isotropy and anisotropy. Where, is called block gold value, which represents the discontinuous variation when the regionalization variable is smaller than the observation scale. C is the structural equation; $C + C_0$ is the base value, which represents the stationary value of semi-variogram variable as the spacing increases to a certain scale. a is the range, which represents the interval when the semi-variogram reaches the abutment value. The

commonly used fitting models include spherical model, exponential model, Gaussian model, power exponential model, logarithmic model.

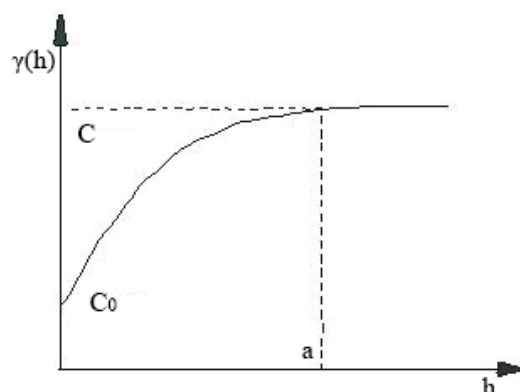


Figure 3. Model variogram.

2.3. Data Collection

The research data mainly included three parts: the remote sensing image data, the basic geographic data and the economic and social data.

(1) The remote sensing image data. Based on Google earth high-definition remote sensing image in 2022, the resolution was 30 m, and using Arcgis10.2 software, through geometric correction, coordinate registration, visual interpretation and vectorization, the rural settlement data in Nanjing were obtained (Figure 2). It was mainly used to analyze the distribution characteristics of rural settlements in Nanjing.

(2) The basic geographic data. DEM data were obtained from the geospatial data cloud platform (<http://www.gscloud.cn>, accessed on 2 September 2022), the resolution was 30 m; river and traffic data were obtained from the national geographic information resources directory service system. It was mainly used to analyze the influencing factors of rural settlement distribution in Nanjing.

(3) The economic and social data. The economic and social data were obtained from Jiangsu Statistical Yearbook, Nanjing Statistical Yearbook, Nanjing National Economic and Social Development Statistical Bulletin and other relevant materials. It was mainly used to analyze the influencing factors of rural settlement distribution in Nanjing.

3. Results

3.1. Distribution Characteristics

3.1.1. Spatial Distribution Characteristics of Rural Settlements

The spatial distribution of rural settlements presented a pattern of “agglomeration” in the metropolitan fringe area. Based on ArcGIS10.2 software, the centroid of patches of rural settlements was extracted and converted into point format. By using the Near tool in GIS software, the nearest spatial distance between rural settlements was calculated, and the R statistic and standardized Z value of rural settlements were calculated. The results showed that the R statistic of rural settlements in Nanjing was less than 1, and the standardized Z value was less than -1.96 , which further indicated that the spatial distribution and aggregation trend of rural settlements were significant, showing the characteristics of “agglomeration type” spatial pattern in Nanjing.

The density distribution of rural settlements showed a “multi-core” center in the metropolitan fringe area, and the high-density were located in the agricultural county far from the built-up area. Based on ArcGIS10.2 analysis software, the vector data of rural settlements in Nanjing were converted into raster data, and the density distribution map of rural settlements in Nanjing was generated by Kernel density analysis method. The density of rural settlements in Nanjing was divided into five grade areas by Jenks natural fracture point method: low-density area ($0\text{--}6.43$ units/ km^2), sub-low-density area ($6.44\text{--}12.87$ units/ km^2), medium density area ($12.88\text{--}19.29$ units/ km^2), sub-high-density

area (19.30–25.73 units/km²), high-density area (25.74–32.16 units/km²), and output the spatial distribution Kernel nuclear density map of rural settlements in Nanjing (Figure 4). As shown in Figure 4: (1) The spatial distribution of rural settlements in Nanjing generally showed a “multi-core” center, and the spatial distribution showed a stepwise decreasing trend from the core to the periphery, showing a typical “core-edge” structure. (2) The areas with high-density of rural settlements were distributed in Luhe and Jiangning, with the density values above 20.08 units/km². These areas were located in plain and polder areas, with flat terrain and rich hydrothermal resources. At the same time, agricultural production and agricultural economy in these areas developed rapidly, which also had a certain impact on the expansion and development of rural settlements. Medium density areas were mainly distributed in Lishui, Gaochun and other areas. The low-density areas were mainly distributed around the urban core area and the periphery of the new urban area, the villages around the urban core area were radiated by the city, and the population was urbanized locally, rural settlements gradually evolved into urban settlements, resulting in a small distribution of rural settlements.

