Research on Land Use Ecological Security Pattern Construction of Hilly Cities in Hunan

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Abstract. The Landsat satellite image of Liuyang City was selected in June 2018, and the land use landscape type map was generated based on RS and GIS technology. The landscape index was calculated by the FRAGSTATS to analyse the landscape pattern of urban land use in Hunan hilly areas, and the minimum cumulative distance model was used to construct the urban ecological pattern. The results showed that: ① The most dominant landscape types in the city area were forest lands with high degree of aggregation and cluster distribution. The fragmentation of landscape types in urban areas was obvious, especially the grassland fragmentation. ② There are few landscape types in the city area, and there are obvious dominant landscapes. ③ The article builds an ecological security pattern by searching for ecological sources, corridors and nodes, and guarantees the ecological security of hilly urban cities.

1. Introduction

Land use/land cover change (LUCC) is a visual reflection of the interaction between human activities and the natural environment. It appears as a mosaic of different types of patches in the region[1]. Ecological Security Pattern is the basic guarantee for the city's stable access to natural resources and ecosystem services[2]. The use of 3S technology to combine land use classification with landscape ecological pattern construction can quantify the ecological pattern of land use in the region and make the construction of urban ecological security pattern more scientific[3]. In recent years, foreign scholars have relied on mathematical models, computer simulations to construct ecological security patterns and use them to predict land use change and climate change[4]. There are many low-lying sloping fields in the hilly area of Hunan. There are hills and mountains interlaced in some areas, and the terrain conditions are more complicated[5]. The natural environmental conditions of the hilly cities are relatively unique. The land use planning and population distribution are subject to obvious factors and topographical factors. In the process of urbanization, there is a significant spatial agglomeration trend, which needs to be studied independently[6-7]. In addition, natural weather disasters occur in the rainy season in hilly cities, and ecological sensitivity is high. Quantifying and analyzing the characteristics of hilly urban landscape pattern and constructing an ecological security pattern can promote the maximum effectiveness of urban ecosystems and lay a theoretical foundation for ensuring urban ecological security and scientific planning of land use.
Liuyang City is located in the northeastern part of Hunan Province, at the north of Liushui (113°10′ -114°14′ E, 27°51′ -28°34′ N), with a city area of 5007.75 square kilometers. It now governs 2 townships, 26 towns and 4 streets. The city has a population of 1.491 million. There are three main mountain ranges—Lianyungang, Jiuling and Dawei. The highest peak is Qixingling, the main peak of Dawei Mountain. The altitude is 1607.90 meters. There are more than 50 peaks above 800 meters above sea level. The water system is densely distributed. There are more than 1,300 tributaries in the three major river systems and Nanchuan River. The overall landform type is mainly hilly, with more precipitation, moderate light and heat, which belongs to the climate type of the hilly basin in central Hunan. The resources of wild animals and plants are very rich.

2. Data sources and research methods

2.1. Data sources and processing

This study is to select TM remote sensing image with ground resolution of 30m×30m and DEM data with spatial resolution of 30m as the basic data source in Liuyang City in June 2018, with 1:50,000 topographic map and land use status in Liuyang City. Administrative division maps, "Liuyang City Master Plan (2001-2020)" and "Liuyang City 2018 National Economic and Social Development Statistical Bulletin" and other data are used as supplementary sources of information. The ENVI 5.1 remote sensing image processing software was used to re-align the TM remote sensing image of June 2018. And cut it according to the administrative division map. Then, according to the topographical characteristics of the study area, the human-computer interaction supervision classification method is used for interpretation. Meanwhile, referring to the national land use status classification standard (GB/T2010-2007), the land use landscape data layer of Liuyang City GIS database is established by using the GIS technology. Combined with the characteristics of land use pattern and ecological utility, the land use landscape types are divided into six categories: construction land, forest land, cultivated land, grassland, water area and unused land (Figure 1).

