Spatio-temporal dynamics and evolution of land use transition and landscape patterns in response to ecological protection project in Guizhou Province, China

Quan Wang (✉ excellent_wangquan@126.com)

Wuhan University <https://orcid.org/0000-0002-5354-0268>

Xuepiao Bai

Beijing Normal University

Research Article

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Abstract

Restoration of degraded ecological environment is a global core issue, particularly in the ecologically fragile mountainous areas where excessive loss of natural vegetation has occurred, and the rational land use and ecological protection need high attention from academia. This study explored the dynamics of land use transition and landscape pattern by using large-scale remote sensing, geological information model, and landscape pattern method, to understand internal mechanism process for spatial difference at the prefecture-level city level. The results showed that the area of forestland, grassland, and urban and rural construction land showed an increasing trend during 1990–2015. The land use transition trend was mainly based on the mutual conversion between grassland, urban and rural construction land, cultivated land, and forestland, and were widely distributed in Guiyang, Qiannan, Zunyi, and Tongren. During 1990–2000 and 2005–2010, the largest changes of land use rising were forestland and grassland; during 2000–2005 and 2010–2015, the areas of land use shrinkage changes were cultivated land and grass land, as well as overall land use transition was becoming more intensive and efficient. Under the interaction of natural environment and human activities, severe land use transition led to the increasing trend of landscape pattern from low density to high fragmentation, patch richness, diversity, and irregular patch shape, enhancing regional spatial heterogeneity. Finally, we put forward realistic policy recommendations to provide a basis for the development of land space planning, regional ecological protection, and sustainable development in mountainous areas.

1 Introduction

Land use is a complex dynamic process of natural and human activities (Debnath et al. 2020). With the acceleration of economic development, the regional land use intensity has undergone significant changes, and the pressure on land use resources has become increasingly prominent (Tellman et al. 2021; Deng et al. 2021). However, local land use has shown the characteristics of diversification, refinement, and complexity. Regional land resources have obvious landscape heterogeneity in terms of quantity, quality, structure, location, which affects the efficiency of land resource utilization and management, and the construction of new urbanization in China (Ullah et al. 2020). At present, the study of land use transition in academia is a new way to comprehensively explore land use/land cover changes (LULCCs), which is a transition process of regional land use forms corresponding to the stage of socioeconomic development (Lambin and Meyfroidt 2010; Qu et al. 2019). The land use transition pattern initially are the changes in the quantitative structure of the main land use types in a certain period of time at a certain area, and then it is expanded into a drastic change in the spatial functional structure of a certain land use type (Gibbes et al. 2017). With the deepening of research in China and other countries, the long-term land use transition has been further defined as dominant form and recessive forms (Tian et al. 2020; Zhu et al. 2018; Long et al. 2020, 2012). The dominant form is the constituent structure of regional land use type in a specific period, while the recessive form is dependent on the dominant form and can be obtained by quantitative analysis (Long and Li 2012).

Existing literature studies have found that land use transition includes the transformation of land use function and potential benefit value, both of which drives the change of regional ecological environment (Drummond and Loveland 2010; Chen and Han 2015; Ouedraogo et al. 2016). Due to the influences of long-term social, economic, and natural environmental factors in different regions, the dominant function of land use transition is spatially and temporally different. The spatial evolution of land use transition is manifested as agglomeration and dispersion effect of land use function (Zhu et al. 2014). The number of land use structure increases or decreases directly lead to the obvious trend of weakening or strengthening some land functions (Wang et al. 2014; Kamwi and Mbidzo 2020). In China's complex mountainous areas, the transition of rural land use in mountainous areas has been accompanied by a reduction in labor input and a decline in intensification (Cheng et al. 2020; Liang et al. 2020). These processes have led to the evolution of ecological forest land from shrinking to expanding and the trend of cultivated land from expanding to shrinking, leading to a trend of restoration of rural land ecological functions (Wang et al. 2014; Achieng et al. 2020). The land use transition around cities has shown a trend of diversification of functions and weakening of ecological functions. Up to now, land use transition mainly focus on the structure and quantity of land use types, quantitative identification of land use function, spatiotemporal characteristics of land use transition, driving mechanism, and ecological environment response (Turnbull and Wainwright 2019; Meiyappan and Jain 2012; Bessah et al. 2019). In addition, some scholars believe that land use transition is a macro process of long-term land use evolution, and its morphological function evaluation is combined with the characteristics of regional land use types (Zhang et al. 2007; Yang et al. 2021). The sustainability of land resource use is based on the dynamic changes of the regional characteristics that conform to the transition of land use types under the socioeconomic transformation in a certain period of time (Gomes et al. 2020). However, the understanding and practical guidance of land use transition in Karst area under the transition of land use function form should be further improved. To strengthen the pertinence of practice guiding land use management in these complex Karst areas, it is necessary to analyze the coordination relationship of landscape ecological pattern on the basis of identifying regional land use functions.

Landscape pattern is the morphological and structural characteristics of complex landscape elements in a certain region in time and space (Buyantuyev and Wu 2007; Yeh and Huang 2009). It is the final result of various natural and man-made factors acting on different spatial and temporal scales, and is manifested as the process of landscape spatial heterogeneity (Sklénicka and Pixova 2004). Quantitative analysis of landscape pattern is the basis of the interrelationship between global and local pattern and processes at different scale, it is also an effective indicator to characterize the complexity of regional change (Garrigues et al. 2008). Land use transition and landscape pattern change are important indicators of system coordination between socioeconomic system and natural ecosystem. With the advancement of urbanization and industrialization, urban and rural landscapes show a significant feature of low density to high fragmentation, and the natural landscape with a single, integral, and discontinuous structure that tends to be complex, heterogeneous, and continuous mixed patches (Morelli et al. 2013; Qiu et al. 2014). Due to the drastic conversion between land use types, the continuous expansion of urban construction scale, the landscape pattern of different regions has been increasingly disturbed and its evolution pattern will become more complicated. In the fragile areas of ecological environment, the problem of deterioration of ecological environment is more prominent

(Costantini et al. 2012). In Karst complex terrain and geomorphology areas, both urban and rural landscape systems are affected by the interaction of natural and human activities, especially in urban areas, human activities are an important driving factor for the formation and evolution of landscape diversity (Deng et al. 2018; Zhou et al. 2019). To explore the ecological environment problems caused by regional land use transition, it is of great significance to discuss the changes of landscape pattern and its driving forces in the process of industrialization and urbanization of Karst complex landform.

