RELATIONSHIP BETWEEN LANDSCAPE PATTERN AND ECOSYSTEM SERVICES VALUE IN THE KARST AREA OF SOUTHWEST CHINA

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Abstract. Ecological problems such as environmental degradation are urgent problems to be solved in karst areas. It is of great theoretical and practical significance to explore the landscape pattern and the relationship between landscape pattern and ecosystem service value (ESV) in karst areas. Based on the remote sensing data of Guiyang City, China, this paper uses landscape index method to evaluate landscape pattern, uses value equivalent factor method to estimate ESV, and uses gray correlation analysis to analyze the relationship between landscape pattern and ESV from patch type level and landscape level. The results showed that: (1) the landscape fragmentation slowed down, the complexity decreased, and the stability increased. (2) The total value of ESV shows an upward-downward-upward trend. Spatially, it showed a law of geographical center as the core, low in the middle and high in the surroundings. (3) ESV value is closely related to landscape aggregation and shape complexity.
Keywords: *grey correlation analysis, rocky desertification, landscape index, remote sensing, Fragstats 4*

Introduction

Ecosystem services and products that humans obtain directly or indirectly from the ecosystem, are closely related to human production and life (Constanza et al., 2014; Kubiszewski et al., 2017). In the 1990s, the evaluation of global ecosystem service value conducted by Costanza et al. (1997) greatly promoted the quantitative study of ecosystem service value. Since then, many scholars have accounted for different regions and different types, and improved the estimation methods (Luo and Yan, 2018; Wang and Li, 2020; Zhu et al., 2020; Zan et al., 2020; Hao et al., 2020; Wang et al., 2020; Xie et al., 2008). At present, the evaluation methods of ecosystem service value have not yet formed a unified framework system (Kubiszewski et al., 2017; Yu and Bi, 2011). Chinese researchers mainly quote the original or revised equivalent based on the value of China’s ecosystem services calculated by Xie et al. (2013, 2015b).

Landscape pattern refers to the spatial structure characteristics of landscape, which is one of the core issues of landscape ecology research (Wu, 2007). Changes in landscape pattern will cause changes in the types and areas of ecosystems (He et al., 2018; Lu et al., 2019). At the same time, the flow of various materials, energy and information in the landscape will also affect ecosystem services to a significant extent, and reflect the impact of human activities to a certain degree (Zhu, 2012; Gardner, 1987). The quantification of landscape pattern changes is a substantial reflection of ESV changes (Wang et al., 2017). Some scholars in China have conducted research on the relationship between landscape pattern and ecosystem service value. For example, Wang et al. (2017), Song et al. (2018) and Zhu et al. (2018) analyzed the relationship between landscape pattern and ecosystem service value from a qualitative perspective. Yu et al. (2021), Tong et al. (2020), Zhang et al. (2010), Su and Fu (2012) tried to

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explore the quantitative response relationship between regional landscape pattern and ecosystem service value. Quantitative analysis methods mainly include correlation coefficient method, regression analysis method and grey correlation analysis method. Among them, grey correlation method has more advantages in exploring the correlation degree. The existing results have laid a good foundation for quantitative research on the response relationship between landscape patterns and ecosystem services, but they still only stay at simple analysis showing the quantitative correlation, and do not dig into its ecological significance (Su and Fu, 2012).

The karst area is nearly 2,200 km^2, accounting for about 15% of the global land area, which seriously affects the production and life of about 1 billion people (Wang, 2003). The karst areas have serious ecological degradation due to the high vulnerability and sensitivity of the geological environment and the multiple pressures of population, economy and society (He et al., 1996). Fragile ecological environment, rocky desertification, prominent contradiction between man and land, environmental degradation, and social and economic backwardness are the main problems that need to be solved urgently in karst areas (Cai, 1996). At present, there are relatively few studies on the landscape pattern and the value of ecosystem services in the southwest karst area. The exploration of the landscape pattern in the southwest karst area, especially the rocky desertification landscape pattern, and the relationship with ESV has important theoretical and practical guidance in the karst area. Few studies have taken rocky desertification landscapes as an independent type of landscapes. As a result, there is a lack of theoretical basis for rational planning and configuration of landscapes in karst areas (Tang et al., 2019). Guizhou Province is one of the experimental areas of ecological civilization in China. There exists a high-grade and large-scale rocky desertification landscape, which is very typical in karst areas (Li et al., 2017). Therefore, Guiyang City was selected as a case study. In this paper, the quantitative relationship between landscape pattern and ecosystem services were discussed both at the landscape level and patch type level using remote sensing data from 1998 to 2018 and revised ecological service value coefficients. It aims to reveal the relationship between landscape pattern and ecosystem services value in the karst area of southwest China, and provide a theoretical basis and reference significance for related research and development planning in karst areas in China and even in the world.

Materials

Study area

Guiyang City (106°~108°E, 26°~28°N) is located in southwest China, with a total area of 8043 km^2 (*Fig. 1*). It is the economic, cultural and political center of Guizhou Province, as well as an important eco-tourism city in China. It is also an Ecological Civilization Demonstration Zone, an important transportation hub and the economic growth pole of southwest China. The annual average temperature of Guiyang is 15.3 ℃, the annual average relative humidity is 77%, the annual average total precipitation is 1129.5 mm, the annual average sunshine hours are 1148.3 h, and the annual snowfall days are few, with an average of only 11.3 days. It has a topography dominated by hilly basins and a large area of karst landscape. It has varied soil types such as yellow soil and fluvo-aquic soil, but the soil erosion is relatively serious and the soil conditions are relatively poor. Artificial vegetation dominated by Masson pine accounts for a great proportion of vegetation cover.

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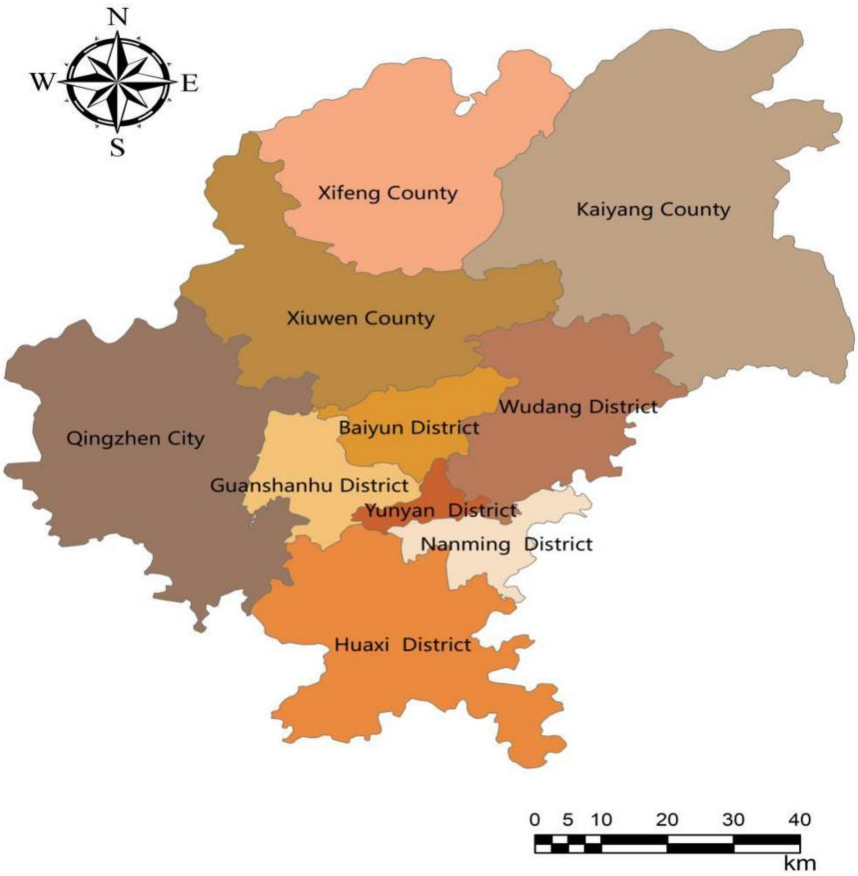

