On the effective organization of rural settlements spatial structure under the transformation and development of mountainous areas in Western China: evaluation measurement based on complex adaptability theory

Xiang Long (longxwriter@163.com)
Chongqing University
Peifeng Yang
Fujian University of Technology
Qingmu Su
Fujian University of Technology

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Abstract

The vast majority of rural settlements in Western China are located in the ecologically sensitive and diverse mountainous environment, which also experienced rapid changes in policy and institutional interventions over the past 40 years. At present, in the transitional period of "post-poverty alleviation", they have more opportunities to re-integrate themselves into the large regional development. However, there is a lack of systematic evaluation and cognition of the related functions of the spatial structure between the settlements at the regional village scale and town scale. Therefore, in this paper, the theory of complex adaptive system and its analytical NK model were introduced, and a quantitative measurement framework was constructed for the adaptability level of this kind of rural settlement spatial structure organization, so as to explore the effective path for its global optimization. Taking Xinglong Town of Chongqing in the western mountainous area as an example, it was found from the analysis that: (1) The number of villages at high comprehensive adaptation level has increased over time, which has an obvious positive correlation with the construction of transportation network, and a structural adsorption effect. (2) The spatial structure of the rural settlement system in the region has changed from weak industrial nodes - traffic single branch connection - public service decentralized coverage in 2010 to the organizational adaptation characteristics of stable industrial agglomeration - traffic expansion and extension - public service continuous coverage in 2019. (3) The spatial elements related to industry and public service in each village have an increasingly significant impact on the reconstruction and differentiation of its spatial structure. Finally, based on the changing trend of adaptability level and the correlation characteristics of regional space, in this paper, the spatial structure optimization strategy of Xinglong Town is put forward, which provides a reference basis for the coordinated development of town and village space under the township level planning in the western region.

1. Introduction

1.1 Effective organization in anti-poverty and sustainable development

Poverty eradication has always been the common goal and task of the entire international community. In September 2015, the United Nations Sustainable Development Agenda clearly called for the elimination of all forms of poverty around the world by 2030. China was once a developing country with the largest number of rural poor people in the world(Tan et al. 2021). The western region of China has always been a region where poverty is concentrated and prominent. In the concentrated and contiguous poverty-stricken areas designated by the Outline of Poverty Alleviation and Development in Rural China (2011–2020) in 2011, many mountainous poverty-stricken areas, such as Qinba, Wuling and Wumeng are involved, accounting for more than 2/3 of the total poverty-stricken counties in that year. Nowadays, thanks to China's comprehensive poverty alleviation in 2020, many mountainous rural settlements in the western region have been involved in the normal development in "post-poverty alleviation era", remaining, however, in the transitional stage of transformation in many aspects(Zhao and Lu 2020; Pinto-Correia et al. 2016).

Seen from the perspective of social space, there are still a large number of relatively poor groups in the urban and rural areas as well as towns and villages in western region(Xue and Huang 2021), the initiative of population at different economic levels also differ, bringing about the risks of expanding the gaps between regions due to insufficient dispatch between the principal part and the material resource allocation, and inefficient spatial organization(Li 2012). It is bound to make the rural settlements in the western region fall back into a passive development situation again.

1.2 Spatial transformation under the social ecological transformation of rural settlements in the western region

At present, the entire spatial system of towns and villages in the western mountainous areas of China is under pressures and challenges due to the adjustments of multiple social and ecological structures(Dame et al. 2019), including but not limited to the intergenerational change of population and the mode of life and production. Before the reform and opening up, the western region was based on a self-sustaining local economy in small-scale, such as decentralized traditional agriculture or handicraft industry(Zhao 2006). The vast majority of rural small-scale farmers' management leas to a kind of self-sufficiency for the regional development, but the towns and villages are independent of each other. With the "de-stratification" reform brought by land ownership and the promulgation of the Rural Land Contract Law, the expansion of the spatial construction of local market town in the western mountainous areas was accelerated, while the transfer of labor force across provinces from the west to the east, as well as the problems of large input and low output of unified agriculture, have resulted in the abandonment of the traditional farmland livelihood space of a large number of marginal villages in the mountainous areas(Shen 2006), and the western rural settlements show an obvious spatial development scene of “no people but things”. Different from the spatial reconstruction path of rural development in the coastal areas in the east, many villages in the western region usually update the spatial elements, and establish the network structure based on the intervention of policies and systems. Taking the advantages of the construction of a series of poverty alleviation projects in rural areas, the land space of rural residential areas and agricultural facilities approaches the gradually improved traffic trunk, forming a scene that the rural settlements are beside the road(Luo et al. 2020); on the other hand, the government system provides guidance to the participation of enterprises, promoting together with the village collective to form a construction tendency of more professional planting, and breed cooperatives and mountain rural tourism development. The agricultural tourism type mountain rural landscape is gradually booming(Li et al. 2021), which is coupled with the reconstruction of local relations, such as the return of population and the entry of rural tourism market, gradually forcing the adjustment and adaptation of the spatial structure of mountain rural settlements in the west. Poverty alleviation in some poverty-stricken villages has become the driving force and growth point in the regional new development spatial structure. Therefore, in the new rural settlement development pattern, it is urgent to find the scientific basis for effective organization, thereby preventing the return to the poverty trap again, and entering the Sustainable Governance of endogenous power cycle growth.

1.3 Introduction of complex adaptability theory in the spatial structure of rural settlements

In urban and rural planning, as the grass-root spatial unit for decision-making and governance in China's urbanization development, villages and towns involve many rural settlements and regional central market towns, which have always been the driving force "reservoir" to maintain urban and rural social spatial stability in the western region(Wang 2014). The rural settlement system integrates the geographically dispersed villages and towns into an organic system with a certain spatial structure through the spatial interaction of villages and towns, which affects and determines the spatial distribution, connection and combination state of villages and towns in the system(Gu 1992). The spatial structure of rural settlements usually refers to the hierarchical scale and functional positioning of the development. The influencing factors, current situation characteristics and development potential evaluation form the main judgment basis(Deng and Li 2021). The establishment of its spatial structure is an important premise for planning and guiding the development of rural order. To avoid subjectivity and one-sidedness in the planning of rural settlements system, scholars try to figure out the evolution and correlation mechanism of spatial structure in village and town system from different perspectives, so as to implement the corresponding optimization strategy. Mainly through data statistical analysis and induction, fractal geometry theory(Zhang, 2013; Wu et al. 2019), gravity model(Wei et al. 2013), social network model(Shi et al. 2020) and other methods are utilized to analyze the scale distribution, element structure characteristics and evolution law of villages and towns in the region. Some scholars proposed the ecological adjustment measures of the "point axis" development model of the rural settlements system from the perspective of ecology(Yu et al. 2010); some scholars combine the gravity intensity model and complex network analysis method for the establishment of the directed weighted complex network model and its analysis indicators, thereby measuring the network structure characteristics of rural settlements system, and put forward the evaluation method of each spatial dimension. However, the studies at this scale often focus on towns or single rural settlement, and lack systematic space-time comparison combined with the impact of local policies and the organizational differences of spatial elements between corresponding villages. Therefore, some limitations exist in the matching between functions and resource allocation in the network linkage of rural settlements, as well as the cognitive judgment of further expansion direction.

