Optimization of the spatial pattern of land use in mountain towns -- a case study of Yuexi county, Anqing city, Anhui province

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Abstract. There are a lot of unused land and land type distribution problems in the land use layout of mountain towns. Mountainous area is widely distributed in China. In the past, scholars focused on the big cities in the planning of land use layout, but paid little attention to the towns in mountainous area. This paper takes Yuexi county, Anqing city, Anhui province as the research area, and based on the principle of multi-objective particle swarm optimization. Firstly, the current land use map was pretreated with unused land and aggregation. The unused land was converted into a high-grade land type according to the suitability map. The aggregation processing increases the aggregation of a certain land type in the eight neighboring areas. Then, the multi-objective function is combined with the particle swarm optimization (PSO) algorithm, and the PSO algorithm is used to update the iterative operation, and the optimal layout scheme is selected. Finally, from the area changes before and after the optimization, economic, ecological benefits and spatial layout of the evaluation. The results showed that the optimized economic and ecological benefits were 9092.7397 million yuan and 40.09377 million yuan higher than the original, respectively. Moreover, after the optimization, the landscape fragmentation index of the original layout was improved by 0.019930486 per hectare compared with that of the original, and the aggregation was greatly improved in space, so the research has corresponding value.

1. Introduction

Mountainous area is widely distributed in China, accounting for 69.1% of the total area of China. Due to the complexity of the geographical forms in the mountainous area, the land distribution in mountainous area is scattered and the coverage of infrastructure is small. In addition to the poor living conditions, there are serious land waste, low ecological benefits and backward economic development. Since the 19th National Congress, apart from developing the economy and improving people's living standards, we have also proposed to promote green development. Therefore, it is of great significance and practical value to rationalize the unreasonable land use pattern and promote the implementation of policies.

Current methods for optimal allocation of land use can be divided into three categories according to modeling theory. The first category is land planning based on suitability evaluation. Tang Z B [1] aimed at rural settlements in karst areas, Vasu D [2], Zhang L [3] et al. replanned and distributed the land according to the suitability of the land in the study area to find the most suitable land layout for the development of this area. The second is to plan the land according to the theories of landscape
ecology. Uy P D [4] uses GIS for land suitability analysis and puts forward the development plan of urban green space. Then, the ecological factor threshold method is used to quantify the green space area. Finally, landscape ecology principle is used to carry out land use planning of green space. Wei D [5] used landscape ecology to optimize the spatial layout and quantity allocation of land use in low-mountain and hilly villages. Third, the land is planned according to the theory of complex adaptive systems. Cellular automata, multi-agent and multi-objective models are commonly used in land use optimization. Yuan M [6] used a multi-agent system and genetic algorithm to optimize land use allocation. Gholizadeh S [7] combines cellular automata with particle swarm optimization to optimize the land layout. The combination of intelligent algorithm and multi-objective model can optimize land use. Sahebgharani A [8], Xiang Q [9] and Hai H [10] respectively combined multi-objective with particle swarm optimization, genetic algorithm and ant colony optimization to optimize the land.

Vulević T [11] used the linear programming method to optimize the land use of mountain farms without considering the problems of aggregation and unused land. Although Sahebgharani A [8] promoted the aggregation objective function in Isfahan Valley of Iran, it did not deal with the unused land. The current land use optimization algorithm is not effective in dealing with a large number of unused land and aggressively dispersed layout problems in mountainous area. In order to solve the problem of unreasonable layout in the mountainous area, this paper carries out aggregation treatment and pretreatment of unused land, and takes the processed land use status map as input data for the experiment. Then multi-objective and PSO algorithms are used to optimize the land layout in mountainous areas.

PSO has memory function and can learn previous experience to get the optimal solution. And PSO algorithm is relatively simple. In this paper, the multi-objective model is combined with the PSO algorithm to pay more attention to ecological benefits and aggregation while considering economic benefits. In the process of index evaluation, the index of landscape patterns in landscape ecology is introduced to verify the spatial optimization of land layout in mountainous towns.

