Spatial distribution characteristics and influencing mechanism of rural settlements in mountainous areas

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Abstract: Spatial distribution of rural settlements can be one of the most important indicators for the state and mobility of rural population agglomeration. The distribution characteristics of rural settlements can greatly contribute to the rural reconstruction and revitalization in mountainous areas. In this study, an attempt was made to quantitatively and qualitatively explore the spatial distribution characteristics of rural settlements in mountainous areas, particularly by combining a research framework and case study. The results indicate that: 1) There were significant differences in the spatial distribution of rural settlements in the mountainous areas. Most of the rural settlements were located in areas with low elevation, gentle topography, low disaster risk, moderate distance from water, and close to towns and roads. Population size and livable environment dominated the development, location, and expansion of rural settlements. 2) There were random, scattered, or uniform patterns of spatial distribution for the rural settlements in high-density areas, while the rural settlements in low-density areas were clustered. The rural settlements were more likely to be concentrated in the areas with a high population density, such as the areas with the lower elevation, gentle slope, moderate distance to the water source, and low risk of geological disasters. 3) The natural, location, social and economic factors were interrelated to form the various coupling patterns in different periods, which determined the quantity and distribution of rural settlements in mountainous areas. There were the gradually weak impacts of natural factors on the spatial distribution of rural settlements, with the development of regional economy and society. Furthermore, the principal driving factors were achieved to change the spatial forms of rural settlements, including the location factors, urbanization, industrial development, traffic conditions, and government policies, such as planning factors. The differential strategies of spatial management were proposed to realize the sustainable land use and optimal distribution of rural settlements. First, it is necessary to transfer the rural settlements from the harsh natural conditions and disaster-prone areas to the better natural and geological conditions. Second, the ecological restoration needed to be performed on the rural settlements in the areas with fragile ecological environment. Third, the living, ecological and production space can be delimited rationally to guide the spatial management and layout of rural settlements, according to the local conditions. Fourth, the rural settlements far from the town center, traffic facilities, and water sources can be transformed from the spatial scattered layout into the centralized residence via the unified spatial planning and infrastructure.

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0 Introduction

World has witnessed the remarkable development of China’s economy and urbanization since the reform and opening-up. Due to the influences of urbanization, industrialization and agricultural modernization, spatial distribution of rural settlements in China is experiencing a profound transition[1-3]. As the basic economic and social units, rural settlements in rural areas reflect the complicated man-land relationship, historical background and socio-political relations[4]. However, due to the influences of natural and socio-economic factors, these relations are quietly transforming and further promoting the rural transition and development. The transitions of rural development not only involve the changes of agricultural enterprises structures, agricultural employment and agricultural productivity, but also involve the transformations of

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rural settlements and sociocultural landscape[5]. The transitions of rural development have exerted crucial influences on rural living space, rural production space, rural ecological space and social and cultural space.

Emerging countries worldwide are currently experiencing rapid industrialization and urbanization. During industrialization and urbanization, the unequal opportunities between urban and rural areas have led to the migration of farmers to urban areas[6-7]. The decrease of rural population has contributed to the low efficiency of land use for rural settlements such as vacancy and abandonment[8-9].In China, rural settlements are generally considered as settlements that provide habitation for rural residents and developmental centers for rural communities[10]. Since the 1940 s, Chinese scholars have been concern about the studies of rural settlements. In the early phase, scholars focused more on the architecture of rural settlements[11]. Since the 1980 s, the theoretical studies on rural settlements have presented the characteristics of multi-methods, multi-directions and multi-disciplines.

Spatial distribution of rural settlements plays an important role in constructing rural living space. Reasonable spatial layout of rural settlements is the premise of regional urban-rural integration development. Therefore, in 1981, scholar Wu Chuanjun believed that “4W” namely Where, When, Why, What, should be adhered and clarified in the study of the spatial pattern of rural settlements[12].Given that the researches on the spatial distribution of rural settlements in China in the past 40 years mainly focused on the characteristics of spatial distribution of rural settlements, the influencing factors of spatial distribution of rural settlements, and the optimal spatial layout of rural settlements. First, existing research on the spatial distribution characteristics of rural settlements has been constantly improved, and the study areas involve plains, hills, mountains[11]. The research objects are developed to the micro scale, and the research methods become more diversified, for example, 3S, spatial analysis technology, and landscape pattern metrics are widely used in the study[5,11]. Second, existing studies on influencing factors of spatial distribution of rural settlements mainly cover natural factors, production environment and socio-economic factors. Among them, demographic factor is believed to be the main drivers[5,13]. The researches on the influencing factors of the spatial distribution of rural settlements have gradually changed from single factor to multi-factor. Third, existing researches on spatial optimal layout of rural settlements focused on how to classify and organize types of rural settlements in combination with natural environment and socio-economic factors according to optimal layout scheme developed by mathematical model[14]. Specifically, it performed qualitative and quantitative analysis from the aspects of resources, environment, ecology, economy and society, and issued scientific and reasonable optimization layout mode according to local conditions.