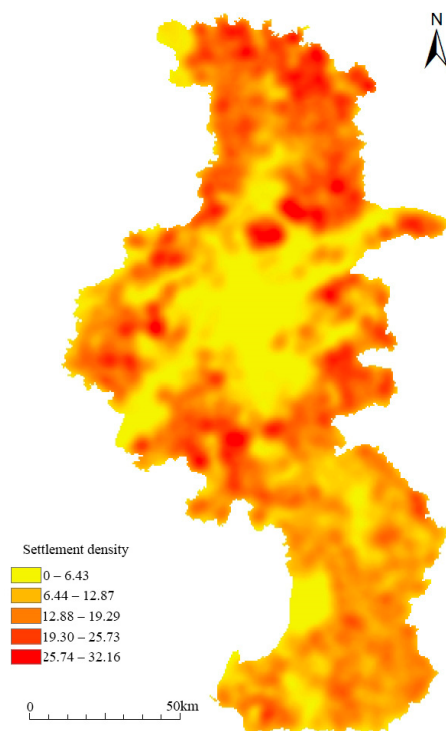


Figure 4. Density distribution of rural settlements in Nanjing.

3.1.2. Scale Distribution Characteristics of Rural Settlements

The scale distribution of rural settlements showed the autocorrelation of agglomeration in the metropolitan fringe area. Taking the rural settlement patch area as the analysis variable, the global $G(d)$ index was used to detect the global agglomeration characteristics of the rural settlement land scale in Nanjing. According to the calculation, the $G(d)$ index value of the rural settlement scale in Nanjing in 2022 was 0.582, and the distribution of rural settlement size in Nanjing showed positive spatial correlation. This indicated that the high value agglomeration characteristics of rural settlement scale distribution were significant in Nanjing.

The scale distribution of rural settlements showed a pattern of “hot spot clustering in the near suburbs and cold spot clustering in the far suburbs”. The hot spot detection tool was used to analyze the characteristics of local scale differentiation of rural settlements, and the G_i^* statistical value of the rural settlement land scale in each administrative village in Nanjing was obtained. The G_i^* score value was divided into cold and hot spots, and the hot spot map of rural settlement scale distribution was produced (Figure 5). Figure 5

showed that: (1) There was a significant spatial difference in the size distribution of rural settlements in Nanjing, showing that the size of rural settlements gradually decreased with the increase in the distance from the central city. The overall distribution pattern was that the size of rural settlements in the near suburbs was large, the size of rural settlements in the outer suburbs was moderate, and the size of rural settlements in remote areas was small. (2) The large-scale rural settlements in Nanjing were concentrated in the suburban areas of the central urban area. The suburban areas mainly attract the rural population, capital, technology and other production factors to the city and the suburbs due to the strong pull of the urban economy, thus changing the location characteristics of rural settlements in the suburbs, and thus changing the scale of rural settlements. (3) The small rural settlements in Nanjing were mainly distributed in rural areas far from the built-up areas, which were limited by the radiation of the metropolis and were still dominated by traditional agriculture. The lack of external power and limited economic development were not conducive to the settlements agglomeration, which led to the small scale of rural settlements.

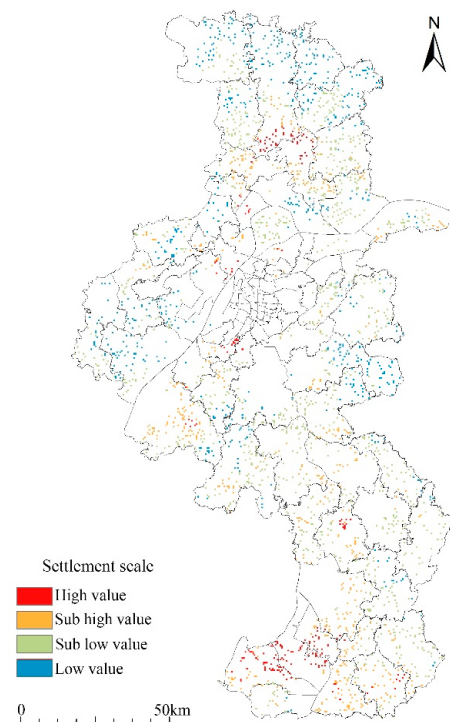


Figure 5. Hot spots pattern of rural settlements scale in Nanjing.