Figure 1. *Administrative map of Guiyang City*

Data sources

This paper selects Landsat 5-tm remote sensing satellite images taken on April 13, 1998, April 11, 2003 and April 8, 2008, and landsat-8 oli remote sensing satellite images taken on September 25, 2013 and March 19, 2018, with a resolution of 30 m. All these remote sensing images come from the geospatial data cloud website (http://www.gscloud.cn). The economic and social data comes from the "Guiyang City Statistical Yearbook" and the "Guiyang City National Economic and Social Development Statistical Bulletin". ENVI5.3 software was used to process the images including map mosaic, geometric correction and atmospheric correction. With reference to "Classification of Land Use Status", combined with the current conditions of Guiyang City, landscape types are divided into forestry landscape, agricultural landscape, construction landscape, rocky desert landscape, and water landscape using Support Vector Machine (SVM) supervision classification method.

Methods

Analysis of landscape pattern

Landscape index method

The prerequisite for studying the relationship between landscape pattern and ecological process is to conduct a quantitative analysis of the landscape pattern and to explore its

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dynamic changes (Wang and Bao, 1999). Landscape index is a general quantitative index to reflect the composition structure and spatial configuration of landscape, which is the concentration of landscape pattern information (Xie et al., 2003). It is often used to study the fragmentation, diversity and other landscape heterogeneity characteristics of the entire landscape or a fixed landscape element in the study area (Chen, 2011). Many landscape indexes express similar landscape meanings and have strong correlation (Bu et al., 2005; He and Zhang, 2009; Zhang et al., 2008). Repeated selection of landscape indexes will lead to more redundancy and less accuracy. Therefore, the indicators with less correlation were selected in this paper (*Table 1*), and the calculation formula and meaning are detailed in the literature (Wu, 2007).

Table 1. *Landscape index*

Index type	Landscape level	Patch level
Patches, density index	Number of Patches (NP) Patch Density (PD) Largest Patch Index (LPI)	Number of Patches (NP) Patch Density (PD) Largest Patch Index (LPI)
Shape Index	Landscape Shape Index (LSI) Mean Fractal Dimension Index (FRAC_MN)	Landscape Shape Index (LSI) Mean Fractal Dimension Index (FRAC_MN)
Contagion Index	Aggregation Index (AI) Interspersion and Juxtaposition Index (IJI) Contagion Index (CONTAG)	Aggregation Index (AI) Interspersion and Juxtaposition Index (IJI)
Diversity Index	Shannon's Diversity Index (SHDI) Shannon's Evenness Index (SHDI)	

Number of patches (NP), reflecting the spatial pattern of the landscape, is often used to describe the heterogeneity of the whole landscape. NP has an impact on many ecological processes, such as determining the spatial distribution characteristics of various species and secondary species in the landscape, and changing the stability of interaction and synergistic symbiosis among species. NP is the total number of patches in the landscape. Value range: NP ≥ 1, no upper limit. NP is equal to the total number of patches of a block type in the landscape at the type level. At the landscape level, it is equal to the total number of patches in the landscape.

$$NP = N \quad \text{(Eq.1)}$$

Patch density (PD) is the number of patches per square kilometer, reflecting the heterogeneity and fragmentation of the landscape as a whole and the fragmentation degree of a certain type, and reflecting the heterogeneity of the landscape per unit area. Value range: PD > 0, no upper limit.

$$\mathrm{PD} = \mathrm{N/A} \quad \text{Eq.2)}$$

The largest patch index (LPI) is equal to the proportion of the largest patch in a patch type occupying the whole landscape area. It is helpful to determine the model land or advantage type of the landscape. Its value determines the abundance of dominant species and internal species in the landscape. The change of its value can change the intensity and frequency of interference and reflect the direction and strength of human activities.

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$$LPI = \frac{Max(a_1,\ldots,a_n)}{A}(100) \quad \text{(Eq.3)}$$

The landscape shape index (LSI) helps to determine the model land or advantage type of the landscape. Its value determines the ecological characteristics such as the abundance of dominant species and internal species in the landscape. The change of its value can change the intensity and frequency of interference and reflect the direction and strength of human activities. The total length (m) of all patch boundaries in the landscape divided by the square root of the total area (m^2) in the landscape and multiplied by the square correction constant. Value range: LSI ≥ 1, when the patch shape in the landscape is irregular or deviates from the square, the LSI value increases.

$$LSI = \frac{0.25E}{\sqrt{A}} \quad \text{(Eq.4)}$$

Mean fractal dimension index (FRAC_MN), which can be intuitively understood as the non-integer dimension of irregular geometry, mainly describes the complex characteristics of patch shape in the landscape, and can reflect the changes of landscape shape to a certain extent. The shape of patch affects many ecological processes and produces edge effects on natural patches. In the formula, K is the proportional constant, and different values are taken according to the different definition of p_{ij} and the shape of the grid: if expressed by the length of one side of the patch, k = 1, and if expressed by actual perimeter, k = 4 (grid is square), or K = 1.26 (grid is circular), or K = 3.72 (grid is hexagonal).

$$FRAC\_MN = \frac{\sum_{i=1}^{m}\sum_{j=1}^{n}\left(\frac{2\ln(0.25P_{ij})}{\ln(a_{ij})}\right)}{N} \quad \text{(Eq.5)}$$

Aggregation index (AI) investigated the connectivity between patches of each landscape type. The smaller the value, the more discrete the landscape is. Where g_{ii} is the number of similar adjacent patches of corresponding landscape type, AI is calculated based on the common boundary length between pixels of the same type of patch. When there is no common boundary between all pixels in a type, the aggregation degree of this type is the lowest; When the common boundary between all pixels in the type reaches the maximum, it has the maximum aggregation index. Value range: AI∈ (0,100].

$$AI = \left[\frac{g_{ii}}{max \rightarrow g_{ii}}\right](100) \quad \text{(Eq.6)}$$

Interspersion and juxtaposition index (IJI), IJI is one of the most important indicators to describe landscape spatial pattern. IJI reflects the distribution characteristics of ecosystems seriously restricted by certain natural conditions. For example, various ecosystems in mountain area are seriously affected by vertical zonality, and their distribution is mostly circular, and the value of IJI is generally low. Where e_{ij} is the total edge length (m) adjacent to patch type i and k (non-adjacent variable). Value range: 0 < IJI ≤ 100.

$$IJI = \left[\frac{-\sum_{k=1}^{m}\left[\frac{e_{ik}}{\sum_{k=1}^{m}e_{ik}}\ln\left(\frac{e_{ik}}{\sum_{k=1}^{m}e_{ik}}\right)\right]}{\ln(m-1)}\right](100) \quad \text{(Eq.7)}$$

