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Multi-scale analysis on spatial morphology differentiation and formation mechanism of rural residential land: A case study in Shandong Province, China

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ABSTRACT

Using the GIS space "hot spot" detection and kernel density estimation model, the spatial differentiation characteristics of rural residential land in Shandong Province are revealed from the perspective of multi-scale feature units of "point-line-surface". Then, a geographical detector is used to analyze its factors and mechanisms. Results show that on the domain-wide scale, the rural residential land has obvious characteristics of spatial agglomeration that are sparsely distributed in a ladder from west to east; on the transect scale, the scale and distribution density of rural residential land present a multi-peak distribution, while the plaque shapes are stochastic equilibrium. On the point scale, the rural residential monomer takes on the feature of banded and serrated diversification. The differentiation is the result of scale difference of different influencing factors. Natural geographical conditions are influencing factors of multi-scale stability, especially in macro scale, which plays a comprehensive role in controlling the formation and changes. The characteristics of rural residential land in meso scale are mainly formed under the influence of dynamic equilibrium of economic and social conditions, the periodic change of institutional policy environment has a profound influence on micro-scale rural residential from rigid constraints and timeliness.

1. Introduction

Rural residential land is the direct manifestation of man-land relationship in rural areas, which also has macro-control function on the regional rural development model (Jin, 1988; Wang, Wang, & Li, 2002). The spatial differentiation and revolution of the scale, structure, layout and other forms of rural residential land can reveal the footprint of the man-land relationship in different areas and different stages (Jiang, He, & Qu, 2016; Ma, Li, & Shen, 2012), while the multi-scale differentiation of spatial morphology is the embodiment of the comprehensive effect from macro environment to micro factors. The systematic study of rural residential spatial morphology, especially from the spatial and perspective of multi-scale, is of great importance to grasp the evolution law and formulate differentiated policies, as well as a vital developing aspect and research area of international rural geography (Cai, Lu, & Zhou, 2004; Woods, 2007).

Influenced by such factors as the natural environment, socio-economic development, and cultural customs, the spatial morphology of rural residential land has obvious regional heterogeneity. Adhering to local conditions and renewal planning are basic principles for analyzing the layout of rural residential land in China (Jiang, Wang, & Yun, 2015), whereas the scientific characterization and multi-scale feature recognition of the spatial morphology of rural residential land are scientific bases for exploring the formation process, evolution laws and regulatory modes (Zhang, Jiang, & Wang, 2015). In the current research, rural residential land is brought into a research framework composed of rural development, rural community planning and construction (Curran, Cain, & Greenhalgh, 2016; Bjarstig and Sandstrom, 2017). Based on the spatial morphology and distribution of rural residential land, it focuses on the flow of population, industry transformation, the constructions of public service facilities and social problems, showing an obvious trend of paradigmatic humanistic society (Sobczyk, 2014; Hedlund and Lundholm, 2015; Pacione, 2013; Cremer, Dominik, & Jean, 2015). Some scholars have paid more attention to material studies of rural residential land, mainly in the spatial structure (Yang, Hao, & Wang, 2011; Min and Yang, 2016), the areal type of rural

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residential land (Ma et al., 2012; Zhang et al., 2015), the revolution of scales under the influence of rapid urbanization (Feng & Yang, 2016), and the "hollowing out" of governance under the drive of new rural construction (Jiang, Ma, & Wang, 2017; Liu, Liu, & Zhai, 2009; Lu & Liu, 2013). These studies show that academia has focused on rural residential land as it becomes gradually mature, which provides abundant theoretical guidance for this research as well.

However, regarding the research methodology, the traditional spatial morphology of rural residential land is qualitatively summarized and described based on singular information, such as the scale and morphology (Yang, Pang, & Song, 2010; Yin & Chen, 1995). Making the best use of GIS spatial analysis, only a few researchers have described its scale, morphology and spatial agglomeration (Jiang, Ma, & Zhou, 2017; Liang, Liu, & Liu, 2017; Zhuang, Jiang, & He, 2015); thus, the development and application of quantitative studies need to be strengthened. In addition, from the perspective of research region and scale, there have been many empirical studies in China, such as along the Yangtze river (Min and Yang, 2016; Long and Li, 2005; Chen & Jin, 2015), Jiangnan region (Chen & Xie, 2016; Li et al., 2014), capital suburb region (Ma, Jiang, & Wang, 2017; Zhang et al., 2015; Zhuang et al., 2015; Zhu, Zhang, & Li, 2014), central region(He et al., 2013; Hai, Li, & Xu, 2013), loess hilly region(Guo, Ma, & Zhang, 2013; Xie, Zhao, & Jiang, 2014), most of which have focused on the spatial division of rural residential land on a large scale; few focus on the mesoscopic or micro scale, especially lack of comparative study on the spatial morphology mechanism characteristics and formation mechanism on different scales. Hence, it is not easy to explore the essential characteristics and regional laws of the multidimensional spatial morphology of rural residential land, and not conducive to analyze the regulation mode and technical specification in different regional environments, leading to the homoplasy of planning and system on different scales. Study on the morphological difference of rural residential land from domain-wide scale, transect scale to point scale can fully reveal the morphological differentiation characteristics, and can also identify the difference and hierarchy of different influencing factors on different scales, which will provide a basis for formulating targeted and multi-scale regulation policies of rural residential land.

Since the reform and opening up, Shandong province has experienced rapid industrialization and urbanization, and gradually formed a pattern with a stable primary production, a dominate second production, and accelerated development of tertiary industry. In 2016, the ratio of output value of three industries in Shandong was 7.3: 45.4: 47.3, close to that of national for the same period (8.4: 44.4: 47.2). In addition, the regional differences of economic development in Shandong Province are significant, including economically developed area in Jiaodong Peninsula, moderated developed area in central Shandong, and economically underdeveloped area in western Shandong, similar to the pattern of economic development in China. Therefore, in a sense, Shandong Province can be seen as a microcosm of China's economic and social development pattern (Qu, Jiang, & Zhao, 2017).

Under the condition of stable economic development and regional differences, Shandong Province is extremely representative because of active changes and diversified spatial morphology of rural residential land. Thus, using exploratory spatial data (ESDA) technology and basic theories of geographical spatial studies, from the perspective of the multi-scale of "point-line-surface", this paper quantitatively deconstructs the differential characteristics of multidimensional spatial morphology of rural residential land in Shandong Province, and thoroughly analyzes its formation mechanism, which will provide a scientific basis for the regional classification and optimal regulation of regional rural residential land.

2. Methods

Rural residential land has large patches and small patches in space, showing the characteristic of scale; while the permutation and combination among different patches in some kind of order makes rural residential land have different morphological characteristics, presented as the complexity of patch boundaries and its agglomeration or discreteness (Zhang et al., 2015).

Since the development and application of landscape pattern software (FRAGSTATS), there have been many indicators to measure the patch boundary and spatial distribution of rural residential land. Due to the high degree of correlation among these indicators, many indicators do not meet the requirements of mutually independent statistical properties (Qi, Qu, & Liu, 2009; Riitters, 1995). Ideally, a group of independent but not redundant morphological measure index system should be used. Therefore, based on the data obtained from remote-sensing image interpretation of rural residential land patches, this passage uses principle components to screen a presentative morphological measure index system. Furthermore, in order to disclosure the internal mechanism and spatial differentiation of its spatial morphology in depth, this paper considers the differences of natural environment and social economic development among eastern, western, central, coastal and inland Shandong, and investigates the characteristics of the spatial morphology from the perspective of " point-line-surface" multi-scale feature unit.

The "surface" unit, namely the domain-wide area of Shandong Province: the research mainly uses "hot spots" detection in GIS space and the nuclear density estimation algorithm to reveal the regional differentiation of the spatial morphology of rural residential land in Shandong Province. Based on the analysis of the belt transect method and Geostatistics trend method (Egenhofer M J, 1998), together with the standard of the International Geosphere-Biosphere Programme (IGBP) (Long, 2012), the "line" unit refers to 5 typical transects, located respectively in eastern, central, western, southern and northern Shandong (as shown in Fig. 1, Table 1). The research projects spatial morphology indexes of rural residential land on the orthogonal plane of the East-West and North-West directions, so the spatial morphology characteristics in different directions can be depicted by the optimal fitting curve made with projection points. The "point" units are based on the analysis of the domain-wide area and transect: to analyze the spatial differentiation characteristics from the microcosmic perspective of patches, using type divisions of spatial morphology of rural residential land, we select several sample points in each type of region. Finally, with the aid of geographical detectors, this paper discusses the influencing factors and formation mechanisms of the spatial morphology differentiation of rural residential land in detail.