Most scholars mainly use the quantitative method of landscape pattern index with the geographical remote sensing (RS) and geographic information system (GIS) spatial technology to explore the landscape pattern and evolution characteristics of plain and mountainous transition regions (Wang et al. 2021; Turner and Pham 2015; Yuan and Zhang 2021), which mainly includes landscape dynamic model and landscape pattern index method (Corry 2005; Kamwi et al. 2015). Remote sensing images of different research areas were collected for correction, interpretation, and processing, the thematic maps of different landscape utilization types were obtained using GIS, and using relevant technical model to explore and monitor the dynamic change process of landscape pattern (Kelarestaghi and Jeloudar 2011). To date, landscape pattern in China have mainly focused on plains and transitional mountainous areas severely affected by human beings, while there are few research perspectives on landscape ecological processes of land use in Karst areas with complex topography and geomorphology in Southwest China. Guizhou Province is located in the Karst region of southwest China with numerous complex and dangerous topography where geological disasters and rocky desertification are prominent, and the ecological environment is extremely fragile (Fig. 1). Land use pattern is deeply influenced by topography and geomorphic conditions (Dai et al. 2017). In this area, the Karst landform is typical, the surface is rugged and broken, soil erosion is serious, and the contradiction between man-land is prominent (Zheng et al. 2019; Yang et al. 2013).

Guizhou Province has been regarded as a national key ecological governance area, and the local government has focused on implementing the stony desertification control project and the policy of returning cultivated land to forest (Huang et al. 2018). In a short period of time, rapid population growth and major infrastructure construction makes the urban built-up area continue to expand, resulting in the rapid change of land use pattern, which also leads to the shortage of land resources and the deterioration of ecological environment among many aspects. Therefore, exploring the response of land use transition process to regional landscape pattern in the process of rapid urbanization from the academic and national levels are of great significance. In this article, our main special goals were: (i) to make full use of RS, GIS spatial technology, and landscape index method to monitor the dynamics of land use transition of Guizhou Province in typical Karst area, southwest China in the past 25 years; (ii) to analyze the spatial-temporal characteristics of land use transition and landscape pattern evolution under the grain for green project; (iii) to quantitatively discuss the driving factors and internal relationship of land use transition and landscape pattern combined with multivariate socioeconomic data; (iv) to put forward relevant policy suggestions on rational land use and landscape pattern planning in mountainous area. Through the practical research of this study can help to provide scientific reference and theoretical support for further land use management and landscape ecological planning in other similar areas.

2 Materials

2.1 Study area

Guizhou Province in southwest China is abbreviated as “Qian” and “Gui”, covering an area of 176,202 km², geographic location is 24°37′~ 29°13′ N, 103°36′~ 109°35′ E, bordering Sichuan Province and Chongqing in the north, Hunan Province in the east, Guangxi Province in the south, and Yunnan Province in the west (Fig. 2). The topography is high in the west and low in the east, tilting from the middle to the north, east and south. Guizhou is China's first national-level comprehensive experimental zone for big data, a world-renowned mountain tourism destination and a major Province for mountain tourism, and a national ecological civilization experimental zone. The landform includes four basic types, i.e., plateau, mountain, hill, and basin, 92.51% of the area is mountain and hill. Guizhou is a subtropical monsoon climate and straddles the Yangtze River and the Pearl River, it is characterized by typical development of Karst landforms. By 2021, Guizhou had 6 prefecture-level cities and 3 autonomous prefectures, with 38.5623 million permanent residents, China's GDP reached 1.68 trillion yuan, of this, the added value of the primary industry was 228.056 billion yuan, the secondary industry was 605.835 billion yuan, and the tertiary industry was 843.07 billion yuan.

2.2 Data acquisition

Research data mainly include land use data for 1990, 1995, 2000, 2005, 2010, and 2015 that were generated by visual interpretation of Landsat TM images in ArcGIS 10.2 by data Center for Resources and Environmental Sciences, Chinese Academy of Sciences (<http://www.resdc.cn>). The analytical accuracy of land use data for six periods was 30 m. By checking and modifying the topology of the land use vector layer in each phase, these data sets were divided into six first-level types, including cultivated land (dry land and paddy land), forest land (forest land, shrub land, sparse forest land, and other forest land), grassland (high coverage grassland, medium coverage grassland, and low coverage grassland), water areas (ditches, rivers, reservoirs and lakes, etc.), urban and rural industrial and mining land (urban land, rural residential land and other construction land), unused land (abandoned land, exposed rock, sandy land and saline land) based on China's land use classification system (GB/T 21010 – 2017). In this study, Guizhou Province has a large scale, so we combined the primary and secondary land use types into 8 categories for detailed analysis (Fig. 3). In particular, the accuracy of the first-level land use data interpreted by the Chinese Academy of Sciences Data Center was over 93.56%, and the second-level land use classification data was over 90.89%. The details and precision of the relevant land use data in this paper can be supported by reference to the published literature (Liu et al., 2002, 2010, 2014, and 2018).

Many potential factors affecting LULC changes were selected based on literature review and actual situation of the research area (Table 1). In the long period of LULC dynamics, a large number of existing literatures show that natural factors, socioeconomic factors and neighborhood factors can significantly influence land use change (Feng and Tong 2019; Abbas et al. 2021). Among them, natural factors include terrain factors and environmental condition factors. It is generally believed that elevation, slope, terrain relief and slope aspect are potentially important driving factors affecting LULC changes (Sahoo et al. 2018; Müller et al. 2010). In the process of real social development, there are a large number of neighborhood factors such as distance to a particular urban land type (Wang et al. 2020), distance to major roads i.e., distance to the highway, the national road, the railways, and county road (Poelmans and Van Rompaey 2009), distances to urban and county centers (Sunde et al. 2014), and distance to the river (Zhang and Xia 2021), as well as socioeconomic factors, for instance, the spatial distribution of GDP and population are also important potential factors driving land use transition (Zhang et al. 2020). Each spatial factor of Guizhou Province is shown in Fig. 4.

