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Impact of land use and land cover change on the landscape pattern and service value of the village ecosystem in the karst desertification control

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Human activities have had a significant impact on ecosystems. Studying landscape patterns and ecosystem services (ES) at the village scale based on land use and land cover (LULC) is essential in addressing current ecosystem issues. Based on GF images, the paper selects village ecosystems of karst desertification control (KDC) as the research object. It uses the landscape pattern index, topographic position index (TPI), and value equivalent method to conduct a spatial and temporal analysis of the ecosystem service value (ESV) of the karst desertification control cycle (2015–2020). The results show that: 1) forest land, orchard land, and construction land increase, and dryland and grassland decrease. The landscape shows an aggregated state, with spreading and connectivity increasing while fragrant diversity is decreasing. 2) The total ecosystem service value increased by CNY 63.45 × 10^4, with regulating and cultural services on the rise and supply and support services on the decline. 3) With the rise of the TPI, the value of the supply services is inversely U-shaped, while the value of the remaining services increases. This study provides a case study about karst desertification areas for village-scale ecosystem services research.

KEYWORDS

karst plateau, land use, ecosystem services, spatial and temporal variation, sustainable development, gf, terrain position

1 Introduction

Land use for producing goods and services is the most significant human change to the planet (Vitousek Peter et al., 1997). Land management for different purposes has produced changes in LULC (Stephens et al., 2019). Humans have transformed nearly a third of the world's land in the last 60 years (Winkler et al., 2021). These transformations pose enormous challenges to global food security, climate change, and biodiversity. Ecosystems respond to these challenges by providing a wide range of valuable services by operating their structures and functions (Fu et al., 2013). Ecosystems, for example, maintain the cycle of soil nutrients and ensure biodiversity. Secondly, provide food, raw materials, and water for humans, regulating the climate and cleaning the environment. Moreover, it creates magnificent landscapes for humans to enjoy. As early as 1977, an article from *Science* described the importance of the benefits of nature's 'services' (Westman Walter, 1977). The concept was named "ecosystem services" in 1981 (Ehrlich and Ehrlich, 1981). ESs, controlled by the structure and function of the ecosystem,

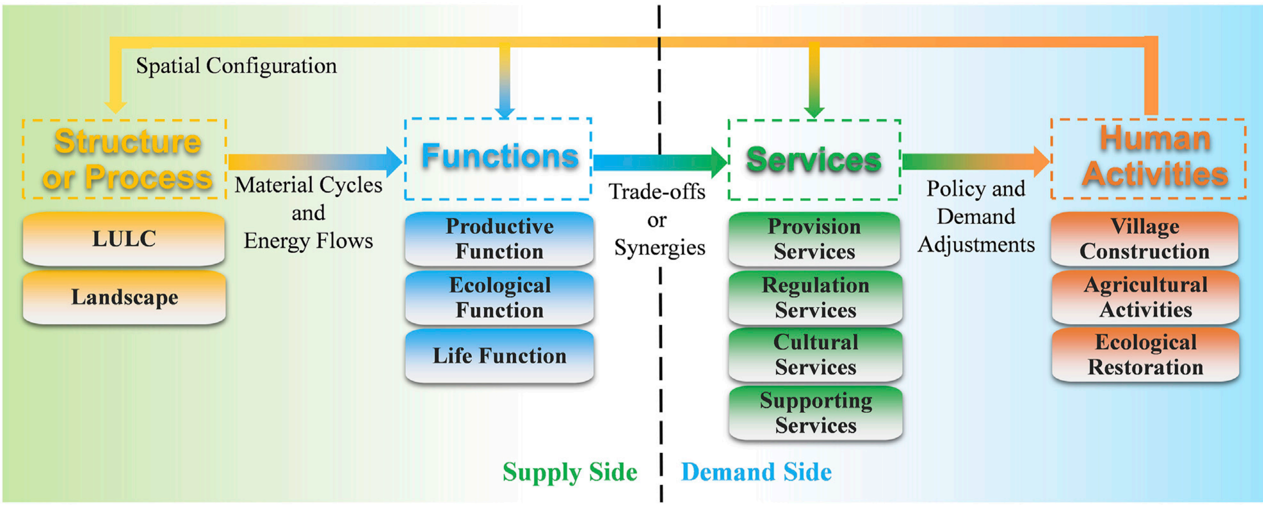

FIGURE 1
A logical framework for the cyclical management of village ecosystems.

are the benefits people derive from ecosystems and are mainly classified as provision, regulation, support, and cultural services (Millennium Eco System Assessment, 2005; Fu et al., 2013). ESs are the best tool for studying human-nature interactions and are essential for improving human wellbeing and achieving sustainable development. Furthermore, have become a hot topic in ecological, economic, and social research (de Groot et al., 2010).

Land cover has been changing rapidly due to solid human activities such as agricultural and urban construction (Stephens et al., 2019). Lack of recognition of the multiple ecosystem service values generated by the landscape and irrational land use has changed the landscape pattern resulting in landscape fragmentation (You et al., 2017). The composition and spatial configuration of the broken landscape directly affect the flow of energy and material circulation in the ecosystem (Vitousek Peter et al., 1997; Mitchell et al., 2015; Fan and Xiao, 2020), leading to the loss of productive, living, and ecological functions and, ultimately, the damage to ecosystem services (de Groot et al., 2010; Lawler et al., 2014; Fischer and Eastwood, 2016). Global ecosystems are continuing to degrade under human interference (de Groot et al., 2012, Bateman et al., 2013), a trend confirmed by the Millennium Ecosystem Assessment (MA) (Millennium Eco System Assessment, 2005). With the awakening of ecological awareness and the promotion of the concept of sustainable development, the needs of human society are gradually being rationalized. Policy interventions are being made to guide sustainable land use to achieve ecosystem management circularly (Wu, 2013; Metzger et al., 2021) (Figure 1). Nevertheless, policies are strongly spatially differentiated, and no one policy fits everywhere. Moreover, single-purpose land-use or land-use policies that are contrary to reality often result in trade-offs between ecosystem services (Bennett et al., 2009; Bateman et al., 2013). They can even lead to a reduction in overall services. Spatially oriented land use policies can optimize landscape patterns, enhance ecosystem services' value and ensure ecosystem services' synergistic development (Bateman et al., 2013). Especially true in regions with high heterogeneity. Hence, research on land use, landscape patterns, and ecosystem services is a prerequisite for developing spatial positioning policies and a key to a virtuous cycle of ecosystems and the sustainable development of human societies (Costanza et al., 2014; Lawler et al., 2014; Liu et al., 2019; de Bremond, 2021).