2.1. Data acquisition and processing

To extract patches of rural residential land in Shandong Province,

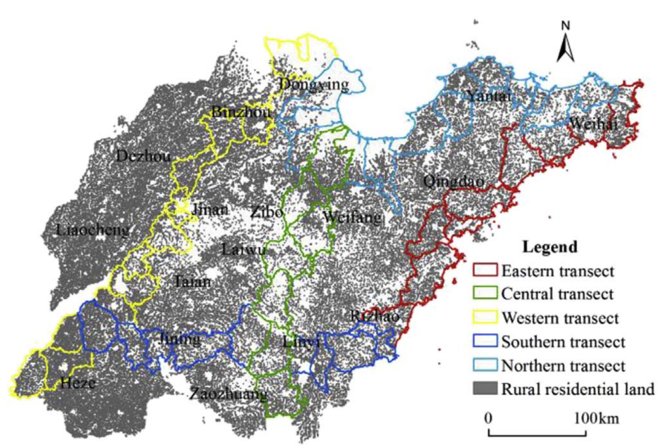


Fig. 1. Distribution of rural residential land and transects in Shandong Province.

Table 1
The basic condition of 5 typical transects.

Transects	Transect length (length*width)/km	Rural residential land in transect/km^2	The proportion of rural residential land in the whole province/%	Regional characteristics of transect
Eastern transect	386.67*72.42	82316.80	6.44	Eastern part of the Yellow Sea hills. Economically developed area
Central transect	321.77*78.02	64487.63	5.05	Transition zone from central mountain to piedmont plain. Economically underdeveloped area
Southern transect	339.42*79.58	107241.63	8.39	The southern Huaihai Plain. Economically moderately developed area
Western transect	505.54*65.28	164701.55	12.89	The plain belt along the Yellow River in the West. Economically backward area
Northern transect	364.78*83.59	106269.64	8.31	The plain area of the Yellow River Delta in the North. Comparatively Developed area

this paper chooses LANDSAT TM satellite remote-sensing images taken in 2013 and 2014 (multi-spectral, 30-m spatial resolution including a panchromatic band with 15-m spatial resolution), which is further processed by geometric rectification, coordinate registration, interpretation and vectorization processing based on the ENVI software. Then, on the basis of 1:50000 topographic map, 56198 patches of rural residential land in Shandong Province are extracted. Moreover, referring to the results of the land-use change survey of Shandong in 2015, the patch area, perimeter, and administrative unit of rural residential land are supplemented. The data of main rivers, coastlines, highways and others are obtained from National Fundamental Geographic Information System (NFGIS) and *Atlas of Shandong Province (Atlas of Chinese province)*; terrain data of Shandong Province is taken from the DEM data; the economic and social data used in the research are obtained from *Statistical Yearbook of Shandong Province in 2015*. Above all, using the operation platform of ArcGIS 10.2, this paper establishes the database of rural residential land in Shandong Province, which includes two scales: the map spot and administrative unit at county level.

2.2. Measuring spatial morphology differentiation of rural residential land

The patches of rural residential land are characterized by individual differentiation and group relationships. Among them, the class area of the rural residential land patch (TA) and the fractionator reflux analog computer (FRAC) are used to reflect individual attributes of each patch, which can be calculated by FRAGSTATS software directly (Wu, 2016), and the method of GIS space "hot spot" detection (Hotspot Analysis - Getis-Ord Gi*) is used to reveal spatial differentiation. Additionally, the patch density of rural residential land reflects the relationship between multiple patches, which requires a fixed cell as data carrier. Since the results of the measurement based on county area, compared with grid cell, are often rough, selected 1 km × 1 km grid cell as basic unit, this paper uses the kernel density estimation to analyze the distribution density of rural residential land.

(1) The "hot spots" in space detection analysis

The "hot spots" in space detection analysis includes the cluster test in general space (Getis-Ord General G) and the cluster test in local space (Getis-Ord General G). The former is used to test whether it is a high-value agglomeration or law-value agglomeration of the general space variable; the latter is used to reveal the distribution of "hot spots" and "cold spots" in space, respectively, corresponding to the high-value agglomeration and low-value agglomeration. The formula is as follows.

$$G(d) = \sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}(d)x_i x_j / \sum_{i=1}^{n}\sum_{j=1}^{n} x_i x_j \quad (1)$$

$$Z(G) = (G - E(G))/\sqrt{\mathrm{var}(G)} \quad (2)$$

where *G (d)* is the test coefficient of general spatial agglomeration, defined by the distance range *d*; w_{ij} *(d)* is the spatial weight defined by distance; x_i and x_j are the observation value of region *i* and region *j*, respectively; *Z (G)* is the normalization of *G (d)*; and *E (G)* and *vra (G)* are the expected value and variance of *G (d)*. *Z (G)* is used to determine whether *G (d)* satisfies a special significant value, and whether there is a positive or negative spatial correlation. When *G (d)* is positive and the statistical significance of *Z (G)* is significant, a high-value cluster exists. When *G (d)* is negative and the statistical significance of *Z (G)* is significant, a low-value cluster exists.

$$G^*(d) = \sum_{j=1}^{n} w_{ij}(d)x_j / \sum_{j=1}^{n} x_j \quad (3)$$

$$Z(G_i^*) = (G_i^* - E(G_i^*))/\sqrt{\mathrm{var}(G_i^*)} \quad (4)$$

Each parameter in the formulas is the same as in Formula (1) and Formula (2). If $Z(G_i^*)$ is positive and statistically significant, the values around region *i* are high, suggesting that region *i* belongs to a "hot spot" of a high-value cluster; if $Z(G_i^*)$ is negative and statistically significant, the values around region *i* are low and region *i* belongs to a "hot spot" of a low-value cluster.

(2) Kernel density estimation

Kernel density estimation is a nonparametric density statistical method based on the distribution characteristics of the object itself. A smooth round surface is established at each point in study region. Then, through a mathematical function, the distance between the point and the reference position is calculated, and all the surfaces of the reference position are summed. Subsequently, a smooth and continuous surface of the peak value of these points is obtained (Ma et al., 2012), which intuitively represents the distribution probability of the subject. The nuclear density value represents the degree of concentration of the study object in spatial distribution. The formula is as follows.

$$f(x, y) = \frac{1}{nh^2}\sum_{i=1}^{n} k\left(\frac{d_i}{n}\right) \quad (5)$$

Where *f(x, y)* is the estimated density at position *(x, y)*; *n* is the value of observation; *h* is the parameter of bandwidth or smoothing; *k* represents the kernel function; and d_i is the distance from spatial position *(x, y)* to the observation position *i*.

2.3. Measuring indexes of spatial morphology

We adopt thirteen indexes to reflect the area, shape and distribution of patches: the class area of rural residential land patch (TA), largest patch index (LPI), number of patches (NP), mean landscape area (AREA-MN), patch size standard deviation (PSSD), shape index (SHAPE), fractionator reflux analog computer (FRAC), landscape shape index (LSI), perimeter-area ratio shape index (PARA), patch density

Table 2
Total variance explained.

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	5.865	45.118	45.118	5.865	45.118	45.118	3.944	30.341	30.341
2	3.652	28.093	73.210	3.652	28.093	73.210	3.893	29.948	60.289
3	1.843	14.178	87.388	1.843	14.178	87.388	3.523	27.099	87.388
4	0.793	6.101	93.489						
5	0.556	4.278	97.767						
6	0.124	0.955	98.722						
7	0.075	0.573	99.295						
8	0.050	0.383	99.678						
9	0.020	0.150	99.829						
10	0.013	0.098	99.926						
11	0.007	0.056	99.983						
12	0.001	0.011	99.994						
13	0.001	0.006	100.000						

Table 3
Rotated component matrix.