The relatively marginal and informal rural settlement spatial structure has the tension of internal network connection, which can complete self-renewal and sustainable development without external support. As rural settlements in Western China are in a special period from policy blood transfusion development to independent power construction, it is highly necessary to objectively measure the stock resources and development potential in the spatial structure of villages and towns for their stable transition and effective reorganization. Currently, the villages and towns in Western China are a complex social spatial system with more openness and mobility than what they were. The internal spatial elements include not only buildings and villagers, but also diversified and coordinated social organizations and production organization relations based on agriculture, tourism, processing industry and so on. In view of the

dynamic development of settlement space, Bateson tried to use the complex adaptive system theory to explain the evolution mechanism(Foxman 1973). Based on the complex adaptive system theory, it can be seen that sociality leads to the organic self-organizing relationship between the parts in the collection of villages and towns. When the parts are slightly adjusted to adapt to the macro environment, new forms and relationships will emerge spontaneously. Therefore, in this research, it is attempted to carry out specific measurement following the relevant methods of complex adaptive systems (CAS) theory, and structural division and quantitative analysis of the relevant systems of the main spatial change elements under the differential development of post poverty alleviation areas.

The theory was established at the end of the 20th century, which was formally constructed by John H Holland, the father of "genetic algorithm", in his book "hidden order", as a theoretical science to explain the complex evolutionary system composed of a large number of adaptive subjects. And "adaptive subject" is its core basic concept. The interaction between individual and environment (including between individuals) is the main driving force of system evolution and evolution. Therefore, this theory provides a research idea and method based on the bottom-up evolution mechanism of subject(Huang 2007). At present, CAS theory is widely used in economic management(Tang 2011), strategic decision-making(Yu and Wang 2021), environmental governance(Li et al. 2018) and other research fields, which is also cited by some scholars in the type identification of the relationship between towns and villages in metropolitan areas(Qiao and Geng 2019) and the optimization of tourism spatial structure(Yang et al. 2019). During their long formation and development process, rural settlements are often in the cycle of four stages, that is, "growth, maintenance, release and reorganization"(Walker and Salt 2006), but the system may also enter the four dilemmas of poverty, rigidity, locking and gambling due to the destruction of system resilience(Wang et al. 2021). Among them, the adaptability of the system is highly important for the resilience in the transformation, which is because that adaptability refers to the ability of the system to absorb interference and basically maintain the original state. In CAS, the adaptive subject interacts with the environment and other subjects to establish an adaptive development model and the characteristics that fit the relationship between its own development characteristics and the environment, so as to promote the evolution of the entire system(Qiao and Geng 2019). The organizational adaptability evaluation of spatial structure means the comparative analysis of the dynamic expansion ability of the accumulated spatial elements in a larger system at a certain spatial stage. Only by clarifying the relative resource benefits of each node in the linkage structure can we identify and invest resources more accurately to improve the overall adaptability, toughness and sustainable development of the system. Therefore, in the study, it is believed that the theoretical basis can be used as a new cycle stage to explain the current independent development of rural areas which gradually integrate into a larger regional environmental collaborative network.

Therefore, the research attempts to understand the series of evolution of the development of poor rural areas under the intervention of policies and systems as the improvement and optimization of the internal and external structural elements of these rural systems. The improvement and strengthening of the relevant elements of the main part of development adaptability form the most core part in the current transformation and evolution process, which are also an important part of the research of the

development organization of rural systems. In the meantime, different from the single-dimension research of traditional socio-economic indicators, this paper will be conducive to the comprehensive correlation of horizontal regional space with the help of the correlation analysis method based on CAS theory.

2. Materials And Methods

2.1 Research regions

Xinglong Town of Fengjie County in the northeastern area of Chongqing is selected as a representative sample. The northeastern area of Chongqing, where the region is located, is a typical area with relatively concentrated poverty in Chongqing. It is also a concentrated and contiguous area in Qinba mountain area, and was one of the 14 concentrated contiguous areas in China (Fig. 1). In recent years, the poverty phenomenon in Chongqing has gradually moved in circles and externally, and the overall poverty and backwardness have also shifted to local areas. The marginalization is more and more obviously relative to the central urban area. In 2014, the poverty-stricken counties in Chongqing were concentrated in Wuling and Qinba located in Qinba Mountain Area (Fig. 2), which belong to the last position in the marginalization of urban development structure. It is a typical development sample of post- poverty alleviation and development in Western China.

Xinglong Town covers an area of 354.20 square kilometers with a total resident population of about 54,600. It has jurisdiction over Sanjiaoba, Jingzhu and Miaowan communities, including 20 administrative villages and 364 communities. The narrow valley terraces with small area and zonal distribution are mostly developed on both sides of the valley (Fig. 3) where the mountainous area in this region is large, the river gradient is high and the sedimentation is not obvious.

The poverty-stricken villages in the town are mainly distributed in strips at the junction of district and county administrative boundaries (Fig. 4), which is weakly related to the radiation driving radius of the regional county center and town center. The mountain attribute is obvious, that is, it has the typical regional development characteristics of poverty-stricken areas in the central and western regions. Therefore, Xinglong Town, as a case, has strong research representativeness, which is similar to the areas that have received comprehensive poverty alleviation in all regions of the country. Besides, the villages located in these areas still show a relatively poor development trend.