The value of ecosystem services is a quantitative indicator of ecosystem services (Costanza et al., 1997; Daily, 1997; Millennium Eco System Assessment, 2005). Estimating the value of ecosystem services is an essential basis for developing land use policies and an essential tool for evaluating the quality of human activities (Millennium Eco System Assessment, 2005; Hou et al., 2020). In order to scientifically assess ecosystem services, scholars worldwide have successfully carried out research on the estimation of service values (Costanza et al., 1997; Daily, 1997; Ouyang et al., 1999). Numerous classification systems and valuation methods for services have been proposed internationally. These include the Millennium Ecosystem Assessment (MA) (Millennium Eco System Assessment, 2005; Carpenter et al., 2006), the Economics of Ecosystems and Biodiversity (TEEB) (De Groot et al., 2012), the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) (Schmeller et al., 2017), and the Common International Classification of Ecosystem Services (CICES) (Haines-Young and Potschin-Young, 2018). Taking a value-equivalent approach to valuing ecosystem services is the commonly used method (Costanza et al., 1997). Based on spatially explicit data types of land use (Tashie and Ringold, 2019), converting the value of different land use types allows ecosystem services to be spatially quantified. Xie et al. (2008) has improved on Costanza's approach by considering the Chinese ecosystem and socio-economic development, and it has been widely applied in China (Xie et al., 2008; Xie et al., 2015). The landscape pattern index reflects the condition of landscape patterns (Wu, 2006). Combining it with the value of ecosystem services is one way of quantifying the interaction of ecosystem structure, function, and human needs (Shi et al., 2018; Li et al., 2022).

A growing body of research on land use, landscape patterns, and ecosystem services aim to address scientific questions arising from specific regions and objectives (Q. J. Zhao et al., 2020). These studies show that the characteristics, trends, and drivers of change vary over time and across regions (Shi et al., 2018; Li et al., 2022; Liu et al., 2022).

Therefore, research on specific periods and regions is key to guiding practice by theory and is a necessary requirement for global sustainable development. However, some things could still be improved in the research scale, research objects, and methods at this stage. Firstly, the research scale is generally significant. Most studies take provinces (Wang et al., 2022a; Liu et al., 2022; Zhang et al., 2022), cities (Hou et al., 2020; Chen and Huang, 2021) (Li et al., 2022), counties (Zhang et al., 2020; Zhang et al., 2021), watersheds (Yushanjiang et al., 2018; Wang et al., 2022b), ecological functional areas (Su et al., 2012), and specific landscape types areas (Zhang et al., 2011; Hou et al., 2020; Zhang et al., 2020) as research units. The data sources are mainly low-resolution remote sensing products. While large-scale studies can express a wide range of spatial and temporal characteristics, they are based on low-resolution remote sensing products that can reduce the accuracy of value assessment and thus interfere with policymaking (Kandziora et al., 2013; Grêt-Regamey et al., 2014). Secondly, research has focused on cities (Estoque and Murayama, 2016) and urban agglomerations (Yang et al., 2021), and there needs to be more research on villages. The impact of urban expansion is not confined to cities but has extended to rural areas (Su et al., 2011). Village ecosystems, a special kind of ecosystem with landscape characteristics (Su et al., 2011; Tang et al., 2022; Zhou et al., 2022), provide a range of goods and services to sustain the livelihoods of rural inhabitants who depend on natural resources and to sustain the functioning of cities (Egoh et al., 2012; Pereira et al., 2005; Sandhu and Sandhu, 2014; Sinare et al., 2016). Thirdly, existing research methods make it difficult to uncover the spatial significance of ecosystem services. Due to the lack of involvement of topographic elements, the spatial analysis of existing studies stays on the orientation description. Such descriptions cannot match spatial features, making it challenging to uncover the spatial connotations of ecosystem services and losing the guiding meaning of spatial analysis. With the development of remote sensing technology, the availability of high-precision data has improved the authenticity and accuracy of studies (Tavares et al., 2019). Therefore, there is an urgent need to conduct studies on the spatiotemporal analysis of village ecosystem services based on high-resolution remote sensing data and to add topographic factors to the spatial analysis to enhance spatial significance in order to fill the existing research gaps.

Karst landscapes are a typical type of carbonate landscape worldwide, with carbonate karst covering more than 10%–15% of the continental area (Ford and Williams, 2007b). Karst as comprising terrain with distinctive hydrology and landforms that arise from a combination of high rock solubility and well-developed secondary (fracture) porosity (Ford and Williams, 2007b). Experience shows that karst environments are particularly fragile and vulnerable to damage compared with most other natural systems (Yang, 1990; Ford and Williams, 2007a). In this environment, the irrational socio-economic activities of human beings can easily lead to soil erosion, resulting in rocky outcrops and a karst desertification landscape (Xiong, 2002). The process and results of karst desertification, in turn, affect human beings' survival, threaten the karst area's ecological and environmental security, and restrict regional economic and social development (Yang, 1990; Zhao and Hou, 2019). This ecological issue is most pronounced in the South China Karst in tropical and subtropical (Sweeting, 1986). Many KDC measures have been carried out in response to this problem. Large-scale scientific studies have shown that implementing these projects has reduced the area of karst desertification (Yue et al., 2022), improved the ecological environment (Wu et al., 2022), and increased the global vegetation cover (Brandt et al., 2018; Tong et al., 2018). However, problems such as the unstable effectiveness of treatment and the recurrence of karst desertification still exist (Zhong et al., 2021). Under the conflicting developments of karst ecological restoration and socio-economic growth, karst desertification control ecosystems' structure, functions, and services undergo complex changes. It is still being determined what changes will occur in the ecosystems of the village scale where KDC measures are implemented. Ecosystem service studies based on high-resolution imagery in karst desert villages can, therefore, not only reveal the characteristics of spatial and temporal changes in ecosystem services at the village scale but also contribute to improving the karst desert environment, enhancing human wellbeing, and achieving sustainable development.