Table 1
List and meaning of each driving factor.

Data type	Code	Resolution/m	Year	File type	Meaning of the spatial variables	Data sources
Natural factors	Elevation	30	-	GRID	The elevation of the terrain	http://www.gscloud.cn/
	Slope	30	-	GRID	The slope of the terrain	http://www.gscloud.cn/
	Aspect	30	-	GRID	The aspect of the terrain	http:// www.resdc.cn
	Topographic relief	30	-	GRID	Distribution of topographic relief	http:// www.resdc.cn
Socioeconomic factors	Population	30	1995, 2005, 2010, and 2015	GRID	Distribution of spatialized population	http:// www.resdc.cn
	GDP	30		GRID	Distribution of spatialized GDP	http:// www.resdc.cn
Neighborhood factors	Dis5WA	30	2010	Shpfile	Distance to the water area	http:// www.resdc.cn
	Dis5HW	30	2010	Shpfile	Distance to the highway	openstreetmap.org
	Dis5NR	30	2010	Shpfile	Distance to the national road	openstreetmap.org
	Dis5RW	30	2010	Shpfile	Distance to the railways	openstreetmap.org
	Dis5CR	30	2010	Shpfile	Distance to the county road	openstreetmap.org
	Dis5CC	30	2010	Shpfile	Distance to the county centers	map.baidu.com
	Dis5UL	30	2015	Shpfile	Distance to the urban land	http:// www.resdc.cn

3 Methodology

3.1 Comprehensive land use dynamic degree

The comprehensive land use dynamic degree (CLUDD) is the overall change of the land use type in the study area during the study period, which can reflect the intensity of the regional comprehensive land use change, and can also be used for the land use change rate between the local and the whole area, and between the local and local areas. (Bessah et al. 2019). Land use change rate and comprehensive dynamic change intensity (Huang et al. 2018) were analyzed by dividing the period into five period nodes. The calculation equation is as follows:

$$K = \sum_{i=1}^n (\Delta S_{ij} / S_i) \times T^{-1} \times 100\% \quad (1)$$

where K is the CLUDD of the study area in the period T , and the larger the value is, the more severe the regional land use change is. ΔS_{ij} is the total area of class i land use type converted to other land use types from the beginning of the study period to the end of the study period. S_i is the total area of category i land at the beginning of the study period. T is the length of monitoring period, when T is set as year, K is the annual change rate of land use in the study area.

3.2 Spatial visualization method

The study area is provincial scale has large study area and long period interval. To more clearly observe the spatial differences of land use transition and landscape pattern in Guizhou Province, each indicator selected in this study are used for dynamic analysis of spatial internal differences by grid division method. According to the situation of the research area, the size of the discriminant unit was set as 3000 m×3000 m, and the research area was divided into 45,191 spatial units.

3.3 Geo-science information method

We built the land use data of different periods into the land use transition map, and the newly generated map code was processed by using the map algebraic superposition operation of the two periods of land use type map unit coding. When land use type ≤ 10 categories, its expression can be synthesized as: $Q = \text{period } A \times 100 + \text{period } B$, Q is the newly generated map code, period A and period B represents the unit codes of land use atlas in the early and late stages of the study, respectively. Thus, we can obtain the land use transition map of Guizhou Province during 1990–1995, 1995–2000, 2000–2005, 2005–2010, and 2010–2015.

3.4 Land use transition trend

The process of land use transition under the influence of social economy includes two dynamic changes, including transfer “into” and transfer “out”. Among them, the transfer “into” is the process of transforming other land use types into local land use types, while transfer “out” is the process of transforming local land use types into other land use types. Using the ArcGIS10.2 platform to overlay the land use data of the two research periods, the newly added area and the shrinking area of a certain land category can be obtained again, that is, it is defined as an uptrend graph and a downtrend graph.

3.5 Landscape pattern characterization index

Landscape pattern is a comprehensive spatial feature with highly complex elements among regions, its theories and methods are universal in geography and landscape ecology (Antrop 2000, Shen et al. 2019). Each landscape pattern index highly concentrates the landscape characteristic information of a specific region, and can quantitatively reflect the spatial structure composition, spatial morphology, and dynamic evolution characteristics through their single and combined operations (Chen et al. 2016, Frazier 2019). To fully analyze the spatial characteristics of landscape pattern fragmentation and diversity of Guizhou Province in the Karst area for 1990–2015. We earnestly selected the patch density (PD), number of patches (NP), landscape shape index (LSI), largest patch index (LPI), patch richness density (PRD), contagion (CONTAG), and Shannon's diversity index (SHDI) to characterize the diversity and spatial heterogeneity of landscape pattern (De Pablo et al. 2012). Existing literature shows that these indexes can better reflect the characteristics of landscape pattern (Long et al., 2010, Ren et al., 2018), and the ecological significance and relevant algorithms of each index are detailed in the references (Table 2).

Table 2 Index and their meaning of landscape pattern.

Index/equation	Variable declaration	Meaning
$PD = N/A$	N is the number of patches, A is the area of A certain type of landscape	PD reflects the degree of landscape fragmentation within a certain area. The greater the patch density, the greater the degree of fragmentation. (2)
$NP = Ni$	Ni is the total number of patches contained by type I in the whole landscape	NP is a measure of the fragmentation of plaque types in a particular study area (3)
$LSI = \frac{E}{minE}$	E is total length of all patch boundaries in the landscape, and $minE$ is all the minimum patch boundaries of the landscape	LSI is a measure of aggregation and dispersion degree of patch. The larger the LSI in a certain area, the more discrete the patch. (4)
$LPI = \frac{\max(a_{ij})}{A} \times 100$	a_{ij} is largest area of the i and j type patch, and A is the total area of A certain patch type.	LPI is the percentage of the largest patch area in the total landscape area, and is a measure of the dominance degree at patch level. (5)
$PRD = \frac{m}{A} \times 10^6$	m is the number of patch types, A is the total area of patch numbers.	PRD reflects the diversity characteristics of local and overall patterns in the study area (6)
$CONTAG = \left[1 + \frac{\sum_{i=1}^m \sum_{k=1}^m \left[P_i \ln(p_i) \left(\frac{g_{ik}}{\sum_{k=1}^m g_{ik}} \right) \right]}{2 \ln(m)} \right]$	m is the total number of patch type, g_{ik} is the number of node of i type and k type, and the perimeter of i type of P_i patch.	CONTAG is the degree of aggregation of different landscape patches in a certain area. (7)
$SHDI = -\sum_{i=1}^m [P_i \ln(P_i)]$	P_i is the proportion of area occupied by the i -th landscape, and m is the number of landscape type.	SHDI reflect the number and proportion of landscape elements in a certain area (8)