2.2 Analytical framework

In CAS theory, the system has four basic characteristics in the process of adaptive evolution, i.e., aggregation, nonlinearity, flow and diversity. On the other hand, there will be selection effects, such as identification, internal model and building blocks under the interaction between individual and environment(John 2000). Combined with this theory, we are able to have a more systematical view of the evolution process of spatial structure of rural settlements in Western China since the implementation of poverty alleviation system and Rural Revitalization Strategy. Under the intervention of institutional

resources and the investment, and the development of market capital, the spatial subject plays the role of inducing and attracting development factors, which greatly strengthens the formation and agglomeration of industrial spatial subjects in the space, and the improvement of transportation network, promotes the flow of factors inside and outside the region, economic growth and optimization of service supporting facilities, and stimulates the consumption return of villagers and tourists. The multi-agent diversified behavior interaction is fed back to the space at the same time, achieving more nonlinear organizational results. Based on the change trend, the multi-agent continues to adjust and reconstruct the behavior, forming the building block space combination of the internal model with certain internal advantage mode and the new competition, and cooperation relationship (Fig. 5).

When applying CAS theory to the study of the adaptability of spatial structure, scholars have deconstructed the adaptability subject of tourism space or town village relationship. In terms of the basic characteristics of CAS, it usually includes the subject composition of population organization, service facilities, core production factors and external related factors(Qiao and Geng 2019; Yang et al. 2016). Besides, it refers to the three characteristic attributes of potential, connectivity and toughness in the adaptive cycle theory, as well as the factor division in the theory of traffic spatial structure index, such as integration and intelligibility in spatial syntax(Wang et al. 2021). Through the study, based on these studies, it is believed that at the current stage, rural settlements show three main spatial structure effects, i.e., networking, nodalization and radiation(Wu et al. 2020). Therefore, the adaptive changes of the spatial structure of rural settlements are mainly mapped to the public service coverage areas of line elements, industrial economic nodes of point elements and surface elements. The structural organization of these three spatial subjects is gradually integrated into the development environment at a higher regional level, forming a complex system with potential energy of cooperation, competition and other relations inside and outside the region. To further objectively measure the connection and interaction of the main elements in the system and the level of spatial adaptation efficiency, the quantitative analysis tool NK model commonly based on CAS theory is used (Fig. 6).

The establishment of NK model can not only build the fitness landscape diagram through adaptive search, thereby quickly and effectively recognizing the optimal solution, but also help to understand the impact of the interaction between the internal elements of the system on the overall adaptability of the system. Therefore, taking the advantages of the index measurement results of each subject factor calculated by using NK model, the comprehensive fitness index of the administrative village system in the town area of the case area is expressed in the form of links, nodes and coverage in network topology, forming the spatial form visualization and space-time comparison of the final data.

2.3 Data processing

The basic elevation and fluctuation range data of the case area are derived from the DEM90m data downloaded from the global geographic information resources, the spatial elements and place name annotations of the town area are mainly derived from the Tianmap API and POI data The data of land use, rural roads, public service facilities, population and industrial distribution of each administrative village are taken from the planning practice project of Fengjie County Land and Space Planning 2019–

2035, the data of three surveys in 2019, resources and environment science and data center of the Chinese Academy of Sciences in 2010 and the author's field survey interview records.

2.4 Models

The NK model based on the CAS theory was used as a quantitative analysis method, in which there are five parameters, namely N, K, A, S and C, with their meanings shown in Fig. 7. The NK model consists of N genes which are evolving continuously, and the fitness value of each gene is denoted as Wi. In addition, the fitness of the entire system is the average fitness of all genes.

To reflect the relevance of quantitative indicators, the entropy method is utilized to assign the weights of each indicator. Entropy is a measure of the degree of disorder in a system. According to this property, the information entropy of each index can be obtained by using the inherent information of each scheme. The smaller the information entropy, the lower the disorder degree of the information, and the larger the utility value of the information and the weight of the index.

2.5 Indicator description

2.5.1 Main factor I: Traffic network connectivity

In the development and construction of poverty alleviation in rural settlements in the western region, both the hardening and upgrading of the overall main roads and the improvement of the accessibility of the road network provide more possibilities for rural resources in poor areas to move from one-way input to internal and external circular feedback to a great extent. After poverty alleviation, the external regional transportation routes of rural settlements have increased, and the driving force for towns and villages to capture regional resources has been greatly improved. The traffic connectivity of villages is an important manifestation reflecting their changes and the adaptation to dynamic development of the region. Such a factor includes the density of roads in towns and villages, the shortest time to towns, the shortest time to urban areas and the degree of important path connectivity.

2.5.2 Main factor II: industrial production initiative

Industrial support and cultivation are also the core undertaking of western rural settlements in poverty alleviation and even at present. In the original limited ecological environment and economic market, the industrial production capacity of western mountainous rural settlements has been greatly released after poverty alleviation. On the other hand, industrial development is the key support for regional sustainable development, and the initiative of industrial production reflects the adaptability of each village in regional resource integration and the market value covering the annual gross product of primary industry, per capita agricultural output, annual output value of secondary industry and annual output value of tertiary industry.

2.5.3 Main factor III: Public service facilities coverability

The allocation and improvement of public service facilities are also the main project of the western mountainous rural settlements under the reform of rural construction system, the resettlement houses in the process of poverty alleviation and relocation, the living environment in the process of rural revitalization and the service supporting system under rural tourism, all of which affect the entry and stay of human resources, such as local population, village collectives, enterprises and talents. The coverage of public service facilities reflects the adaptability of each village in terms of capital stability of regional public space construction, including the number of public services, per capita public service construction area and per capita construction land area.

2.6 Data measurement

Main calculation methods:

(1) To eliminate the difference of unit measurement between different nature indicators, standardization and translation formula are used to process the values of the measurement of indicators, and unified standardized values of different system dimension data in each village are obtained as;

For the indicator of “the smaller the better”:

(2) Due to significant difference between spatial construction and pattern status in 2010, the weights are measured according to the data of the same year (Table 1), and the final score of each principal factor is calculated based on the standardized values and weights of each index. The fitness state of the measurement data of the main factors of each village was judged afterward, marking the value higher than the average value of the indexes as '1' (high adaptability), and lower as '0', i.e., low adaptability;

(3) In the NK model, N refers to the number of main factors, and in the current study, N = 3. Assuming that the fitness change of each administrative village unit sample only depends on itself, that is, K = 0, A value is (0,1), and there are 23 = 8 adaptation levels. The average value of the same fitness state data values of each factor is the fitness contribution value of the factor, and the comprehensive fitness value of each combination state is the average value of fitness contribution values of three factors.