Indexes	Component		
	1	2	3
TA	0.936	-0.035	-0.234
NP	0.897	-0.349	-0.161
LPI	0.865	-0.403	-0.150
PSSD	0.853	-0.384	-0.218
ANN	-0.689	-0.204	0.041
PD	0.040	-0.972	0.026
AREA_MN	-0.089	0.959	0.028
COHESION	-0.323	0.855	0.211
AI	-0.153	0.836	-0.402
FRAC_MN	-0.073	-0.144	0.914
LSI	0.068	0.193	0.908
PARA_MN	-0.291	0.116	0.875
SHAPE_MN	-0.283	0.233	0.859

(PD), average nearest-neighbor index (ANN), cohesion index (COHESION), and aggregation index (AI). From a correlation analysis via software SPSS, the significantly correlation and information redundancy exist between multiple indexes. Then, the principal component analysis is used to reduce the data dimensionality. Through converting the original variable data to eliminate the overlap of numerous information, and using a few new variables to represent the original variable data structure, we find a KMO inspection of 0.709 and concomitant probability of Brelett Sphericity test of 0.000 (less than the significant level 0.05, suitable for factor analysis). According to principle that the eigenvalues must be greater than 1, three principle variables are extracted (Table 1, Table 2). TA, NP, LPI, PSSD, and ANN have higher loads in the first principle component, reflecting the scale information of rural residential land; PD, AREA-MN, COHESION, and AI have higher loads in the second principle component, indicating agglomeration information of rural residential land; FRAC-MN, LSI, PARA-MN, and SHAPE-MN have higher loads in the third principle component, reflecting the shape information of rural residential land. Therefore, according to the principle of independence and simplification, the maximum load factor TA, FRAC-MN and PD are selected as the representative indexes of the spatial morphology of rural residential land (Table 3).

2.4. The mechanism method of geographical detector

The geographical detector was first used to explore the influencing factors of endemic diseases. By studying the distribution of the incidence of some diseases in different geological space, the dominant factor of the disease was determined (Wang et al., 2010). Recently, some scholars have applied this idea and measurement method to study the formation mechanism of county area urbanization (Liu & Yang, 2012); changes of multiple-crop index of cultivated land (Yang et al., 2013); and changes in urban-rural construction land use (Cai & Pu, 2014), which gives this study profound enlightenment. On the basis of existing research, the natural background is the foundation of the formation and development of the spatial pattern of rural residential land; the level of economic development is the inherent power of spatial differentiation; the improvement of social living condition is the external inducement factor; while the change of macro policy system is an important inducing factor leading to the change of spatial form and quantity scale. In view of this, through the rational selection of influencing factors, this study explores the geological detection mechanism of spatial differentiation of rural residential land from 4 aspects (Table 4): natural background conditions, economic development level, social living conditions and policy systems.

$$P_{D,U} = 1 - \frac{1}{n\sigma_U^2}\sum_{i=1}^{m} n_{D,i}\sigma_{U_{D,i}}^2 \tag{6}$$

where $P_{D,U}$ is the detection index of the influencing factors of spatial differentiation; $n_{D,i}$ is the number of samples in the sub region; n is the number of samples in the whole region; m is the number of the sub region; σ_U^2 is the variance of the spatial morphology variable of rural residential land in the whole area; $\sigma_{U_{D,i}}^2$ is the variance of the sub region. Adopting the natural breakpoint clustering method for each influencing factor in ArcGIS, the sub region is divided into three grades in the domain-wide scale. If $\sigma_{U_{D,i}}^2 \neq 0$, the model is established and the range of $P_{D,\ U}$ is [0,1]. When $P_{D,\ U} = 0$, it is suggested that some factors have no explanatory power for the spatial morphology differentiation of rural residential land; the greater the value of $P_{D,\ U}$, the greater influence the factor has.

3. Results and analysis

3.1. Differentiation characteristics of rural residential land at domain-wide scale

(1) Scale of rural residential land

According to the frequency distribution of the scale of rural residential land in Shandong Province (Fig. 2), the frequency has a skewed distribution, with the data deviating from centrality, and the distribution is also lack of symmetry. The skewness is 5.21, far greater than 0, but the mid-value is smaller than the mean value, indicating that there is a large low-value cluster distribution and high-value discrete distribution of the scale of rural residential land in Shandong Province. The kurtosis is 5.21, far greater than 3, showing that there is a

Table 4
The influencing factors selecting.

Category	Influencing factors	Remark
Natural background condition	F_1 Elevation	Reflecting topographic condition
	F_2 Distance along river	Reflecting water resources condition
	F_3 Distance to downtown	Reflecting geographical position
	F_4 Distance along the coastline	Reflecting geographical position
	F_5 Mileage of rural road	The degree of development of external traffic
	F_6 Distance from roads above county level	The degree of development of external traffic
Level of economic development	F_7 GDP per capital	The ratio of regional GDP to resident population. An effective tool to grasp the macroeconomic operation of a region.
	F_8 Non-agricultural industry rate	The ratio of the population engaged in secondary and tertiary industries to the total population, reflecting the regional employment structure.
	F_9 Fixed asset investment	Reflecting the scale, speed, proportion and direction of investment in fixed assets
	F_{10} Per capital income of farmers	Reflecting the average income level of rural residents in a region
Social living condition	F_{11} Per capital cultivated area	The number of cultivated land per capita in a region, reflecting the status of cultivated land resource.
	F_{12} Per capital yield	The average grain yield per person in a region, reflecting the level of grain production
	F_{13} Urbanization rate	The proportion of the urban resident population in a region to the total resident population, reflecting the process of urbanization
	F_{14} Population density	The number of people living on the land per unit area, indicating the population density and population structure.
Institution and policy	F_{15} The scale control index of rural residential land in 2020 in overall land use planning	Quantitative control of rural residential lands from scale and space based on land-use planning (2006–2020).
	F_{16} The scale of rural and urban construction land increase and decrease in the hook until 2015	Rational optimization of rural residential land from the structure and direction of land use based on land-use planning (2006–2020).

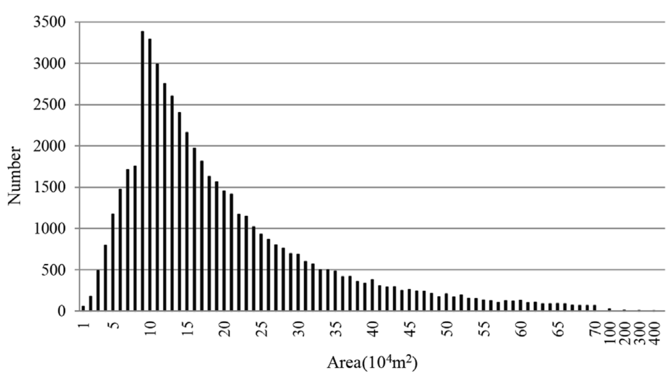


Fig. 2. Frequency distribution of scale of rural residential land in Shandong Province.

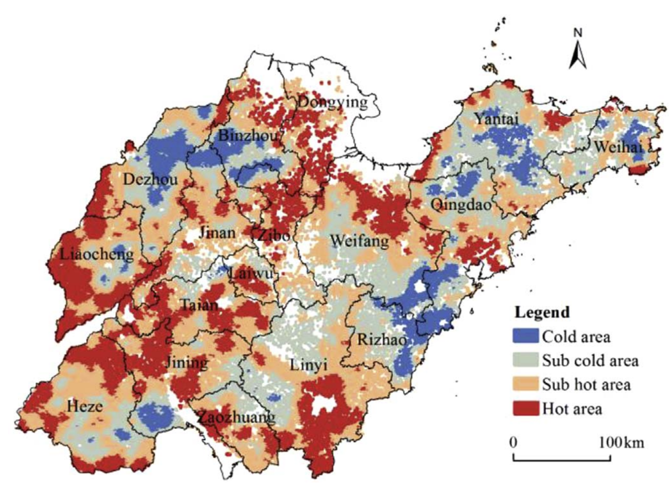


Fig. 3. Hot spot mapping for scale of rural residential land in Shandong Province.

wide distribution of a “fat tail” as well as a narrow distribution of a “spire”. It is clear that the scale of rural residential land in Shandong Province is generally low. The number of small-scale rural residential land is large, while the number of large-scale is small.