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Contagion index (CONTAG), where Pi *is* area percentage of type i patch; g_{ik} is the number of adjacent patches of type i and type k, m is the total number of patch types in the landscape. If the CONTAG value is large, indicating that the dominant patch types in the landscape form a good link. On the contrary, it shows that the landscape is a spread pattern with multiple factors. CONTAG was negatively correlated with edge density and highly correlated with dominance and diversity index. Value range is 0 < contact ≤ 100.

$$CONTAG = \left[1 + \frac{\sum_{i=1}^{m}\sum_{k=1}^{m}\left[(Pi)\left(\frac{g_{ik}}{\sum_{k=1}^{m} g_{ik}}\right)\right]\left[\ln(Pi)\frac{g_{ik}}{\sum_{k=1}^{m} g_{ik}}\right]}{2\ln(m)}\right] \quad \text{(Eq.8)}$$

Shannon’s diversity index (SHDI), a measurement index based on information theory, is widely used in ecology. This index can reflect landscape heterogeneity, especially sensitive to the unbalanced distribution of each block type in the landscape, that is, it emphasizes the contribution of rare block types to information, which is also different from other diversity indexes. The proportion of each patch type in the total landscape area multiplied by its logarithm, and then summed to take a negative value. Value range: SHDI ≥ 0, no upper limit. When there is only one patch type in the landscape, SHDI = 0. When the patch type increases or the area proportion of each type of patch tends to be similar, the value of SHDI increases accordingly.

$$SHDI = -\sum_{i=1}^{m}(P_i \ln(Pi)) \quad \text{(Eq.9)}$$

Shannon’s evenness index (SHEI) is equal to Shannon’s diversity index divided by the maximum possible diversity under a given landscape abundance (each block type is equally distributed). SHEI = 0 indicates that the landscape is only composed of one kind of block without diversity’s = 1 indicates that all block types are evenly distributed and have the greatest diversity. Like SHDI index is also a powerful means for us to compare the diversity changes of different landscapes or the same landscape in different periods. When the value of SHEI is small, the dominance is generally high, which can reflect that the landscape is dominated by one or a few dominant block types. When SHEI approaches 1, the dominance is low, indicating that there is no obvious dominant type in the landscape, and each block type is evenly distributed in the landscape.

$$SHEI = \frac{-\sum_{i=1}^{m}(P_i \ln(Pi))}{\ln(m)} \quad \text{(Eq.10)}$$

Landscape dynamics

The dynamic calculation formula is as below:

$$K = \frac{|U_b - U_a|}{U_a} \times \frac{1}{T} \times 100\% \quad \text{(Eq.11)}$$

K is the dynamics of the landscape in a certain research period, U_a is the initial landscape area of the research period; U_b is the landscape area at the end of the research period, and T is the length of the research period.

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ESV estimation

Coefficient correction

Existing studies indicate that the economic value of an ecosystem value in China was equivalent to 535.16 dollars/hm^2 in 2010 (Xie et al., 2015a, b; Zhang et al., 2017; Xu et al., 2019; Lei et al., 2020). The average grain output per unit area was 4,947 kg/hm^2 in China in 2010, and Guiyang's grain output was 5,301 kg/hm^2 in the same year. Consequently, the ecosystem service value for 1 standard equivalent factor in Guiyang is 570.48 dollars/hm^2 using a correction coefficient of 1.066, and the ecosystem service value coefficient per unit area in Guiyang is determined as in *Table 2*.

Table 2. *Ecosystem service value coefficient of unit area in Guiyang (dollars/hm^2)*

Service function	Cultivated land	Woodland	Grassland	Water area	Construction land	Unused land
Gas regulation	285.21	1996.59	456.37	0.00	0.00	0.00
Climate regulation	507.69	1540.22	513.43	262.39	0.00	0.00
Water conservation	342.26	1825.43	456.37	11625.73	0.00	17.08
Soil conservation	832.87	2224.74	1112.40	5.67	0.00	11.41
Waste disposal	935.57	747.32	747.32	10370.79	0.00	5.67
Biological protection	404.99	1859.66	621.80	1420.43	0.00	193.92
Food production	570.48	57.05	171.16	57.05	0.00	5.67
Raw materials	57.05	1483.16	28.49	5.67	0.00	0.00
Entertainment culture	5.67	730.17	22.82	2475.72	0.00	5.67
Total	3941.80	12464.34	4130.17	26223.47	0.00	239.44

ESV estimation

Based on the ecosystem service value proposed by Costanza et al. (1997), combined with the revised ecosystem service value coefficient per unit area, the ecosystem service values in study area were estimated using the formula as follows:

$$ESV = \sum_{1}^{n} A_k \times V_k \qquad \text{(Eq.12)}$$

ESV is the total value of all ecosystem services in the study area; K is the number of land types in the study area; A_k is the k-th type of land use area in the study area, and V_k is the ecosystem service per unit area of the k-th land type value.

Grey correlation analysis

Grey correlation method is a research method to calculate the degree of correlation between two variables. In this paper, NP, LPI, LSI, FRAC_MN, CONTAG, IJI, SHDI, SHEI and AI were selected as the environmental variable groups at the landscape level, and NP, LPI, LSI, FRAC_MN, IJI, and AI were selected as the environmental variable groups at the patch type level, and the grey correlation analysis was carried out to access the relationship between those landscape indexes and ecosystem service value.

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First, the values of various ecosystem services in the study area were chosen as the reference sequence, and the landscape pattern indexes at patch type level and landscape level were chosen as the comparison sequence. Second, all these numbers were nondimensionalized using the range-standardization method. Finally, the correlation coefficients and correlation degree between the landscape pattern index and ecosystem services were calculated. The detailed calculation formula refers to the literature (Sun, 2010).

Results

Landscape pattern

Dynamics of landscape area

According to the area calculation results (*Table 3*), the forestry landscape area accounts for 54% in 2018. The forestry landscape has increased by 1,014.72 km^2 from 1998 to 2018. The growth trend of the construction landscape is also obvious, increasing from 359.95 km^2 in 1998 to 935.84 km^2 in 2018. Both agricultural landscape and rocky desertification landscape show a downward trend, of which agricultural landscape has decreased the most obvious (*Fig. 2*), and the area has decreased by 1,324.84 km^2 in 20 years.