Therefore, we have selected village ecosystems as the object of study within the demonstration area where the KDC project is implemented (Xiong et al., 2016). The project is part of the 13th Five-Year Plan for Economic and Social Development of the People's Republic of China. The study uses the 13th Five-Year Plan implementation cycle as the time frame (2015–2020). The land use matrix, landscape pattern index, TPI, and value equivalent factor were used to study the village ecosystems of KDC based on the GF-2 images. This study attempts to answer three questions. 1. What changes have occurred in the structure of village ecosystems during KDC? 2. What changes in village ecosystem services have occurred under the influence of land use and landscape patterns? 3. What are the characteristics of the spatial distribution of ecosystem services in villages with KDC?

2 Materials and methods

2.1 Study area

The study area is a village ecosystem consisting of Chaoying Village, Chongfeng Village, and Zhongshan Village, located in Salaxi Town, Qixingguan District, Bijie City, Guizhou Province, China (Figure 2), between 105°2′1″-105°7′29″ East and 27°13′28″-27°16′19″ North, with a total area of 2,306.4 hm^2, encompassing 1,165 households and 4,624 people. The area is a typical karst plateau mountainous landscape, with an elevation value from 1659 m to 2141 m, a humid subtropical monsoon climate, an average annual temperature of 12.8°C, and annual precipitation of 984 mm and plenty of light, average annual sunshine hours of 1,360 h. The forest vegetation is mainly mixed coniferous and broad forests and shrubs. The main tree species are birch, Chinese pine, firethorn, horse mulberry, tree structure, and laurel. The planted economic forests are mainly walnuts, plums, cherries, prickly pears, and chestnuts. There is no paddy land in the study area, only dry land, so food crops are mainly maize and potatoes. During the 13th Five-Year Plan period, the study area has adopted measures to control karst desertification, such as mountain reforestation, returning farmland to forest, artificial afforestation, agroforestry, and energy structure optimization.

2.2 Data sources

Land use data is obtained through remote sensing classification, manual visual interpretation, and field surveys. The original images are from the GF-2 satellite and the in-formation for the required images was retrieved from the China Centre for Resources Satellite Data and