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**Figure 1. Type of landscape in Liuyang City.**
2.2. Research methods

2.2.1. Selection of landscape ecological pattern analysis indicators. The landscape ecological pattern index reflects the landscape structure and spatial allocation characteristics of the study area. By selecting multiple landscape pattern indicators, the comprehensiveness of the analysis results can be improved to some extent, and the subjective factors are reduced\[8\]. The analysis of plaques is based on type, so the landscape pattern index can be simplified into two categories: landscape type index and landscape general characteristic index[9]. On the basis of the principles of totality, generality and simplification. This paper selects plaques at the level of landscape type. Including Type area (CA), ratio of plaque type to landscape area (PLAND), number of plaques (NP), plaque density (PD), average plaque area (AREA_MN), maximum plaque index (LPI), 10 indicators including average plaque fractal dimension (FRAC_MN), degree of polymerization index (AI), scatter and juxtaposition index (IJI), and plaque binding index (COHESION); plaque density (PD) was selected at the overall landscape feature level. Including maximum plaque index (LPI), edge density (ED), landscape shape index (LSI), average plaque area (AREA_MN), average plaque fractal dimension (FRAC_MN), spread index (CONTAG), spread and juxtaposition 11 indicators including index (IJI), connectivity index (CONNECT), Shannon diversity index (SHDI), Shannon uniformity index (SHEI).

2.2.2. Minimal cumulative resistance model. Based on the “plaque-corridor-matrix” landscape structure model and the ArcGIS platform, the city area of Liuyang is divided into 30m×30m grids by using the minimal cumulative resistance model (MCR). All kinds of landscape resistance values are given, and the consumption surface is generated based on the GIS platform, and then the landscape ecological network is constructed. In the natural environment, species, matter, information and energy need to overcome the landscape resistance to flow. The more diverse the landscape functions, the higher the value of landscape services and the less the landscape resistance[10]. The minimal cumulative resistance model is as follows:

\[
C_i = \min \sum (D_{ij} \ast R_i) \quad (i = 1, 2, 3, ..., m; \quad j = 1, 2, 3, ..., n)
\]

Among them, \(D_{ij}\) is the physical space distance from the ecological source \(j\) to the target point landscape element \(i\); \(R_i\) is the resistance value of landscape \(i\) to a certain movement in the process from source \(j\) to the target point, and \(C_i\) is the cumulative cost value of the \(i\)-th landscape element to the ecological source. \(m\) is the total number of units.

3. Analysis of land use landscape ecological pattern

The above-mentioned land use landscape type map was analyzed and calculated by FRAGSTATS 4.3 software, and six types of landscape patch related indexes were obtained (Table 1, Table 2, Figure 2). It can be seen from Table 1 and Figure 2(a) that the total construction land area of Liuyang City is 557.39 km², with a proportion of 11.15%, mainly including urban construction land, rural residential areas, industrial and mining land, transportation and water conservancy facilities and other construction land. The total area of agricultural land (forest land, cultivated land, grassland) is 4150.04km², accounting for 83.06% of the total land area of the city, of which the forest land area is 2655.76km², accounting for 53.13%; the cultivated land area is 912.39 km², accounting for 18.25%; the grassland area is 583.89 km², accounting for 11.68%. The landscape types (forest land, grassland, and water area) with higher ecological value have a total area of 3,503.38 km², accounting for 70.43%, ecological resources are abundant. Liuyang City still has some unused land, with an area of 8.50 km², mainly tidal flats and wasteland. Through the analysis of various types of landscape plaques and the proportion of the landscape, it can be seen that the forest land is the dominant landscape type of Liuyang City, which is the base of the urban landscape, followed by the cultivated land, and some grasslands and waters. This is inseparable from the geographical location of Liuyang in the hilly areas and water system of Hunan province.
Table 1. The patch landscape metrics of Liuyang City (1).

| Landscape type | CA(km²)  | PLAND(%)  | NP(per)  | PD(per/km²) | AREA_MN (hm²) |
|----------------|---------|----------|---------|-------------|---------------|
| Construction land | 557.39  | 11.15    | 10427   | 2.09        | 5.35          |
| Woodland        | 2655.76 | 53.13    | 4606    | 0.92        | 57.66         |
| Arable land     | 912.39  | 18.25    | 10199   | 2.04        | 8.95          |
| Grassland       | 583.89  | 11.68    | 22966   | 4.59        | 2.54          |
| Waters          | 280.73  | 5.62     | 13581   | 2.72        | 2.07          |
| Unutilized land | 8.50    | 0.17     | 451     | 0.09        | 1.88          |

Table 2. The patch landscape metrics of Liuyang City (2).

| Landscape type | LPI(%)  | FRAC_MN | AI(%)  | IJI(%)  | COHESION(%) |
|----------------|---------|---------|--------|---------|-------------|
| Construction land | 1.74    | 1.03    | 35.07  | 72.25   | 74.79       |
| Woodland        | 39.17   | 1.25    | 76.20  | 78.37   | 99.81       |
| Arable land     | 3.27    | 1.06    | 50.36  | 80.03   | 96.74       |
| Grassland       | 0.05    | 1.09    | 22.76  | 59.37   | 56.69       |
| Waters          | 0.39    | 1.31    | 24.47  | 81.01   | 64.79       |
| Unutilized land | 0.01    | 1.06    | 18.53  | 36.34   | 44.14       |

Figure 2. Class landscape metrics of Liuyang City.