3.6 Modified multiple logistic regression (MMLR) model

MMLR model can well screen out the occurrence probability and intrinsic relationship of different types of factors to events at different times, and generate regression coefficients of significant factors, which can directly represent the contribution intensity of spatial factors to land use change (Overmars et al. 2003). Therefore, the MMLR model was used in this study to analyze the influencing mechanism between eight types of land use and

each spatial factor in Guizhou Province for 1990-2015. After multicollinearity test, the variance inflation coefficient VIF was all less than 5, indicating that there was no multicollinearity between each factor, which could be analyzed in detail by the MMLR model. The mathematical equation is as follows:

$$Pk = \frac{p(y=k|x)}{p(y=0|x)} = \beta_{0k} + \beta_{1k}x_1 + \beta_{2k}x_2 + \cdots \beta_{pk}x_p \tag{9}$$

where y is dependent variable, x is independent variable, there are m dependent variables and $y = 0$ as the reference group, then $k = 0, 1, 2, m-1$. $P(y = kx)$ is the conditional probability of y , β is the coefficient of the logistic regression equation, which indicates the correlation degree between independent variables and dependent variables.

4 Results

4.1 Characteristics of land use transition

The area of cultivated land in Guizhou Province decreased by 838.91 km² for 1990–2015, with an average annual change rate of 0.35% (Table 3). During 1990–1995, the area of forestland increased to 1326.84 km², with a change rate of 0.28%. During 2000–2005, the area of forestland increased the most, with an increase of 1360.27 km² (0.29%). During 2005–2010, the change rate of grassland was 0.56%, and its area decreased to 852.73 km². During 2010–2015, the change rate of grassland area was the lowest (0.13%), but the change trend of unused land area was opposite to that of grassland. Water area, urban land, rural residential land, and other construction land showed an increasing trend from 1990 to 2015. Among them, the area changes of water category from 2005 to 2010 reached 238.77 km², and the change rate was 11.77%. For 2010–2015, the areas change of urban land, rural residential land, and other construction land reached 290.04, 45.24, and 746.11 km², respectively, with the change rate of 16.63, 3.40, and 65.33%, respectively. The change trend of cultivated land area was similar to that of grassland, with a small increase at first and a significant decrease later. In the previous period, the industrialization development of Guizhou Province was very backward due to the local natural condition, the local government began to implement ecological engineering management. At the same time, the policy of returning cultivated land to grassland began to take effect, and the reduced cultivated land was mainly converted into urban land, rural construction land, and grassland.

Table 3
Change rates of land use transition in Guizhou Province.

land use type	1990–1995		1995–2000		2000–2005		2005–2010		2010–2015	
	Area change/km ²	Change rate/%	Area change/km ²	Change rate/%	Area change/km ²	Change rate/%	Area change/km ²	Change rate/%	Area change/km ²	Change rate/%
Cultivated land	-1098.13	-0.44	1220.90	0.50	48.52	0.02	-307.82	-0.12	-702.38	-0.28
Forest land	1326.84	0.28	-1816.43	-0.38	1360.27	0.29	704.47	0.15	-267.61	-0.06
Grassland	-239.96	-0.15	541.80	0.35	-1424.64	-0.89	-852.73	-0.56	-199.65	-0.13
Water area	-1.87	-0.10	17.92	0.93	4.30	0.21	238.77	11.77	87.91	2.73
Urban land	-0.38	-0.03	30.41	2.75	11.35	0.90	85.80	6.52	290.04	16.63
Rural residential land	-16.47	-1.37	21.45	1.92	11.21	0.91	9.41	0.73	45.24	3.40
Other construction land	22.29	4.72	-9.88	-1.69	-2.45	-0.46	123.94	23.73	746.11	65.33
Unused land	7.68	3.93	-6.23	-2.66	-8.55	-4.22	-1.80	-1.12	0.29	0.19

4.2 Comprehensive land use transition

As shown in Fig. 5 that the spatial distribution of dynamic degree of comprehensive land use in Guizhou Province shows obvious differences in five periods. With the development of time, the dynamic transition of land use in Guizhou Province showed a trend of decreasing first and then increasing as a whole, which decreased from 5.96% for 1990–1995 to 2.06% for 2005–2010, and increased to 6.37% for 2010–2015. During period of 1990–2000 and 2000–2005, the high concentration of comprehensive land use transition was mainly concentrated in Zunyi in the north and Qiandongnan in the east of Guizhou Province. From 2005 to 2015, the high value of comprehensive land use dynamics was mainly concentrated in Guiyang, Bijie, Anshun, and Qiannan. During the period of 1990–2005, the dynamic degree of comprehensive land use continued to rise. Mountain cultivated land, unused land, and grassland are gradually transformed from agricultural land to non-agricultural land. On the whole, the dynamic transition of comprehensive land use change in the central region was more obvious than that in other regions.