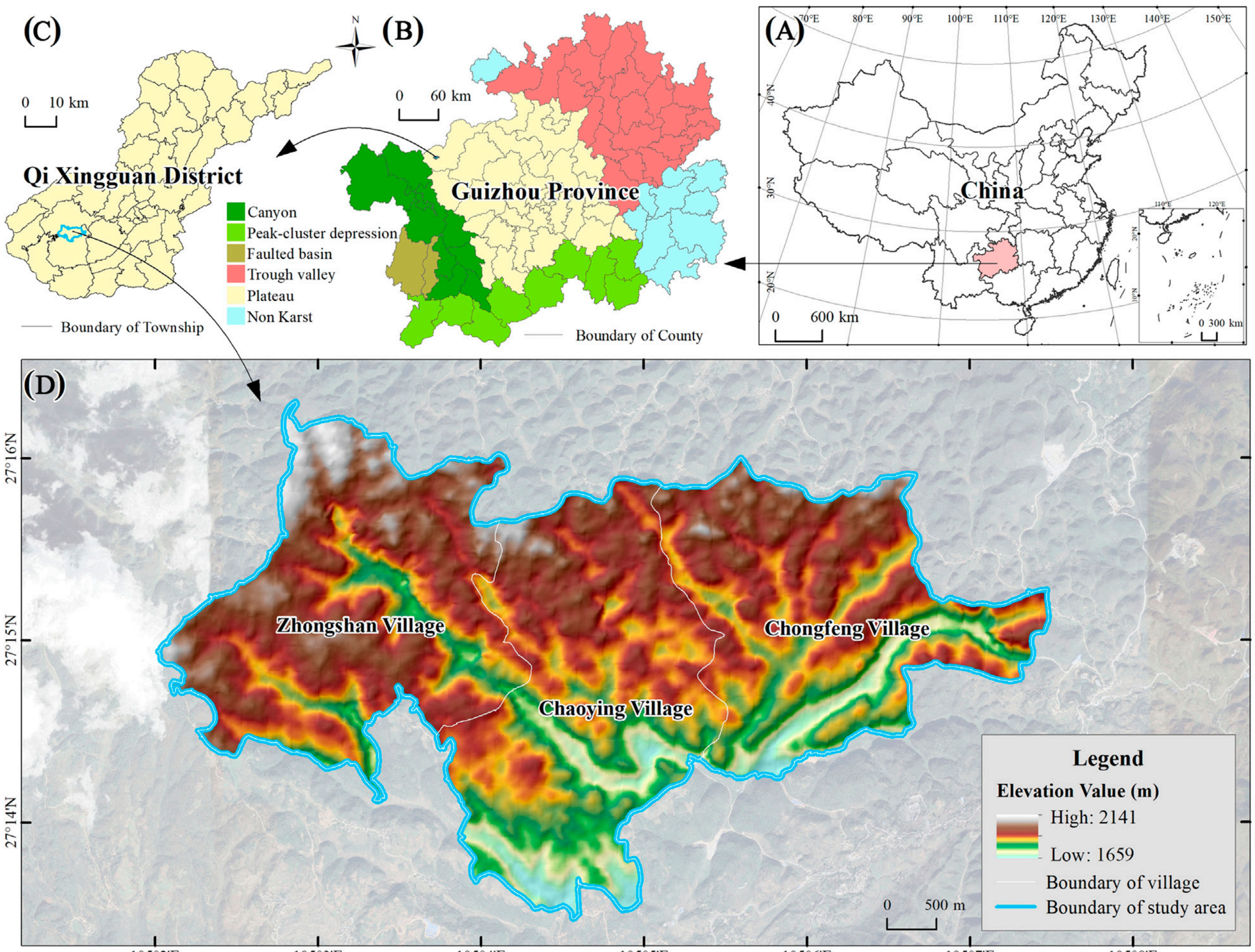

FIGURE 2
Geographical information map of the study area. In this map: **(A)** This panel is the location of Guizhou Province in China; **(B)** This panel is the karst landscape subdivision of Guizhou Province; **(C)** This panel is the location of study area; **(D)** This panel is the elevational distribution range of the study area.

Application website (http://36.112.130.153:7777/DSSPlatform/index.html), with data provided by the GF Guizhou Centre. The GF-2 satellite was launched in 2014 and equipped with two PAN/MS cameras. The instrument collects one PAN band (0.45–0.9 μm) of 1 m spatial resolution and four MS bands (0.45–0.52 μm, 0.52–0.59 μm, 0.63–0.69 μm, and 0.77–0.89 μm) of 4 m spatial resolution. The swath width of 45 km, and the repetition cycle of 5 days (Ren et al., 2020). Two images from July 2015 and July 2020 were selected with product numbers 931897 and 4902583, respectively. Remote sensing images were first pre-processed with ENVI 5.3 for radiometric calibration, atmospheric correction, correction, and fusion of multispectral and panchromatic images. Secondly, using the current land use classification criteria (GB/T 21010-2017) as a reference, the maximum likelihood method was used to classify current land use in the study area. Due to the small size of the study area and the absence of paddy fields and water distribution, land use was divided into seven categories: dryland, woodland, orchard, shrubland, grassland, construction land, and bare land, and the classification of the study area was actually modified according to the experience of manual identification of features. Thirdly, 100 random points were generated by default through the toolbox in the ArcGIS 10.1 software, and these random points were evenly distributed across the extent of the study area. The overall accuracy of 89% and 91% for 2015 and 2020 was calculated in excel using the confusion matrix method by validating the GF-2 images and Google historical images against the classification results.

2.3 Research methods

2.3.1 Selection of landscape pattern indices

The landscape pattern index is the most effective measure of information about the composition and spatial structure of the landscape (You et al., 2017). This paper first refers to the related research results (Liu et al., 2020; Zhang et al., 2021), then combines the ecological significance and application scale of landscape pattern indices (Fu, 2001) (Table 1), and selects landscape pattern indices that reflect the area, agglomeration, morphology, dispersion, density, and diversity measures from the class level and landscape level to study. All landscape pattern indices calculations were performed in Fragstats 4.2.

TABLE 1 Selection of landscape pattern indices and their ecological significance.

	Abbreviations	Full name	Application scale	Ecological significance
Area indicator	CA	Class area	class	Reflecting the size of the type
	PLAND	Percent of landscape	class	Refers to the relative proportion of the overall landscape area occupied by a particular type
	LPI	Largest patch index	class	Used to identify the dominant patch types in the landscape, reflecting the extent to which landscape change is disturbed by human activity
Shape indicators	LSI	Landscape shape index	class/landscape	Reflects the degree of dispersion and regularity of landscape and patch shapes, with higher values indicating more complex landscape shapes
Dispersion indicators	IJI	Interspersion and Juxtaposition index	class/landscape	Reflects the segregated distribution of plaque types
	AI	Aggregation index	class/landscape	Measures the degree of aggregation of a landscape or a patch type
	CONTAG	Contagion index	landscape	It is one of the most important indices of landscape pattern, describing the degree of clustering or tendency of different patch types to spread across the landscape
Density indicators	PD	patch density	class/landscape	Reflects the heterogeneity and fragmentation of the landscape as a whole and the degree of fragmentation of a type
Diversity indicators	SHDI	Shannon 's diversity index	landscape	Reflects landscape heterogeneity and is particularly sensitive to the uneven distribution of patchwork types in the landscape

2.3.2 Calculating the value of ecosystem services

Xie et al. (2015) proposed an accounting method based on Costanza's framework (Costanza et al., 1997) that is appropriate for the Chinese context, which improves the accuracy of the assessment results on the Chinese scale, but the difference between the Chinese scale and the study area scale can lead to different results. Therefore, this paper adopts the equivalence table of ESV proposed by Xie et al. (2015) as the calculation framework and adopts the farmland-based revision method (Xu et al., 2012) to correct the equivalence factor table for the study area scale to better match the actual situation in the study area.

$$\theta = \frac{Q}{Q_0} \tag{1}$$

$$E_i = \theta \times E_{i0} \tag{2}$$

In the Eqs 1, 2, θ is the revision factor of the study area, Q and Q_0 are the average yield per unit area of the study area and the country, respectively. E_i denotes the modified equivalent factor of land use type i , and E_{i0} denotes the equivalent factor of the same land use type as determined by Xie et al. (2015).

The socio-economic survey and the statistical yearbook (https://data.cnki.net/yearbook/Single/N2021110004) showed that the grain yield per unit area of arable land in 2020 was 6.73 t/hm^2 and 5.73 t/hm^2 for the study area and the whole country, respectively. The equivalent revision factor for ecological services in the study area was derived from Eq. 1 as 1.17.

According to the literature (Xiao et al., 2003), the economic value provided by natural ecosystems is one-seventh of the economic value of the food production services provided per unit area of available arable land.

$$E_a = \frac{1}{7}\sum_{i=1}^{n} \frac{m_i p_i q_i}{M} \tag{3}$$

In the Eq. 3, E_a is the economic value per unit area of farmland ecosystem providing food production services (CNY/hm^2), i is the crop type; p_i is the unit price of i crops (CNY/kg); q_i is the yield of i food crops (kg/hm^2); m_i is the area of i food crops (hm^2); M is the total area of n food crops (hm^2).