3.1. Landscape fragmentation
The degree of landscape fragmentation reflects the complexity the heterogeneity of landscape plaque to some extent. The commonly-used indicators to measure the degree of fragmentation are plaque
number (NP) and plaque density (PD). The more plaques, the greater the plaque density, indicating that the degree of fragmentation of landscape plaques is more serious. It can be seen from Table 1 and Figure 2(b) that the number of plaques and the plaque density in grassland and water area is large, and the degree of fragmentation is serious. The grass plaque density is much larger than other plate types, and the degree of fragmentation is the highest. The number of construction land and cultivated land patches are also at a high level, and the degree of landscape fragmentation is relatively high. The field survey found that the construction land and cultivated land are generally in a relatively flat area, before the human construction activities occurred, the types of landscape patches were mostly grassland and waters. With the continuous improvement of human land use activities, the population density is increasing. This has led to an increase in fragmentation of grassland and waters, indicating a significant positive correlation between human development activities and fragmentation of grasslands and waters. As the landscape matrix of Liuyang City, woodland has a small number and density of patches, and the landscape patches have high integrity and the smallest degree of fragmentation. The area of unused land is the smallest and the ecological value is low, which has a weak impact on human construction activities and ecological environment.

3.2. Landscape heterogeneity

Landscape heterogeneity refers to the complexity and imbalance of spatial and temporal distribution of land use landscape patches in the region, mainly through the analysis of the maximum patch index (LPI), average patch fractal dimension (FRAC_MN), average patch area (AREA_MN), etc. According to the index, the smaller the maximum plaque index, the larger the average plaque dimension, and the smaller the average plaque area, indicating the higher the landscape heterogeneity. It can be seen from Table 1, Table 2 and Figure 2(c) that the maximum plaque index in the water area is small, and the average plaque area is small, indicating that the landscape shape is the most complex and the heterogeneity is the highest. The maximum plaque index of forest land is 39.17%, the average zonal fractal dimension is higher, and the average plaque area is the largest, indicating that the overall protection of forest landscape is good, but the spatial boundary shape of forest landscape around the urban built-up area is complex, indicating that human activities have begun to affect the landscape of forest land. The construction land and cultivated land are mainly human activity areas; the largest plaque index is small, and the natural ecological landscape is unstable. The maximum landscape index of grassland and unused land is at a low level. The average fractal dimension of grassland is higher than that of unused land, which limits the ability to maintain species diversity in the region. At the same time, around the grassland landscape, there are few natural vegetation and the stability of the landscape system is low.

3.3. Landscape dispersive

Landscape dispersibility refers to the degree of aggregation between landscape plaque components and reflects the spatial configuration characteristics of landscape structures. Commonly used indicators for measuring the vergence of landscape are the degree of aggregation index (AI), the distribution and juxtaposition index (IJ1), and the plaque binding index (COHESION). It can be seen from Table 2 and Figure 2(d) that the aggregation degree index, dispersal and juxtaposition index of forest plaques are the highest, and the distribution and juxtaposition index are higher, indicating that the forest landscape consists of a small number of large plaques. It is clustered and has good connectivity. The distribution and parallel index of construction land are at a relatively high level, and the aggregation degree index and plaque binding index are low, indicating that there are more landscapes around the construction area, but the distribution of internal functional components of construction land is more chaotic, and the degree of polymerization is low, which is not conducive to species migration. Cultivated land polymerization index, dispersal and juxtaposition index, and plaque binding index are all at a high level, mainly due to the clustering of cultivated land landscape and good connectivity, which is conducive to material and energy exchange with other landscapes. The polymerization index and plaque binding index of grassland and water area are low, indicating that the two types of landscape
distribution are scattered and the connectivity is poor. The water area has the highest distribution and juxtaposition index, and the surrounding landscape types are the most abundant. The main reason is that water sources are required for activities such as human construction, species migration and landscape vegetation growth. The unused areas are small, the patches are scattered, and the animals and plants are scarce, so the three indices are the lowest.

