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Article

# **Comprehensive Development Potential Evaluation and Spatial Pattern Optimization of Rural Residential Areas**

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**Abstract:** To optimize the layout of rural settlements in hilly areas, 10 indicators were selected from three aspects of nature, location, and infrastructure based on the research on the rural settlements in Miaoqian Town, Dangyang City where the development potential was evaluated and graded. The result shows that the areas of rural residential areas in the first-, second-, third- and fourth-level development potential areas were 342.23, 337.84, 172.66, and 155.91 hm<sup>2</sup>, respectively, accounting for 33.93, 33.49, 17.12, and 15.46%. According to the level of the potential of comprehensive development, the residential areas were divided into four categories: scale agglomeration, renovation and improvement, control and expansion, and consolidation and relocation. Corresponding optimization measures were proposed in this study for each category. The study result provides a reference for the optimization of the spatial pattern of residential areas in Miaoqian Town and also a research idea for the optimization of the same type of residential areas.

Keywords: Rural settlements, Spatial layout, Evaluation of development potential, AHP, Optimization measures

# 1. Introduction

For farmers' production and life, rural settlements are an important part of rural land use [1]. Under the continuous increase in the urbanization rate and the gradual reduction of the rural population, the rural land use needs to be intensive and compact, and the smart growth of rural development through the smart use of the living space [2] is an important way to improve the efficiency of land and resource utilization. Scholars have researched the optimization of the spatial layout of rural settlements and the location, spatial distribution characteristics, layout evolution, and policy guidance of rural settlements to discuss the optimization of settlements layout and spatial reconstruction [3–5]. Chinese scholars have recently started research on related issues such as the spatial distribution characteristics of rural settlements [6] and optimization strategies [7]. Liu et al. classified rural settlements from the aspects of urban radiation, layout suitability, and land coordination and put forward corresponding optimization measures [8]. Li et al. selected four types of evaluation factors: location conditions, production attributes, natural conditions, and social economy, and used random forest algorithm to evaluate the suitability of rural residential land in the Hechuan District [9]. Jia et al. analyzed the distribution pattern of residential areas in Lingshui County, Hainan Province using Voronoi diagrams, and proposed four optimization suggestions based on the results of the suitability evaluation [10]. To sum up, the research on the layout and optimization of rural settlements has become increasingly mature, and the research perspectives and methods have been gradually enriched. However, there are few studies on the evaluation of the development potential of settlements. Thus, we explored the optimization scheme of the spatial layout of rural residential areas by calculating the comprehensive development potential of Miaoqian town of Dangyang city with the data for 2020. The result provides multiple impact factors and ideas for the optimization of the same type of residential areas.

#### 2. Study Area

Dangyang city is located at the easternmost tip of Yichang City, Hubei Province, and in the transition zone from western Hubei mountain to Jianghan Plain. The terrain of the whole city varies greatly and there are many soil types. Miaoqian town is located on the West Bank of Zhanghe River in the northwest of Dangyang city. Its geographical location is  $111^{4}1'34''-111^{55'51''}$  east longitude and  $30^{4}9'58''-31^{5'9''}$  north latitude. The landform is mainly hilly. The terrain is high in the northwest and low in the southeast. Miaoqian town is 13 km away from downtown Dangyang. It is adjacent to Yuan'an County in the West and North, the Baling street in the south, Zhanghe River in the East, Yuxi town across the river, and 348 national highway and Jiaoliu railway pass



through. In 2020, the town has 18 administrative villages, 13991 households in total, with a total population of 38463, including 35581 agricultural people, and a town area of 33240.23 hm<sup>2</sup>. The rural homestead area is 1008.64 hm<sup>2</sup>, Cultivated land area is 8593.99 hm<sup>2</sup>.



Fig. 1. Elevation map of Miaoqian Town.

Fig. 2. Slope map of Miaoqian Town.

#### 2.2. Data Source and Data Preprocessing

The land use maps, trunk lines, and river systems used in this study were extracted from the data of the third national land survey in Dangyang City. The elevation data and geological hazard data of Miaoqian Town were from the Dangyang Municipal Bureau of Natural Resources and Planning and Dangyang City POI. The data was crawled through the Gaode map. The relevant social and economic data comes from the "Dangyang 2021 Statistical Yearbook" by Dangyang Statistics Bureau. As the main part of rural residential land, the land use characteristics directly reflect the distribution pattern of rural residential land to a large extent. Thus, we selected the homestead in Miaoqian Town as the rural residential land. After preprocessing, a total of 3790 residential patches were included in this study.