3.1.3. Morphological Distribution Characteristics of Rural Settlements

The morphological distribution of rural settlements had good stability, and the spatial self-organization of morphological distribution was strong in the metropolitan fringe area. The semi variation function was used to express the morphological distribution characteristics of rural settlements in Nanjing. Taking landscape shape index (LSI) of rural settlements as an indicator, it was given to the geometric center of each town as attribute data. The sampling step was set to 2000 m, and the experimental variation function was calculated, respectively. The best model was fitted and selected, and Kriging interpolation was carried out (Table 1, Figure 6). (1) From the perspective of the abutment value and nugget value indicators, the abutment value $C + C_0$ was 0.0402, while the nugget value C_0 was 0.0378, which had a medium degree of spatial autocorrelation. This indicated that structural factors (topography, geomorphology and other geographical and environmental factors) and random factors (economic development, policies and systems, etc.) jointly played a role in the differentiation of rural settlements. (2) From the model selected for fitting, the spatial fitting model selected by the least square method

was Gaussian model, and the determination coefficient R^2 reached 0.895, indicating that the distribution of rural settlements had good stability, and the spatial self-organization of rural settlements was strong in Nanjing. (3) From Kriging interpolation fitting diagram, the $\gamma(h)$ curve in each direction had a certain regularity, indicating that the distribution pattern of rural settlement morphology had the characteristic of autocorrelation. The spatial distribution morphology had a unique internal structure, showing a “bimodal” morphological distribution characteristic.

Table 1. Fitting parameters of variation of rural settlement morphology distribution.

Indicators	a	C + C ₀	C ₀	Fitting Model	R ²
Parameter value	797,024	0.0402	0.0378	Gaussian	0.895

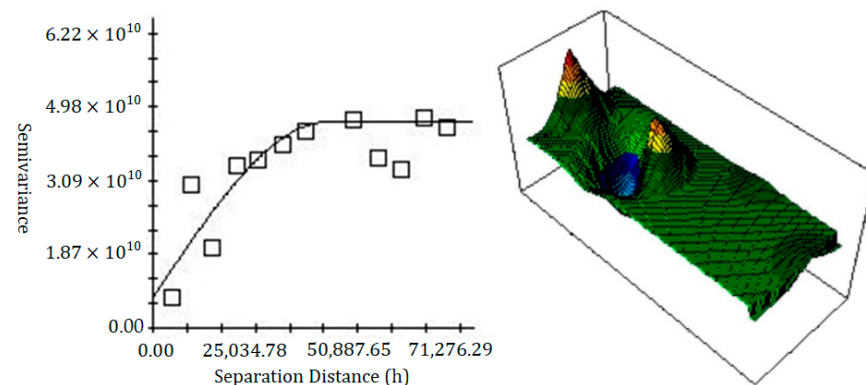


Figure 6. Variation function diagram of rural settlement morphology distribution in Nanjing.

The rural settlements morphology has significant spatial differentiation characteristics in the metropolitan fringe area. In order to more accurately consider the differences in rural settlement morphology in the metropolitan fringe, based on the interpretation and analysis of remote sensing images of Nanjing and the field visits and surveys of villages in different distribution locations such as Qixia District, Jiangning District, Luhe District, Pukou District, Lishui District, Gaochun District, it was found that the rural settlement morphology in the metropolitan fringe mainly existed four types (Table 2, Figure 7).

Table 2. The morphological types and basic characteristics of rural settlements in Nanjing.

Type	Distribution	Features
Strip type	It is mainly distributed in Qixia District, such as Liudong Village, Shuangqiao Village, Wangpeng Village.	The river network is dense, and the agricultural production mode is mainly traditional paddy field planting. The cultivation radius is small, and the distribution along the riverbank highland is in the form of strip extension.
Arcbelt type	It is mainly distributed in Gaochun District, such as Shangshang Village, Laozhuang Village, Xinyang Village.	The settlements are built along the river, affected by the trend of the river, the rural settlements are arc-shaped. The farming radius is large and the village scale is small, but the spatial layout is compact.
Cluster type	It is mainly distributed in Lishui District and Jiangning District, such as Qingwei Village, Jiufangdian Village.	The cultivated land is rich and has a large farming radius, which is easy to form large-scale settlements. The rural settlements have a regular shape, a large distribution density and a cluster distribution rural settlement pattern.
Scatter type	It is mainly distributed in Luhe District and Pukou District, such as Hewang Village, Xialiang Village.	The cultivated land resources are relatively rich, and the river system is relatively developed. However, affected by the hilly terrain, the distribution pattern of small and medium density scattered rural settlements has been formed.