In summary, although existing research on the spatial distribution of rural settlements has achieved much positive progress, the research on the quantitative analysis of spatial layout of rural settlements and the summary of the law remains unqualified. Furthermore, existing studies rarely focus on the spatial patterns of rural settlements, especially the random, clustering or uniform patterns of rural settlements in geographical space, overlooking in-depth discussion on the mechanism of their formation. In terms of research methods, existing studies mainly employed 3S to examine the spatial distribution characteristics of rural settlements, and fractal theory was less used to analyze the spatial form of rural settlements.

As a matter of fact, with the rapid development of urbanization, rural population shrinks quickly, spatial reconstruction of rural settlements has become an essential component of China’s rural revitalization strategy[15-16]. Consequently, understanding the spatial characteristics of rural settlements in mountainous areas, reconciling the contradiction from spatial regional land use and creating the landscape ecological effect in the special areas through making spatial panning will greatly contribute to urban-rural integration development in China[5,16]. Actually, as the basic administrative unit in China, towns are key linkages between countryside and county[17]. Thereby, it is of great significance to understand the spatial characteristics of settlements at the micro town scale for sake of guiding the spatial reconstruction of rural settlements and realizing rural revitalization.

Based on the theoretical value and practical significance, this paper firstly constructed an analysis framework, and summarized the basic rules of spatial differentiation, spatial fractal and spatial layout characteristics of rural settlements in mountainous areas using fractal theory, Kernel Density Function and Ripley's K Function. In the discussion part, the influencing factors of spatial morphological characteristics of rural settlements in mountainous areas are discussed qualitatively, which can offer a reference for the spatial optimization and layout reconstruction of rural settlements in mountainous areas. We believe the contributions of the study lie in (i) constructing and developing conceptual framework, ideas and methods for understanding the spatial distribution characteristics of rural settlements in mountainous areas at the micro (town) scale, and (ii) revealing the main divers affecting the spatial distribution of settlements in mountainous areas based on the constrains such as terrain and landform.

1 Conceptual framework

Spatial differentiation characteristics of rural settlements refer to spatial regular changes of rural settlements owing to the influences from the site selections of rural settlements[18]. The spatial layout and functional evolution of rural settlements in mountainous areas are inevitably influenced by regional socio-economic development, town planning, industrial layout and natural factors. Natural factors such as elevation, slope, geological disasters and water bodies, location factors such as traffic facilities, distance to towns and socio-economic factors such as urbanization, population, industry, policy have

significant influences on the spatial differentiation characteristics of rural settlements in this special area. Natural factors, locational factors and socio-economic factors are interrelated and present different coupling modes in different periods, which determine the number and distribution of rural settlements in mountainous areas. Specifically, natural factor is the prime force to change rural settlements distribution. The areas with low elevation, gentle slope, moderate distance to water source and low risk of geological disasters are generally selected as the sites of rural settlements at the beginning. Further, with the development of economy and society, the impacts of natural factors on the spatial distribution of rural residential areas are gradually weakened, however, location factors, urbanization, industrial development, traffic condition and government policies such as planning, have become important forces to change the spatial form of rural settlements.

Spatial form is the simple, complex, ordered and disordered state of geographical elements. Spatial fractal characteristics of rural settlements are the forms of rural settlements in the space[19]. Fractal theory is an important method to understand spatial form of geographical elements. As a kind of methodology and epistemology, fractal theory has some important implications. First, the similarity between the fractal whole and the local form inspires people to understand the entirety through the part and to understand the infinite from the finite. Second, fractal theory reveals a new kind of form and order among whole and part, order and disorder, complexity and simplicity[20-22]. We can accurately understand the overall spatial distribution of rural settlements by simulating local irregular spatial form based on fractal algorithm. As summarized by Wu et al.[23], there are currently three fractal dimensions for measuring land use spatial characteristics, namely, the boundary dimension, the radius dimension and the information entropy dimension. The boundary dimension (see Table 1) is used to express the complexity and randomness of land use patches[24-25], and the radius dimension is used to quantitatively describe the centrality of land use patches[26]. The information entropy dimension is applied to reveal the balance of spatial distribution of land use[27]. In view of the special characteristics of rural settlements in mountainous areas, the Boundary dimension is selected to estimate the whole spatial distribution of rural settlements.

Table 1　Schematic of multidimensional fractal model[23]

Fractal dimension	Boundary dimension	Radius dimension	Information entropy Dimension	Lacunarity dimension
I	Simple boundary shape	Accumulative distribution	Non-uniform distribution	Multi-centers
II	Complex boundary shape	Diffused distribution	Uniform distribution	Discrete distribution
Spatial characteristic	Complexity	Centrality	Equilibrium	Self-organization

Note: I and II refer to two opposite patch features or spatial distributions for a given land use.