According to the estimation of General G for the scale of rural residential land in Shandong Province (Table 5), we find the *G(d)* is lower than *E(d)* (−21.4525), indicating that the possibility the low-value clustering model of rural residential land in Shandong Province is generated by a stochastic process is no more than 1%. That is, the scale distribution of rural residential land in Shandong Province exhibits significant spatial clustering and presents a small amount of village agglomeration.

In terms of the hot spot mapping for the scale of rural residential land in Shandong Province (Fig. 3), the scale of rural residential land in western and southern Shandong is large, while the scale is smaller in eastern, central and northern parts of Shandong. The spatial distribution of rural residential land scale shows a “dumbbell-like” structure. Specifically, there is a “hot spots” of large-scale concentrated distribution of rural residential land, including Liaocheng, Jining, and Heze city in western Shandong; Tai'an, Laiwu, and Zibo city in central Shandong; Dongying and Weifang in eastern Shandong, and occasionally a sparse distribution of “hot spots” in east coast of Shandong. In most parts of the Jiaodong Peninsula, Binzhou and Dezhou city in northwestern Shandong, as well as the west bank of the Weishan Lake in the southwest and the central section of Liaocheng, there is a “cold spots” of small-scale concentrated distribution. In addition, the secondary high-value and low-value areas of rural residential land scale are distributed mainly in the form of diffusion, around the periphery of the low-value and high-value areas of rural residential land scale. In sum, the low value of rural residential land scale is mostly distributed in the plain area in western, southern and northern Shandong; the high value of rural residential land scale is more distributed in the hilly area in the Jiaodong Peninsula and the mountainous area in central southern Shandong.

Table 5
Estimation of General G for the scale of rural residential land in Shandong Province.

Name	*G(d)*	*E(d)*	*Z(d)*	*P(d)*
Value	0.000001	0.00001	−21.4525	0.000000

(2) The shape of rural residential land patches

Displayed by the FRAGSTATS software (Fig. 4), the fractal

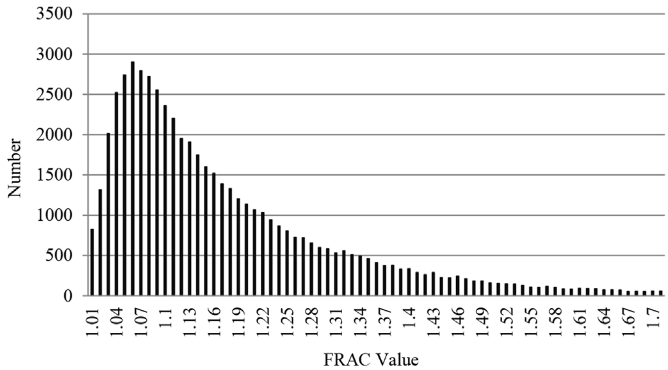


Fig. 4. Frequency distribution of the FRAC value of rural residential land in Shandong Province.

dimension of rural residential land patches is between 1.01 and 1.76, with a mean value of 1.16 and a coefficient of standard deviation of 21.45%. It can be concluded that there are significant differences between the shapes of rural residential land patches.

The distribution frequency of the fractal dimension shows a skewed distribution, with a skewness of 6.29, far greater than 0, and the mid-value is less than the mean. Moreover, the fractal dimension of rural residential land tends to be law-value agglomeration and high-value discrete distribution; the kurtosis is 38.76, far greater than 3, indicating that there are also characteristics of concentrated "fat-tail" distribution and agglomeration "spire" distribution. The fractal dimension of rural residential land in Shandong is low overall, and the shape of patches mainly tends to be relatively regular, except that some areas, influenced by special factors, show irregularity to some degree.

In terms of estimating the General G for FRAC value of rural residential land (Table 6), *G(d)* is lower than *E(d)*, and the value of *Z(d)* is −50.2665, thus strengthening the conclusion: the possibility that low-value clustering model of the FRAC value is generated by a stochastic process is no more than 1%. That is, the fractal dimension distribution of rural residential land in Shandong Province shows significant spatial agglomeration, and it is a village-clustering distribution with a relatively square shape.

From the "hot spots" mapping for FRAC value of rural residential land in Shandong Province (Fig. 5), we find that the FRAC values of rural residential land in the Jiaodong Peninsula and central Shandong are large, where the shape of patches tends to be complex. However, in western and northern Shandong, the FRAC values are relatively small, and the shape of patches is regular; the spatial distribution of the fractal dimension shows a "ring-shape" structure. Specifically, in Zibo, Laiwu, Tai'an, Jinan city in central Shandong, and Yantai, Weihai, Qingdao city in Jiaodong Peninsula, there forms a complex shape of "hot spots" agglomerations of rural residential land. It also occurs in Dongying, the north of Binzhou, Linyi and southern Zaozhuang. However, in Liaocheng, Dezou and Heze in western Shandong, Binzhou,Weifang in northern Shandong, a simple shape of "cold spot" agglomeration of rural residential land is formed, which also occurs in eastern Shandong, including northern Qingdao, southern Weifang and western Rizhao. In addition, the secondary high-value and secondary low-value areas of the FRAC value are also distributed in the form of diffusion, around the periphery of the low-value and high-value areas of the FRAC value. The former is distributed in the hilly area in the western Jiaodong Penisula

Table 6
Estimation of General G for the FRAC value of rural residential land in Shandong Province.

Name	*G(d)*	*E(d)*	*Z(d)*	*P(d)*
Value	0.000001	0.00001	−50.2665	0.000000

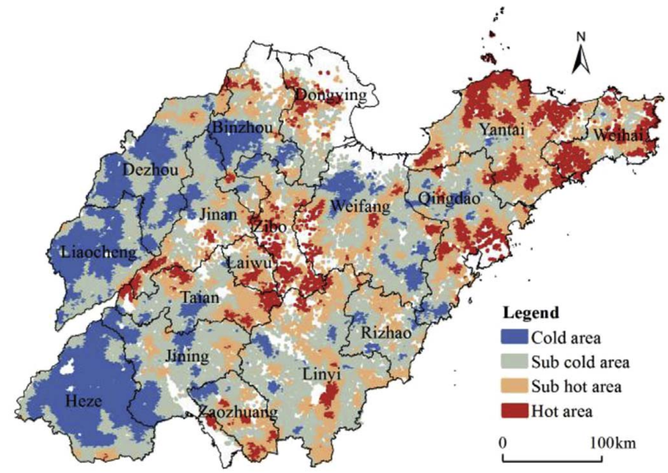


Fig. 5. Hot spots mapping for FRAC value of rural residential land in Shandong Province.

and mountainous land in central Shandong, while the latter is mostly distributed in the plain area in western, southern and northern Shandong.

(3) Distribution density of rural residential land

From the density of the distribution of rural residential land in Shandong Province (Fig. 6) (obtained by the Kernel method), the overall density of rural residential land in Shandong Province is 6.84 settlements/km^2, which belongs to the dense area of rural residential land. The result is consistent with the conclusions of Tian Guangjin (Tian, 2002) and others. Specifically, the rural residential land along the Yellow River in western Shandong has a relatively dense distribution. In the interior of Yellow River Flood Plain, there is a high-density area with an average density of 15–20 settlements/km^2; in the mountainous area in central Shandong, the Yellow River Delta in northern Shandong and the hilly area in the Jiaodong Peninsula, the rural residential land has a sparse distribution. In contrast, in the northern slope of the Taishan Mountain, Mengshan Mountain and the coast of the Yellow River estuary, the average density of rural residential land is less than 3 settlements/km^2; In the piedmont clino-plain of northern Jiaodong Peninsula, together with the transition zone from mountainous area in central Shandong to the plain area in southwestern Shandong, the distribution of rural residential land is at a medium level. Taken together, the spatial distribution of rural residential land in Shandong Province is highly correlated with the physiognomy types.