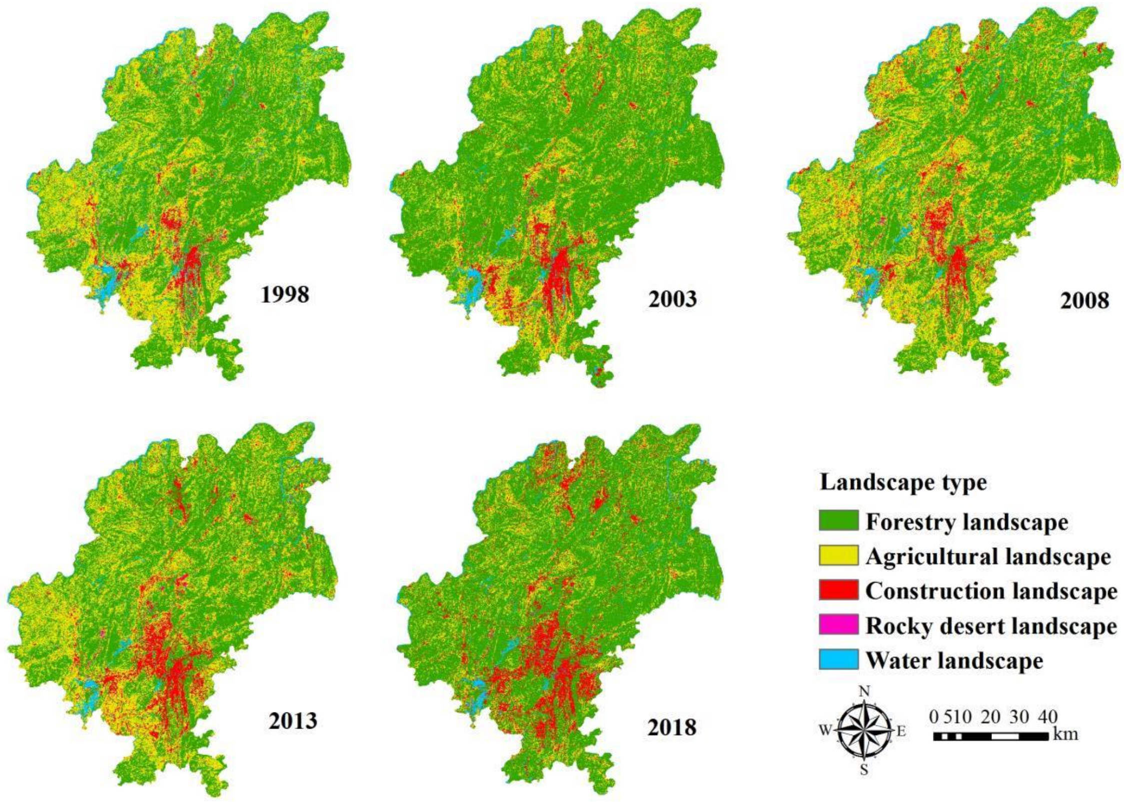

Figure 2. *1998-2018 land use distribution*

According to the calculation results of the dynamic degree (*Table 4*), the construction landscape has the highest dynamic degree of 8.00% from 1998 to 2018, followed by the

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rocky desert landscape at 3.53%, and the forestry landscape has the least dynamic degree of 1.14%. The dynamic degree of different landscape types varies over different time periods. The dynamic degree of forestry landscape is only 0.60% over the period from 2008 to 2013, and it is basically maintained at 4.0%-5.0% over the period from 2013 to 2018. For agricultural landscape, the dynamic degree of is the largest over the period from 2003 to 2008, which reaches 10.14%, and it is the smallest over the period from 2008 to 2013, which is only 1.06%. For construction landscape, the dynamic degree shows a trend of first declining and then rising, it is all above 5.0% except the period from 2003 to 2008. For rocky desertification landscape, the dynamic degree varies greatly, which is 35.28% over the period from 2003 to 2008, and only 6.29% over the period from 2008 to 2013. For water landscape, the dynamic degree shows a continuous downward trend, but the decline rate is gradually decreasing.

Table 3. *Dynamic change of landscape type area in Guiyang from 1998 to 2018 (km^2)*

Year	Forestry landscape	Agricultural landscape	Construction landscape	Rocky desert landscape	Water landscape	Total area
1998	4,450.28	2,729.69	359.95	56.93	444.30	8,041.15
2003	5,370.96	1,910.58	523.51	19.83	216.27	8,041.15
2008	4,262.47	2,879.70	536.48	54.82	307.68	8,041.15
2013	4,391.16	2,727.19	692.58	37.59	192.63	8,041.15
2018	5,465.01	1,404.85	935.84	16.76	218.69	8,041.15
Changes from 1998 to 2018	1,014.72	-1,324.84	575.89	-40.17	-225.61	

Table 4. *Dynamic degree of different landscape types in Guiyang from 1998 to 2018 (%)*

Landscape type	1998-2003	2003-2008	2008-2013	2013-2018	1998-2018
Forestry landscape	4.14	4.13	0.60	4.89	1.14
Agricultural landscape	6.00	10.14	1.06	9.70	2.43
Construction landscape	9.09	0.50	5.82	7.03	8.00
Rocky desert landscape	13.03	35.28	6.29	11.08	3.53
Water landscape	10.27	8.46	7.48	2.71	2.54

According to the transition matrix of landscape types (*Table 5; Fig. 3*), forestry landscapes are mainly transferred into agricultural landscapes and construction landscapes, with the transferred areas being 220.53 km^2 and 198.75 km^2 respectively. Agricultural landscapes are mainly converted to forestry landscapes and construction landscapes, with an area of 1,221.57 km^2 and 436.53 km^2 respectively. Rocky desertification landscapes are mainly converted to construction landscapes, agricultural landscapes, and forestry landscapes, with a transfer area of 19.57 km^2, 18.59 km^2, and 12.06 km^2 respectively. Water landscapes are mainly converted to forestry landscapes with an area of 215.43 km^2 and a small amount of them are converted to construction landscapes. In general, the main landscape type which is transferred into is construction landscape, of which the area transferred from forestry landscape and agricultural landscape is the largest.

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Table 5. *Transfer matrix of different landscape types in Guiyang from 1998 to 2018 (km^2)*

Landscape type	**Forestry landscape**	**Agricultural landscape**	**Construction landscape**	**Rocky desert landscape**	**Water landscape**
Forestry landscape	3,995.93	220.53	198.75	5.22	51.58
Agricultural landscape	1,221.57	1,056.91	436.53	7.08	10.44
Construction landscape	64.40	62.47	218.57	1.15	7.21
Rocky desert landscape	12.06	18.59	19.57	2.41	0.41
Water landscape	215.43	19.47	55.26	0.29	140.14

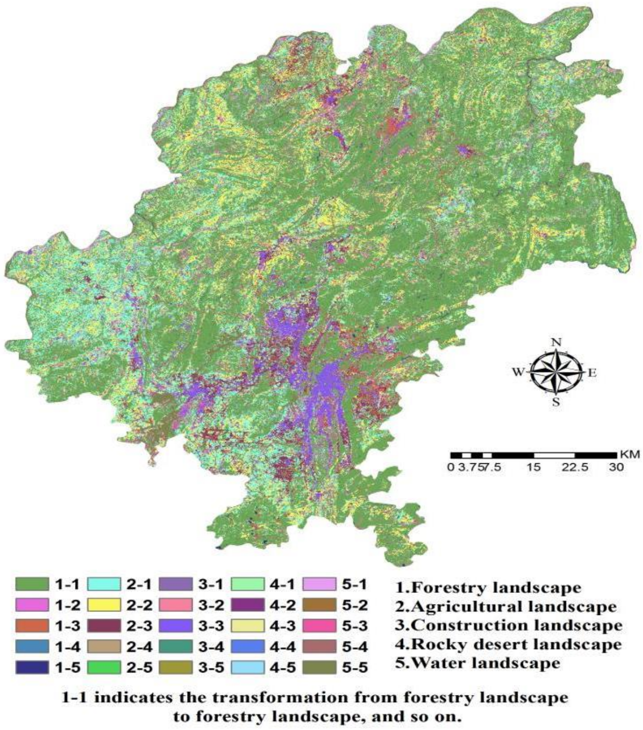

Figure 3. *land use transfer from 1998 to 2018*

Landscape index

Landscape index at landscape level

At the landscape level (*Table 6*), the number of patches and patch density show a clear descending trend from 1998 to 2013, and then slightly increased from 2013 to 2018. The number of patches decreased by 11,418 in total, and the patch density dropped from 21.477 to 20.057, and both decreased by 6.6%. The largest number of patches shows a fluctuating growth trend, from 36.339 in 1998 to 50.904 in 2018, indicating that the process of landscape fragmentation in the study area has slowed down in the past 20 years. The average fractal dimension remains almost unchanged from 1998 to 2018, and the patch shape index shows a decreasing-increasing-decreasing trend, reaching a maximum of 237.945 in 1998. It shows that the complexity of the landscape has decreased, human interference has tended to be less, the boundary of the landscape has become more regular, and the stability has increased. Both the spreading index and the aggregation degree show an increasing-decreasing-increasing trend, and