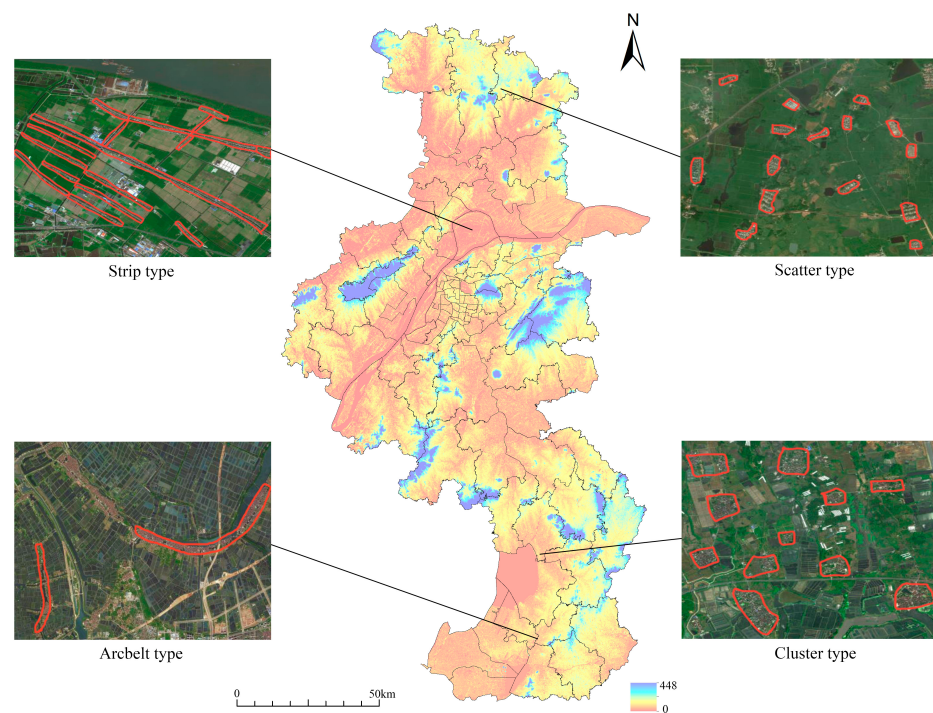


Figure 7. Distribution of rural settlement types in Nanjing.

3.2. Analysis of Influencing Factors

Theoretically, the distribution of rural settlements is closely related to natural, economic, social, cultural and policy [60,61]. From the terrain, river system, traffic, economic and social development and policy factors, this paper mainly discussed the influencing factors of rural settlement distribution in the metropolitan fringe area.

3.2.1. Rural Settlements Distribution and Terrain Factors

Terrain condition is an important factor affecting agricultural production and life, as well as the basic factor forming the spatial pattern of rural settlements. According to the topographic characteristics of the study area, the altitude was divided into five levels: ≤ 100 m, 100~200 m, 200~300 m, 300~400 m and ≥ 400 m. The DEM raster data was carried forward into vector data according to the classification and analyzed by stacking with the distribution map of rural settlements. It revealed the internal relationship between the spatial distribution of rural settlements and the topography in the metropolitan fringe (Table 3). According to Table 3, within the altitude of 200 m, the distribution of rural settlements was the largest, and the proportion of the distribution of rural settlements gradually decreased with the increase in elevation. The patch density of rural settlements also showed an obvious decreasing trend with the increase in elevation. At the same time, with the increase in altitude, the distance index also gradually increased, indicating that the spatial distribution of rural settlements was more dispersed, and the density was weakening. It showed that the spatial distribution of rural settlements had a significant “altitude location directivity” in the metropolitan fringe area.

Table 3. Landscape index of spatial distribution of rural settlements at different altitudes.