Spatial pattern is defined as the spatial distribution and configuration pattern of ecological or geographical elements, which mainly describes the spatial clustering, randomness or uniformity of ground objects at the macro level. Due to the influence of natural factors, rural settlements as the dot features present clustered, random and uniform pattern in mountainous and hilly areas. The formations of the three spatial distribution characteristics are the results of rural settlements development in different stages (see Fig.1). In the early stage, socio-economic development is not adequate enough, and location and distribution of rural settlements are scattered or uniform due to the influence from the natural factors. With the rapid socio-economic development, locational factors, traffic factors and infrastructures play important roles in changing the layout of rural settlements. Rural settlements in this stage present a certain degree of clustered pattern and central agglomeration. Central village as the center of clustered distribution gradually expand and play the key role in forming the spatial random distribution, meanwhile, more and more public infrastructures are emerging in central village, and it attracts more and more elements to the central village. Further, with the constant expansion of central village, capacities of radiation and diffusion are further enhanced, more and more natural rural settlements are accommodated into the central village, forming the prototype of a large-scale cluster. Such villages have a considerable scale, with relatively perfect traffic conditions and living facilities. Finally, the central village maintains close ties with the surrounding towns, forming regional functional zones, eventually it become a part of mountainous city. Thereafter, we continue to explore the spatial distribution characteristics and laws of rural settlement in mountainous areas through empirical study.

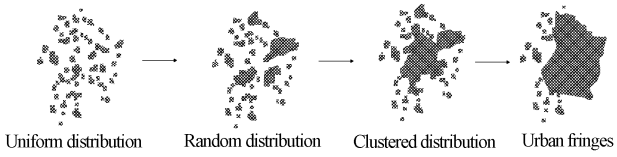

Fig.1　General rules of rural settlements evolution in mountainous areas

2　Material and methods

2.1　Study area

We selected Shichuan town in Chongqing, Southwest China as the study area. Shichuan town is located in the northwestern fringe of Chongqing (Fig.2). Shichuan town is a typical hilly landform with the overall terrain tilting slowly from the northwest to the southeast toward the valley of Yangtze River. The highest elevation is 843 m. The climate of the town is the north sub-tropical humid monsoon characterized by mild weather and abundant rainfall. Yulin River is a key water system across the Shichuan town.

Shichuan town covers an area of approximately 75.5 km^2 with 25 villages. The population of the town is nearly 70 000 with 58 000 rural residents and 12 000 urban

residents in 2016 according to Yubei District Statistical Yearbook. The infrastructures in the town are relatively perfect, and some of them are directly connected to municipal facilities. According to the land use existing data of Shichuan, the total patch number of rural settlements in the study area is 3 607, covering 25 villages, and the total area of rural settlements is 1 029.71 hm^2, making up 8 percent of the study area. The per capita residential area is 168.22 m^2, which is higher than the per capita standard of 150 m^2 set by the local government. Thus, the land use of rural settlements in the study area is relatively extensive.

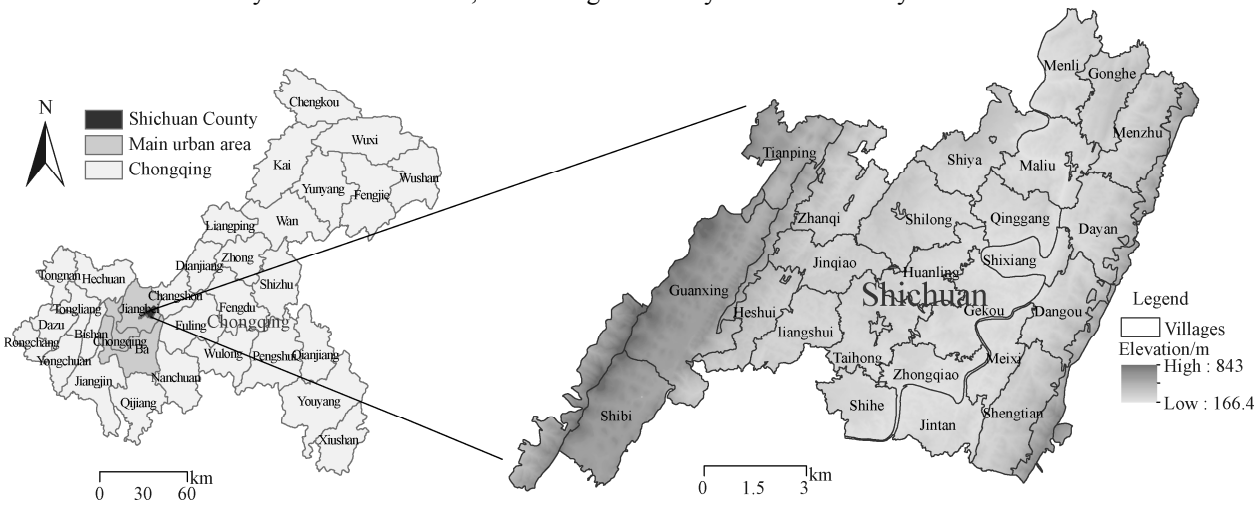

Fig.2 Location of the study area

2.2 Data collection and processing

The majority of data used in this study are derived from government, public databases and websites. Most data of the study area are acquired from government or public databases or websites. Land use existing data of the study area in 2016 in vector format (1:10 000) are from government public databases established by Chongqing Bureau of Planning and Natural Resources. DEM data with a cell size of 30 m are available at http://www.gscloud.cn/. Data of geological disaster distribution are derived from the Geological Disaster Prevention map of main urban areas in Chongqing (short for GDPC, digital vector map, 2014). Finally, we extracted slopes from DEM, obtained water bodies, roads and urban land by using the reclassification tool, buffered and overlay the vector data of rural settlements in study area.