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the maximum value appeared in 2003. The scatter and juxtaposition index, the Shannon diversity index and the Shannon uniformity index all show a decreasing trend, indicating the landscape diversity and uniformity have decreased. Although a certain dominant landscape still has good connectivity, the probability of interpenetration among landscape patches has decreased, hindering the flow of material and energy, and reducing biological safety.

Table 6. *Landscape index changes at landscape level from 1998 to 2018*

Year	NP	PD	LPI	LSI	FRAC_MN	CONTAG	IJI	SHDI	SHEI	AI
1998	172,745.00	21.477	36.339	237.945	1.046	51.351	58.269	1.029	0.639	84.210
2003	147,796.00	18.375	51.821	213.032	1.044	57.472	46.113	0.901	0.560	85.876
2008	146,365.00	18.197	31.253	233.908	1.046	51.180	54.118	1.044	0.649	84.481
2013	125,845.00	15.646	33.546	226.726	1.047	52.625	45.556	1.023	0.636	84.962
2018	161,327.00	20.057	50.904	222.823	1.048	55.539	55.336	0.929	0.577	85.220

Landscape index at patch-type level

In terms of the patch and density index (*Fig. 4*), the agricultural patches have the largest patch number and patch density, and the rocky desertification patches have the smallest patch number and patch density. The patch number and patch density of agricultural patches and construction patches show an upward trend, while the rocky desertification patches, forestry patches and water body patches show a downward trend. The maximum patch index of forestry patches is significantly higher than that of other patch types, and it shows a trend of fluctuating increasing. The maximum patch index of other patch types fluctuated slightly within a certain range, remained almost the same or slightly increased. It shows that the fragmentation of agricultural patches is the largest, and that of rocky desertification patches is the least. The fragmentation of agricultural patches and construction patches is intensified, and that of other patch types tends to be gentle.

In terms of the shape index (*Fig. 4*), the patch shape index and average fractal dimension of agricultural patches are at the highest level and those of rocky desertification patches are at the lowest level. The patch shape index and average fractal dimension of agricultural and construction patch types show an upward trend, and the other patch types show a fluctuated downward trend. This shows that the shape of agricultural patches is the most complex and irregular, and the shape of rocky desert patches is relatively simple and regular. In addition, the shape of agricultural and construction patches has become more complex, tending to develop in an irregular direction, and are more and more seriously affected by the interference of human activities. The situation of forestry and water patches is just the opposite.

In terms of the index of spreading degree (*Fig. 4*), the forestry patches are the largest agglomeration, and the rocky desert patches are the smallest. The degree of agglomeration of forestry patches remained basically unchanged. The degree of agglomeration of agricultural patches declined, and those of the other patch types increased in fluctuation. The scatter and parallel index are more complicated. On the whole, only the forestry patch shows an increasing trend, and the rest show a significant decreasing trend. It shows that the distribution of forest patch types is the most concentrated, and the distribution of rocky desert patch types is more scattered. Agricultural patches tend to be in a scattered distribution, and the tendency of interpenetrating with other types of landscape patches is increasing.

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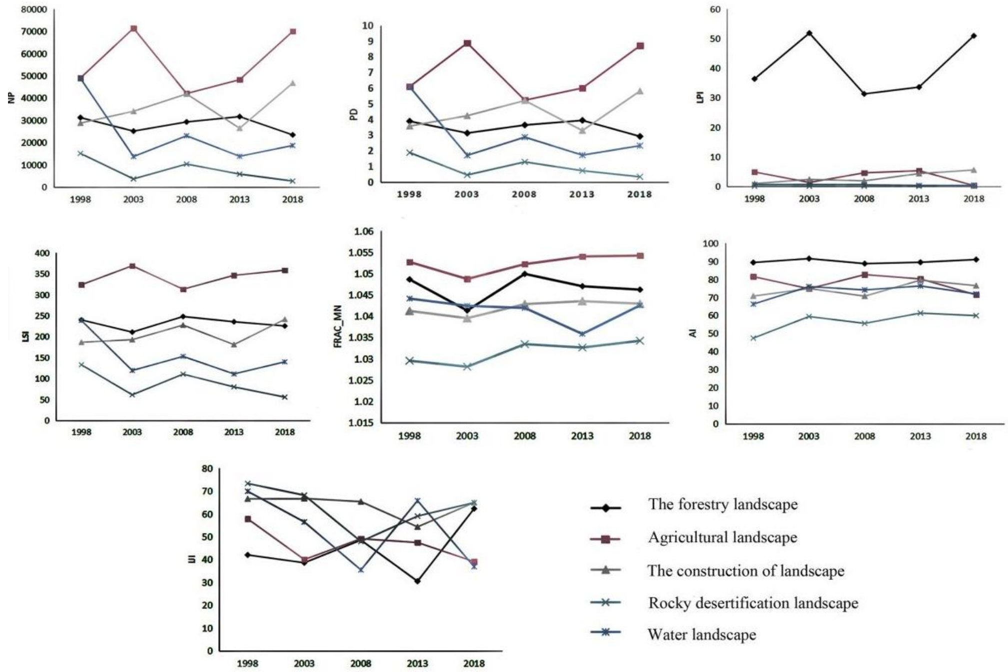

***Figure 4.** Changes in the landscape index of patch types from 1998 to 2018*

Ecosystem services value

The total value of ESV shows a trend of first increasing, then decreasing, and increasing again. It increased from 1998 to 2003, decreased continuously from 2003 to 2013, and began to rise again from 2013 to 2018, and reached the maximum value of 8.0152 billion dollars in 2003. The total value of ESV increased 0.1499 billion dollars from 1998 to 2018. Regulating services contribute the most to the total value of ESV in Guiyang, followed by supply services and cultural services. In terms of the secondary service types, the value of all service types has increased except the food production and waste treatment functions in the past 20 years, indicating that the climate, soil and water sources of Guiyang have improved to a certain extent in recent years (*Table 7*).