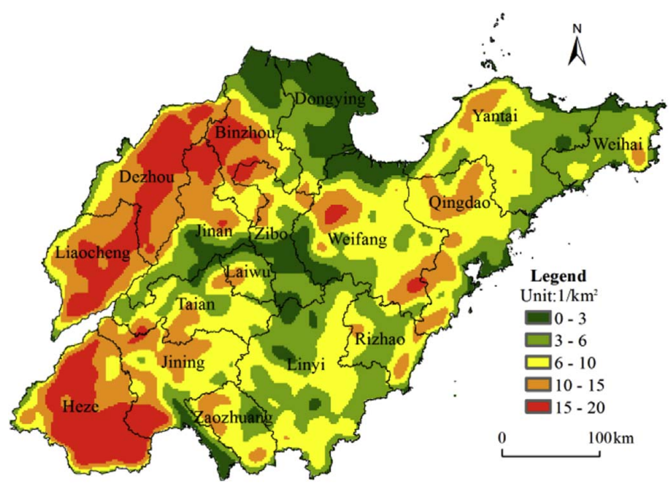
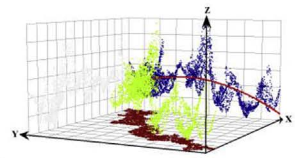
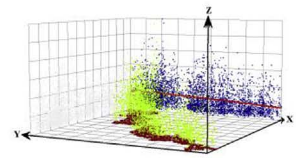
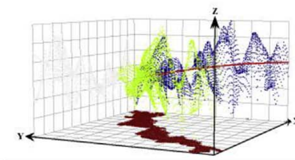
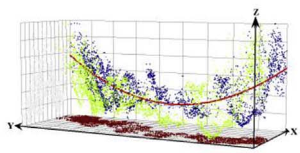
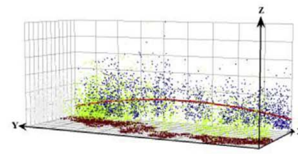
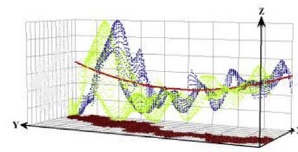
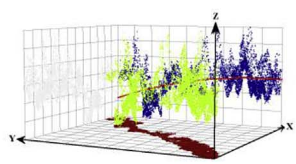
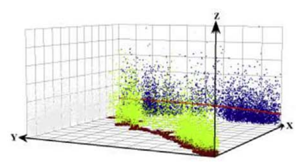
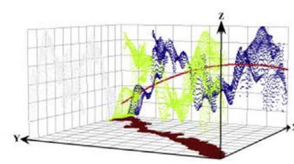
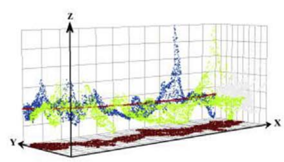
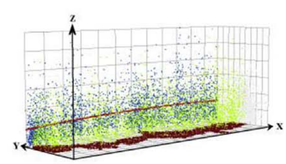
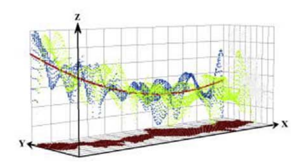
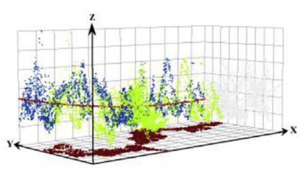
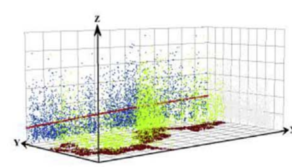
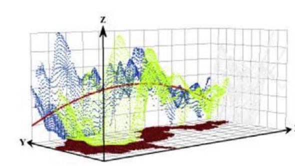


Fig. 6. Density of the distribution of rural residential land in Shandong Province.

Table 7
Charts of spatial metrics of rural residential land in transects of Shandong Province.

Types	TA	FRAC	PD
Eastern transect			
Central transect			
Western transect			
Southern transect			
Northern transect			

In addition, from the comparison of spatial distribution of rural residential land scale, patch shape and distribution density (Figs. 3, 5 and 6), the local positive and negative correlation exist simultaneously between the spatial distribution density and the distribution of land-use scale. The positive correlation is represented in the distribution of rural residential land in western Shandong, showing high-density and large-scale agglomeration, while in eastern Shandong is low-density and small-scale agglomeration. The negative correlation is represented in northwestern and southeastern Shandong, where the rural residential land shows a high-density and small-scale agglomeration, and a low-density and large-scale agglomeration in northern and central Shandong. However, there is a significantly positive correlation between the distribution density of rural residential land and the spatial distribution of the patch shape, characterized by the coexistence of high density regularization and low density complexity.

3.2. Differentiation characteristics of rural residential land at transectscale

From the charts of spatial metrics of rural residential land in transects (Table 7), the rural residential land scale in 5 transects shows a multimodal distribution, indicating that the transect distribution is complicated. In terms of the fitting curve, in the southern and northern transects, the rural residential land scale changes gradually. However, the differences lies in that the peak value of the southern transect appears in Linyi city, located in the eastern position, whereas in the northern transect, the peak value appears in Dongying city, located in the western position. As a result, there is no significant difference in patch scale in the southern transect, but it decreases slightly from west to east in the northern transect. However, the difference of rural residential land scale in the eastern, central, and western transects is significant: it decreases obviously in the eastern transect, where the peak value appears in Qingdao city but decreases rapidly to Rizhao city in southern Shandong; the scale in the western transect is just the opposite, increasing from north to south gradually until reaching its peak value; the central transect shows differential characteristic performance that the north and south ends are high and the middle is low.

From the aspect of FRAC value of rural residential land, the scattered point distribution of 5 transects is random, showing that there is an equalization of the patch shape and a gentle spatial distribution. In terms of the fitting curve, except the central transect, the other 4 transects show a flat linear change. The FRAC value in the eastern and western transects decreases slightly from north to south, and the differences lie in that the scattered points are distributed evenly in each value segment in eastern transect, but the scattered points are concentrated in the low-score region in western transect, indicating that the rural residential land in western transects is more regular. In addition, in the southern and northern transects, the FRAC value increases slightly from west to east, with an even scattered point distribution but a higher overall FRAC value, indicating that the shape of rural residential land in the two transects is complex. In the central transect, there are ups and downs of the change process from north to south, with greater complexity but fewer scattered points in the central area, in contrast to the relatively regular shape and greater number of scattered points at each end.

On the distribution density of rural residential land, the scattered point distribution shows a multimodal morphology, indicating that the distribution density tends to be complex as well. In terms of the fitting curve, in the eastern and western transects, characterized by the density increasing gradually from north to south, we find the spatial agglomeration of rural residential land enhancing in the south area. In addition, the differences between two transects lies in that in the eastern transect, the density peak appears in Qingdao city, located in central Shandong, while in the western transect it appears in Rizhao city, located in eastern Shandong. The difference means that the change intensity in western transect is higher, compared with eastern transect. In the central transect, the density of rural residential land is higher at north and south sides, and obviously low in the central area, with the peak value presented in Weifang city, located in northern Shandong. In contrast, in the southern transect, the density of rural residential land is higher at east and west sides but low in the central area, and the peak value is in Heze city, located in western Shandong. The distribution in northern transect is exactly the opposite: it is relatively scattered at both ends of the east and west. Linyi city, located in the central area, cuts through the dense distribution area of small-scale rural residential land, but the peak value of the northern transects still appears in Heze city.

3.3. Differentiation characteristics of rural residential land at spot scale

From the perspective of the distribution of domain-wide area and transects, the spatial morphology of rural residential land in Shandong Province displays apparent heterogeneity. On the three different manifestations: land-use scale, patch shape and distribution density, there are not only large-scale regional agglomeration but also small-scale local differences.