4.3 Spatiotemporal analysis of land use transition

4.3.1 Quantitative analysis of land use transition

We sorted the transition of land use type with large transition degree based on the area size, and found that 19 types of atlas units accounted for the most significant changes in the area of map units (Table 4). From 1990 to 2015, the cultivated land → forestland (code 102), cultivated land → grassland (code 103), forestland → cultivated land (code 201), forestland → grassland (code 203), grassland → cultivated land (code 301), and grassland → forestland (code 302) that were the most significant atlas units, accounting for 78.89% of the total unit area, mainly distributed in the south and northeast of Guizhou Province. The second is the atlas type of “forest land→ other construction land (code 207), cultivated land→ urban land (code 105)”, accounting for 7.87% of the total atlas unit area, mainly distributed in the middle. The third is the mutual conversion of urban land, cultivated land, and rural residential land, accounting for 2.67%, 3.21%, and 2.93% of the total map unit area, respectively. With the development of time, the transition categories mainly concentrated for 1990–1995, 1995–2000, and 2000–2005. For 2005–2010 and 2010–2015, the transfer areas of urban land, rural residential land, and other construction land began to change significantly. The areas of grassland converted to unused land, cultivated land, and forest land were 81, 940, 72, 044, and 41, 039 km², respectively, and the cumulative conversion rates was 37.72%, the areas of the three transferred to grassland were 80,646, 68,145, and 41,039 km², respectively. The cumulative transfer rates were 37.57%, and the net transfer rates of grassland was 0.15%.

Table 4
Main land use transition processes in Guizhou Province from 1990 to 2015.

Order	Code	land use type conversion	1990–1995		1995–2000		2000–2005		2005–2010		2010–2015	
			Transfer area/km ²	Change ratio/%	Transfer area/km ²	Change ratio/%	Transfer area/km ²	Change ratio/%	Transfer area/km ²	Change ratio/%	Transfer area/km ²	Change ratio/%
1	102	CuL→FoL	938.29	25.99	59.35	1.66	530.61	21.66	82.50	4.16	0.46	0.04
2	103	CuL→GrL	387.78	10.74	53.05	1.49	55.73	2.27	75.89	3.83	2.97	0.23
3	104	CuL→WaL	4.73	0.13	7.16	0.20	2.16	0.09	83.43	4.21	43.87	3.36
4	105	CuL→UrL	9.85	0.27	32.75	0.92	5.62	0.23	62.86	3.17	179.48	13.74
5	106	CuL→RuRL	4.54	0.13	22.40	0.63	3.15	0.13	12.16	0.61	52.70	4.03
6	107	CuL→OtL	5.32	0.15	5.61	0.16	0.26	0.01	48.51	2.45	439.39	33.64
7	201	FoL→CuL	132.34	3.67	1002.02	28.09	159.94	6.53	22.12	1.12	7.61	0.58
8	203	FoL→GrL	700.21	19.40	1403.52	39.35	95.41	3.90	245.79	12.40	11.24	0.86
9	204	FoL→WaL	1.77	0.05	4.03	0.11	0.01	0	95.73	4.83	33.01	2.53
10	205	FoL→UrL	3.07	0.08	1.28	0.04	0.25	0	13.46	0.68	31.11	2.38
11	207	FoL→OtL	19.99	0.55	4.82	0.14	1.86	0.08	50.27	2.54	178.81	13.69
12	301	GrL→CuL	77.02	2.13	390.57	10.95	483.26	19.73	33.05	1.67	4.18	0.32
13	302	GrL→FoL	1244.40	34.47	517.09	14.50	1079.89	44.08	1049.53	52.94	3.31	0.25
14	304	GrL→WaL	2.47	0.07	7.43	0.21	2.80	0.11	59.03	2.98	11.87	0.91
15	307	GrL→OtL	3.38	0.09	2.03	0.06	0.93	0.04	24.80	1.25	157.36	12.05
16	401	WaL→CuL	7.07	0.20	0.78	0.02	0.71	0.03	0.27	0.01	0.81	0.06
17	501	UrL→CuL	12.43	0.34	3.83	0.11	0.13	0.01	0.20	0.01	1.48	0.11
18	601	RuRL→CuL	19.57	0.54	1.94	0.05	0.49	0.02	1.87	0.09	0.61	0.05
19	702	OtL→FoL	1.67	0.05	18.90	0.53	0.05	0	0.13	0.01	2.51	0.19
Note: CuL-cultivated land, FoL-forest land, GrL-grassland, WaL-water land, UrL-urban land, RuRL-rural residential land, OtL-other construction land, UnL-unused land.												

4.3.2 Analysis of land use rising

As shown in Fig. 6, during 1990–1995, the area of unchanged land use in Guizhou Province was 172,498.87 km², and the area of changed land use was 3609.90 km². The areas of newly added forest land and grassland were the largest in the change area, with area of 2189.29 and 1095.85 km², respectively. The areas of newly added cultivated land, urban land, and other construction land were 252.80, 16.83, and 29.58 km² respectively. The areas of newly added water area, rural residential land, and unused land were the smallest. During 1995–2000, the area of unchanged land use was

172,542.32 km², and the area of changed land use was 3566.87 km². The newly added areas of cultivated land, forest land, and grassland were 1401.23, 1601.17, and 1465.12 km², respectively. From 2000 to 2005, the area of unchanged land use was 173,659.16 km², and the area of changed land use was 2449.63 km². The areas of newly added cultivated land, forest land, and grassland that accounted for 26.37%, 66.08%, and 6.20% of the change areas, respectively. From 2005 to 2010, the area of unchanged land use was 174,126.49 km², and the area of changed land use was 1982.63 km². The areas of newly added cultivated land, forestland, and grassland accounted for 2.90%, 57.21%, and 16.38%, respectively. For 2010–2015, the area of unchanged land use was 176,109.18 km², and the area of changed land use was 1277.51 km², respectively. The areas of newly added cultivated land, forestland, and grassland accounted for 1.33%, 0.56%, and 1.23%, respectively.

The areas of newly added forest land, grassland, and urban and rural construction land in central Guizhou Province were the largest. The areas of newly added grassland and cultivated land were the largest in Qiannan and Tongren. Guizhou Province mainly increased forestland and grassland during 1990–1995 and 1995–2000; during 2000–2005, 2005–2010, and 2010–2015, it mainly increased rural residential land, especially urban land and other construction land. Among them, the central part of Guizhou Province was mainly newly added urban and rural construction land. In the five periods, the main newly added land use types in Guizhou Province were cultivated land, urban land, and rural construction land. But the increase rates of urban and rural construction land had far exceeded that of cultivated land in the latter period.