2. Overview of the research area and data pre-processing

2.1. Overview of the research area

Yuexi County is located in Anqing City, Anhui Province. It is in the southwest of Anhui Province and the west of Anqing City. It is the hinterland of the Dabie Mountains. The area is 2398 square kilometers between E115° 55’ -116° 33’ and N30° 39 ‘- 31° 11’. The terrain of Yuexi County as a whole is medium and low mountains, with the slope ranging from 30° to 60°. The average altitude is 600m. The highest terrain is located in the northwest corner, and the descending direction is southward. Across the Huaihe River and the Yangtze River, the north subtropical humid monsoon is the climate type of Yuexi County, with the average temperature of 14.4 degrees Celsius and the average annual precipitation of 1445.8 millimeters. Vegetation coverage is greater than 75%. Yuexi County includes 14 towns, 10 townships and another development zone. By the end of 2018, the registered population was 412418, up 7.7 percent year-on-year. The population density was 172 people per square kilometer. China's gross domestic product (GDP) reached 9.87505 billion yuan, of which 14.5 percent was the primary industry, 54.3 percent was a secondary industry and 31.2 percent was tertiary industry. The per capita income of urban residents was 25987 yuan, up 8.5 percent year-on-year, and that of rural residents was 11676 yuan, up 10.6 percent year-on-year.

2.2. Data preprocessing

The main data sources of the experiment are as follows: (1) Land use status data: This data is retrieved from GF1 data (16m×16m) through remote sensing cloud mart and through eCognition software interpretation. (2) DEM data: (30m×30m) were downloaded from remote sensing cloud mart and obtained by boundary shear. (3) Adjustment and Improvement Plan of General Land Use Plan of Yuexi County (2006-2020) [12] (4) Anhui Statistical Yearbook 2017 [13] (5) Vegetation inversion data obtained from GF1 data by ArcGIS software inversion. (6) Slope, aspect and topographic map all have
DEM data extracted by ArcGIS software. The suitability map of suitable cultivation, garden, forest and grazing is divided into four grades. The higher the grade is, the higher the suitability will be. The land use suitability distribution map is reclassified after superposed by the raster calculator function of ArcGIS software. Among them, the suitability of suitable cultivation = 0.15DEM + 0.21slope + 0.05 aspect + 0.13topography + 0.18water + 0.28cultivated land. The other three suitability maps are similar. The coefficients are calculated by the Analytic hierarchy process (AHP) according to the research area. Considering the data size and operation speed, all data are resampled to 100m×100m grid.

3. The research methods

3.1. The establishment of a multi-objective system

3.1.1. Economic benefit function

\[ F_{1\max} = \sum_{i=1}^{M} \sum_{j=1}^{N} \sum_{k=1}^{K} E_{ij}^{k} x_{ij}^{k} \]  

(1)

In formula 1, i and j represent the number of rows and columns where the pixel is after rasterization, and k represents the corresponding land type. \( E_{ij}^{k} \) is the GDP (unit area) calculated by the current year price of the land type k corresponding to the location of a pixel (i, j).

Reference Liu J H[14] economic efficiency coefficient method in the article, the reference "Anhui statistical yearbook 2017"[13] in various land types corresponding to the gross domestic product, get the corresponding economic coefficient as follows: The cultivated land is 11.0890 million yuan /hm\(^2\), the forest land is 170599 yuan /hm\(^2\), the water is 13.8610 million yuan /hm\(^2\), the unused land is 0, the building land is 195.626 million yuan /hm\(^2\), the grassland is 181600 yuan /hm\(^2\), and the garden land is 283800 yuan /hm\(^2\).

3.1.2. Ecological benefit function

\[ F_{2\max} = \sum_{i=1}^{M} \sum_{j=1}^{N} \sum_{k=1}^{K} e_{ij}^{k} x_{ij}^{k} \]  

(2)

In formula 2, i and j represent the number of rows and columns where the pixel is after rasterization, and k represents the corresponding land type. \( e_{ij}^{k} \) is the ecological benefit coefficient corresponding to land type k at the location of image pixel (i, j).