***Table 7.** Distribution of ESV in Guiyang city (billion dollars)*

Year	ESV total value	supply service		Adjustment service						Cultural service
		Food production	Raw materials	Gas regulation	Climate regulation	Water conservation	Soil conservation	Waste treatment	Biological protection	Entertainment and culture
1998	7.7895	0.1836	0.6758	0.9663	0.8356	1.4224	1.2177	1.0488	1.0023	0.4366
2003	8.0152	0.1409	0.8077	1.1269	0.9299	1.2973	1.3542	0.8044	1.1072	0.4468
2008	7.2561	0.1904	0.6488	0.9332	0.8108	1.2345	1.1883	0.9071	0.9541	0.3891
2013	7.0544	0.1818	0.6669	0.9545	0.8199	1.1189	1.2042	0.7831	0.9552	0.3698
2018	7.9394	0.1126	0.8186	1.1313	0.9187	1.3000	1.3330	0.7666	1.1046	0.4540

Counted by counties (*Table 8*), the total value of ESV of Huaxi district, Kaiyang county, Xiuwen county and Qingzhen city, which are outside the geographic center of Guizhou city, all increased to a varying extent from 1998 to 2018. The largest increase occurred in Qingzhen city, which is located in the west of Guizhou city, with the increase of 0.17 billion dollars. Xifeng county, which is also on the periphery, showed a decreasing trend, as well as the six regions near the geographic center, of which Xifeng

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county showed the largest decrease of 54.36 million dollars. Obviously, it shows that the landscape pattern of Qingzhen city and Xifeng county has changed drastically. Yunyan cistrict, Nanming cistrict, Baiyun district and Guanshan Lake district have the smallest proportion of ESV total value, while Kaiyang dounty and Qingzhen city have the largest proportion. In general, the ESV in Guiyang city has a spatial pattern with the geographic center as the core, and the greater the value toward the periphery (*Fig. 5*).

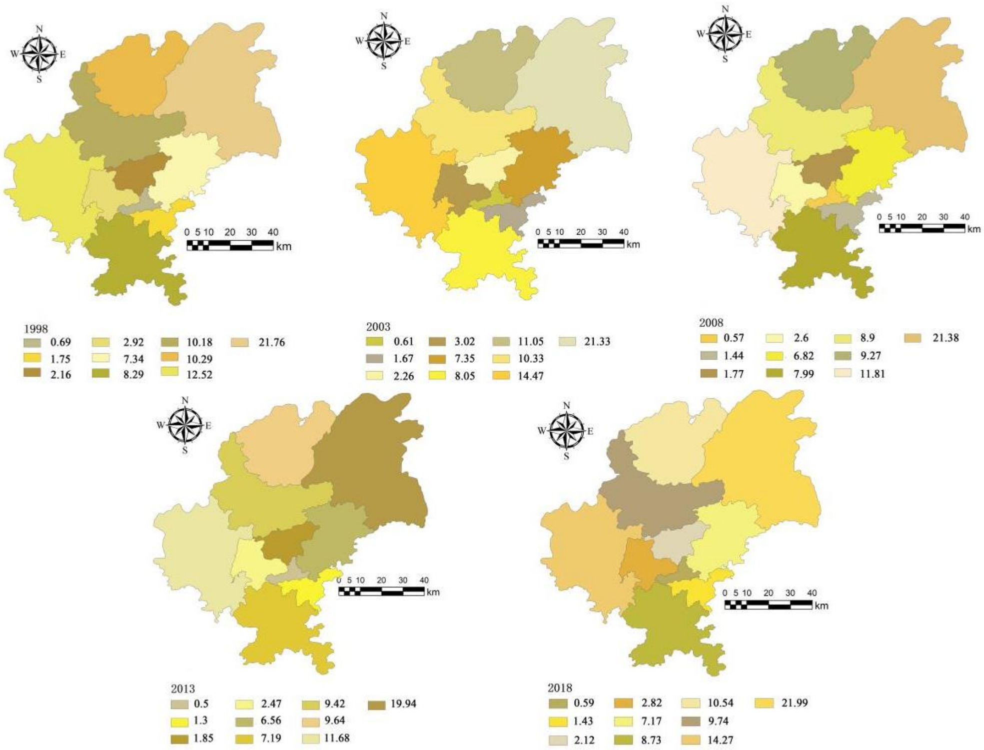

Figure 5. *ESV spatial distribution indifferent years (unit: 100 million dollars)*

The relationship between landscape pattern and ESV

Landscape level

At the landscape level (*Table 9*), the correlation between the landscape index and the total value of ESV in descending order is AI > FRAC_MN > CONTAG > LPI > IJI > LSI > SHDI > SHEI > NP, all above 0.663, and the AI with the highest correlation degree is 0.863, indicating that the total value of ESV is closely related to the degree of landscape aggregation, landscape shape complexity, and fragmentation degree. NP, IJI and LSI have the greatest correlation with water conservation. LPI has the greatest correlation with gas regulation. FRAC_MN, AI, CONTAG have the greatest correlation with soil conservation, and SHDI and SHEI have the greatest correlation with food production, which indicates that the number of landscape patches, scattered and juxtaposed conditions, and the complexity of patch shapes are the main factors affecting the water conservation function. The proportion of the largest patch number is closely related to the gas regulation function. The degree of landscape agglomeration and spread profoundly affect the soil conservation function. The diversity and uniformity of the landscape greatly affect the function of food production.

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Table 8. *Distribution of ESV in districts and counties of Guiyang city*

Administrative district	1998		2003		2008		2013		2018	
	Total value /100 million dollars	**Percentage/ %**	**Total value /100 million dollars**	**Percentage /%**	**Total value /100 million dollars**	**Percentage /%**	**Total value /100 million dollars**	**Percentage /%**	**Total value /100 million dollars**	**Percent-age /%**
Nanming District	1.75	2.24	1.67	2.09	1.44	1.99	1.30	1.84	1.43	1.80
Yunyan District	0.69	0.89	0.61	0.76	0.57	0.79	0.50	0.71	0.59	0.74
Huaxi District	8.29	10.64	8.05	10.04	7.99	11.01	7.19	10.20	8.73	10.99
Wudang District	7.34	9.43	7.35	9.17	6.82	9.40	6.56	9.30	7.17	9.03
Baiyun District	2.16	2.77	2.26	2.82	1.77	2.44	1.85	2.62	2.12	2.67
Guanshan Lake	2.92	3.75	3.02	3.77	2.60	3.58	2.47	3.50	2.82	3.55
Kaiyang County	21.76	27.94	21.33	26.62	21.38	29.46	19.94	28.27	21.99	27.70
Xifeng County	10.29	13.21	10.33	12.89	9.27	12.78	9.64	13.66	9.74	12.27
Xiuwen County	10.18	13.06	11.05	13.78	8.90	12.26	9.42	13.35	10.54	13.28
Qingzhen City	12.52	16.08	14.47	18.06	11.81	16.28	11.68	16.56	14.27	17.97

Table 9. *Correlation between landscape level index and ecosystem service value*

Landscape index	**ESV total value**	**Waste treatment**	**Climate regulation**	**Gas regulation**	**Biological protection**	**Food production**	**Water conservation**	**Soil conservation**	**Entertainme nt culture**
NP	0.663	0.784	0.577	0.551	0.591	0.574	0.856	0.575	0.700
LPI	0.762	0.685	0.755	0.776	0.772	0.651	0.721	0.750	0.756
LSI	0.748	0.603	0.741	0.702	0.754	0.692	0.772	0.742	0.682
FRAC_MN	0.838	0.580	0.814	0.772	0.782	0.715	0.691	0.828	0.784
CONTA-G	0.791	0.579	0.929	0.861	0.893	0.691	0.651	0.941	0.764
IJI	0.762	0.797	0.658	0.634	0.680	0.682	0.844	0.654	0.751
AI	0.863	0.576	0.823	0.776	0.793	0.709	0.678	0.836	0.810
SHDI	0.678	0.597	0.711	0.691	0.674	0.760	0.741	0.726	0.628
SHEI	0.677	0.596	0.709	0.689	0.672	0.759	0.741	0.724	0.627

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Patch-type level

At the patch type level (*Table 10*), the total value of ESV has the greatest correlation with the FRAC_MN for water patches, agricultural patches, construction patches, and rocky desertification patches, and the total value of ESV has the greatest correlation with AI for forestry patches. Generally speaking, in terms of the characteristics of fragmentation, the degree of fragmentation of water patches is closely related to waste treatment.