According to the socio-economic survey of the study area in 2020, the yield of maize and potatoes, food crops in the region, was 1,333,200 kg and 1,579,500 kg, respectively. The sown areas were 222.2 hm^2 and 210.6 hm^2, respectively. Price obtained from the official website of the Bureau of Agriculture and Rural Development of Bijie City (https://www.bijie.gov.cn/bm/bjsnyncj/gk_5126790/scxq/index_ 1.html). Corn and potatoes cost CNY 2.763 per kg and CNY 2.613 per kg, respectively. Thus, according to Eq. 3, the economic value of food production services provided per arable unit area in the study area was CNY 18,047.26 ($ 2,696.26 in 2020), and the economic value of an ecological service value factor in the study area is CNY 2,578.18/hm^2 ($ 385.18/hm^2 in 2020), resulting in the ecological service value of different ecosystem unit areas in the study area (Table 2).

2.3.3 Topographic position index (TPI)

The TPI is a composite reflection of the influence of two topographic factors, elevation, and slope, on the value of ecosystem services. The equation is as follows.

$$\mathrm{T} = \lg\left[\left(E/\bar{E} + 1\right) \times \left(S/\bar{S} + 1\right)\right] \tag{4}$$

In the Eq. 4, T denotes the topographic position index, E and $\bar{E}$ represent the arbitrary and average elevation of the study area, and S and $\bar{S}$ represent the arbitrary and average slope of the study area.

The TPI of the study area is a normal distribution characteristic, and the Jenks natural breakpoint method is used in the study area. The Jenks natural breaks classification method, also known as Jenks Optimization, is a data classification method used to determine the best alignment of values between classes. This is done by minimizing each class's average deviation from the class mean while maximizing each class's deviation from the means of the other groups (Chen et al., 2013). Based on the related literature (Han et al., 2020), the TPI is divided into five categories

TABLE 2 Value of ecosystem services coefficients for different land uses in the study area.

Type	Category	Attribute	Dry land	Wooded land	Shrub land	Grass land	Orchard land	Bare land
Provision Services	Food production	Equivalence factor	0.99	0.32	0.22	0.44	0.27	0.00
		Value factor	2,564.00	824.50	573.13	1,146.26	698.82	0.00
	Raw material production	Equivalence factor	0.47	0.74	0.50	0.66	0.62	0.00
		Value factor	1,206.59	1900.38	1,297.08	1,689.22	1,598.73	0.00
	Water Provision	Equivalence factor	0.02	0.38	0.26	0.36	0.32	0.00
		Value factor	60.33	985.38	663.62	935.11	824.50	0.00
Regulation Services	Gas regulation	Equivalence factor	0.78	2.43	1.65	2.30	2.04	0.02
		Value factor	2021.04	6,254.15	4,253.22	5,942.45	5,253.69	60.33
	Climate regulation	Equivalence factor	0.42	7.25	4.95	6.10	6.10	0.00
		Value factor	1,085.93	18,702.12	12,759.67	15,715.81	15,730.89	0.00
	Environmental purification	Equivalence factor	0.12	2.11	1.50	2.01	1.80	0.12
		Value factor	301.65	5,439.70	3,861.08	5,188.33	4,650.39	301.65
	Hydrological regulation	Equivalence factor	0.32	4.52	3.92	4.47	4.22	0.04
		Value factor	814.45	11,653.63	10,105.18	11,522.92	10,879.40	90.49
Support Services	Soil conservation	Equivalence factor	1.21	2.95	2.01	2.81	2.48	0.02
		Value factor	3,106.96	7611.56	5,188.33	7239.53	6,399.95	60.33
	Maintenance of nutrient cycles	Equivalence factor	0.14	0.23	0.15	0.21	0.19	0.00
		Value factor	361.98	583.18	392.14	542.96	487.66	0.00
	Biodiversity	Equivalence factor	0.15	2.69	1.84	2.55	2.26	0.02
		Value factor	392.14	6,927.83	4,735.86	6,575.91	5,831.84	60.33
Cultural Services	Aesthetic landscape	Equivalence factor	0.07	1.18	0.81	1.12	0.99	0.01
		Value factor	180.99	3,036.58	2081.36	2,895.81	2,558.97	30.16

by the natural breakpoint method, namely TPI I (0.736077–1.005849), TPI II (1.00585–1.117105), TPI III (1.117106–1.223024), TPI IV (1.223025–1.34546) and TPI V (1.345467–1.661047).

3 Results

3.1 Land use and land cover change (LULCC) analysis

Land use status in the study area for 2015 and 2020 (Table 3) shows that during the project implementation phase, dryland areas in the study area decreased by 89.24 hm^2, woodland increased by 117.27 hm^2, orchard land increased by 44.05 hm^2, shrubs increased by 141.58 hm^2, grasslands decreased by 235.75 hm^2, construction land increased by 22.29 hm^2 and bare land decreased by 0.2 hm^2. The most significant change in area was the decrease in grassland, which was found through the transfer matrix (Table 4) and Sankey map (Figure 3) to be mainly converted to shrubland. Grassland within the study area is dominated by scrub and grass, a process of positive vegetation succession, which is the main reason for the increase in shrubby woodland, the second most significant change. The third major change is the increase in tree woodland, with the main contribution coming from shrub woodland and dryland shifts. Worth noting is the increase in orchard land, which is mainly cash crops planted on the farmers' cultivated land, and the increase of orchard land resulted in the decrease of cultivated land. During the research period, a series of ecological restoration projects and

TABLE 3 Status of land use in the study area 2015–2020.