According to the method in Liu J H[14], the corresponding ecological coefficient was obtained as follows: cultivated land was 5.91 thousand yuan /hm\(^2\), forest land was 18.2 thousand yuan /hm\(^2\), unused land was 360 yuan /hm\(^2\), water was 360 yuan /hm\(^2\), building land was 360 yuan /hm\(^2\), grassland was 6208 yuan /hm\(^2\), and garden land was 8360 yuan /hm\(^2\).

3.1.3. Compactness objective function

\[ F_{3\max} = \sum_{i=1}^{M} \sum_{j=1}^{N} \sum_{k=1}^{K} \alpha_{ij}^{k} x_{ij}^{k} \]  

(3)

In formula 3, i and j represent the number of rows and columns where the pixel is after rasterization, and k represents the corresponding land type. \( \alpha_{ij}^{k} \) is the aggregation coefficient corresponding to the location of pixel (i,j).

In the experiment, the aggregation coefficient is determined by the number of pixels in the image 8 neighborhood space which is the same as the central pixel land type k. As shown in Figure 1, assuming these 8 neighborhoods, the aggregation coefficient corresponding to land type k = 2 was calculated. The calculation formula is shown in formula 4.

\[ \alpha_{ij}^{k} = x_{i-1,j}^{k} + x_{i+1,j}^{k} + x_{i,j-1}^{k} + x_{i,j+1}^{k} + x_{i-1,j+1}^{k} + x_{i-1,j-1}^{k} + x_{i+1,j+1}^{k} + x_{i+1,j-1}^{k} \]  

(4)
The aggregation coefficient of the land type $k=2$ in the 8 neighborhood is $\alpha_{ij}^k=1$.

![Figure 1. 8 neighborhood space.](image)

### 3.2. Constraint conditions

#### 3.2.1. Area constraints

The available land resources in the region are limited. The balance of land type in quantity and space layout should be paid attention to in the optimization of land use. The area of a certain type of land use should be within a certain range, as shown in formula 5.

$$M_k \leq \sum_{i=1}^{M} \sum_{j=1}^{N} x_{ij}^k \leq N_k$$

(5)

According to the overall land use planning of Yuexi County, the cultivated land area shall be greater than 16666.67 hectares, the lower limit of forest land shall be 179476.92 hectares, and the lower limit of water shall be 3162 hectares.

#### 3.2.2. Land type constraint

In rasterized image pixels, the land-use type in each pixel can only be unique. As shown in formula 6.

$$\sum_{k=1}^{K} x_{ij}^k = 1$$

(6)

#### 3.2.3. Aggregation constraint

In an 8-neighborhood space, the location of the upper, lower, left, and right pixels is at least one of the same types of land use as the current pixel. As shown in formula 7.

$$x_{(i-1)j}^k + x_{(i+1)j}^k + x_{(j-i+1)}^k + x_{(j+1)i}^k \geq 1$$

(7)

### 3.3. Optimization of land use allocation based on particle swarm optimization

#### 3.3.1. The mapping relationship of PSO on land layout

In the optimization of land use information, each particle in the particle swarm represents a land use layout configuration. The dimension of particles should be set according to the size of the research area. The dimension of Yuexi County is 237074. The particle velocity corresponds to the probability of converting one land type to another on the grid of the study area. The position of the particle can be $(l_1, l_2, \ldots, l_n)$, each $l$ corresponds to the value of the land type corresponding to the grid. The updating formulas of particle swarm velocity and position are shown in formula 8 and formula 9.

$$v_n(t) = \delta v_n(t-1) + c_1 r_1 [l_n(t-1) - l(t-1)] + c_2 r_2 [l_n(t-1) - \bar{l}(t-1)]$$

(8)

$$l_n(t) = l_n(t-1) + v_n(t-1)$$

(9)

Where, $\delta$ is the inertia factor, $c_1$, $c_2$ is the learning factor set as 2, $r_1$, $r_2$ is the random number from 0 to 1, $v_n$ is the particle velocity at a certain moment, $l_i$ is the individual optimal position at a certain moment, $\bar{l}$ is the global optimal position at a certain moment. The particle swarm size is set to 30.