Altitude	Area (km ²)	Density (Units/km ²)	Distance Index (Units/km ²)
≤ 100 m	20,345	0.56	0.32
100~200 m	18,973	0.52	0.35
200~300 m	10,294	0.43	0.44
300~400 m	5903	0.33	0.47
≥ 400 m	1003	0.15	0.55

3.2.2. Rural Settlement Distribution and River System Factors

The distribution of river system is also an important factor affecting the spatial pattern of rural settlements in the metropolitan fringe area. This paper, based on the river system in Nanjing, calculated the shortest distance D from rural settlements (points) to rivers (lines), and divided the shortest distance D into six levels: $D \leq 500$ m, $500 \text{ m} < D \leq 1000$ m, $1000 \text{ m} < D \leq 1500$ m, $1500 \text{ m} < D \leq 2000$ m, $2000 \text{ m} < D \leq 2500$ m, $2500 \text{ m} < D \leq 3000$ m. By counting the percentage of rural settlement patches within different distance levels between rivers and rural settlements, the relationship between the spatial pattern of rural settlements and the distribution of river system was analyzed (Table 4). Table 4 showed that when the shortest distance D from rural settlements to the river was less than 1000 m, the total number of patches in rural settlements was 14,679, accounting for 80%; while when D was more than 2000 m, the total number of patches in rural settlements was 325, accounting for only 1.8%. Therefore, with the increasing radius from the river, the number of rural settlement patches showed a decreasing trend. The farther the distance from the river system, the less the distribution of rural settlements, and the spatial distribution of rural settlements showed a significant “hydrophilic distribution location directiveness”.

Table 4. Number of patches at different distances from rural settlements to rivers in Nanjing.

Minimum Distance	Number of Plaques (Units)	Proportion (%)
≤ 500 m	8786	48.78
$500 \text{ m} < D \leq 1000$ m	5893	32.71
$1000 \text{ m} < D \leq 1500$ m	2134	11.84
$1500 \text{ m} < D \leq 2000$ m	876	4.86
$2000 \text{ m} < D \leq 2500$ m	239	1.32
$2500 \text{ m} < D \leq 3000$ m	86	0.48

3.2.3. Rural Settlement Distribution and Traffic Factors

Transportation is a prerequisite for commodity exchange, which has an important impact on the spatial distribution pattern of rural settlements in the metropolitan fringe area. The road is the axis connecting rural settlements, and the main channel for material flow and information flow transmission between settlements. With the increase in settlement scale, the demand for people flows and logistics between settlements will increase synchronously, and the density of road network between settlements will also increase rapidly. The convenience of transportation will also promote the expansion of settlement scale, and there is a certain mutual promotion between them [62].

In order to quantitatively reflect the relationship between traffic and rural settlements, based on ArcGIS10.2 analysis software, taking 500 m as the buffer radius, the road network was analyzed for buffer zone, and the 12 buffer zones obtained were superimposed, and analyzed with the layer of rural settlements in Nanjing to obtain the relationship between the distribution of rural settlements and the traffic network (Figure 8). Figure 8 showed that the first section (<1500 m) was a stable section, where rural settlements were mainly distributed. The second section ($1500\sim 4500$ m) was a rapid reduction section, and the number and area of rural settlement patches were significantly reduced compared with the first section. The third section (>4500 m) was a slowly decreasing section, with a stable decline rate and a small number of rural settlements. Therefore, traffic factors played an important role in the distribution of rural settlements in the metropolitan fringe area, showing the characteristics of “road affinity” distribution.

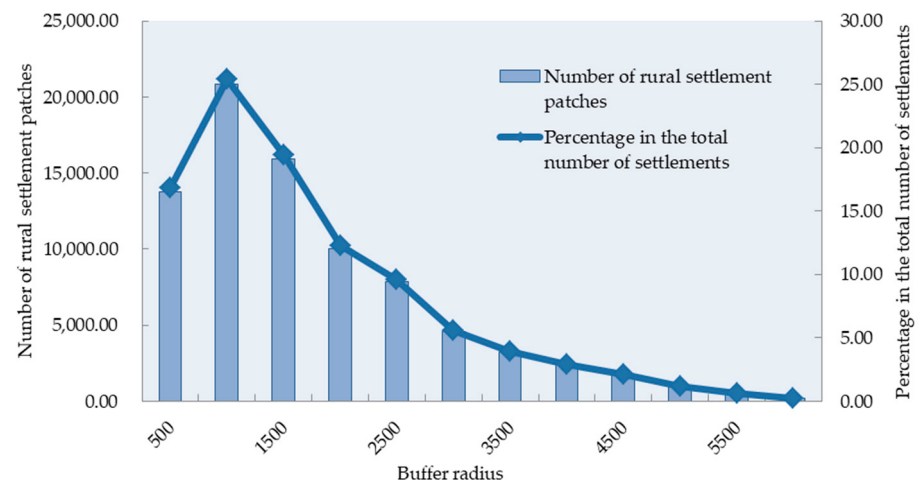


Figure 8. The rural settlements in different distance zones to roads in Nanjing.