Therefore, to further clarify the regional agglomeration and local differences of spatial morphology of rural residential land in Shandong Province, this paper considers the point to reflect surface. Using the county administrative distinct as basic unit, referring to Mao Minkang's "geomorphologic regionalization map of Shandong Province" (Mao, 1993), the initial clustering results are partially adjusted, and we adopt three simplified indexes as variables to hierarchical cluster: the rural residential land scale (TA), fractal dimension (FRAC), and distribution density (PD). After the partial modification of topographic factors, the rural residential land in 137 county-level administrative units in Shandong Province is classified into 10 types (Fig. 7). Using Landsat TM, ETM + or CBERS data as major information source, high resolution (1m*1m) remote sensing image data is completed in the map system of Shandong Province (http://www.sdmap.gov.cn/) in 2016, from where the typical sample points of each type are selected for comparison (Fig. 8).

1SMB represents the small-plot, medium-density block pattern in the Jiaodong coastal, a coastal fishing village area with a relatively small population in western Shandong. Each village has its own fishing grounds. To facilitate fishing, the residential buildings are built on the highlands near fishing grounds, forming relatively concentrated, small-scale rural residential land with a block pattern structure.

2SLZ represents the small-plot, low-density zigzag pattern in the Jiaodong hills, which is primarily a low hill area. Because of the limitations of topographical conditions, the cultivated land is scattered in the center of the hillock, the area of the valley side and the valley terrace. With a small farming radius, the rural residential land is mostly scattered around the cultivated land, characterized by small-scale, scattered distribution and irregular shape.

3BMB represents the large-plot, medium-density block pattern in the Jiaolai River plain, forming from a common shock by the Jiaolai River, Dagu River and Weihe River. The low-lying area is prone to floods due to dense river network and many ponds. Therefore, the rural residential land is established in relatively high terrain, characterized by relatively large scale, concentrated living, a regular shape and dense distribution.

4BLB represents the large-plot, low-density block pattern in the northern coastal plain. It is the coastal reclamation area in northern Shandong. In the initial stage of development, the farmers built a large amount of water conservancy to prevent seawater flowing backward. In order to facilitate cultivation and management, their houses are mostly located near the cultivated land and drainage facilities, forming large-scale rural residential land with a crumbly structure, but the layout is scattered.

5SLR represents the small-plot, low-density ribbon pattern in the mountainous area in central Shandong, containing the Taishan Mountain and Mengshan Mountain. There, the soil is poor, and there are few water resources; the cultivated radius is large, and the yield is relatively low. The rural residential land mostly assumes elongated stripes, distributed in the valley area with a small size and relatively sparse distribution.

6SMB represents the small-plot, medium-density block pattern in the Wen River basin, the collection area of the water flow in the mountainous area in central Shandong. Owing to the deep soil layer, great fertility, suitable agricultural production conditions and small cultivation radius, the rural residential land is mostly built along the river and near the cultivated land. The shape is regular, the scale is small and the distribution is relatively intensive.

7SLZ represents the small-plot, low-density zigzag pattern in the Nishan hills. It is the piedmont transition zone from the mountainous land in central Shandong to the plain in southwest Shandong, and it mainly includes denudation land and hilly land. Because of abundant cultivated land resources and sparse river system, the cropping system is dry farming mostly. Influenced by the topographic conditions, the rural residential land scale is small, showing a sparse spatial distribution and an irregular zigzag shape.

8BMR represents a large-plot, medium-density ribbon pattern in Shu River plain. It is the estuarine plain in the middle and lower reaches of the Shu River, Yi River and Si River. The agricultural production is a combination of paddy fields and dry land, with a relatively large cultivation radius and intensive population. The rural residential land scale is large, shaped in wide and short bands. The distribution density is moderate.

9BHZ represents the large-plot, high-density zigzag pattern in the northwest plain, the hinterland of the Yellow River Flood Plain. The water resources are abundant and the agricultural production efficiency is high. Owing to the large rural population, large settlements scale and dense distribution, it is a high-yield area of grain and economic crops in Shandong. However, influenced by the development of rural industry, the tendency of rural residential land to expand outwards is obvious, mostly in an irregular zigzag shape.

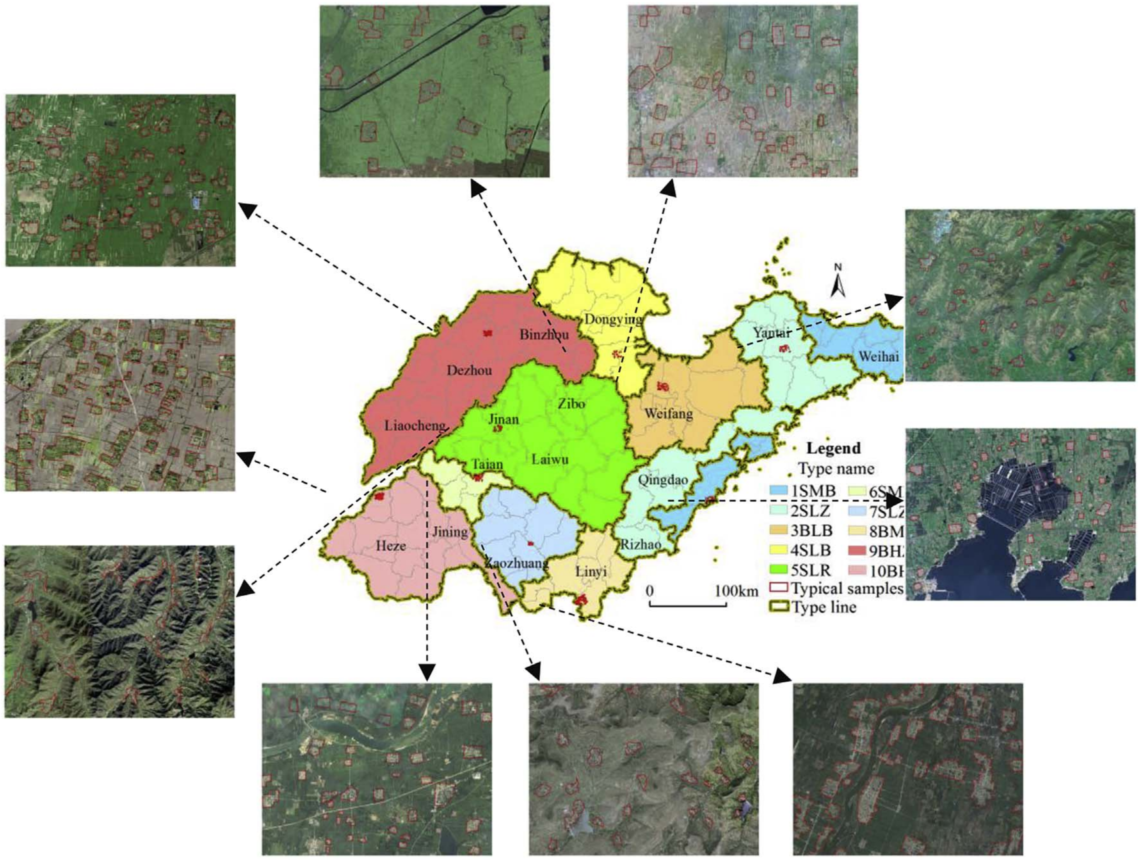
10BHB represents the large-plot, high-density block pattern in the southwest plain, the intersection of the floodplain of Yellow River and lacustrine plain in western Shandong. The river network is dense and the basis of agricultural production is relatively better, resulting in a great potential for developing diversified business. As a result of large population and living near the fields, the rural residential land scale is large, characterized by a regular shape and dense distribution.

3.4. Formation mechanism of spatial differentiation of rural residential land

(1) Screening on influencing factors

The spatial differentiation of rural residential land is influenced by many factors. According to the procedural of site selection and development, and referring to the previous research results (Feng and Yang, 2016; Li et al., 2014; He, Zeng, & Tang, 2013), this paper theoretically screens the influencing factors of spatial differentiation of rural residential land in Shandong Province.

The natural background condition mainly includes the topography, water resources, location and traffic conditions. First, the topography and water resource conditions are the most important factors of the initial location of rural residential land, so we use elevation (F_1) and



Notes : 1SMB: Small-plot medium-density block pattern in the Jiaodong coastal area; 2SLZ: Small-plot low-density zigzag pattern in the Jiaodong hlls; 3BMB: Large-plot medium-density block pattern in the Jiaolai River plain; 4BLB: Large-plot low-density block pattern in the northern coastal plain; 5SLR: Small-plot low-density ribbon pattern in the central mountains; 6SMB: Small-plot medium-density block pattern in the Wen River basin; 7SLZ: Small-plot low-density zigzag pattern in the Nishan hills; 8BMR: Large-plot medium-density ribbon pattern in the Shu River plain.