#### 3.3.2. Encoding mode

In this paper, integer coding is adopted to divide the land types in the study area into seven categories, respectively labeled as 1, 2, 3, 4, 5, 6 and 7, corresponding to the unused land, water, garden, forest land, cultivated land, grassland and building land in the land types. For raster cells outside the boundary, MATLAB labels them as 127, and this part is removed during land type conversion without operation. When operating, mask operations should be performed for relatively fixed land types such as 2-water and 7-building land.
3.3.3. Calculation of fitness. Fitness is obtained by synthesizing the objective function. The objective function is further expressed as fitness, as shown in formula 10.

$$F_{\text{max}} = \frac{\alpha F_{1\text{max}} + \beta F_{2\text{max}}}{\gamma F_{3\text{max}}}$$

Where, $\alpha$, $\beta$, $\gamma$, and are the weights of corresponding functions, which should be set according to the characteristics of the study area, and set to 1, 0.5 and 1 respectively.

3.3.4. Preprocessing of land use status map. The present situation of land use was pretreated by aggregating and unused land. Aggregation treatment: if only the central grid is a land type within the 8 neighborhoods, it is converted to the same land type as the surrounding land type. Unused land processing: since unused land does not contribute significantly to economic and ecological benefits, it should be analyzed according to the suitability evaluation map of cultivated land, forest land, garden and grassland. If the grassland has the greatest adaptability on a certain grid, it will be converted to grassland, if the grassland and forest land are the same, it will be converted to either type, and then it will be screened and converted through the update of subsequent particles.

3.3.5. Flow of algorithm. (1) Encode the land use status map. (2) Preprocess the land use status map, including aggregation constraint and conversion of unused land. (3) Initialize particle swarm. (4) Calculate the fitness to obtain the historical best individual position and the global best position. (5) The velocity and position formulas are used to update the particle swarm. (6) Judge whether the end condition is reached; if it is, output the corresponding land use allocation plan. If not, return step (4).

4. Experiment and result analysis

4.1. Results and analysis of land use optimization

The layout comparison diagram before and after land use optimization is shown in Figure 2.

![Comparison diagram before and after optimization](image)

**Figure 2.** Comparison diagram before and after optimization.

After the optimization, the forest, cultivated land area increased, the garden land, grassland and unused land area decreased, and the building land area did not change significantly. In 2017, all types of land in Yuexi County before and after optimization and the area of change are shown in Table 1.

| Land Type     | Original Area (hm²) | Optimized Area (hm²) | Area of Change (hm²) |
|---------------|---------------------|----------------------|----------------------|
| Forest        | 178347              | 180656               | +2309                |
| Garden        | 16192               | 15974                | -218                 |
| Cultivated Land | 19677             | 20406                | +729                 |
| Grassland     | 6069                | 5487                 | -582                 |
| Building Land | 11016               | 11020                | +4                   |
| Water         | 3532                | 3532                 | 0                    |
| Unused Land   | 2241                | 0                    | -2241                |
In terms of economy, the overall economic benefit after optimization is 9092.7397 million yuan higher than the original one. In terms of ecology, the overall ecological benefit after optimization is 40.09377 million yuan higher than the original one. The results show that the economic and ecological benefits are improved compared with the original land use layout after the quantity optimization.