3.2.4. Rural Settlement Distribution and Economic Social Development Factors

Economic social development factors are important factors affecting the spatial distribution of rural settlements, which are mainly reflected through agricultural population growth, industrial structure adjustment and urbanization [63,64]. In view of this, the paper selected 10 factors reflecting the economic social development and used factor analysis to reveal the economic social development factors that affect the spatial distribution of rural settlements in Nanjing. Firstly, SPSS18.0 software was used to conduct KMO and Bartlett tests. The results showed that KMO was 0.658, and Bartlett's p value was $0.0495 < 0.05$, indicating the feasibility of factor analysis. Secondly, according to the data calculation, the characteristic root was greater than 1, and there were two common factors that met the requirements. According to Table 5, the cumulative variance contribution rate was 86.69%, so two common factors could be extracted to replace the original data indicators.

Table 5. Factor analysis results.

Common Factor	Characteristic Value	Contribution Rate	Cumulative Contribution Rate
1	7.52	58.76	58.76
2	4.88	27.93	86.69

Table 6 showed that, the common factor 1 was mainly determined by indicators X_1 , X_4 , X_9 and X_{10} , which mainly reflected that agricultural population was the direct power to affect the distribution pattern of rural settlements. The premise of rural settlement construction was to meet the residential needs of farmers, so the increase in agricultural population and rural labor force was positively related to the size of rural settlement space. With the development of urbanization, the increase in the proportion of urban population was conducive to the regularization of the spatial distribution of rural settlements and promoted the development of rural settlements towards urban settlements. The common factor 2 was mainly determined by indicators X_3 , X_5 , X_6 and X_8 , which mainly reflected the development status of rural economy. The level of rural economic development indirectly affects the spatial distribution pattern of rural settlements. With the development of rural economy, it provides economic guarantee for the development of rural settlements, the villages with the higher income of farmers have the larger area of rural settlements. Therefore, the distribution characteristics of rural settlements were mainly affected by agricultural population and rural economic development in the metropolitan fringe area.

Table 6. Selection of explanatory variables.

Variable	Amount of Load	
	The Common Factor 1	The Common Factor 2
Total agricultural population X_1	0.983	−0.343
Total grain output X_2	0.563	−0.422
Agricultural income X_3	0.523	0.936
Rural labor force X_4	0.974	0.378
Per capita net income of farmers and herdsman X_5	0.632	0.902
Total output value of agriculture, forestry, animal husbandry and fishery X_6	−0.453	0.927
Primary industry income X_7	0.378	0.785
Secondary industry income X_8	0.403	0.893
Urbanization rate X_9	0.945	0.342
Population density X_{10}	0.967	−0.203

3.2.5. Rural Settlement Distribution and Cultural Policy Factors

Cultural and policy factors play an important role in regulating the distribution pattern of rural settlements. Cultural factors include cultural customs, religious beliefs, etc, these are important components of China's traditional culture, which have a profound impact on the ideology of farmers and have an important impact on the distribution and form of regional rural settlements, which is the main reason for the formation and morphological evolution of many famous villages in Nanjing [65]. Policy factors had an important impact on the distribution of rural settlements in the metropolitan fringe. On the one hand, policy factors affect the distribution pattern of rural settlements through direct administrative mechanisms; on the other hand, it affects the behavior of residential location by indirectly acting on the behavior subject of farmers [66]. Land use planning, industrial structure adjustment and administrative division adjustment have a profound impact on the development and layout of rural residential areas in Nanjing. In recent years, with the implementation of the national strategy of rural revitalization, the spatial renovation policies of Nanjing, such as comprehensive land consolidation, the removal of villages and towns, and the construction of central villages, have affected the form and scale of rural settlements in Nanjing, it has promoted the transformation of rural construction space into a spatial layout form of large dispersion and small concentration. In addition, the adjustment of administrative divisions in Nanjing has changed the infrastructure level of some rural settlements, which had also become an important factor affecting the distribution and spatial reconstruction of rural settlements.

To sum up, the physical geographical environment (terrain, river, etc.) provided the basic conditions for the distribution of rural settlements in the metropolitan fringe area. With the continuous development of urbanization, traffic accessibility, agricultural population growth, rural economic development, cultural and policy have become the dominant factors for the distribution of rural settlements in the metropolitan fringe. The interaction of these factors has an increasing impact on the evolution and reconstruction of rural settlements in the metropolitan fringe in the future (Figure 9).