#### 3. Research Methods

#### 3.1. Spatial Layout of Rural Settlements

In statistics, kernel density estimation is often used to infer the distribution of population data based on limited samples. It is a nonparametric estimation method for distribution density [11] (Eq. (1)).

$$f(X) = \frac{1}{nh} \sum_{i=1}^{n} K\left(\frac{X_i - X}{h}\right) \tag{1}$$

where f(X) is the kernel density value; *n* is the number of patches of rural settlements, *h* is the search radius, *K* is the kernel function, and  $(X_i - X)$  is the *X* th settlement to the *i* th settlement point distance. In this study, the results of kernel density estimation were used to analyze the spatial layout of rural settlements in Dangyang City. The larger the value, the higher the aggregation degree of rural settlements, and vice versa.

#### 3.2 Evaluation of Comprehensive Development Potential of Rural Settlements

Many factors affect the layout and development of rural settlements, not only external objective factors such as natural environment and geographic location, but also internal driving factors such as resources, facilities, and economic development. Based on scientificity, comparability, and data availability, we selected a total of 10 indicators from three aspects, including natural

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factors, location factors, and infrastructure factors, to establish an evaluation index system by combining the actual situation of Miaoqian Town.

# (1) Natural factors

Natural factors have restrictions on the site selection of rural residential areas. Since ancient times, people have chosen natural locations in the livable environment as their places of residence. In this study, elevation, slope, aspect, distance from geological disaster sources, and distance from water sources have been selected as evaluation indicators. The higher the elevation, the more complex the terrain, which is not conducive to the construction of rural settlements. The increase in slope has a great impact on the villagers' housing construction and agricultural production. The lighting is better when the slope faces south. There are 22 potential geological disaster points in the study area, where the loss of life and property of local villagers are easily caused. Water resources are the essential material for human production and life so the construction site selection of rural residential areas has a certain tendency to be close to water [12].

## (2) Location factors

The location has a direct impact on the development direction and agglomeration of rural settlements. The distance to the town and the distance to the main traffic road was selected as the evaluation indicators. With regional development, the location of county government and town (township) government has a strong attraction to rural settlements in the surrounding areas. Trunk roads can guide the agglomeration of settlements, and the closer to the trunk roads, the more convenient for villagers to travel and material transportation.

#### (3) Infrastructure factors

With the development of the economy and society, people's demand for infrastructure is increasing day by day. We selected the distance from commercial points, the distance from medical facilities, and the distance from primary school as evaluation indicators. Residential areas close to commercial sites have more employment and sales opportunities for agricultural and sideline products while obtaining higher living convenience and having higher comprehensive development potential. The increased distance from medical facilities increases the possibility of residents not seeking medical treatment after illness [13]. The distance from school affects students' studies and life and impacts students' families.

#### 3.2.2. Quantification of Evaluation Indicators and Determination of Weights

We used the Likert five-point scale to assign values to various evaluation indicators. The higher the score, the greater the development potential. The weights of indicators reflect the importance of each indicator. This study adopted the Analytic Hierarchy Process in the subjective weighting method to determine the weight of each indicator [14,15]. The division, data standardization, and weight determination of the evaluation indicators for the comprehensive development potential of rural settlements in Miaoqian Town are shown in Table 1.

Target		T 1' / 1		<b>N</b> 7 ' 1 (				
layer	Criterion layer	Indicator layer	Level I	Level II	Level III	Level IV	Level V	weights
Compre- hensive develop- ment potential of rural settle- ments	Natural factors (0.3276)	Elevation /m	≤100	100-150	150-200	200-250	>250	0.0553
		Slope /(°)	≤5	5-10	10-15	15-20	>20	0.0733
		Aspect	South	Southeast, southwest	East, west	Northeast, northwest	North	0.0709
		Distance from the geological disaster point /m	>250	200–250	150-200	100–150	≤100	0.0681
		Distance from water source /m	≤500	500-1000	1000-1500	1500-2000	>2000	0.0600
	Location factor (0.3769)	Distance from town /m	≤1500	1500-3000	3000–4500	4500-6000	>6000	0.1735
		Distance from main road /m	≤500	500-1000	1000–1500	1500-2000	>2000	0.2034

Table 1. Evaluation Index System of Comprehensive Development Potential of Rural Residential Areas.