Table 10. *Correlation between horizontal landscape index of each patch type and ecosystem service value*

Landscape type	**Landscape index**	**ESV total value**	**Waste treatment**	**Climate regulation**	**Gas regulation**	**Biological protection**	**Food production**	**Water conservation**	**Soil conservation**	**Entertainment**	**Culture raw materials**
Water landscape	NP	0.544	0.617	0.524	0.516	0.528	0.598	0.579	0.523	0.552	0.513
	LPI	0.656	0.729	0.591	0.568	0.601	0.628	0.703	0.590	0.676	0.559
	LSI	0.565	0.686	0.536	0.526	0.542	0.672	0.619	0.535	0.578	0.522
	FRAC_MN	0.840	0.581	0.821	0.779	0.787	0.722	0.693	0.835	0.785	0.756
	IJI	0.674	0.729	0.645	0.629	0.662	0.792	0.682	0.641	0.654	0.623
	AI	0.699	0.527	0.802	0.771	0.782	0.610	0.592	0.810	0.689	0.734
Forestry landscape	NP	0.725	0.800	0.715	0.706	0.712	0.817	0.708	0.718	0.674	0.702
	LPI	0.762	0.685	0.755	0.776	0.772	0.651	0.721	0.750	0.756	0.793
	LSI	0.698	0.587	0.727	0.689	0.687	0.773	0.729	0.724	0.646	0.675
	FRAC_MN	0.830	0.579	0.810	0.769	0.777	0.719	0.693	0.824	0.776	0.746
	IJI	0.730	0.732	0.711	0.708	0.714	0.697	0.780	0.710	0.741	0.708
	AI	0.884	0.582	0.843	0.795	0.812	0.709	0.681	0.857	0.827	0.769
Agricultural landscape	NP	0.734	0.671	0.774	0.796	0.766	0.678	0.704	0.771	0.734	0.811
	LPI	0.709	0.701	0.712	0.709	0.712	0.752	0.683	0.712	0.685	0.708
	LSI	0.781	0.587	0.919	0.889	0.895	0.654	0.652	0.914	0.752	0.849
	FRAC_MN	0.836	0.580	0.813	0.771	0.781	0.715	0.692	0.827	0.782	0.748
	IJI	0.681	0.867	0.618	0.605	0.634	0.758	0.780	0.614	0.729	0.601
	AI	0.698	0.601	0.734	0.705	0.694	0.753	0.756	0.737	0.649	0.690
Rocky desert landscape	NP	0.590	0.662	0.568	0.562	0.574	0.619	0.630	0.567	0.603	0.560
	LPI	0.662	0.618	0.679	0.691	0.678	0.620	0.641	0.679	0.662	0.698
	LSI	0.635	0.755	0.600	0.592	0.609	0.680	0.702	0.597	0.658	0.589
	FRAC_MN	0.838	0.579	0.812	0.769	0.780	0.716	0.689	0.825	0.784	0.745
	IJI	0.662	0.667	0.577	0.549	0.590	0.559	0.834	0.575	0.698	0.538
	AI	0.639	0.533	0.698	0.739	0.688	0.591	0.576	0.699	0.628	0.766
Construction landscape	NP	0.737	0.623	0.754	0.776	0.759	0.661	0.664	0.751	0.714	0.784
	LPI	0.625	0.611	0.631	0.634	0.630	0.620	0.617	0.631	0.623	0.635
	LSI	0.784	0.606	0.799	0.795	0.795	0.698	0.670	0.795	0.758	0.801
	FRAC_MN	0.837	0.578	0.811	0.769	0.780	0.715	0.689	0.825	0.783	0.745
	IJI	0.825	0.639	0.735	0.687	0.731	0.609	0.778	0.741	0.830	0.665
	AI	0.793	0.573	0.850	0.783	0.833	0.655	0.649	0.861	0.772	0.752

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The degree of fragmentation of forestry patches, agricultural patches and construction patches is highly related to raw materials. The degree of fragmentation of rocky desertification patches also greatly affects waste treatment and water conservation functions. In terms of the complexity of landscape shapes, the shape complexity of water patches is mainly closely related to food production. The shape complexity of forestry patches and construction patches are closely related to waste treatment. The complexity of agricultural landscapes and rocky desertification landscapes are closely related to soil conservation and entertainment culture. In terms of landscape aggregation, the degree of agglomeration of water bodies and construction patches mainly affects the value of soil conservation. The degree of agglomeration of forestry patches mainly affects entertainment culture. The agglomeration of rocky desertification patches and agricultural patches play an important role in the function of water conservation.

Discussion

Landscape pattern

In this study, the agricultural landscape mainly includes arable land, tea gardens and orchards, and the forestry landscape mainly includes woodland and shrubland. In terms of landscape area, the water body landscapes fluctuate greatly during study period due to the variations in annual precipitation, of which the annual precipitation of Guiyang City in 1998 and 2008 was significantly higher than that in 2003, 2013 and 2018. The landscape matrix of Guiyang City is forestry landscape. During the study period, the construction landscape expanded rapidly, and the forestry and agricultural landscapes were inevitably invaded during the process of urbanization. Meanwhile, certain area of construction land was changed into the forestry and agricultural landscapes due to the measures of construction land reclamation and reforestation. Guiyang City has implemented a series of measures such as returning farmland to forests for rocky desertification control, which has led to a continuous decline in the area of rocky desertification landscapes, some of which have been transformed into agricultural landscapes, and a considerable part of agricultural landscapes have also been transformed into forestry landscapes. This shows that the phenomenon of rocky desertification has improved and the control measures have achieved a certain degree of effectiveness.

Ecosystem services

The ESV evaluation results of this study are similar to that of Wei et al. (2015) and Han et al. (2020) in Guiyang. Although the total value of ESV is not exactly the same, the change trend of ESV is consistent, showing a fluctuating upward trend with the development of urbanization. Existing studies have shown that under normal circumstances, economic and social development and the increase in the area of construction land landscapes will lead to a decline in ESV. For example, Mobeen et al. (2020) evaluated the ecosystem service value of land use/cover change and found that the simultaneous conversion of vegetation and unused land into construction land resulted in a net ESV reduction of $7.96 million in Lahore city, Pakistan. Meng took a case study in Ningbo City and found that economic urbanization and land urbanization had a significant negative impact on ESV (Meng, 2016). Qu and Guo took a case study

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in Nanjing City to quantitatively study the coupling between urbanization level and ESV, and found that the development of urbanization will inevitably cause damage to the ecological environment (Qu and Guo, 2016). In this study, the ESV of Guiyang city shows a spatial pattern with the geographic center as the core, low in the middle and high around it. The main reason is that the nearby area of geographic center that has the most developed economy and construction landscape is poor in ecological environment, while the regional economic development outside the geographic center is relatively backward, and the degree of land use development is low. However, since 2013, with the rapid expansion of the construction landscape, the ESV has also increased in Guiyang city. This is mainly due to the policy of returning farmland to forests and some measures such as rocky desertification control and natural forests protection projects. Although the area of water landscapes and agricultural landscapes has decreased, the area of forestry landscapes with a higher coefficient with ESV per unit area has shown an increasing trend, and rocky desertification landscapes have also decreased. This is similar to the conclusions of the study conducted by Bai et al. (2020) on the coupling relationship between urbanization and ESV in Guiyang city.