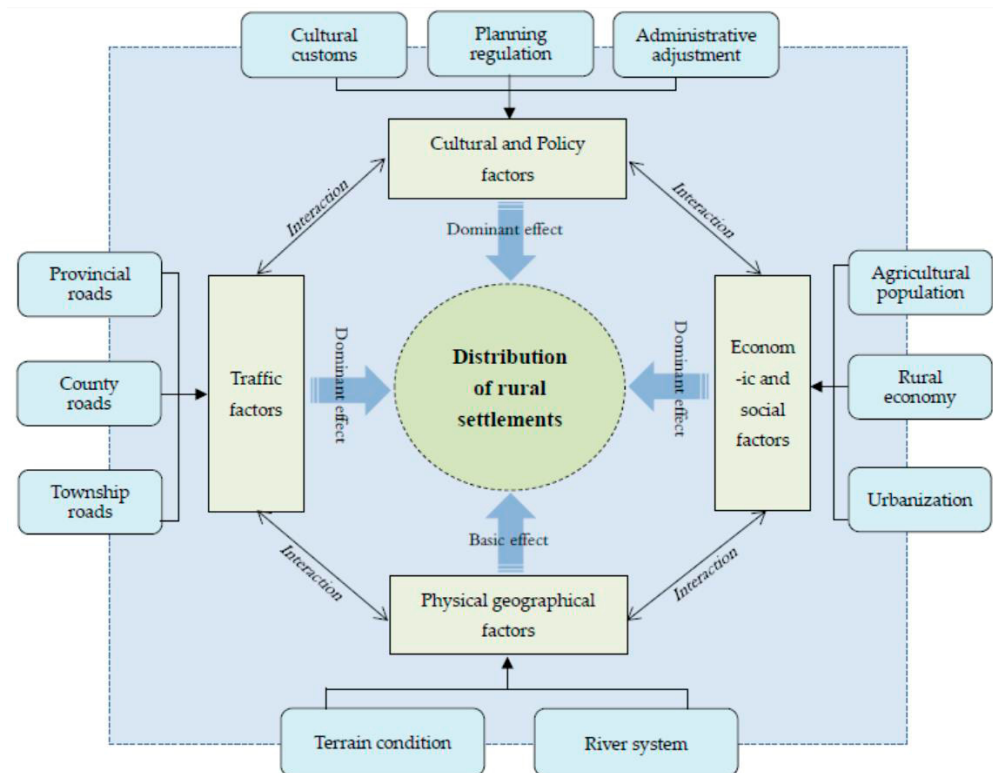


Figure 9. Impact mechanism of rural settlement distribution in the metropolitan fringe area.

4. Discussion

(1) Rural settlement is the evolution of the long-term integration of human and nature. Rural settlement is a complex system involving social, economic, ecological, resource and other factors. The distribution of rural settlements is characterized by regional differences. At present, the academic community has carried out research on the distribution law of rural settlements in different regions. Tang [67], Guo [68], Ma [69] and others have focused on the distribution law of rural settlements in northwest China. They have selected Yulin City in Shaanxi Province, Qin'an County in Gansu Province, Tongwei County in Gansu Province, such as case to carry out empirical research. They found that rural settlements in northwest China presented a small-scale decentralized distribution pattern; the natural geographical environment (elevation, slope, river, farmland, etc.) had a decisive impact on the distribution of rural settlements in northwest China, and the change of natural environment directly affected the distribution of rural settlements.

By comparison, this paper chose the rural settlements in the metropolitan fringe area as the research object. Through the empirical analysis of Nanjing, it was found that the distribution of rural settlements in the metropolitan fringe area presented a large-scale agglomeration distribution pattern, which was mainly affected by economic and social development factors, while the natural environment factors had less impact on the distribution of rural settlements. This conclusion was quite different from the distribution law of rural settlements in northwest China. This difference was mainly attributed to the fact that the metropolitan fringe area was a transitional zone between cities and villages. The rural settlements in the metropolitan fringe area were a concentrated reflection of the human-land relationship, with significant characteristics of rapid economic development and urbanization. Under this influence, the rural settlements in the metropolitan fringe area were facing or experiencing dramatic spatial evolution and modern transformation, and their spatial distribution and evolution patterns were different from those of the rural settlements in other regions.