2.3 Methods

2.3.1 Method for spatial differentiation

According to the framework, site selection of rural settlements is influenced by natural conditions and human activities. According to and Yang et al[5,28], we select elevation, slope, geological disaster, river system, urbanization and transportation to understand the spatial differentiation of rural settlements in mountainous areas (see Table 2).

In this study, we divided elevation and slope into four grades according to China's Landform Classification Standards. Geological disasters are divided into three levels, namely, high-incidence or easy-incidence area, medium-incidence area and low-incidence or non-incidence area in accordance with the Geological Disaster Prevention Map of Chongqing (2014). In addition, other indicators such as river system, urbanization, and transportation are also classified by buffer distances according to Jenks in ArcGIS10.2.

Table 2 Indicators for spatial differentiation characteristics of rural settlements in study area

Indicators	Indicator grading			
Elevation/m	[0,300]	(300,400]	(400,600]	(600,843]
Slope/(°)	[0,8]	(8,15]	(15,25]	(25,85]
Slope direction	North, Northeast	East, Southeast	South, Southwest	North, Northwest
Geological disaster	high-incidence or easy-incidence area		medium-incidence area	low-incidence or non-incidence area
Rivers buffering/m	[0,400]	(400,800]	(800,1 200]	(1 200,1 500]
Town center buffering/m	[0,400]	(400,800]	(800,1 200]	(1 200,1 500]
Roads buffering/m	[0,200]	(200,500]	(500,1 000]	(1 000,3 000]

2.3.2 Method for fractal characteristics

According to the framework, fractal dimension (D) can be calculated and simulated by Boundary, Radius, information entropy and Lacunarity methods (see Table 1). The higher the dimension value is, the higher the spatial self-similarity of geographical phenomena is. The fractal dimension of rural settlements reveals the patch characteristics of rural settlements, and it can indicate the spatial complexity and stability of rural settlements. $D \in [1,2]$, when D =1, the square patch has the simplest shape. When D = 2, the square patch has the most complex shape. In short, the higher the D value is, the more complex the shape of square patch is. The smaller the value is, the simpler the shape is. In accordance with the framework, we constructed the fractal dimension model on perimeter-area relation of rural settlements' spatial distribution structure based on Boundary method, as follows:

$$\ln A = \frac{2}{D}\ln P + C \quad (1)$$

Where, A is the patch area, P is the patch circumference, D is the fractal dimension, and C is the constant.

2.3.3 Method for spatial patterns

1) Multi distance spatial clustering (Ripley's K Function)

Multi distance spatial clustering is an important method to understand the spatial pattern of incident point data. A remarkable feature of this method is the ability to summarize spatial dependence (feature clustering or feature dispersion) over a range of distances. Ripley's K function illustrates how the spatial clustering or dispersion of feature centroids changes with neighborhood size[28]. It can be structured as:

$$K(d) = \sqrt{\frac{A\sum_{i=1}^{n}\sum_{j=1,j\neq i}^{n} k_{i,j}}{\pi n(n-1)}} \quad (2)$$

Where, d is the distance, and n is the total number of features. A is the total area of features, and $k_{i,j}$ is the weight. If no boundary correction exists, then the weight would be equal to 1 when the distance between i and j is less than d. Otherwise, the weight is equal to 0. Using a given edge correction method will modify $k_{i,j}$ slightly.

2) Kernel Density Estimation

We use Kernel Density Estimation (KDE) to further understand the spatial pattern characteristics of rural settlements. KDE is a nonparametric way to estimate the probability density function of a random variable[28-29]. In this study, KDE is uses as a moving cell (equivalent to a window) to gauge the density of rural settlements in the surrounding search radius. KDE can also be used to measure the changes of local density of rural settlements' areas with a complex distance attenuation function and to explore the hotspots of its spatial distribution. KDE is generally given as follows:

$$f_n(x) = \frac{1}{nh}\sum_{i=1}^{n} k\left(\frac{x - x_i}{h}\right) \quad (3)$$

Where, k is a probability kernel, and x-x_i is the distance from estimation point x to the sample x_i. h is the search radius (h>0). Therefore, the selection of h has an important impact on the result. When h increases, the smoothness of the density increases and when h decreases, the density changes unevenly. In practice, we need to test h value, multiply, to seek the kernel density surface with high agreement with the practical situation.