Table 1
Main factor indicators and their weights

Main adaptive factors adaptability of NK model	Factors	Factors attribute	Weight assignment in 2010	Weight assignment in 2019
Traffic network connectivity	Highway network density	+	0.34	0.25
	The density of highway network is the shortest time from village to town	-	0.13	0.26
	The shortest time from village to County town	-	0.18	0.20
	Connection degree of important path	+	0.35	0.29
Industrial production initiative	The first industry out put	+	0.20	0.30
	Per capita agricultural output	+	0.23	0.26
	The second industry out put	+	0.23	0.21
	The third industry out put	+	0.33	0.23
Public service facilities coverability	Number of public service facilities	+	0.28	0.32
	Public service construction land area	+	0.23	0.21
	Per capita public service construction area	+	0.26	0.23
	Per capita urban construction area	+	0.23	0.25

3. Results

Through the establishment of NK model in Xinglong Town in 2010 and 2019, the type data results of 8 types of fitness feature combinations of 3 factors in each village in the town are measured. The calculation results of comprehensive fitness corresponding to 8 types of adaptation level state combinations from high to low are shown in the tables 2-3, and the numerical results of fitness levels of each village are shown in Figure 8.

In CAS theory, adaptability indicates whether the structure of the subject itself can be coupled and matched with its functions, so as to better support its sustainable development under certain environmental conditions. Meanwhile, a preliminarily judgment of the optimal path for the development of low adaptability villages to the ones at high adaptability level in the corresponding time stage is also made.

Table 2 Comprehensive fitness value of each state combination of Xinglong Town spatial structure in 2010

Type characteristics	Adaptive state	Traffic network connectivity factor	Industrial production initiative factor	Public service facilities coverability factor	Comprehensive fitness value
The three subjects have strong adaptability	1-1-1	1.771	1.338	1.301	1.470
Production initiative is weak, and the other two are strong	1-0-1	1.771	1.081	1.301	1.384
The matching of life function is weak, and the other two are strong	1-1-0	1.771	1.338	1.034	1.381
Regional connectivity is weak, and the other two are strong	0-1-1	1.320	1.338	1.301	1.320
Regional connectivity is strong, and the other two are weak	1-0-0	1.753	1.338	1.301	1.464
The coverage of living facilities is strong, and the other two are weak	0-0-1	1.296	1.081	1.301	1.226
Production initiative is strong, and the other two are weak	0-1-0	1.296	1.338	1.034	1.223
The adaptability of the three subjects is weak	0-0-0	1.296	1.081	1.034	1.137

Table 3 Comprehensive fitness value of each state combination of Xinglong Town spatial structure in 2019

Type characteristics	Adaptive state	Traffic network connectivity factor	Industrial production initiative factor	Public service facilities coverability factor	Comprehensive fitness value
The three subjects have strong adaptability	1-1-1	1.643	1.397	1.336	1.459
Production initiative is weak, and the other two are strong	1-1-0	1.643	1.397	1.090	1.377
The matching of life function is weak, and the other two are strong	1-0-1	1.643	1.138	1.336	1.372
Regional connectivity is weak, and the other two are strong	0-1-1	1.318	1.397	1.336	1.351
Regional connectivity is strong, and the other two are weak	1-0-0	1.643	1.138	1.090	1.290
The coverage of living facilities is strong, and the other two are weak	0-1-0	1.318	1.397	1.090	1.269
Production initiative is strong, and the other two are weak	0-0-1	1.318	1.138	1.336	1.264
The adaptability of the three subjects is weak	0-0-0	1.318	1.138	1.090	1.182

3.1 Adaptability of Spatial Structure of Villages in Xinglong Town in 2010-2019

According to the adaptability state of factors, the 8 types of combined data in the study also show specific adaptability in the framework of NK model. The empirical results show that: (1) In 2019, the two innermost villages in Xinglong Town close to the central market town and Jingzhu community in the northeast as the central village have the highest adaptability to the spatial structure, that is, 1-1-1 villages. These three villages enjoy the traffic location advantage of G242, and the core natural landscape resources close to Tiankeng Difeng Scenery, accounting for 13.64% of the total number of villages in the whole town. (2) Secondly, there are two villages showing better adaptation to two factors, including two villages near the central town with better adaptation to 1-1-0 traffic and industry- related spatial structure, and the intersection of national and county roads in the west; 5 villages along the national highway are well adapted to the spatial structure related to 1-0-1 transportation and public service, accounting for the highest proportion. The central village Miaowan community and another village in the west are better adapted to the spatial structure of 0-1-1 industry and public service, accounting for 9.09%,

22.73% and 9.09%, respectively. (3) Only one spatial structure factor is well adapted, while the other two are poorly adapted, including 2 villages with better adaptation of 1-0-0 traffic related spatial structure, 3 villages with better adaptation of 0-1-0 industry related spatial structure, and 1 village with better adaptation of 0-0-1 public service related spatial structure, accounting for 9.09%, 13.64% and 4.55%, respectively. (4) The rural settlements with relatively poor adaptation to the three factors, namely 0-0-0 villages, have 4 villages in total, accounting for 19.18%.

Compared with the data of 2010: (1) There are 2 1-1-1 villages with high adaptability, accounting for 9.09%. (2) The villages with good adaptation to the two factors include 3 villages of type 1-0-1, 2 villages of type 1-1-0, and the villages of type 0-1-1 are excluded, accounting for 13.64% and 9.09%, respectively. (3) One is better adapted to the spatial structure, while the other two are poorly adapted to the spatial structure, including 5 villages of 1-0-0 type, 3 villages of 0-0-1 type and 2 villages of 0-1-0 type, accounting for 22.73%, 13.64% and 9.09%, respectively. (4) There are 5 villages of 0-0-0 type, accounting for 22.73%. Seen from the numerical changes of the overall adaptation degree and the relationship between spatial structure, the spatial structure and organizational adaptability of Xinglong Town has undergone three main transformation trends: (1) the number of villages at high comprehensive adaptation level has increased over time, and the comprehensive adaptation level of adaptation type villages dominated by traffic and Industry-related main factors has a higher increase rate. Besides, the proportion is the largest, and the results are significantly and positively correlated with the construction of transportation network and the performance of structural adsorption. (1) In 2010, the village and town system of Xinglong Town mainly showed the spatial distribution structure characteristics of weak industrial nodes - traffic single branch connection - public service decentralized coverage, while in 2019, it illustrated the structural characteristics of stable industrial agglomeration, traffic expansion and extension - public service continuous coverage. (Figure 9) (3) In 2010 and 2019, the adaptability performance of traffic elements in the spatial structure has the highest contribution to the comprehensive adaptability. Secondly, in 2010, the contribution rate of public-service-related adaptability is higher than that of industry-related adaptability, while in 2019, the contribution rate of industry-related adaptability is higher than that of public-service-related adaptability. The above changes are mainly due to the planning and construction of relevant poverty alleviation strategies and Rural Revitalization strategies in the western region of Xinglong Town. The construction benefits of transportation system elements have been steadily improved in the evolution of the spatial structure of Xinglong Town, while the construction of industrial and public service system elements has a greater impact on the reconstruction and differentiation of the spatial structure of each village. Based on the change structure and influencing factors of each adaptive subject factor, the details are as follows:

3.1.1 Spatial structure adaptability in transportation

From the perspective of the spatial structure of the main factor of traffic network connectivity, the traffic adaptability advantages of each village gradually radiate from the original central community to the central town, national highway and special traffic roads, in another word, the adaptability changes from single branch connecting traffic to outward expansion and extension. It is difficult for the transportation

of rural settlements in the western mountainous areas to get a large span. However, taking the advantages of the implementation of poverty alleviation and other projects, Xinglong Town has realized the hardening of 205 kilometers of roads and the upgrading of national highway G242. In the meantime, it has formed a characteristic tourism transformation ring connecting the nodes of scenic spots, such as Tiankeng Difeng Scenery and Heiwan Maocaoba, focusing on ecotourism resources. The internal and external circulation of life service commuting forms a multidimensional and extended traffic skeleton.

3.1.2 Spatial structure adaptability in industry

From the perspective of the spatial structure of the main factors of industrial production initiative, the adaptability spatial distribution of high industrial production initiative originally centered around the town center, central north and northwest central communities in the town has been gradually and comprehensively upgraded and developed in the town, especially the marginal villages in the west of the town. And the relevant villages in the west of the industry around the central village system of Miaowan community have been significantly improved, that is, it has realized the transformation from the distribution of weak industrial nodes to that of stable industrial agglomeration. This is also driven by the industrial poverty alleviation project. Rural enterprises, village collective economy and land circulation condense the local expansion of more productive factors, and rely on more industrial centralized demonstration areas to promote the value of rural land production level, such as traditional Chinese medicine planting demonstration bases, agricultural planting and processing professional cooperatives cultivated by multiple villages, and rural characteristic tourism demonstration belt.

3.1.3 Spatial structure adaptability in public service

Regarding the coverage of public service facilities, the export of post-urbanization in western mountainous rural settlements affected by internal and external influences and region constraints is obvious, during which education and employment have become the core driving forces of population transfer. This is because that more rural families have chosen the mode of life near the city and away from the land. From the perspective of internal changes, the rural public service facilities originally scattered on the edge have not reached the threshold scale, and gradually stopped after the centralization of land policy construction and the networking of road traffic. Consequently, the spatial distribution of the coverage of public service facilities in Xinglong Town has changed from the original decentralized coverage distribution to the agglomeration and contraction close to the town center, central village and characteristic village. It also shows the continuous coverage improvement synchronized with the traffic structure as a whole.

3.2 Adaptive change characteristics before and after the construction of poverty relief village policy and system

Poor villages are an important unit that has long restrained the overall spatial balance and effective development in the western region. Besides, the impact mechanism of its development adaptation is also the key part of the research. The comprehensive adaptability level of the original six poor villages in the

rural settlement system of Xinglong Town has been mostly improved. Due to the appreciation of industrial factors, Liuya Village and Gaoping Village have leapt from the third gradient adaptation level to the second one, and Longmen Village has leapt from the fourth gradient adaptation level to the third one. However, the level of Fangdong remains unchanged, and Xiaozhai Village and Meihua Village show a decrease (Fig. 10). The impacts of these spatial transformation paths on the village are illustrated as follows:

(1) Liuya Village and Gaoping Village were originally poor rural settlements at medium and lower adaptation level, but they have leapt to a higher adaptation level through the identification cultivation of leading industries and the comprehensive strengthening of public service supporting coverage. This path includes building industrial concentration demonstration films, focusing on land circulation and developing specialized and large-scale planting bases and industrial park space with the goal of leading industries in villages and income-increasing projects for households, and promoting the upgrading of tourism service space with the help of historical and cultural landscape with its own traffic location advantages.

(2) Longmen Village has upgraded from the most backward adaptation level to the type of poverty-stricken rural settlements with better industries, which is mainly due to its ecological + tourism linkage, promoting its spatial cluster effect. Based on the overall guidance of a series of ecological poverty alleviation measures and the Municipal Tourism Administration, combined with the retention of local architectural elements, and the villagers' autonomy to participate in the transformation, Longmen Village has completed a large-scale Alpine ecological summer resort and characteristic rural tourism home stay. With the feedback of the market, it promotes the agricultural production, urban and rural participation, rural home stay transformation and other model revitalization space development projects, and guides the further clustering of relevant industrial space with the experience of rural home stay lifestyle as the core.

(3) However, Xiaozhai Village, Fangdong Village and Meihua Village show a slight downward trend in the entire evolution of the spatial organization of rural settlements. This trend originates from the contraction of rural settlements space under the control of ecological constraints. The special geographical environment of Xinglong Town also has high restrictions on the function of ecological conservation and protection. In addition, the space for village agricultural production and relevant livelihood activities of farmers will be gradually withdrawn and limited.

In the rural construction of "deagriculturalization", the space development of some villages is compact and contracted.

4. Discussion

Taking the advantages of CAS theory, the study expounds the organizational adaptation of the spatial structure of the case area at a specific time stage, which has certain theoretical innovation significance

for the cognitive measurement of the spatial structure. In the meantime, the analysis model under the theoretical framework illustrates universal application prospects for the quantitative evaluation of the spatial structure of most rural settlements, but it has more reference value for rural settlements in less developed areas, such as southwest China due to the long-term lack of power or mismatched development direction of rural development in this area. In particular, at present, the rural areas in this region are at a special stage of withdrawal from the regional policy system and the transformation to the independently induced system. By using this theoretical method, we can more actively select and use the key resources in spatial development for expansion, so as to effectively promote the sustainable evolution of the area. In addition, the analysis results of spatial topology and NK model in complex adaptive system theory, as well as the comparison of time and space and the contribution rate of each adaptive subject factor used in this study can be used to more intuitively and objectively recognize and evaluate the adaptive transformation characteristics of the spatial structure of each village, and finally put forward the organizational path from local promotion to overall optimization.