4.3.3 Analysis of land use shrinking

As shown in Fig. 7 that the shrinking areas of cultivated land, forest land, and grassland in Guizhou Province were the largest during 1990–1995, their areas were 1350.93, 862.47, and 1335.79 km², respectively; the second is rural residential land and urban land, accounting for 0.70% and 0.48%, respectively. The shrinking areas of other construction land and unused land were smaller, accounting for less than 0.21%. During 1995–2000, the total shrinking area of land use was 3566.87 km², accounting for 2.03%. The shrinking areas of cultivated land, forest land, and grassland were 180.33, 2417.54, and 923.32 km², respectively, followed by 23.70 km² of other construction land. For 2000–2005, the total shrinking area of land use was 2449.63 km², accounting for 1.39%. The shrinking areas of cultivated land, forest land, and grassland were 597.53, 258.45, and 1576.56 km², respectively. From 2005 to 2010, the total shrinking area of land use was 1982.63 km², accounting for 1.13%. The shrinking areas of cultivated land, forest land, and grassland were 365.34, 429.73, and 1177.55 km², respectively. From 2010 to 2015, the total shrinking area of land use was 1277.51 km², accounting for 0.73%. The shrinking areas of cultivated land, forest land, and grassland were 719.32, 274.69, and 215.42 km² respectively, followed by rural residential land and other construction land, accounting for 2.14% and 2.63%, respectively.

The shrinking land use types in the west and northwest of Guizhou Province were grassland and cultivated land, which were consistent with the newly increased land use types. However, in the eastern part of Guizhou Province, the main type of shrinking land was cultivated land. From 1990 to 2015, the areas and structures of different shrinking land use types in Guizhou Province had a high spatial similarity with newly added land use types. It is worth noting that the shrinking areas of forestland, grassland, and cultivated land had increased compared with the previous period, while the shrinking areas of urban land, rural residential land, and other construction land had decreased compared with the previous period. This feature was particularly evident in Zunyi, Tongren, Qiandongnan, Qiannan, Qianxinan, Liupanshui, and Bijie areas. with the rapid development of urbanization in recent years, the demand for a large amount of construction land is difficult to meet, which has led to an increase in the amount of cultivated land occupied by urban land in some areas (Li et al. 2017).

4.4 Evolution characteristics of landscape fragmentation

As shown in Fig. 8 that the PD and NP of prefecture-level cities showed a similar relationship from 1990 to 2015, basically decreasing first and then increasing. From 1990 to 2015, the PD and NP in Bijie, Liupanshui, Guiyang, Qiannan, Qianxinan, Qiandongnan, Zunyi, and Tongren showed the biggest fluctuation, showing a “W” shape, both of them reached a turning point for 2000. By 2015, the PD and NP were at their maximum, the reason is that a large number of local infrastructures, roads, and urban and rural construction land expansion that have led to the strongest disturbance of regional land use landscape patches, and the spatial fragmentation was more and more obvious. The prefecture-level cities with the most obvious changes were Bijie (PD: 0.4468 number·km⁻¹, NP: 21940), Guiyang (PD: 0.3712 number·km⁻¹, NP: 5740), and Tongren (PD: 0.4123 number·km⁻¹, NP: 16,259), and Zunyi (PD: 0.4001 number·km⁻¹, NP: 24,199), followed by Anshun (PD: 0.2371 number·km⁻¹, NP: 4498), Qiandongnan (PD: 0.2491 number·km⁻¹, NP: 14,054), Qiannan (PD: 0.2479 number·km⁻¹, NP: 14,446), and Qiannan (PD: 0.4123 number·km⁻¹, NP: 24,199).

As shown in Fig. 9 that the changes in LPI and LSI of each prefecture-level city in Guizhou Province showed opposite trends during the period of 1990–2015. The LSI in the Anshun, Bijie, Guiyang, Qiandongnan, Qiannan, Tongren, and Zunyi showed an overall decreasing trend, while the LSI in the Liupanshui and Qianxinan showed an increasing trend. In terms of LPI, the Qiandongnan, Guiyang, and Zunyi showed a trend of increasing demand on the whole, while Anshun, Bijie, Liupanshui, Qiannan, and Tongren showed a trend of continuous decrease on the whole, and only the LSI in the Qianxinan remained basically unchanged. The LPI of Guizhou Province was mainly dominated by forestland, cultivated land, and grassland. From 1990 to 2015, forestland and grassland showed an increasing trend, while cultivated land showed a change of decreasing first and then increasing. During 1990–2000, the area of cultivated land showed expansion, while the area of forest land decreased first. On the whole, the LPI of remote cultivated land was larger than that of forest land. From 2000 to 2015, the patches of forest land and grassland increased successively. For 1990–2015, the urban land, rural residential land, and other construction land in prefecture-level cities expanded rapidly under the strong influence of local people, resulting in the segmentation and encroachment of regional landscape types, and enhancing in the diversification and fragmentation of landscape types.

4.5 Analysis of landscape diversity

As shown in Fig. 10, the PRD and SHDI in Guizhou Province showed basic consistency in spatial distribution during 1990–2015, with high values mainly concentrated in the Guiyang, Anshun, and Liupanshui, and gradually migrating from the central region to the western region. The low values were mainly distributed in Zunyi in the north, Qiandongnan in the east, and Qiannan in the south of Guizhou Province. From 1990 to 2015, the CONTAG index was mainly distributed in the Zunyi, Tongren, Guiyang, and Qiannan, which were concentrated in the central region from the periphery with time passing. From 1990 to 2015, it is clear that the evolution of landscape patch types showed high fragmentation and spread connectivity. With the continuous improvement of the social economy and the influence of human activities, i.e., artificial ecological governance, road traffic construction, communication network construction, and rural tourism construction), the land use patches in the study area were constantly divided, which led to the continuous decentralization of the patch types within the landscape, forming a variety of landscape utilizes. The urban land expansion, the increase of roads and land for rural residents, and the decrease of cultivated land make the natural landscape patch types continuously segmented and derived more single patches (Travaglia and Torsello 2017). As a result, the landscape characteristics area was fragmented, with high patch connectivity, maximum diversity, and relative richness, and finally generating a high degree of landscape spatial heterogeneity.