(2) The spatial distribution of settlements can be used as a basis to show the comprehensive relationship between human activities and the natural environment in a region

and has reference value for the optimization of the spatial pattern of settlements. Based on the analysis of the distribution characteristics and influencing factors of rural settlements, combined with the field research in this typical region, the optimization of the layout of rural settlements in the metropolitan fringe area was attempted to be divided into four types: urban transformation type, key development type, limited development type, and relocation type [70–72].

- **Urban transformation type.** This type refers to the rural settlements distributed at the edge of the county seat and the central town and near the main traffic arteries. Suggestions for optimizing layout: bring rural residential areas close to built-up areas or central towns into the urban planning system, actively guide the transformation of rural residential areas into urban residential areas, increase the construction of transportation and other infrastructure, emphasize the functional zoning of internal land, and form an all-round and multi-level land use pattern.
- **Key development type.** This model mainly refers to the rural settlements which are far away from the urban center, large scale, transportation location and good level of economic development. Suggestions for optimizing layout: the rural residential areas with small scale and poor conditions in towns and townships should be relocated to the central village nearby, focusing on the construction of the central village within the city scope; and improve the basic and public service facilities of central village, based on the resource advantages of central village, develop and expand the characteristic industries, attract the surrounding small natural villages to gather in the central village.
- **Limited development type.** On the premise of the stability of the original spatial pattern of rural residential areas, this type of rural residential areas should be rebuilt and reasonably developed. Through promoting the renovation and construction of rural residential areas, the potential of the village's internal land use should be fully exploited, and the village, especially the hollow village, should effectively "lose weight" to improve the intensive use of rural residential land in hilly areas.
- **Relocation type.** This type of rural residential area is mostly located in areas with poor suitability level of urban residential areas, with shortage of cultivated land resources, inconvenient transportation and more villagers going out to work. Suggestions for optimizing layout: gradually move to another place by taking multiple approaches such as urban resettlement, central village resettlement, small villages merging into large villages and building independent new villages.

5. Conclusions

This paper took the rural settlements in the metropolitan fringe area as the research object, taking Nanjing as a typical case. From three aspects of spatial distribution, scale distribution and form distribution, this paper analyzed the distribution characteristics of rural settlements in the metropolitan fringe area. On this basis, this paper tried to reveal the influencing factors in the distribution of rural settlements in the metropolitan fringe area. The following conclusions were drawn:

(1) The spatial distribution of rural settlements was significant in the metropolitan fringe area, it showed the characteristics of "agglomeration" spatial pattern. The spatial distribution of rural settlements generally presented a "multi-core" center, and a spatial distribution trend of stepwise declined from the core to the periphery, showing a typical "core-edge" structure. The core of rural settlements in the metropolitan fringe was mainly distributed in the agricultural counties in the outer suburbs, while the surrounding villages in the main urban area were radiated by the city, and the population was urbanized locally. Rural settlements gradually evolved into urban settlements, resulting in less spatial distribution of rural settlements.

(2) There were significant differences in the scale distribution of rural settlements in the metropolitan fringe area, showing that the scale of rural settlements gradually decreased with the increase in the distance from the central city. The overall distribution pattern was that the scale of rural settlements in the near suburbs was large, the scale of rural

settlements in the outer suburbs was moderate, and the scale of rural settlements in remote areas was small. The closer the rural settlement was to the built-up area, the more affected by human activities and policy factors, the easier it was to form a large-scale rural settlement distribution.

(3) The morphological distribution of rural settlements had good stability in the metropolitan fringe area, and the spatial self-organization of the distribution of rural settlements was strong, which showed that structural factors (topography, geomorphology and other geographical environmental factors) and random factors (economic development, policy system, etc.) jointly played a role in the differentiation of rural settlements in the metropolitan fringe area. The morphology of rural settlements mainly included strip, arc belt, cluster, scatter types, the formation of different settlement types was closely related to the natural geographical environment, historical and cultural factors.

(4) The distribution of rural settlements in the metropolitan fringe area was mainly affected by topography, river system, traffic, economic development, cultural and policy. Among them, the distribution of rural settlements had the location orientation of “low altitude, close to river and close to road”, and the natural geographical environment has laid the foundation for the distribution pattern of rural settlements in the metropolitan fringe area. The increase in agricultural population and the development of rural economy played a leading role in the distribution of rural settlements in the metropolitan fringe area; the cultural and policy factors played an important guiding role in the distribution and reconstruction of rural settlements in the metropolitan fringe area.

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