Year	Type	Dry land	Wooded land	Orchard land	Shrub land	Grass land	Construction land	Bare land
2015	Area (hm^2)	707.11	67.38	0.03	1,248.20	236.45	47.01	0.24
	Percentage/%	30.66	2.92	0.00	54.12	10.25	2.04	0.01
2020	Area (hm^2)	617.87	184.65	44.08	1,389.78	0.69	69.30	0.04
	Percentage/%	26.79	8.01	1.91	60.26	0.03	3.00	0.00
change	Area (hm^2)	−89.24	117.27	44.05	141.58	−235.75	22.29	−0.20
	Percentage/%	−3.87	5.08	1.91	6.14	−10.22	0.97	−0.01

TABLE 4 Land use transfer matrix for 2015–2020 in the study area (hm^2).

	2020							
	TYPE	Dry land	Wooded land	Orchard land	Shrub land	Grass land	Construction land	Bare land
2015	Dry land	—	23.09	37.66	93.06	0.52	20.46	0.03
	Wooded land	8.88	—				3.44	
	Orchard land			—				
	Shrub land	35.67	89.95	3.21	—	0.02	5.72	0.01
	Grass land	35.20	14.09	3.18	179.81	—	4.03	
	Construction land	5.62	2.47		3.26	0.01	—	
	Bare land	0.20			0.03		0.01	—

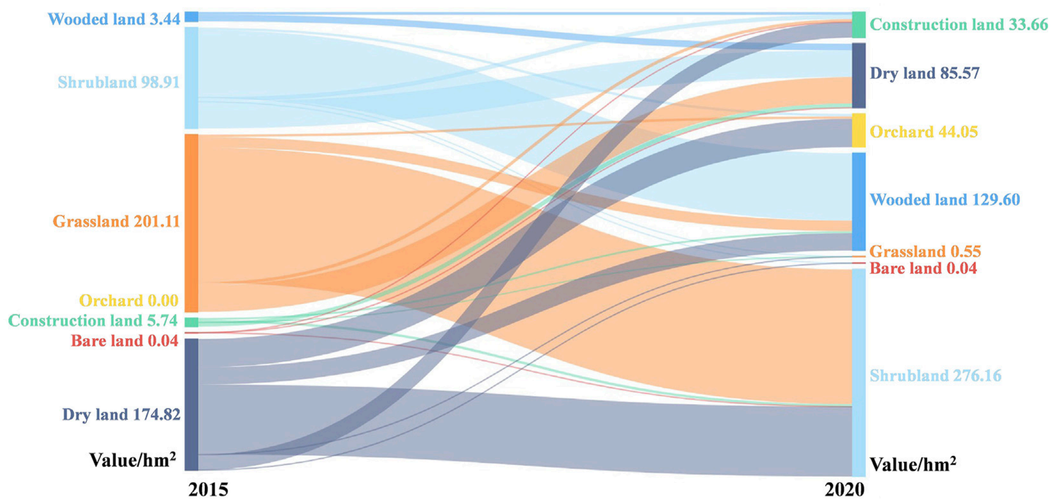

FIGURE 3
Land use transfer Sankey map 2015–2020.

industrial structural adjustment KDC were carried out in the research area to achieve win-win eco-logical protection and economic development. For example, the project of returning farm-land to forest, the project of closing mountains for reforestation, and the project of artificial reforestation have been carried out continuously. Among them, the targets of the mountain closure and reforestation are tree and shrub forests, and the tree species are mainly bright-leaved birch, Huashan pine, and Yunnan pine, while the main tree species implemented in the following reforestation projects are walnuts, plums, prickly pears, cherries, and chestnuts, all of which have economic benefits. These measures not only improve the ecological environment but also increase residents' income and promote the achievement of China's precise poverty alleviation goals. Construction land increased by 22.29 hm^2 over the 5 years, mainly due to the

TABLE 5 Landscape pattern indices at the patch level in the study area for 2015–2020.

Type	Year	CA	PLAND	PD	LPI	LSI	IJI	AI
Dryland	2015	707.093	30.6578	26.0145	5.0373	53.5965	58.2266	98.021
	2020	634.1672	27.4959	20.7249	2.5186	51.193	49.9513	98.0059
Wooded land	2015	67.3751	2.9212	39.4987	0.2349	33.7034	64.6313	96.0101
	2020	184.6486	8.0059	11.0562	1.8812	23.4382	63.2519	98.3473
Orchard land	2015	0.025	0.0011	3.8155	0	11.7188	71.4647	26.7094
	2020	27.7627	1.2037	1.4742	0.2126	11.4307	62.5927	98.0162
Shrubland	2015	1,248.2063	54.1191	37.6777	3.1775	44.3227	57.357	98.7734
	2020	1,389.785	60.2576	14.4814	4.5417	32.8608	49.8423	99.1451
Grassland	2015	236.4504	10.2519	22.069	0.7753	42.0751	50.049	97.3265
	2020	0.6916	0.03	0.2168	0.0187	3.4491	27.4113	97.007
Construction land	2015	47.0155	2.0385	13.094	0.6986	55.1771	63.9794	92.0835
	2020	69.3117	3.0052	4.9861	2.4654	68.9154	59.2798	91.828
Bare land	2015	0.2402	0.0104	0.0867	0.0101	2.0707	46.2903	97.7471
	2020	0.0387	0.0017	0.0434	0.0017	1.25	33.0934	98.6376

construction of rural roads, which took up farmers' arable land, resulting in a decrease in arable land. Because the construction land includes residential, road, and construction land, some rural roads produce temporary land during construction and are restored after construction. In the transfer matrix, there are some situations in which construction land is converted to dry land, woodland, thicket, and grassland, but this situation rarely occurs.