5 Discussion

5.1 Driving mechanism of land use transition and landscape pattern evolution

The Walds statistics and standard error were used as estimation factors to represent explanatory variables in the relative weight model of each regression coefficient, and the contribution strength of each explanatory variable could be evaluated by combining significant (Liang et al. 2020). As shown in Fig. 11 and Table 5, the ROC test statistics of all land use types in Guizhou Province were over 0.70, indicating that the selected driving factors showed good explanatory ability in explaining land use transition and landscape pattern evolution. For 1990–2015, M and B were important factors affecting the transition of cultivated land, showing a strong positive correlation. The contributions of C, L, and P to cultivated land were also strong, but which showed a negative correlation. Forest land was mainly affected by C, D, M, Q, and N. D and L were negative explanatory variables of grassland, indicating that grassland was less likely to occur in population distribution areas. GDP, topographic relief, and population had become important factors restricting the development of urban land expansion. Rural residents were mainly affected by local topography, population, and GDP. Other construction land was mainly affected by population, traffic lines, and terrain factors. In addition, landscape pattern evolution and land use transition are mutually influencing processes (Zebisch et al. 2001), and local soil organic matter still plays an important role in their evolution. Forestland, grassland, and cultivated land were mainly distributed in high slope and altitude remote areas, and the factors were highly constrained by terrain. Urban land, rural residential land, and other construction land were mainly affected by socioeconomic factors. In addition, elevation, slope, nearest river, distance to the nearest town center, and distance to the nearest county center that were positive explanatory abilities of construction land. Guizhou Province is a complex terrain area with high mountains, low mountains, valleys, trough valley, and other terrain. The local topographic conditions are the main factors affecting land use transition and landscape pattern evolution, followed by socioeconomic factors.

Table 5
Contribution capacity of each factor driving.

Variable code	Cultivated land	Forest land	Grassland	Water land	Urban land	Rural residential land	Other construction land	Unused land
	<i>Exp(β)</i>	<i>Exp(β)</i>	<i>Exp(β)</i>	<i>Exp(β)</i>	<i>Exp(β)</i>	<i>Exp(β)</i>	<i>Exp(β)</i>	<i>Exp(β)</i>
A	-4.264	3.474***	-5.73	-1.597***	-0.335***	-1.222***	-0.276***	99.379
B	21.42	0.606***	47.24	-71.568	-39.608	24.737	-9.187***	-968.492
C	-79.912	23.301	5.594***	-6.705***	-42.954	-105.307	-51.221	182.155
D	-63.001	-28.692	-80.457	53.433	58.524	-8.675***	24.381	415.286
E	-0.704	0.156***	0.590	-19.789	1.389	0.066***	0.958	1.773
F	0.945	-0.728	0.473***	6.435	-15.621	-2.427	-2.599	0.338***
G	-1.469	-0.171***	-1.323	-3.431	-9.387	-0.457	-2.185	-3.751
H	-0.405	-0.428	1.632	-2.207	-0.482	0.126***	-0.227***	4.403
I	-0.032***	-1.327	-0.074***	0.030***	-0.808	0.683	0.356	-5.418
J	-0.909	0.241***	3.057	-0.775	-1.644	1.767	-1.031	-0.218***
K	-0.144***	0.630	-2.387	0.741	0.482***	-0.552	-0.838	2.241
L	-40.279	-57.326***	-80.746	5.458***	-47.456	-63.94	-22.503	-1518.377
M	136.801	-86.43	20.973	22.951	75.903	115.798	54.849	-87.037
N	4.829***	16.969	12.014	-27.632	19.377	22.269	14.204	9.822***
O	8.592***	-1.455***	-0.616***	16.966	6.437***	3.050***	4.187	-564.663
P	-42.394	-8.017***	1.684	-5.129***	-7.97	-6.454	-3.718***	-659.99
Q	12.581***	76.242	17.475***	-7.725***	39.422	60.572	22.499	1531.432
R	-1.36	1.958	0.298	-7.021	-1.119	-0.958	-1.145	0.254***
S	2.637	1.145***	1.702	-2.678	6.557	5.887	3.786	4.663
T	-0.118***	0.251	0.198	-0.395	0.237***	0.139	0.146	0.607
U	-9.859	-1.143***	-4.637	-0.733***	-50.064	-43.779	-31.964	-37.593
Constant	0.809	-0.283	-0.61	3.584	3.445	1.23	1.824	1.357
ROC	0.863	0.912	0.893	0.886	0.869	0.910	0.902	0.885
**** indicates that some factors have not passed the 0.05 significance test. A-GDP (2010), B-GDP (2015), C-POP (2010), D-POP (2015), E-Dis5WA, F-Dis5CC, G-DIS5UL, H-Dis5NR, I-Dis5HW, J-Dis5CR, K-Dis5RW, L-POP (1995), M-pop (2005), N-GDP (1995), O-GDP (2000), P-GDP(2005), Q-POP (2000), R-Elevation, S-Slope, T-Aspect, U-Topographic relief.								

On the whole, Guizhou Province has undergone major changes in land use from 1990 to 2015, which were mainly manifested in the mutual conversion of grassland, cultivated land, and forest land, as well as the mutual conversion of urban land, rural residential land, other construction land, and cultivated land. Under the dual influence of local natural conditions and human activities, the change frequency of cultivated land to forestland and grassland was the highest. On the one hand, regional climate, soil type, and soil organic quality factors lead to a large amount of conversion from grassland to cultivated land and forest land (Guo et al. 2019). On the other hand, Guizhou Province has made great efforts to build the ecological environment in recent years, the local government has implemented the comprehensive rocky desertification and the policy of returning cultivated land to forest, so the areas of forest land and grassland has been replenished. Under the mechanism of various factors, various land use types underwent drastic transformation, and at the same time, landscape pattern changed in spatial consistency.