	Distance from business point /m	≤1000	1000–2000	2000-3000	3000-4000	>4000	0.0992
factor	Distance from medical facility /m	≤1000	1000-2000	2000-3000	3000-4000	>4000	0.1036
(0.2955)	Distance from primary school /m	≤1500	1500-3000	3000-4500	4500-6000	>6000	0.0927

#### 3.2.3. Comprehensive Development Potential Score

The weighted superposition analysis of each evaluation index was carried out, and the evaluation scores were weighted and summarized to calculate the comprehensive development potential score of rural residential areas in Miaoqian Town by using Eq. (2).

$$Z_i = \sum_{i=1}^n A_{ii} \times B_{ii} \tag{2}$$

where  $Z_i$  is the comprehensive development potential score of settlement I, *n* is the number of evaluation indicators,  $A_{ij}$  is the quantitative score of the *j* th evaluation index, and  $B_{ij}$  is the corresponding weight.



Fig. 3. Kernel density map of rural settlements.



Fig. 4. Classification of comprehensive development potential of rural settlements.

### 4. Results and Analysis

# 4.1. Morphological Characteristics of Spatial Layout of Rural Settlements

Using the feature-to-point tool in ArcGIS10.6 software, the center of the rural settlements in Miaoqian Town was found, and then the density map of the distribution of rural settlements in Miaoqian Town was generated by the method of kernel density analysis. The overall layout of rural settlements in Miaoqian Town is characterized by aggregation in the southeast and scattering in the northwest. Among them, the high-density areas are mainly distributed in Jinggang Village, Yanji Village, Tongshuya Village, and Yingxiong Village in the southeast. In the northwest, the characteristics of band-like agglomeration are also formed along with Shima Village, Miaoqian Village, and Lidian Village. These areas are close to townships or main roads and have good development conditions. Yanji Village has the town government, and several residents moved to urban areas, so the density of rural settlements is lower than that of Jinggang Village on the south side. The low-density areas are mainly distributed in Gonghe Village, Shanfeng Village, Shahe Village, and Changchun Village in the northwest. Gonghe Village is located in a water source protection area, and there are few settlements. While mountain villages with higher altitudes are located with complex terrain and large slopes, which

are not conducive to the life of residents, resulting in a low density of settlements. The sub-high-density areas are mainly concentrated in Qingpinghe Village, Xuguang Village, Liwan Village, Anshan Village, Linqiao Village, Tonghu Village, and Pujisi Village. These are mainly dominated by hilly areas as a transition from high-density areas to low-density areas.

### 4.2. Classification of Comprehensive Development Potential of Rural Settlements

There are 3790 evaluation units of rural settlements in Miaoqian Town with a total area of 1008.64 hm<sup>2</sup>. The comprehensive development potential score ranges from 1.46 to 5.00, with an average value of 3.18 and a standard deviation of 0.76. In this study, the natural breakpoint method was selected to classify the comprehensive development potential of the rural settlements in Miaoqian Town. According to the classification results, the rural settlements in Miaoqian Town were divided into four levels. The potential value range of the first-level development potential area was 1.46–2.53, the potential value range of the second-level development potential area is 3.21–3.88, and the potential value range of the fourth-level development potential area is 3.88–5.00. The results are shown in Fig. 4.