3 Results

3.1 Spatial differentiation characteristics of rural settlements

First, spatial distribution of rural settlements in the study area presents significant differentiations at various elevations. However, the number and area of rural settlements patches gradually decrease as elevation increases. Specifically, 61.83% of patches are distributed within the range of elevation [0,300], accounting for 62.66% of total residential areas. Second, 25.95 % of patches are located in the areas within the range of altitudinal between (300,400], accounting for 24.63 percent of the total residential areas. Second, spatial distribution of rural settlements regularly changes with different slopes in the study area. That is, as slope increases, the number and area of rural settlements patches decrease. 18.13% of patches are more than 25°. Third, geological disasters can impact the distribution of rural settlements. Residential sites should avoid collapse, debris flow, landslides and other natural disasters. Our result reveals that 3 330 patches accounting for 92.32% are in low-incidence or non-incidence area. Therefore, the total risk of geological disasters in study area is not high. Fourth, river systems significantly influence the sites selection of rural settlements, agricultural production and farmers' life. The results present that 2 299 patches, or 63.74% of total patches, are more than 800 m away from the rivers. By contrast, only 588 patches that account for 16.31% of total patches are less than 400 m away from the rivers. In summary, most rural settlements in the research area are far away from rivers. Fifth, urbanization might be another important factor that influences the distribution of rural settlements. Rural settlements close to town center are likely to become a part of town in the future. The number and area of rural settlements patches also increase gradually with growth of distance to the town. The results present that 2 833 patches, or 78.54% of the total, are more than 1 200 m away from town center. By contrast, only 115 patches, or 3.19% of total patches, are less than 400 m away from town center. Sixth, transportation could substantially change the distribution of rural settlements. Our result shows that the number of rural settlements patches gradually decreases with the increase of roads buffered distance. Rural residential areas and patch numbers in the study area are mainly distributed within 500 m of roads buffering distance. Specifically, the number and area of rural settlements patch within the buffer distance of 500 m account for 76.56% and 73.12%, respectively. Apparently, most rural settlements in this area are relatively close to main roads. The majority of rural settlements in mountainous areas present the band-shaped distribution along the main traffic lines. Nevertheless, 276 patches are more than 1 000 m away from the road.

3.2 Spatial fractal characteristics of rural settlements

According to the framework and Formula 1, we obtained the Table 3 and Fig.3. As seen in Fig.3, the structure of fractal dimension (D) of rural settlements in the study area is generally characterized by "U-curve". The D value is between 0.96 and 1.29. Therefore, the patches of rural settlements in Shichuan are relatively regular, and land use for rural settlement is comparable intensive. Villages, like Shibi, Guanxing, Tianping, Shengtian, Dangou, and Menzhu, are located in "the edge of U-curve". Thus the patches in these areas are relatively regular, and land use is comparable intensive. Other villages, such as Dayan, Gekou, and Gonghe, are located in the areas characterized with "the middle of U-curve". The pattern of rural residential land use is more complex than that located in "the edge of U-curve".

Consequently, the spatial planning of these villages need be made urgently to improve the intensive level of rural residential land use in these areas.

Table 3 Distribution of rural settlements in different fractal dimensions

Fractal dimension	Patch number of rural settlement	Area of rural settlement/m^2	Percentage of total patch number/%	Percentage of total residential area/%
[0.96, 0.99]	1 116	160.09	30.94	15.55
[1.00,1.02]	1 058	256.09	29.33	24.87
[1.03,1.05]	794	272.00	22.01	26.42
[1.06,1.09]	475	236.37	13.17	22.96
[1.10,1.29]	164	105.16	4.55	10.21
Total	3 607	1 029.71	100	100

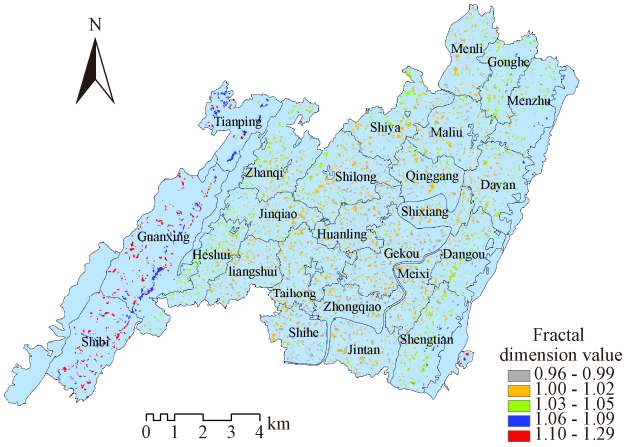

Fig.3 Distribution of rural settlements in different fractal dimensions

3.3 Spatial pattern characteristics of rural settlements

3.3.1 Results of Ripley's K function

Fig.4 was estimated by Ripley's K function. The result presents that except for fully urbanized regions, the spatial distribution of rural settlements exhibits clustered, uniform, and random. Specifically, Dayan, Gonghe, Jintan, Maliu, Minli, Qinggang and Shiya are uniform. Guanxing, Menzhu, Shibi and Tianping are random, and the rest 14 villages are clustered.