5.2 Ecological significance of land use transition and landscape pattern evolution

Land use transition and landscape pattern evolution are a process of mutual influence (Deng et al. 2009). In the process of land use type evolution, local change produces overall horizontal spatial chain change, and finally presents landscape heterogeneity (Sklenicka and Pixova 2004). Scientifically mastering the evolution path of land use transition and the dynamic direction of landscape pattern can help to balance regional socioeconomic development and powerful measures of ecological environmental protection. In recent years, China has been pursuing rapid socioeconomic development and has made outstanding achievements in various fields. At the same time, the rationality of regional ecological environment protection and efficient utilization of land resources is the final guarantee for the construction of national ecological civilization. This study mainly analyzed the spatiotemporal characteristics of the transition of land use types and the evolution of landscape pattern in Guizhou Province, which can help in local long-term policy formulation and ecological protection is of great significance. With the clear requirements of ecological civilization construction in China, mountainous

areas should bear more responsibility for ecological management. In recent years, the relevant departments of Guizhou Province cooperated with each other has scientifically implemented a series of land remediation projects and ecological protection projects according to local natural geographical characteristics and socioeconomic development trends, which have improved the regional ecological environment quality and enhanced land use efficiency (Fig. 12), such as rock desertification governance and ecological migration projects. According to the characteristics of different types and stages of land use transition and landscape pattern evolution, it is of great significance to adopt the regional expansion and contraction strategies to drive the landscape ecological level of the surrounding area, so as to improve the ecological effect of this complex mountain area.

5.3 Policy implications in mountainous areas

Land sustainable management and ecological protection has always been a hot issue from the government and academic circles. It is very necessary to formulate a series of land use and ecological protection policies for Karst, a typical ecologically fragile area. With rapid population growth and lack of cultivated land resources in mountainous areas, forest land to maintain ecological environment is a key project in the region. In recent decades, although China has formulated a series of policies on returning farmland to forest and forestry management, which have significantly improved the ecological environment of the whole region, there are still some problems in the balance between forestry management and land use policy. Based on the results of this study, we further put forward some reasonable suggestions to promote the forest management, land use transition, and landscape planning in Karst areas. (1) Policy makers need to combine hydrogeology and soil type characteristics in Karst regions for land use protection and plantation forests in high-altitude areas. (2) The government should actively encourage farmers to return farmland and grassland to forest in areas with steep slopes greater than 25°, increase vegetation coverage and reduce soil erosion; there should also be a compensation system for farmers. (3) Collaborative cooperation among multiple departments, interactive policy consultation, and joint training of comprehensive management staff to carry out biological, chemical and physical engineering to enhance land production capacity and improve the fragile ecological environment of Karst, so as to maximize the ecological environment for ecological and economic benefits Beneficial. (4) Actively improving farmer's knowledge level, cultivating their awareness of ecological environment protection, reducing the damage to the forest ecological environment as far as possible in the planting process, and eliminating the waste of land resources. In essence, efficient land use and ecological environment protection can be realized only from the main body of farmers. (5) Actively introducing high and new technologies and industries to promote traditional agriculture to be replaced by modern mechanical farming system. Traditional land use and resource management methods should improve technology and machinery investment by increasing the intensity of modern agriculture. At the national and regional levels, the balance between ecological environment, land use, and social economy should be comprehensively coordinated. In the following research process, promoting the progress of social civilization and orderly ecological environment is an important topic, which is also worthy academic topic for in-depth discussion.

6 Conclusions

This study took Guizhou Province in mountain areas of typical Karst as the research object and revealed the mechanism process of land use transition and landscape pattern evolution in the past 25 years through geographic information atlas and landscape pattern method. Some interesting practical conclusions are as follows: exploring the land use transition and landscape pattern evolution laws and their spatiotemporal characteristics in typical Karst areas, the internal change mechanism between them was clarified. Analyzing the formation principle of their differences in spatiotemporal was an inevitable requirement of the major strategy of national guidance for regional development, and also plays an important strategic role in balancing ecological governance and land use optimization management in accordance with local conditions in each region of the country. At the same time, it also can provide theoretical reference for decision-makers in different regions.

Declarations

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CRediT authorship contribution statement

Quan Wang contributed to conceptualization and methodology, software writing—original draft preparation. Xuepiao Bai contributed to formal analysis, writing – review & editing, validation.

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Availability of data and materials

The data sets generated and analyzed during the current study are not publicly available due to the signing of the confidentiality agreement but are available from the corresponding author on reasonable request.

Consent to publish

As a result of the research, we unanimously agree that this paper can be published in your journal.

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Figures

Figure 1

The landscape of rural and rocky desertification in Guizhou Province. (a): Distribution of cultivated land and rural settlements in mountainous areas, (b): Afforestation in rocky desertification area.

Figure 2

Location of the study area.

Figure 3

Land use map of Guizhou Province

Figure 4

Visualization of each driving factor

Figure 5

Spatial distribution of comprehensive land use in Guizhou Province

Figure 6

land use growth atlas in Guizhou Province.

Figure 7

Land use shrinkage atlas in Guizhou Province.

Figure 8

The evolution characteristics of PD and NP in the prefecture-level cities of Guizhou Province.

Figure 9

Evolution characteristics of LPI and LSI in prefecture-level cities of Guizhou Province.

Figure 10

Spatial evolution characteristics of PRD, SHDI, and CONTAG in Guizhou Province.

Figure 11

Statistical values of Walds and standard error of various land use types in Guizhou Province. (a)-Cultivated land, (b)-Forest land, (c)-Grassland, (d)-Water land, (e)-Urban land, (f)-Rural residential land, (g)-Other construction land, (h)-Unused land. A-GDP (2010), B-GDP (2015), C-POP (2010), D-POP (2015), E-Dis5WA, F-Dis5CC, G-DIS5UL, H-Dis5NR, I-Dis5HW, J-Dis5CR, K-Dis5RW, L-POP (1995), M-pop (2005), N-GDP (1995), O-GDP (2000), P-GDP(2005), Q-POP (2000), R-Elevation, S-Slope, T-Aspect, U-Topographic relief.

Figure 12

Ecological effects of land use transition and landscape pattern.