4.2. Evaluation of optimization effect based on landscape pattern

Spatially optimized landscape pattern index is used for verification and evaluation. Mean patch size (MPS) represents the average area occupied by a certain type of patch in units of one hectare. The Largest plaque index (LPI) represents the proportion of a certain type of plaque to the total plaque of that type in percentage (%). Patch density (PD) represents the density of patch distribution in a certain type of patch in units of per hectare. Landscape fragmentation index (LFI) represents the density of patch distribution in the image of the overall map in units of per hectare. The specific landscape pattern index pairs are shown in Table 2.

| land type       | original MPS | optimized MPS | original LPI | optimized LPI | original PD | optimized PD |
|-----------------|--------------|--------------|--------------|--------------|-------------|--------------|
| water           | 1.958957     | 1.958957     | 1.778944     | 1.778879     | 0.510476    | 0.510476     |
| garden          | 11.60717     | 14.1488      | 0.774697     | 7.852761     | 0.086154    | 0.070677     |
| forest          | 69.53099     | 81.52347     | 53.7556      | 57.08916     | 0.014382    | 0.012266     |
| cultivated land | 2.981364     | 3.664213     | 2.282142     | 2.319906     | 0.335417    | 0.272910     |
| grassland       | 0.622334     | 0.696055     | 3.367804     | 3.903955     | 1.606855    | 1.436668     |
| building land   | 1.427498     | 1.439582     | 2.499655     | 3.678494     | 0.700527    | 0.694646     |

It can be observed from the data in the table that the optimized MPS and LPI are larger than the original layout, while the optimized PD is smaller than the original layout. Because the amount and plaque of the unused land are 0 after optimization, it does not participate in the discussion. The water is masked, and the landscape pattern index will not be changed in the whole process. The larger MPS indicates the larger the area occupied by each patch, indicating that the aggregation has been improved to a certain extent. Among them, the indexes of garden land, forest land and cultivated land have increased significantly, and the aggregation has been improved. The increase of the LPI indicates that a certain type of plaque is gathering, in which the index of garden, forest land and building land increases significantly, and the aggregation is enhanced. The decrease of PD indicates the decrease of patch distribution in a certain area, and also indicates the increase of aggregation laterally, which is reflected in the garden, forest land, cultivated land and grassland. The fragmentation index of the overall layout is 0.13067497 per hectare on the original layout and 0.11074601 per hectare on the optimized layout, indicating that the landscape is more concentrated on the whole. Compared with other countries, China is committed to promoting the process of building a new countryside. So it is very necessary to improve the clustering of mountain towns.

To sum up, not only the partial and global aggregation has been significantly improved, but also the economic and ecological benefits have been improved, which indicates that this study is of significance and the optimization scheme has certain reference value.

5. Conclusions

Aiming at the core problem of unreasonable land use in towns in mountainous areas, this paper optimized the pretreatment methods of unused land conversion and improved aggregation, combined with multi-objective particle swarm optimization, and took Yuexi County in Anqing city as the research area to carry out the research. The main conclusions are as follows:

(1) It is not only necessary to consider the economic benefits of the research area, but also the environmental protection policies of the current era, taking ecological benefits into consideration. After the optimization, the economic and ecological benefits will be increased by 9092.7397 million yuan and 40.09377 million yuan respectively compared with the original layout. (2) In the study area,
the urban land pattern distribution in the mountainous area was decentralized to obtain aggregation optimization. In each land type and the whole, the spatial optimization is achieved and the aggregation is improved. The overall landscape fragmentation index after optimization is 0.019930486 per hectare higher than the original layout. (3) The optimized amount of land types in Yuexi County conforms to the basic trend and requirements of the overall land use plan. It shows that it is feasible to optimize the layout of urban land use in mountainous area by using the method of pretreatment and multi-objective particle swarm optimization.

Aiming at the irrationality of land layout in mountainous area, this paper only studies the transformation and aggregation of unused land. However, this research fails to combine advanced artificial intelligence algorithms with a large number of remote sensing data, and fails to make full use of public data sources. Combining with big remote sensing data and artificial intelligence algorithms to further carry out the optimal allocation of land use is the focus of future research.

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