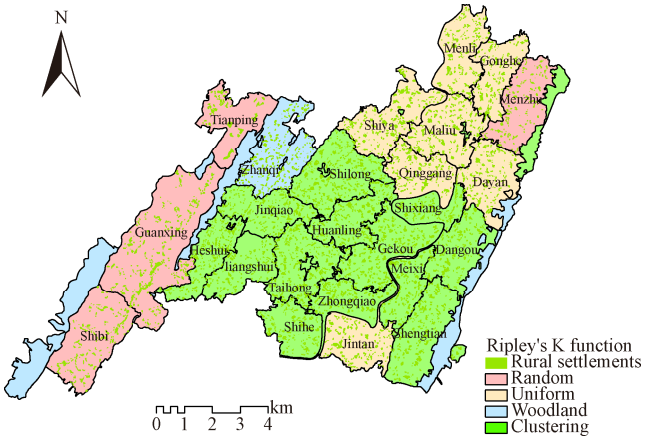

Fig.4 Spatial patterns of rural settlements in village scale

Further study indicates that rural settlements surrounding the study area are almost in random distribution, whereas those far away from the town center are mostly in clustered or uniform distribution. The rural settlements close to the town center are likely to be in a random distribution due to the frequent exchange of elements and strong radiation from town center.

3.3.2 Characteristics of KDE

We set the searching radius to 2 000 m and use ArcGIS10.2 to estimate the Kernel Density, then use the Jenks to divide the spatial pattern of rural settlements into 5 levels (>0-7, >7-20, >20-33, >33-46, >46-88 /hm^2).

The results of KDE (Fig.5) show that rural settlements in the study area are overall scattered or uniform. However, the internal spatial distribution of rural settlements displays a certain spatial agglomeration. Specifically, the KDE of Heshui is the largest and mainly concentrated in the range of 46-88 plot/hm^2. The KDE of Jinqiao, Liangshui, Taihong, Huangling, Shilong, Shihe, Chongqiao and Gekou are relatively high and mainly concentrated in the range of >33-46 plot/hm^2. However, the KDE of Tianping is the smallest and mainly concentrated in the range of >0-7 plot/hm^2.

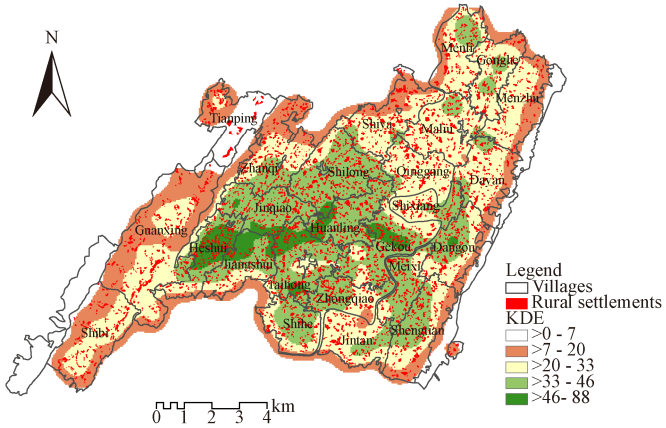

Fig.5 Results of Kernel Density Estimation (KDE) of rural settlements in study area

In summary, the spatial distribution of rural settlements in Shichuan is relatively concentrated and characterized by a relatively high density in the middle, a significantly lower density in the west than the east and a lower density in the northeast than the southeast.

4 Discussions

4.1 Spatial characteristics of rural settlements in mountainous areas present regular changes

In terms of spatial differentiation, due to the influence of natural and socio-economic factors, there are some significant differences in the spatial distribution of rural settlements in the mountainous areas. Specifically, most of the rural settlements are located in areas with low elevation, gentle topography, low disaster risk, moderate distance from water, and close to towns and roads. Obviously, population size, livable environment and other factors affect the development, location and expansion of rural settlements. The distribution and mobility of rural population also have important effects on the formation, development and differentiation of rural settlements. Generally, developed

areas have higher population density, conversely, the areas with low density of rural settlements have lower mobility of rural population. The rural settlements with high-density located in the traditional agricultural areas and mountainous areas are usually in better environment and richer in cultivated land and agricultural resources.

In terms of spatial pattern, the distribution density of rural settlements is closely related to the spatial distribution pattern of rural settlements. Fig.4 and Fig.5, gauged by KDE and Ripley's K function, show that the spatial distribution patterns of rural settlements in high-density areas are random, scattered or uniform, while the rural settlements in low-density areas are clustered. Rural settlements are more likely to be concentrated in areas with high population density, such as the areas with lower elevation, gentle slope, moderate distance to water source and low risk of geological disasters. Rural settlements in these areas are close to each other, which is more likely to form the spatial distribution of clusters. Furthermore, the spatial distribution density of rural residential areas is lower in areas with high elevation, steep slope, high risk of geological disasters and long distances to the water, traffic and towns. The distance among adjacent villages is relatively long, and the spatial distribution of settlements is often in a random state.

4.2　Influencing mechanism of rural settlements distribution in mountainous areas is more complicated

The spatial layout and functional evolution of mountainous settlements are inevitably affected by regional socio-economic development, urban planning, industrial layout and natural factors. Natural factors, location factors and social and economic factors are interrelated and show different coupling patterns in different periods, which determine the quantity and distribution of rural settlements in mountainous areas. With the development of regional economy and society, the impacts of natural factors on the spatial distribution of rural settlements have gradually weakened, however, location factors, urbanization, industrial development, traffic conditions and planning factors have become important divers that change the spatial form of rural settlements in mountainous areas (Fig.6).