3.2 Landscape pattern change analysis

The LPI represents the proportion of the maximum plaque area to the total area, allowing for identifying dominant types (Table 5). The dominant type in the study area in 2015 was dryland landscape, with an LPI of 5.0373. Still, as the landscape changed, dryland decreased significantly, and the LPI slipped to 2.5186. The dominant type changed to shrubland as the shrubland LPI increased from 3.1775 to 4.5417. This is due to the implementation of rocky desertification control measures such as sealing of mountains and afforestation in the study area, which improved the ecological environment and increased the maximum patch index of thickets. In the LSI, the morphological complexity of construction land, dryland landscapes, and shrubland landscapes remain high, with slight variation over 5 years. The most complex shape is for built-up land in 2020, with an LSI of 68.9154, due to the implementation of precision poverty alleviation measures in China, which have accelerated the construction of rural roads, resulting in a high degree of meandering due to the complex karst topography, and hence the most extensive shape index. The most significant decrease in the IJI is in grassland, indicating that other types of landscapes around grassland landscapes are gradually decreasing, while the changes in the remaining types are relatively small. The agglomeration index of all types of landscapes in the study area is very high and shows the characteristics of agglomeration. In 2015, only orchard is scattered due to their small number, while in 2020 they showed the agglomeration characteristic as fallow, afforestation and planting were implemented. PD, which reflects the degree of fragmentation, is an essential indicator of the karst landscape. The most extraordinary fragmentation in 2015 was in forested and shrubland lands, with PD values of 39.4987 and 37.6777, respectively. By 2020, the PD values are 11.0562 and 14.4814, respectively. Forest fragmentation has been dramatically improved thanks to the implementation of ecological restoration measures. However, dryland landscapes become the most fragmented patches. In karst areas, the fragmentation of cultivated land is also very prominent.

At the landscape level (Table 6), the LSI, IJI, and PD all declined in the study area, suggesting that landscapes are becoming more regular and less connected and dispersed between landscapes. The CONTAG is increasing and at a high level of the index, indicating that connectivity between landscapes is gradually increasing and at a high level. The SHDI is declining, indicating low and uneven richness among different landscape types. However, the AI of different landscape types has increased, and the tendency for land use clustering has emerged. The landscape pattern karst desert environment has been improved, and the fragmentation of the landscape has been reduced through the implementation of precise poverty alleviation, afforestation projects, and plantation projects. At the same time, however, the instability of the village ecosystem has increased.

3.3 Time-change analysis of ecosystem services value

In KDC for 5 years, the value of ES in the study area has increased by CNY 63.45 × 10^4, with the most significant increase being in the transfer of services (Table 7). Gas regulation, climate regulation, environmental purification, and hydrological regulation services

TABLE 6 Landscape pattern indices for 2015–2020 landscape levels in the study area.

Year	Total area (hm^2)	PD	LSI	CONTAG	IJI	SHDI	AI
2015	2,306.4	142.256	45.8548	68.6759	57.7997	1.1119	98.1764
2020	2,306.4	52.9829	37.2534	71.4869	51.6117	1.0235	98.5339

TABLE 7 Value of ecosystem services in the study area (CNY/10^4).

Year	Type	Dry land	Wooded land	Shrub land	Grassland	Orchard land	Bare land	Total	
2015	Provision Services	270.89	25	316.27	89.15	0.01	0	701.32	8,421.05
	Regulation Services	298.62	283.31	3,866.81	907.23	0.09	0.0108	5,356.07	
	Support Services	273.02	101.89	1,287.68	339.5	0.03	0.0029	2002.13	
	Cultural Services	12.8	20.46	259.8	68.47	0.01	0.0007	361.53	
2020	Provision Services	242.95	68.51	352.15	0.26	8.67	0	672.53	8,484.5
	Regulation Services	267.82	776.43	4,305.42	2.65	101.38	0.0018	5,453.71	
	Support Services	244.86	279.23	1,433.74	0.99	35.32	0.0005	1994.15	
	Cultural Services	11.48	56.07	289.26	0.2	7.11	0.0001	364.12	
Changes	Provision Services	−27.94	43.51	35.87	−88.89	8.66	0	−28.79	63.45
	Regulation Services	−30.8	493.12	438.61	−904.58	101.29	−0.01	97.63	
	Support Services	−28.16	177.34	146.06	−338.51	35.28	0	−7.98	
	Cultural Services	−1.32	35.61	29.47	−68.27	7.1	0	2.59	

were significantly enhanced due to the increase in woodland and shrubland as well as orchard land, with the value of regulation services increasing by CNY 97.63 × 10^4. Woodland, shrubland and orchard land contributed CNY 493.12 × 10^4, CNY 438.61 × 10^4, and CNY 101.29 × 10^4 respectively. At the same time, the lesser amount of grassland offset the value of regulating services by CNY 904.58 × 10^4. The total decrease in provisioning services was CNY 28.79 × 10^4. While woodland, bushland, and orchard land contributed to provision services, grassland and dryland experienced more significant value loss, with decreases of CNY 88.89 × 10^4 and CNY 27.94 × 10^4, respectively, resulting in a reduction in total provisioning services. The value of supporting services in the study area decreased by CNY 7.98 × 10^4, even though the value of supporting services provided by forests increased by CNY 177.34 × 10^4 and CNY 146.06 × 10^4, respectively. The value of orchards increased by CNY 35.28 × 10^4. However, more services such as soil conservation, maintenance of nutrient cycling, and biodiversity were lost due to the reduction of grasslands and drylands. The cultural service's value increased by CNY 2.59 × 10^4, mainly due to the increase in the aesthetic value of the forest landscape, but the grassland reduction largely offset this. Implementing KDC projects such as artificial afforestation, returning farmland to forest, and forest closure has increased the amount of tree woodland, shrub woodland, and orchard land. The expansion of these three types of landscapes has positively affected provision services, regulating services, support services, and cultural services, and has contributed to the ecological recovery of karst areas.

3.4 Spatial analysis of the value of ecosystem services

In the last 5 years of KDC, the spatial variation of ESV in the study area fluctuated wildly. The increase or decrease was more significant, indicating that the value of ES in the study area did not form a stable trend and ES could be more stable. This also indicates that the karst village ecosystem is highly susceptible to external interference and has vulnerabilities. The areas where changes in ESV show decreasing trends are mainly in the north-western region and the eastern region of the study area, while the south-western region shows an increase in ESV (Figure 4). These trends are mainly due to changes in forests, where the increase in the number of trees and shrub forests has contributed significantly to the increase in the value of ES. In contrast, the transfer of forests takes away more of the value of ES, leading to a decline in value. From a spatial perspective, higher ESV tend to accumulate gradually in the southwestern study area, indicating better control of karst desertification and significant ecological improvements in this region (Figure 5).