The relationship between landscape pattern and ecosystem services

The correlation relationships between landscape patterns and ESV are roughly the same at the landscape level and at patch type level (*Tables 9* and *10*). At the landscape level, the highest correlation with food production is the Shannon Diversity Index and the Shannon Uniformity Index, which is a little different with the correlation at the patch type level. The main reason is that these two indices are not available at the patch type level. Exclude these factors, the correlation degree of the patch type level is basically consistent with the landscape level. There are still individual differences in the correlation degree between landscape type level and the patch type level. Therefore, when exploring the relationship between the landscape pattern and ESV in the southwest karst area, analysis at the patch type level can get more accurate and detailed results.

Highlights and limitations

Highlights

(1) Dividing the rocky desertification landscape into an independent category

At present, few studies have divided rocky desertification landscapes into an independent landscape type in the researches on ecosystem services of karst areas (Wei et al., 2015; Xiao et al., 2013; Ivajnsic and Kaligari, 2014; Luo et al., 2021). Rocky desertification landscapes in karst areas account for a large proportion, and it is the most serious ecological problem in southwestern China, which severely restricts the sustainable development of the local economy. Therefore, it is of great significance to classify rocky desertification landscapes into one category in karst areas. It is possible to further analyze and study the relationship between rocky desertification landscapes and ecosystem service values, to lay the foundation for subsequent further research and to a certain extent quantify and reflect the control effects of various rocky desertification ecological projects. In addition, it can also provide theoretical support for the scientific management of rocky desertification from the perspective of landscape ecology.

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(2) Using the grey-level correlation analysis method

Most of the existing studies on the relationship between landscape pattern and ecosystem services use correlation and regression methods, which often require a large sample size and obvious distribution characteristics. Correlation analysis is essentially a linear relationship analysis between two variables (Wang et al., 2017; Song et al., 2018; Zhang et al., 2010; Yohannes et al., 2021). However, existing studies have also shown that the landscape pattern and the value of ecosystem services are not simple linear relationship (Zhong, 2019). The gray-level correlation analysis method can more accurately measure the correlation between two variables based on its advantages in comprehensively analyzing the multi-factor interaction of the system (Tan and Deng, 1995). This study attempts to use the gray-level correlation analysis method to analyze the relationship between landscape pattern and ecosystem services, and obtain more reasonable research results, which provides a new idea for the study of the impact relationship between landscape pattern and ecosystem services.

Limitations

This research is a case study, taking Guiyang, the capital of Guizhou Province, as the study area, using local data for research and analysis, so as to draw some specific conclusions. The study area is located in the center of East Asia, one of the three karst concentrated distribution areas in the world. Many problems of karst area in the world need to be studied and solved here (Yu, 2008). The complexity of Guizhou ecosystem, the vulnerability of karst environment and the emergence of rocky desertification are very representative in China and even the world. According to the principle of comparability of climate background and karst characteristics, Li selected several karst areas worldwide to compare with karst in southern China, and found that they are similar to karst in southern China (Li, 2014). Therefore, although this is a local study, the results can be generalized to other karst areas in the world, which can provide theoretical basis and reference significance for the rational allocation of landscape pattern and the implementation of ecological restoration technology in other karst areas in the world, and further enrich relevant research theories. In addition, the ideas and research methods of this paper can also be used for reference to the research on the relationship between other landforms and ecosystems, so as to provide new ideas and methods.

Another limitation is that our research only focuses on the relationship between landscape pattern and ESV, whereas it might be important to include the mechanism of the relationship as well. In fact, the inclusion of the mechanism in the future study would enable us to improve our understanding of the interaction between landscape pattern and ESV.

Conclusions

Landscape pattern

The landscape matrix of Guiyang City is forestry landscape. During the 20 years of the study period, the water body landscape remained basically unchanged. The agricultural landscape and rocky desertification landscape decreased, and the forestry landscape and construction landscape increased. Both the construction landscape and the rocky desertification landscape maintain a high degree of dynamics. The rocky desertification landscape is mainly converted to the construction landscape, but the

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construction landscape is mainly transferred from the agricultural landscape and forestry landscape. The phenomenon of rocky desertification in Guiyang City has improved, and the corresponding control measures have achieved results. The fragmentation of the landscape slows down, the complexity decreases, and the stability increases. However, the diversity and uniformity of the landscape are showing a downward trend, the material flow, information flow, and energy flow between patches are reduced, and the biological safety is reduced. The agricultural patch type has the largest degree of fragmentation, the patch shape is the most complex and the most irregular, and the rocky desert patch type is just the opposite. Agricultural patches and construction patches have become more fragmented, more complex in shape, and tend to develop in irregular directions, and are more and more seriously affected by interference from human activities. Forestry and water patches have the opposite situation. The distribution of forest patch types is the most concentrated, while the distribution of rocky desertification patch types is more scattered. The trend of mutual penetration between agricultural patches and other types of landscape patches is increasing, while the situation of other patch types is just the opposite.

Ecosystem services

The total value of ESV shows a trend of first increasing, then decreasing and then increasing. The most important contribution to the total value of ESV is the regulation service. Among the secondary service types, except for the reduction of food production and waste treatment functions, the rest have increased. The climate, soil and water resources of Guiyang City have been improved to a certain extent. In terms of spatial distribution, the west has the most value-added, and the north has decreased significantly. ESV presents a law of geographic center as the core, low in the middle and high around it.

The relationship between landscape pattern and ecosystem services

The total value of ESV is closely related to the degree of landscape aggregation, the degree of complexity of landscape shape and the degree of fragmentation. The number of landscape patches, their dispersal and juxtaposition, and the complexity of patch shapes all mainly affect the water conservation function. The proportion of the largest patch number is closely related to the gas regulation function. The degree of agglomeration and spread of the landscape has a profound impact on the soil conservation function, while the diversity and uniformity of the landscape greatly affects the food production function. At the patch type level, the total ESV value has the greatest correlation with the average fractal dimension of water landscapes, agricultural landscapes, construction landscapes and rocky desertification landscapes, and the degree of aggregation of forestry landscapes. On the whole, the degree of association between each landscape type and the secondary service type is different in terms of fragmentation characteristics, complex shapes, and aggregation and dispersion.

In the future, we will conduct the study on the interaction direction between karst area, landscape pattern and ecosystem service value, so as to further study the specific correlation mechanism between them. The evaluation method of ecosystem service value in karst area can be innovated to be more in line with the actual situation of karst area. In addition, we should strengthen the implementation of measures such as returning farmland to forest and rocky desertification control to help improve ESV.

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