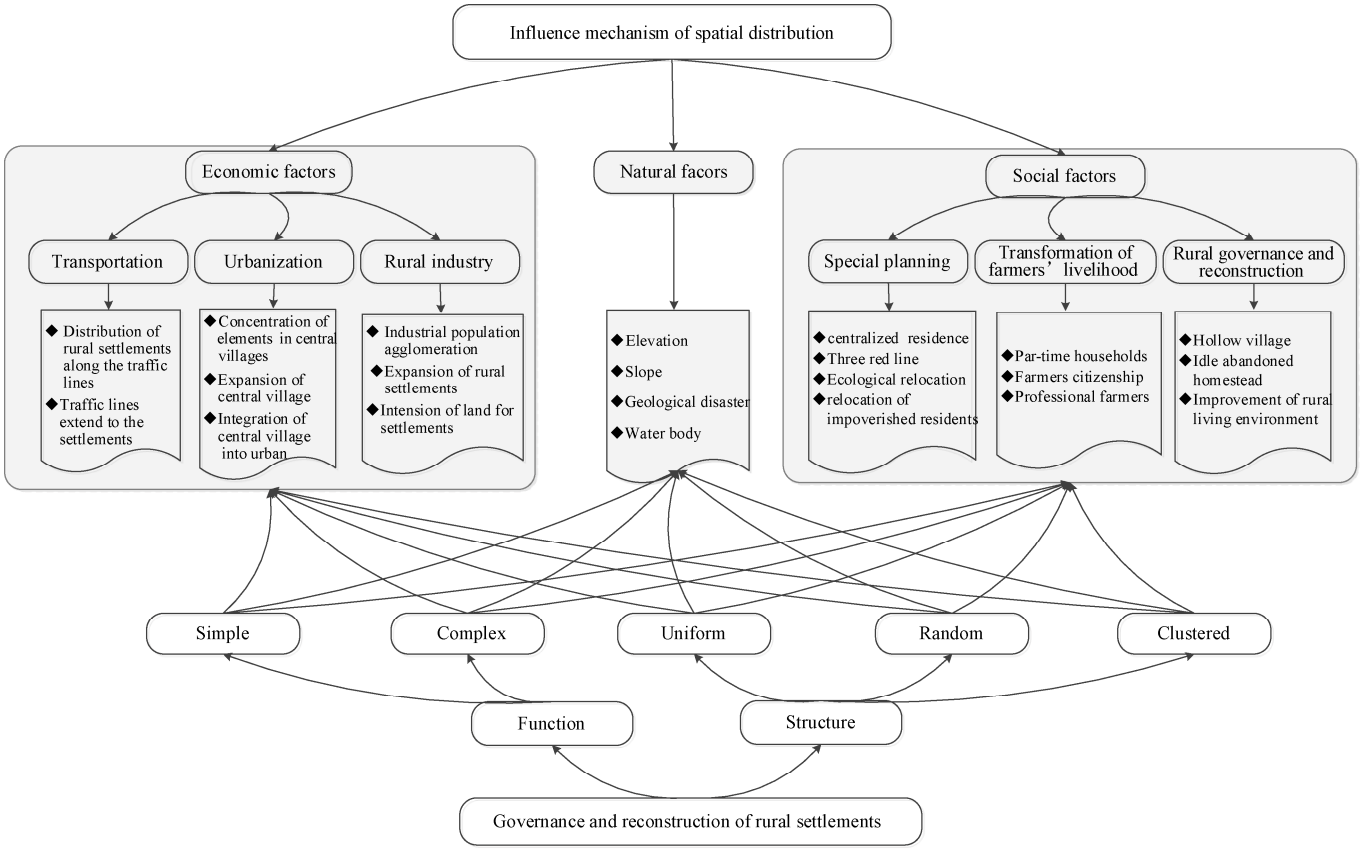

Fig.6　Flow chart of influence mechanism of rural settlements distribution

Traffic condition is an important factor affecting the spatial distribution of rural settlements and the process of regional urbanization. Even in the mountainous areas, the larger central villages are usually traversed by high-grade roads. Thereby, the external traffic conditions directly determine the regional economic prosperity and social development and enhance the economic ties between the surrounding areas.

Urbanization also affects the spatial distribution of rural settlements. Urbanization is the process of transferring rural population to urbanization[5,30]. In the process of urbanization expansion, rural settlements in mountainous areas are gradually exposed to the radiation from the town center and attraction from the built-up areas, and the site selection of rural settlements prefers to expand towards the built-up urban areas. Then, rural settlements are more close to urban built-up areas, and finally integrate into urban built-up areas in spatial form. In addition, the reconstruction of production, living and ecological space in the life service circle of towns has also exerted strong influences on the

spatial forms and distribution of rural settlements.

Industry is also a significant diver that affects the distribution of rural settlements in the mountainous areas. Different modes of production and leading industries have different effects on the distribution of rural settlements. Under the traditional economic conditions, the dominant factors affecting spatial distribution of rural settlements are the range of economic activities and the social relations between rural settlements. Meanwhile, the population migration caused by the development of non-agricultural industries and agricultural modernization also affects the spatial distribution of rural residential areas.