## 4.3. Spatial Distribution of Rural Settlements at Different Levels

Miaoqian Town has 18 administrative villages including Yanji Village, Tongshuya Village, and Linqiao Village. The comprehensive development potential of rural residential areas is generally at a medium and high level, and the statistical results are shown in Table 2. The area of rural residential areas in the first-level development potential area is 342.23 hm<sup>2</sup>, accounting for 33.93% of of the total area. This type of residential area has obvious advantages in development. It is mainly distributed around towns or market towns, and most of them are distributed along the main traffic roads such as National Highway 348. There are more distributions in Liwan Village, Tonghu Village, and Yanji Village, all of which exceed 50 hm<sup>2</sup>. Among them, the east side of Tonghu Village is close to Yuxi Town, which has the location advantage of cross-regional development. The area of rural residential areas in the second-level development potential area is 337.84 hm<sup>2</sup>, accounting for 33.49% of the total area. Most of these settlements are distributed in the peripheral areas of the first-level development potential area, and there is a certain distance from the core gathering area. They are mostly distributed in Jinggang Village, Qingpinghe Village, and Tongshuya Village. There is also a small amount of distribution in Miaoqian Village in the northwest where comprehensive conditions are relatively weak. The area of rural residential areas in the third-level development potential area is 172.66 hm<sup>2</sup>, accounting for 17.12% of the total area. The distribution of such settlements is relatively scattered, except for Liwan Village and Xuguang Village, which cover the remaining 16 villages, with more distribution in Shima Village. The area of rural residential areas in the fourth-level development potential area is 155.91 hm<sup>2</sup>, accounting for 15.46% of the total area. This type of residential area is distributed in the northern region with relatively worse economic conditions. Most of them are located in mountainous areas, mainly in Gonghe Village, Lidian Village, Pujisi Village, and Changchun Village. Among them, 99.33% of Gonghe Village residential areas belong to this category. Gonghe Reservoir, as a national first-level freshwater source protection zone, has a great restrictive effect on the development of Gonghe Village's settlements.

Table 2. Spatial distribution of rural settlements at all levels in Miaoqian Town.

	Level I		Level II		Level III		Level IV		T ( 1
Administrative Village	Area/ hm²	Proportion	Area/ hm²	Proportion	Area/ hm²	Proportion	Area/ hm²	Proportion	/ hm <sup>2</sup>
Anshan Village	16.94	38.55%	18.10	41.20%	8.82	20.06%	0.08	0.19%	43.94
Gonghe Village	0.00	0.00%	0.00	0.00%	0.20	0.67%	29.61	99.33%	29.81
Jinggang Village	36.12	40.48%	52.67	59.03%	0.44	0.49%	0.00	0.00%	89.23
Lidian Village	0.00	0.00%	1.52	2.81%	19.20	35.47%	33.41	61.72%	54.12
Liwan Village	52.73	99.96%	0.02	0.04%	0.00	0.00%	0.00	0.00%	52.75
Linqiao Village	1.61	4.11%	21.04	53.79%	13.55	34.62%	2.92	7.47%	39.12
Miaoqian Village	0.00	0.00%	50.96	69.45%	19.12	26.06%	3.29	4.49%	73.38
Pujisi Village	0.00	0.00%	0.00	0.00%	4.20	10.23%	36.83	89.77%	41.03
Qingpinghe Village	8.77	11.98%	58.64	80.16%	5.75	7.86%	0.00	0.00%	73.15
Shahe Village	23.16	47.68%	8.60	17.71%	12.98	26.72%	3.84	7.90%	48.57
Shanfeng Village	0.06	0.30%	6.75	35.40%	7.01	36.74%	5.26	27.57%	19.08
Shima Village	0.00	0.00%	2.51	3.50%	54.35	75.96%	14.70	20.54%	71.56



Tonghu Village	50.61	74.59%	12.59	18.55%	2.83	4.17%	1.82	2.69%	67.86
Tongshuya Village	34.17	34.46%	63.04	63.57%	1.96	1.98%	0.00	0.00%	99.18
Xuguang Village	26.31	55.97%	20.69	44.03%	0.00	0.00%	0.00	0.00%	47.00
Yanji Village	62.65	90.81%	6.12	8.87%	0.22	0.32%	0.00	0.00%	68.98
Yingxiong Village	29.11	50.04%	14.58	25.06%	13.33	22.92%	1.15	1.98%	58.17
Changchun Village	0.00	0.00%	0.00	0.00%	8.70	27.45%	22.99	72.55%	31.70
Total	342.23	33.93%	337.84	33.49%	172.66	17.12%	155.91	15.46%	1008.64

#### 4.4. Optimization of the Spatial Layout of Rural Settlements based on the Evaluation of Comprehensive Development Potential

According to the comprehensive development potential classification of rural residential areas in Miaoqian Town, they were divided into four types: scale agglomeration type, renovation and improvement type, control expansion type, and consolidation and relocation type.