Fig. 7. Influence mechanisms of the spatial changes of rural residential land in Shandong Province.

distance along river (F_2) as influencing factors. On the location condition, the central town has a strong affection to employment and living of rural residents. As a result of the radiation of coastal economy and marine resources, the change in rural residential land in the eastern coastal is obviously faster than that in inland areas, so the distance to downtown (F_3) and distance along the coastline (F_4) are selected as location influencing factors; on the traffic condition, the road is main factor that influences the spatial distribution of rural residential land, and the development of external transportation has a direct impact on the economic prosperity of rural residential land, so we choose the mileage of rural road (F_5) and distance from roads above county level (F_6) as traffic influencing factors.

The level of economic development is related closely to productive land. On the one hand, the land, especially the construction land, bears

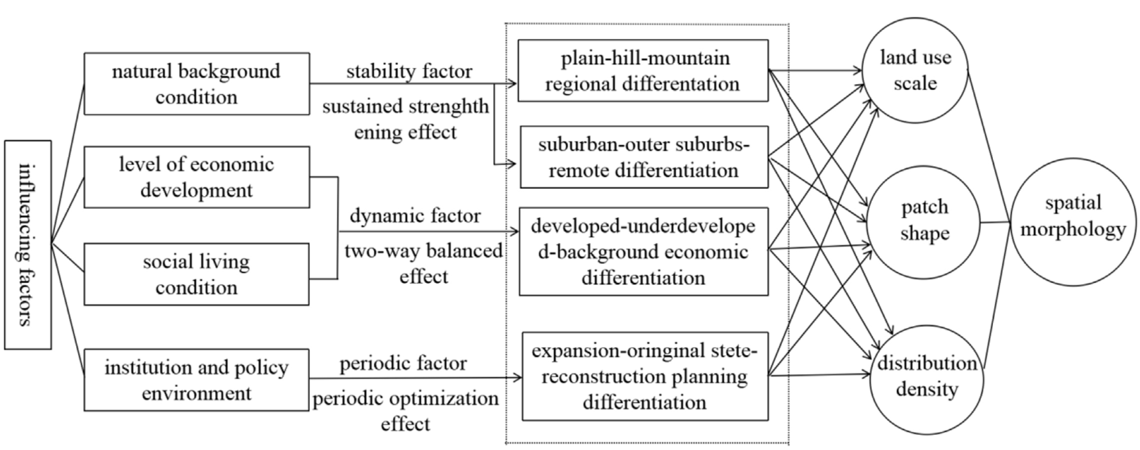


Fig. 8. Influence mechanism of the spatial changes of rural residential land in Shandong Province.

the most of the economic activities of mankind; on the other hand, the promotion of economic development has continuously encouraged the expansion of construction land. With regional economic development, farmers' demand for social services has gradually increased, which has stimulated the rapid development of non-agricultural industries and lead to the improvement of farmers' income and living conditions; in addition, improving the rural living environment is urgently required because of the economic improvement, resulting in an increase of investment in fixed assets accordingly. Therefore, we choose GDP per capital (F_7), non-agricultural industry rate (F_8), fixed asset investment (F_9) and per capital income of farmers (F_{10}) as economic influencing factors.

The social living conditions include the means of production and the population distribution. In the traditional small-scale peasant economy development environment, the site selection and evolution of rural residential land are closely related to cultivated land resources and grain production, and farmers need to solve food and clothing problems, which are the most basic issues in their lives. With the rapid development of urbanization and an accelerated growth of urban and rural population, more rural populations are moving to non-agricultural industries and towns, thus led to a change in the farmer's life and consumption conception, as well as rural residential land. Therefore, we choose per capital cultivated area (F11), per capital yield (F12), urbanization rate (F13) and population density (F14) as social influencing factors.

For the institution and policy, the government regulates and configures rural residential land directly by formulating policies such as overall land use planning, increasing or decreasing rural and urban construction land in the hook. The former emphasizes quantified control from the scale and space, whereas the latter rationally optimizes the land use structure and direction. Therefore, the scale control index of rural residential land in 2020 in overall land use planning (F_{15}) and the scale of rural and urban construction land increase and decrease in the hook until 2015 (F_{16}) are taken as policy system influencing factors.

(2) Analysis of geographical detection mechanism

From the results of the detection on the influencing factors of spatial changes of rural residential land (Table 8), it can be concluded that the influencing factors selected above have a significant effect on the differentiation of the scale, shape, and density. Among those factors, the background of natural condition has an integrated effect on the spatial morphology changes of rural residential land, as the values of F_1, F_2, F_3 and F_6 on geographical detector for scale, shape, and density are all above 0.40; the rest factors are overlapped or separated. For instance, F_{11}, F_{12}, F_{14}, F_{15} and F_{16} have significant effects on the scale and density of rural residential land, whereas F_5 has a significant effect on shape and density. F_{10} has a significant effect on the scale and shape. F_4, F_8 and F_{13} only have a significant effect on shape, and F_9 only has a significant effect on scale. F_7 has no significant effect on any indicators. It is obvious that the influencing factors of spatial morphology changes of rural residential land are complex and diverse: natural conditions play a fundamental role in maintaining the long-term stability of rural residential land, while the influence of social, economic and policy factors are relatively complex, diverse and profound.

First, the natural background conditions are influencing factors of multi-scale stability, especially in macro scale, which plays a comprehensive role in controlling the formation and changes, affecting the spatial form of rural residential land initially and directly. On the one hand, on the plain-hill-mountain terrain gradient, the plain has relatively abundant water resources, high agricultural production efficiency, and a large population. In addition, the rural residential land in plains is relatively large in scale and is mainly distributed in the shape of compact and structured blocks. In the mountainous area, there is a shortage of water, lagging development of agricultural production, a lower population and smaller rural residential land, relatively, distributed along the river valley. The moderate resources of soil and water in the hill result in a moderate population and the dominate distribution of scattered branches.

On the other hand, on the suburban-outer suburbs-remote geographical gradient, rural area in the suburbs has convenient transportation, which leads to efficient goods, materials and cultural exchanges. These conditions benefit the development of agricultural production and the concentration of the population, thus advancing the expansion of the rural residential land scale and the complexity of the shape. Rural traffic in remote areas is limited, production resources are scarce and the population is sparse. Their economic relation with the outside is weak. Therefore, the rural residential land there is small in scale and stable in shape. Overall, the natural background condition is an important factor that influences the spatial arrangement and location of rural residential land, as well as a critical role in affecting the size, scale and stability of the shape. On account of the long-term stability of regional differences and continuous influence on the shape, the natural background conditions are considered to be a stability factor, which has a continuous impact on intensifying the spatial differentiation of rural residential land.

Second, the characteristics of rural residential land in meso scale are mainly formed under the influence of dynamic equilibrium of economic and social conditions. The level of economic development and social living conditions are key factors for the spatial differentiation of rural residential land. In developed areas, with the higher level of urbanization, the non-agricultural industries in rural area have changed the scale and original form of rural residential land, which drives the collective steady economy growth and the continuous increase of village construction funds. It also gradually improves the production conditions and living environment, resulting in an increase of farmers' income and the centralization of the population. In addition, in economically underdeveloped and backward areas, using cultivated land as the main means of production, the main economic source is grain production. The relatively low level of urbanization is not conductive to the open development of urban and rural areas, which weakens farmers' way of life and production and subjective ideology. Thus rural residential land is embedded in the fields relatively neatly. Overall, regional environmental development and the level of urbanization will continue to increase, and gradually improve and promote social and living conditions, finally changing the spatial morphology of rural residential land. This paper classifies it as dynamic factors, which play a different role in the spatial morphology of rural residential land in different stages of development. That is, in the early stage, since the regional economic development is in a low-level equilibrium stage, the influence what this class of factors has on the spatial morphology of rural residential land is relatively weak; with the rapid development of

Table 8
Indicators and results of geographical detectors on the spatial changes of rural residential land in Shandong Province.