4. Construction of ecological security pattern in Liuyang City
Combining the landscape type analysis and the overall landscape feature analysis results, the land use landscape type map is imported into the GIS software, and the cumulative cost distance model is generated by applying the minimum cost distance model. Extract the cost value of each grid for spatial neighborhood analysis; set the threshold according to the landscape type partition and landscape features, and refer to the “plaque-cabin-matrix” theory to determine the location of the ecological source, ecological corridor and ecological node. Construct a landscape ecological security pattern and obtain the final ecological security pattern construction results (Figure 3).

![Figure 3. Landscape pattern optimization of Liuyang City.](image)

According to the analysis of the urban landscape ecological pattern, the ecological source is basically in the forest land with high ecological value. It is necessary to maintain the structural stability and ecological function integrity of the ecological source region. Meanwhile, it is determined that large-scale nature reserves, forest land with stable land use type and area greater than 2000hm², and water bodies with an area larger than 250hm² are used as ecological sources. Among the urban landscape patterns, forest land accounts for the largest proportion and its continuity is the best. According to the simulated potential ecological corridors and the current urban roads and river corridors, the overall layout of the ecological corridor planning of Liuyang City is proposed as the “four horizontal and four vertical” spatial patterns. The “four horizontal and four vertical” takes the urban river basin, large forest land and traffic route as the main ecological axis. Based on the existing ecological patches, according to the different, scales and functions of the plaques, forming a large plaques along the river layout, small plaques scattered layout, and combining large and small plaques to improve the landscape quality of Liuyang City. According to the different locations of ecological
nodes, the first-level ecological nodes are distributed at the intersection of the first-level ecological corridors, and the second-level ecological nodes are distributed at the intersection of primary and secondary ecological corridors and the intersection of secondary ecological corridors.

5. Conclusion

(1) The largest dominant landscape type in Liuyang City is forest land, with high degree of polymerization, cluster distribution and good connectivity. The area is 2655.76 km², accounting for 53.13% of the urban land area. It is the base of urban landscape. The number of grass patches is 22,966, which is the largest number, with poor connectivity, the most serious landscape fragmentation, and the highest degree of interference from human activities.

(2) There are few landscape types in Liuyang City with obvious dominant landscapes. The landscape fragmentation phenomenon is serious, the landscape connectivity is low and the spatial distribution is uneven, and the heterogeneity is not high. The ecosystem is greatly disturbed by human activities, which is not conducive to the maintenance of the current land use landscape ecological pattern.

(3) The article builds an ecological security pattern by searching for ecological sources, corridors and nodes, and guarantees the ecological security of hilly urban cities.

References

[1] Mooney H, Duraipappah A, Larigauderie A. (2013) Evolution of nature and social science interactions in global change research programs. Proceedings of the National Academy of Sciences of the United States of America, 110(S1):3665-72.

[2] Su Y, Chen X, Liao J, et al. (2016) Modeling the optimal ecological security pattern for guiding the urban constructed land expansions. Urban Forestry & Urban Greening, 19:35-46.

[3] Chang H, Li F, Li Z, et al. (2011) Urban landscape pattern design from the viewpoint of networks: a case study of Changzhou city in Southeast China. Ecological Complexity, 8 (1):51–59.

[4] Saleh A, Biswajeet P. (2018) Land use change modeling and the effect of compact city paradigms: integration of GIS-based cellular automata and weights-of-evidence techniques. Environmental Earth Sciences, 77:251.

[5] Fu X, Liu J, Shao W, et al. (2017) Study on the Potential Development of Rainwater Utilization in the Hilly City of Southern China. IOP Conference Series: Earth and Environmental Science, 100(1):012157.

[6] Li Z, Zhang Q, Fang Y, et al. (2010) Examining social-economic factors in spatial and temporal change of water quality in red soil hilly region of South China: a case study in Hunan Province. International Journal of Environment and Pollution, 42(1-3):184-198.

[7] Li Z, Zeng G, Zhang H, et al. (2007) The integrated eco-environment assessment of the red soil hilly region based on GIS - A case study in Changsha City, China. Ecological Modelling, 202(3-4):540-546.

[8] Li W, Chen Q, Cai D, et al. (2015) Determination of an appropriate ecological hydrograph for a rare fish species using an improved fish habitat suitability model introducing landscape ecology index. Ecological Modelling, 311:31-38.

[9] Pasher J, Mitchell S, King D, et al. (2013) Optimizing landscape selection for estimating relative effects of landscape variables on ecological responses. Landscape Ecology, 28(3):371-383.

[10] Li X, Wang M, Liu X, et al. (2018) Mcr-modified ca–markov model for the simulation of urban expansion. Sustainability, 10(9):3116.