#### 4.4.1. Scale Agglomeration Type

The residential area in the first-level development potential area was defined as a scale agglomeration type, covering an area of 342.23 hm<sup>2</sup>. This type of settlement is generally closer to the central town or market town, with obvious location and geographical advantages, and a good social and economic foundation. Among them, more than 90% of the settlements in Liwan Village and Yanji Village belong to this type. In future planning, attention must be paid to the improvement of infrastructure to improve its expansion, attract scattered surrounding settlements to gather, and set aside a part of the land as the resettlement and development reserve land for villagers. In recent years, Miaoqian Town has vigorously developed sightseeing tourism and leisure agriculture, and the living standards of the villagers have been continuously improved. The scale agglomeration settlements can be used as an extension of the urban service scope, which is conducive to the promotion of urbanization in Dangyang City.

#### 4.4.2. Remediation and Improvement Type

The residential area in the second-level development potential area was defined as a remediation and improvement type, covering an area of 337.84 hm<sup>2</sup>. This type of settlement is a certain distance from the central town, mainly distributed in the southern plains, and a small amount in the northern hillocks. Its regional characteristics are small fluctuations in terrain, good traffic conditions, abundant water resources, and a certain population size, but the degree of land use is not high, and the internal development potential is large. According to the land use planning of Dangyang City and the red line for the protection of permanent basic farmland, it is recommended to carry out land consolidation and rational development of such residential space on the premise of retaining the original texture and integrity. Through the management of the village living environment, the potential of rural residential land use is fully released. The space of rural residential areas can be decreased in an orderly manner, and the level of intensive use of rural residential land improves.

#### 4.4.3. Control Expansion Type

The residential area in the third-level development potential area was defined as a controlled expansion type, covering an area of 172.66 hm<sup>2</sup>. The distribution of such settlements is relatively scattered, far from central towns, roads, and infrastructure, and there is great resistance to development. Several settlements have gradually disappeared with the departure of the elderly and population migration. In the process of optimizing the layout of residential areas, the expansion of such residential areas needs to be controlled. Focusing on local optimization and on-site arrangement through the arrangement of infrastructure and policy guidance, the connection with the surrounding central villages needs to be strengthened..

#### 4.4.4. Consolidation and Relocation Type

The residential area in the fourth-level development potential area was defined as the controlled expansion type, covering an area of 155.91 hm<sup>2</sup>. This type of residential area is mainly distributed in the northeastern and northwestern mountainous areas, with complex terrain, inconvenient location conditions, and imperfect infrastructure. Many residential areas have been no longer suitable for people's production and life, and the problem of hollowing out villages is obvious. Regional development and construction are difficult, and it is easy to cause pollution and damage to ecological forest reserves and water conservation areas. Therefore, this residential area should be relocated from different places and resettled to areas with better comprehensive conditions nearby. In the implementation process, it is necessary to comprehensively consider the willingness of the villagers and the cost of relocation,

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gradually advance in stages, and properly handle the social security issues of the villagers after the relocation. Measures such as reclamation and reforestation of the replaced rural residential land need to be carried out to improve the regional ecological environment.

# 5. Conclusions

Taking Miaoqian Town, Dangyang City as the research object, we analyzed the distribution characteristics of rural settlements with kernel density based on the data of rural homesteads. An index system was established to quantitatively evaluate its comprehensive development potential, and optimization measures were explored for the spatial layout of residential areas at different levels. The result indicates the following.

- (1) The overall layout of rural settlements in Miaoqian Town is characterized by agglomeration in the southeast and dispersal in the northwest. The high-density areas are mainly concentrated in the southeastern plains, while low-density areas are distributed in the hills and mountains in the northwest. However, small-scale belt-like clusters have been formed in Shima Village, Miaoqian Village, and Lidian Village, which are distributed along both sides of the county road.
- (2) The comprehensive development potential of rural residential areas in Miaoqian Town is evaluated to provide data for the optimization plan for the spatial layout of residential areas. The results show that the overall development potential of rural residential areas in Miaoqian Town is relatively large. The area of residential areas in the first- and second-level development potential areas is 680.07 hm<sup>2</sup>, accounting for 67.42% of the total residential areas.
- (3) According to the classification of the comprehensive development potential value of rural settlements, the rural settlements in Miaoqian Town are divided into four types: scale agglomeration type, renovation and improvement type, control expansion type, and consolidation and relocation type. According to the type, scientific and reasonable optimization suggestions were put forward. The results provide a decision-making reference for land use planning and land consolidation in Miaoqian Town and ideas for the optimization of the same type of residential areas.

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