4.1 Optimization path 1: the effective path direction of resource optimization shifts from public service allocation to industrial factor accumulation

The comprehensive fitness scores of the 8 combinations were measured by using the contribution values of the result data (Fig. 11). In 2010, the comprehensive fitness of the first gradient "1-1-1" type village was the highest, which was followed by the second gradient "1-0-1 > 1-1-0 > 0-1-1", and the third gradient "1-0-0 > 0-0-1 > 0-1-0". For example, if the third gradient "0-1-0" type village wants to improve the overall fitness at the fastest speed, because the comprehensive index of the two types with high fitness "0-1-1" is greater than "1-1-0" and "1-0-1", the optimal path is "0-1-0" to "0-1-1" and finally to "1-1-1". Therefore, it can be seen that when the traffic foundation is improved in an all-round way, in 2010, the public service category will have a more obvious gain effect than the industrial category in the selection of optimization factors. In the middle of 2019, the comprehensive adaptability of the second gradient combination is "1-1-0 > 1-0-1 > 0-1-1", indicating that at the post-poverty alleviation stage, the optimization of industrial elements is a more effective choice **Fig. 11** Schematic diagram of combination type optimization path from 2010 to 2019 based on NK model

for the overall improvement of the spatial structure adaptability of each village.

The difference in the optimization path between 2010 and 2019 mainly comes from the phased guidance of the construction of western mountainous villages, towns and their benefits. From the above optimization direction, we can see that the optimization of local public service system in 2010 can promote the global optimization of the overall spatial structure adaptability of Xinglong Town more effectively, and that in 2019 depends more on the drive of industrial system. This result is basically consistent with the current rural development situation. At the poverty alleviation stage, the upgrading of human settlements and industrial cultivation are key construction projects promoted by western mountainous villages and towns, but the spatial materialization allocation of public services is more direct for the agglomeration of population factors, and the cultivation of industries often requires more

time for transition. At the current post poverty alleviation stage, the top-down policy organizations in rural areas are gradually withdrawn, which requires the expansion of the independent development capacity of villages and towns. At this stage, industrial production will bring more gain effects to the stability and agglomeration of rural resources. For example, the industrial projects established by using the "three-dimensional poverty alleviation model" have begun to take shape in some villages, forming tourism + health preservation, commerce and trade, food and drug safety, besides, agritainment and other villages adopt industrial spatial structures, such as leading industries and income-increasing projects.

4.2 Optimization path 2: kinetic energy synergy in spatial structures

It can be seen from the above analysis that in the town space, the regional external output path and the growth node of spatial resources are highly related and complementary, and the development potential of nearby villages and towns is greater. First of all, the selection and optimization of the village construction project in the circle of the development center are an important direction for the town village system under the land and space planning to build a stable dynamic structure and support the overall effective development of the region. Based on the adaptability transformation characteristics of the spatial structure of Xinglong Town and the adaptability level of the existing villages, the optimization strategies of the three spatial structures of the core circle, the secondary central village circle and the surrounding scattered characteristic villages in Xinglong Town are put forward (Fig. 12). Firstly, in the utmost core circle of the town, the current fitness level shows a good matching degree of regional mobility and living functions, but the production dynamic force is weak. At the next stage, the village should break through the limitation of internal production capacity as soon as possible, forming the interactive relationship between industries in the town under the help of the flow of the central region, and strengthening the kinetic energy of the central circle of the town to drive benefits. Secondly, the coincidence of tourism landscape resources between the town center of Xinglong Town and the core Tiankeng Difeng Scenery is high, and the neighboring villages should consider more tourism-service-supporting facilities and the shaping of relevant characteristic industrial culture in the structural functions of towns and villages. For the development of the circle structure of secondary central villages, in addition to strengthening the connection and flow with towns and external resources, we should also strengthen the integration and agglomeration of surrounding development elements. The central village of Jingzhu community in the north is also supported by certain Tiankeng Difeng Scenery core landscape tourism resources and the transportation advantage of strong connection to the outside world. At present, individual villages in the north are somewhat disconnected from the comprehensive development level of the circle. Combined with the reality and referring to the above adaptive optimal path, these villages should choose the improvement of production kinetic energy as the most effective breakthrough direction, that is, to build a faster connection path with the Tiankeng Difeng Scenery joint, and build sightseeing agriculture and rural tourism-supporting-service facilities with strong landscape display related to its functions. The overall circle level of Fangdong Central Village in the middle and Gaomiao Community Central Village in the west is not as good as the development level of the middle and north of Xinglong Town. However, the

improvement of its external traffic mobility in recent years and the construction of the demonstration node for the integration of agriculture and tourism in Longmen Village make the development of these two sub-center circles have a certain resource integration development, and Gaoping Village and other villages can consider belt type attachment linkage, and strengthen the agglomeration and deepening of elements of rural tourism characteristic cultural industry, alpine vertical agriculture and central community life service circle on the basis of traffic connection.

5. Conclusions

Under China's special development system, the development of villages and towns in Southwest China has experienced long-term and continuous system construction of poverty alleviation, which has compensated for the lack of development of regional villages. More resource elements adapt to the transformation in the space-time transformation of regional coordination and town/village optimization, and then produce more spatial benefits of agglomeration. Therefore, it is very important to fully understand the logic of rural development in poverty-stricken areas, and constantly build a new organizational order in the process of poverty alleviation to "post poverty alleviation" rural revitalization and land space governance. In this paper, the organizational adaptive changes and influence characteristics of rural spatial structure in poor areas are studied and analyzed under the background of poverty alleviation and transformation society. Combined with the measurement of various main characteristics of towns and villages, this paper includes a deep discussion of the micro development and related spatial structure optimization in rural areas in poor areas, so as to provide a reference for a more timely and effective implementation path of rural development planning in subsequent sustainable development.

This study suffers two limitations which have to be noted. Firstly, the fitness analysis index of spatial structure is limited by the availability, leading to the insufficient coverage of spatial structure types. Secondly, the observation period based on data and research phenomena is limited, and its accuracy has to be compared and tested in a longer time and space sample period.