$P_{D,U}$ value	F_1	F_2	F_3	F_4	F_5	F_6	F_7	F_8	F_9	F_{10}	F_{11}	F_{12}	F_{13}	F_{14}	F_{15}	F_{16}
Land use scale	0.67	0.83	0.52	0.28	0.34	0.44	0.30	0.18	0.47	0.43	0.56	0.51	0.38	0.67	0.43	0.48
Patch shape	0.48	0.43	0.57	0.52	0.43	0.47	0.38	0.40	0.37	0.41	0.24	0.27	0.40	0.20	0.31	0.33
Distribution density	0.58	0.63	0.43	0.25	0.45	0.48	0.29	0.23	0.32	0.28	0.47	0.44	0.22	0.53	0.40	0.51

urbanization, this class of factors has changed obviously in different areas, resulting in spatial morphology differences in rural residential land, in particular, strengthening the developed-underdeveloped-background economic gradient. However, with the development of the economy, society and urbanization gradually to high levels, such an intensification of differentiation will gradually decrease, leading to new balanced development.

Finally, the periodic change of institutional policy environment has a profound influence on micro-scale rural residential from rigid constraints and timeliness. The institution and policy environment are the relatively profound factors that influence the spatial morphology of rural residential land, especially regarding to the problem of "population decrease but land increase" in recent years, which is drawing high levels of attention to the concerned government department. Such institutions as "rural and urban construction land increase and decrease in the hook", " new rural planning and construction" and "rural land use planning" came into being, playing an important role in regulating the spatial morphology of rural residential land. On the one hand, in the concentrated area where the amount of rural population outflow is large and the rural residential land has high idle capacity, we should put forward a scale control of rural residential land. Applying such measures as exploiting the potential stock of land, site reconstruction and spatial transfer, the scale reduction, regularization and layout standardization of rural residential land can be realized. On the other hand, on the basis of retaining the original form of rural residential land that possesses greater strength, formulating a scientifically red line of space development and internal land use structure not only ensures the land demand of rural economic development, but also reduces the risk of scale expansion and free disorder diffusion. The rigid constraints of system, policy and utilization regulations impact the spatial morphology of rural residential land; however, the system policy is often targeted and timely. If the scale of rural residential land is controlled in a reasonable range, the shape and layout tend to be standardized; the effectiveness of relevant systems and policies will be weakened. Therefore, this paper classifies it as periodic factor that plays a phased optimization role in the spatial morphology of rural residential land.

4. Conclusions and discussions

(1) The spatial morphology of rural residential land has multi-dimensional and significant regional differences. To eliminate the multicollinearity and redundancy between quantitative indicators that are commonly used for spatial morphology, adopting Principle Component Analysis, this paper screens out three typical indexes, patch area, fractal dimension and distribution density, from three aspects: scale, shape and spatial distribution. Using GIS "hot spot" detection and nuclear density estimation model, based on the multi-scale feature unit "point-line-surface", the regional differentiation characteristics and formation mechanism of the spatial morphology of rural residential land in Shandong Province are analyzed in depth. The study will provide a systematic framework for the theoretical and empirical research on the differentiation and characteristics of spatial morphology of rural residential land, and provides an empirical basis for formulating targeted and multi-scale regulation policies of rural residential land.

① On the domain-wide scale, the scale, shape and density of rural residential land in Shandong Province have remarkable spatial agglomeration characteristic. Specifically, the patch size of rural residential land is generally small, characterized by the distribution with a "fat tire and spire" shape: there are "hot spots" of large-scale rural residential land distribution in western, southern, and northern Shandong, together with "cold spots" of small-scale agglomeration in the Jiaodong Peninsula and northwestern Shandong. Furthermore, the fractal dimension of rural residential land patches is close to 1.0, and the distribution of the patch shape tends to be regular in space. However, the Jiaodong Peninsula and central Shandong are the "hot spots" of high-value fractal dimensions of rural residential land, where the patch shapes are more complex. In contrast, western, northern and southeastern Shandong are the "cold spots" of low-value, and the patch shapes are relatively regular. The overall density of rural residential land in Shandong Province is $6.84/km^2$, belonging to an intensive area in China. For specific performance: the rural residential land is densely distributed in the Yellow River Flood Plain in western Shandong, and sparsely stepped distributed from northern to central Shandong in turn. In sum, the overall distribution of rural residential land is highly correlated with geomorphic types.

② On the transect scale, the morphological index measures 5 transects: eastern, central, western, southern and northern. The patch scale and distribution density of rural residential land show a complex distribution of multimodal valleys, while the patch shape exhibits randomly distribution equalization. In the eastern transect, the scale and fractal dimension decrease from north to south, but the distribution density increases gradually; in the central transect, the scale and fractal dimension are low in the middle, high at both ends from north to south, while the patch shape of the middle is slightly above both ends; in the western transect, the scale and fractal dimension increase gradually from north to south, but the patch shape is on the contrary; in the southern transect, the shape and patch shape are basically the same, but the distribution density decreases significantly; and in the northern transect, the scale of rural residential land decreases slightly from west to east with a relatively stable patch shape, and the distribution density shows the characteristic of low at ends and high in the middle.

③ On the sample point scale, using the county administrative areas as basic unit, according to the hierarchical clustering of scale, density and shape of rural residential land, the rural residential land in Shandong Province is divided into ten types: respectively, a small-plot medium-density block pattern in the Jiaodong coastal; a small-plot low-density zigzag pattern in the Jiaodong hills; a large-plot medium-density block pattern in the Jiaolai River plain; a large-plot low-density block pattern in the northern coastal plain; a small-plot low-density ribbon pattern in the central mountains; a small-plot medium-density block pattern in the Wen River basin; a small-plot low-density zigzag pattern in the Nishan hills; a large-plot medium-density ribbon pattern in the Shu River plain; a large-plot high-density zigzag pattern in the northwest plain; a large-plot high-density block pattern in the southwest plain. From the geographical environment and agricultural production, this paper analyzes the development process and basic features of the rural residential land spatial morphology in different sample spot areas.

④ The spatial morphology differentiation of rural residential land in Shandong Province is the combined effect of multiple factors, including the regional natural geographical conditions, the level of economic development, social living conditions, and the system and policy environment. However, the degree, direction and effect of each factor differ. Natural geographical conditions are influencing factors of multi-scale stability, especially in macro scale, considered as a stability factor that comprehensively influences the spatial differentiation of rural residential land. Through regional gradient differences in the plain-hill-mountain and geographical gradient differences in the suburban-outer suburbs-remote area, the scale, shape and dense distribution of rural residential land have been continuously strengthened; the characteristics of rural residential land in meso scale are mainly formed under the influence of dynamic equilibrium of economic and social conditions, which belong to dynamic factors. The developed-underdeveloped-background economic gradient plays a two-way balanced role in the spatial form of rural residential land in different stages of development; the periodic change of institutional policy environment has a profound influence on micro scale rural residential form from rigid constraints and timeliness. It plays a staged optimization role in the spatial morphology from planning and management aspects, including moderate expansion, retained state and new site construction of rural residential land.

(2) The connation of spatial morphology of rural residential land is a relatively broad concept, which can be defined in a narrow sense and broad sense. The narrow sense mainly embodies the single land use attributes, such as scale, shape and layout. Taking rural residential land areas as space carriers, the broad sense can be understood as the morphological character of a complex system of human-land relations, including not only the narrow content but also the structure, function and model of the system. Since the study object of this article covers tens of thousands of rural residential land in Shandong Province, the rural statistical data on a broad level are huge and difficult to obtain in a comprehensive way. Thus, considering the consistency of the content between multi-scales of "point-line-surface", this paper studies the spatial morphology of rural residential land in a narrow sense. However, based on the complexity and systematic nature of the interaction between rural people and land, the follow-up will select more points to reflect the differences of rural areas. After getting basic data of rural population, industries, land, facilities and construction through in-depth investigations and interviews, the follow-up will develop a pedigree study on the spatial evolution of rural residential land in a broad sense, as well as a spatial optimization paradigm and regulation policies that are suitable for regional features.

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