The policies, such as town planning and village planning, also have important impacts on the distribution of rural settlements in the mountainous areas. The spatial planning performed by governments can also change the nature, form and function of land use, and impose strong influences on the spatial accumulation of economic and social elements, such as population, industry and capital in a certain period. For instance, the establishment of concentrated areas for rural residents or industrial zones, the arrangement of important traffic lines or other infrastructures in a certain area will profoundly affect the spatial distribution and form of rural settlements in mountainous areas.

4.3 Research prospects and future work

In this study, we have mapped out the spatial distribution characteristics of rural settlements in mountainous areas with special geomorphic unit, nevertheless, this study also suffers from some limits. Our study is observational and cannot quantitatively provide insight into the drivers of spatial distribution characteristics of rural settlements in mountainous areas. If future studies can gather more town-level tightness data, we will qualify the divers of spatial distribution characteristics of rural settlements in mountainous areas. Furthermore, due to the lack of patch data such as planning data, and industrial data, we can't explore the influences of planning and rural industry on the spatial distribution of rural settlements in the empirical analysis. If data are available, distribution characteristics of rural settlements in other special regions and spatiotemporal dimensions can also be examined based on the same methodology.

5 Conclusions

Our study has illustrated that mountainous area is the special area disturbed by human activities and natural factors. Mountainous area is the area, with the acute contradiction of man-land relationship. In essence, the spatial distribution of rural settlements reflects the state and mobility of rural population agglomeration. The spatial distribution characteristics of rural settlements in this area present significant regional differences due to the impacts of human activities and natural factors.

First, the spatial distribution of rural settlements in mountainous areas is uniform, and the patches of rural settlements are generally small due to the topographic restriction. Consequently, certain measures, such as reclamation and centralized construction of rural settlements need be taken to optimize the spatial scale and land use mode of rural settlements. Second, rural settlements in mountainous areas generally exhibit significant spatial differentiations due to the impacts of elevation, slope, geological disaster, river system, urbanization, and transportation. Thereby, differentiated spatial planning and village planning need be made to improve spatial governance. Third, fractal dimension of rural settlements in the study area appears obviously asymmetric, which is generally characterized by "U-curve" .Certain villages are located in "the middle of U-curve" whereas others are in "the edge of U-curve". Thus, the fractal characteristics of rural settlements are complex in mountainous areas. Fourth, rural settlements in mountainous areas present three kinds of distribution, namely, clustered, uniform and random at the micro scale. Although the overall distribution of rural settlements in study area is scattered and uniform, its internal spatial layout still appears as a certain spatial agglomeration, exhibiting a relatively high density in the middle, a significantly lower density in the west than in the east and a lower density in the northeast than in the southeast.

In this paper, we also revealed the drivers of rural settlements distribution, including natural factors and socio-economic factors. Natural factors are the prime impetus to alter rural settlements distribution. The areas with lower elevation, gentle slope, moderate distance to water source and low risk of geological disasters are generally selected as the sites to construct rural settlements at the beginning. With the development of economy and society, the influences of natural factors on the spatial distribution of rural settlements are gradually weakened, however, location factors, urbanization, industrial development, traffic conditions and government policies, such as planning factors, have become more important divers to change the spatial form of rural settlements in mountainous areas. Therefore, some differentiated strategies, such as relocation, centralized residence, delimiting "ecological space and ecological red line" and making unified spatial planning need be performed to improve ability of spatial governance, reconstruct rural settlements and alleviate the contradiction of man-land relationship in mountainous areas.

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山地丘陵区农村居民点空间分布特征及影响机制分析

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摘　要：山地丘陵区是受人类活动和自然因素干扰的特殊区域，也是人地关系矛盾突出的地区，是国土空间治理的重点与难点区域。分析山地丘陵区农村居民点的分布特征，对实现乡村重建与乡村振兴具有重要意义。 该研究试图构建研究框架，结合重庆石船镇的案例，从定量和定性两方面探讨山区农村居民点的空间分布特征。结果表明：1）山地丘陵区农村居民点空间分布存在显著差异；农村居民点大多位于低海拔、平缓地形、低灾害风险、离水中等距离、靠近城镇和道路的地区，人口规模、宜居环境等因素影响农村居民点的发展、选址和扩张。2）山地丘陵区高密度地区农村居民点空间分布呈现随机分布、分散分布或均匀分布的特征，而低密度地区农村居民点空间分布呈现聚集分布的特征。 农村居民点更有可能集中在人口密度高的地区，如海拔较低、坡度较缓、距水源中等、地质灾害风险低的地区。3）自然因素、区位因素和社会经济因素相互关联，在不同时期表现出不同的耦合模式，决定了山区农村居民点的数量和分布。随着区域经济社会的发展，自然因素对乡村聚落空间分布的影响逐渐减弱，而区位因素、城镇化、产业发展、交通条件、政府政策等规划因素是改变山区农村居民点空间形态的主导力量。 空间治理的差异性策略是实现山区乡村聚落可持续利用和优化布局的必要条件。

关键词：农村居民点；空间分布特征；概念框架；案例研究；山地丘陵区