Declarations

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Ethical Approval

Not applicable

Consent to Participate

Not applicable

Consent to Publish

Not applicable

Authors Contributions

Conceptualization, X.L.; methodology, X.L.; validation, Q.S. and P.Y.; formal analysis, X.L.; investigation, X.L. and P.Y.; resources, X.L. and P.Y.; data curation, X.L.; writing—original draft preparation, X.L.; writing—review and editing, X.L.; visualization, X.L.; supervision, Q.S.; funding acquisition, P.Y. All authors have read and agreed to the published version of the manuscript.

Competing Interests

The authors declare no competing interests

Availability of data and materials

Data and materials will be available upon request.

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Figures

Figure 1

Location map of Xinglong Town

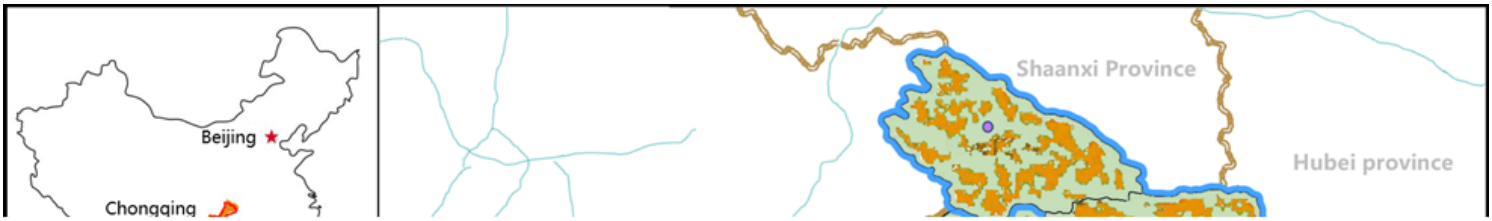

Figure 2

Spatial distribution map of poverty-stricken villages in Chongqing and Xinglong Town in 2014

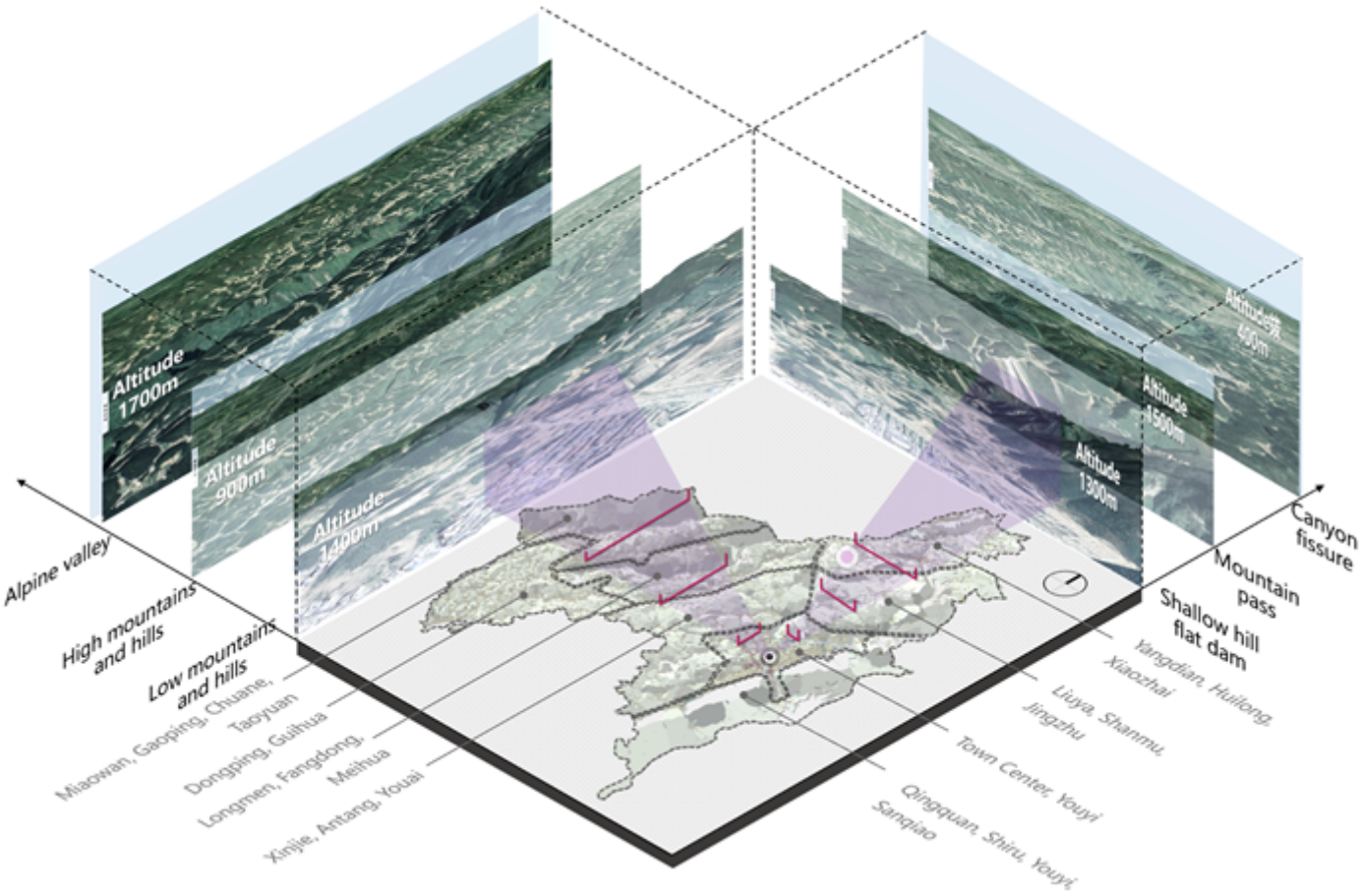

Figure 3

Geography section of Xinglong Town

Figure 4

Distribution of poor villages in Xinglong Town

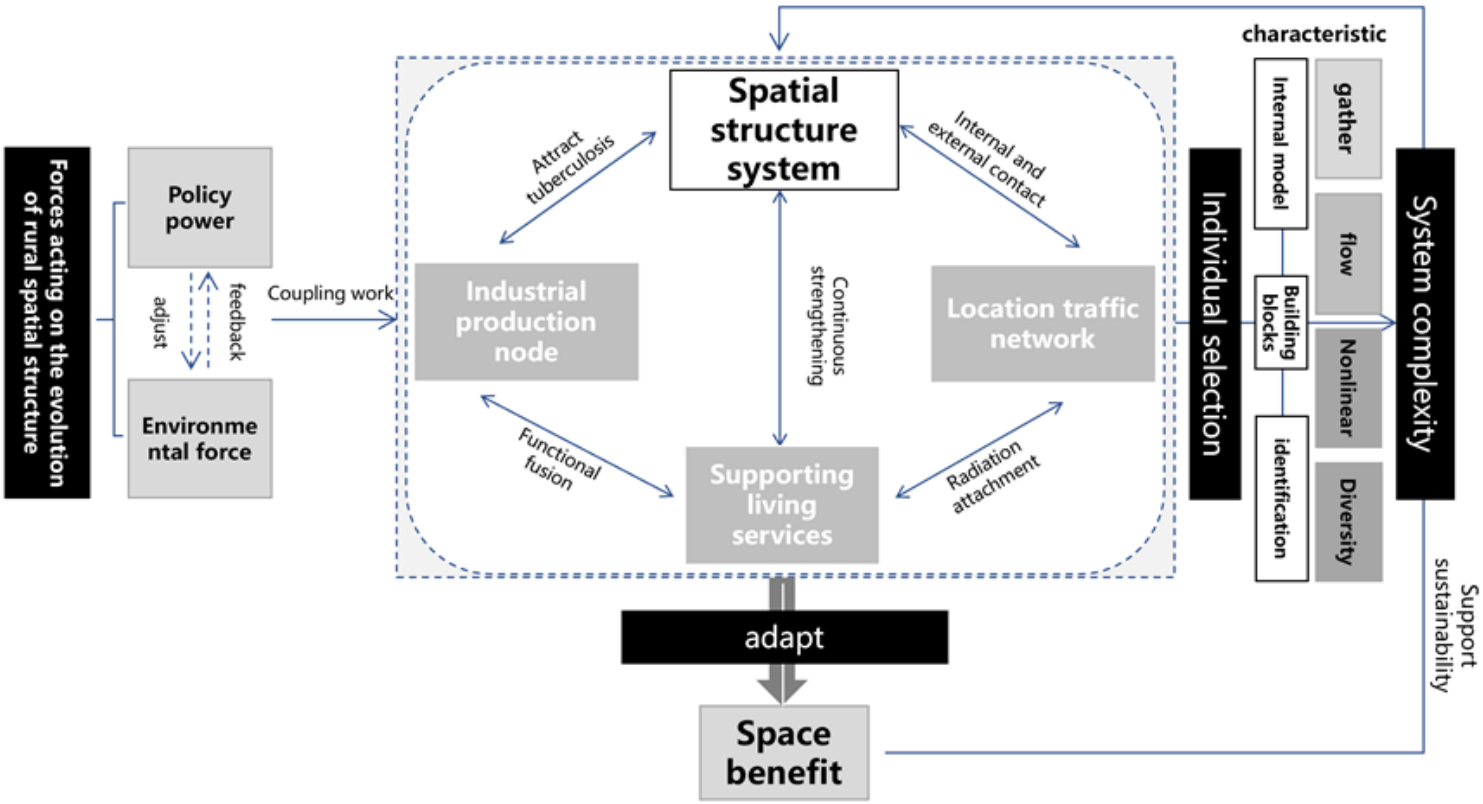

Figure 5

Schematic diagram of complex adaptive system of rural settlements spatial structure

Figure 6

Research framework

Figure 7

Interpretation of parameter meaning of NK model

Figure 8

Spatial distribution of fitness level of villages in Xinglong Town

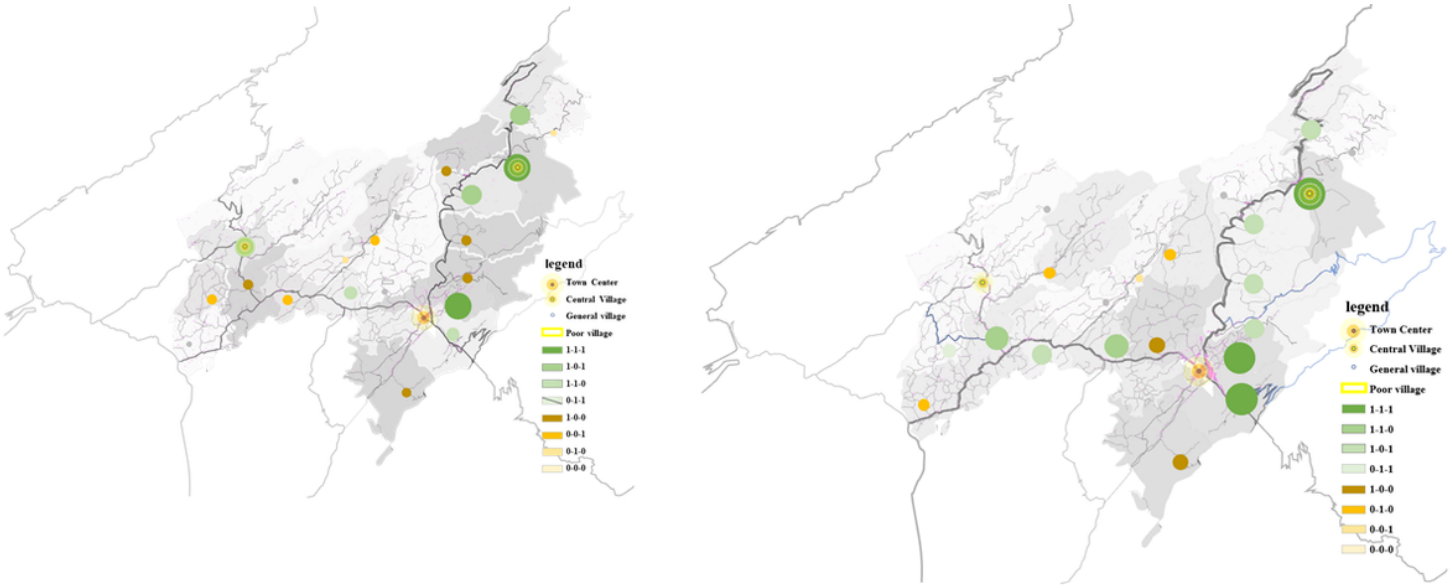

Figure 9

Comparison diagram of adaptability of spatial structure organization of Xinglong Town from 2010 to 2019

Figure 10

Comparison of fitness levels of villages from 2010 to 2019

Figure 11

Schematic diagram of combination type optimization path from 2010 to 2019 based on NK model

Figure 12

Schematic diagram of spatial structure organization optimization of Xinglong Town and village