The services are classified according to the value per unit area on different TPI gradients. Provision services show an inverted U-shape as the TPI increases, reaching a maximum in the TPI III gradients. Regulating, support and cultural services all increase with the TPI, and the total service value follows the same trend (Figure 6). Thus, the high values of ecosystem services in karst plateau villages are concentrated in areas with a high TPI. The lower the TPI, the lower the value of

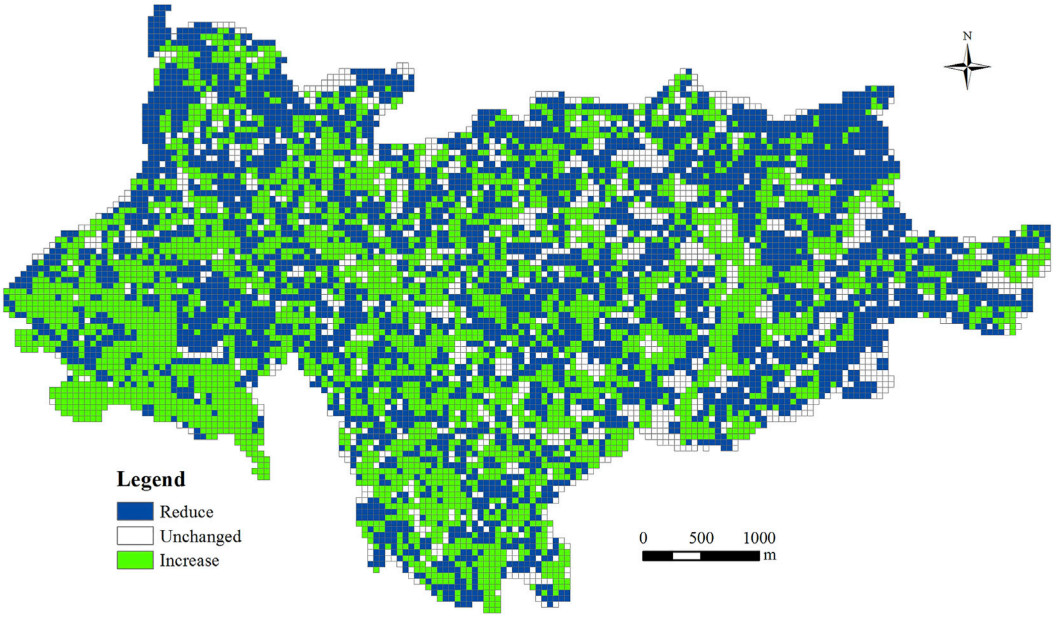

FIGURE 4
Changes in the value of ecosystem services, 2015–2020.

ecosystem services. Over the 5 years of KDC, provisioning services showed a decreasing trend at each TPI. The rate of change in the V TPI was lower than that of the remaining TPI. Regulating services increased in all TPI. Support services show a slight decrease at TPI III and IV, while the rest of the gradient increases at a lower rate. Cultural services only decrease in TPI IV while the rest of the gradient increases.

4 Discussion

4.1 Village-based land use planning is key to optimizing landscape patterns in KDC ecosystems

LULCC is a fundamental driver of change in landscape patterns and ecosystem services. Different land uses different patterns of landscapes. Moreover, landscapes can sustain the long-term, landscape-specific ecosystem services that are essential for maintaining and improving human wellbeing (Wu, 2013). The implementation of KDC measures, such as mountain closure, returning farmland to forest, and artificial afforestation, has led to expanding forests and orchards and decreasing arable land and grassland in the study area. This trend is consistent with the changing trend of the same regional study (Liu et al., 2020; He et al., 2022). However, it shows inconsistent performance in terms of landscape pattern (Liu et al., 2020; Shu et al., 2022). The positive successional change trend in vegetation makes forests the dominant landscape, providing a large concentration of ecosystem services, primarily regulating services. Although the spreading and connectivity of the landscape are gradually increasing and the value of ecosystem services is rising. However, the richness of landscape types is weakened by the more homogeneous succession process, leading to an unstable ecosystem. In particular, the landscape's lack of paddy and water hinders the ecosystem's ecological, productive, and living functions. The ecosystem services farmers can enjoy are greatly diminished. The construction of orchards, roads, and houses on arable land is the main reason for reducing arable land. The transfer from cropland to built-up land does not generate ecosystem services. However, such changes are less drastic than in cities. The transfer of cropland to orchards compensates for some of the loss of food production and provides more regulating services. These land use changes above have reduced the fragmentation of the landscape, which is the contribution of KDC measures and poverty alleviation efforts in China. However, it is worth noting that the fragmentation of arable land is still at a high level, which, if not improved, will continue to hinder food production and the intensive use of agricultural land in the karst mountains, and undermine the provision of ecosystem services (Ge et al., 2020). Even in the same type of region, differences in research scales can still lead to inconsistent results and conclusions. LULC and landscape patterns are essential expressions of structure and stability. A reasonable village spatial planning guarantees the structure and stability of the village ecosystem. It is an essential prerequisite for future rural development and the improvement of the village ecosystem. The study of village scale can provide a meaningful reference for village spatial planning and design.

4.2 Enhancing the supply capacity of village ecosystem services and promoting the economic transformation of service values is a win-win path to ecological restoration and economic development in karst desertification areas

This study corrects the equivalent value factor for ES. The value per unit area in 2015 and 2020 is CNY 36,512 and CNY 36,787, respectively. This value is similar to the corrected values from other karst ecosystem services studies (Gao and Xiong, 2015; Han et al., 2020). It shows that the revised

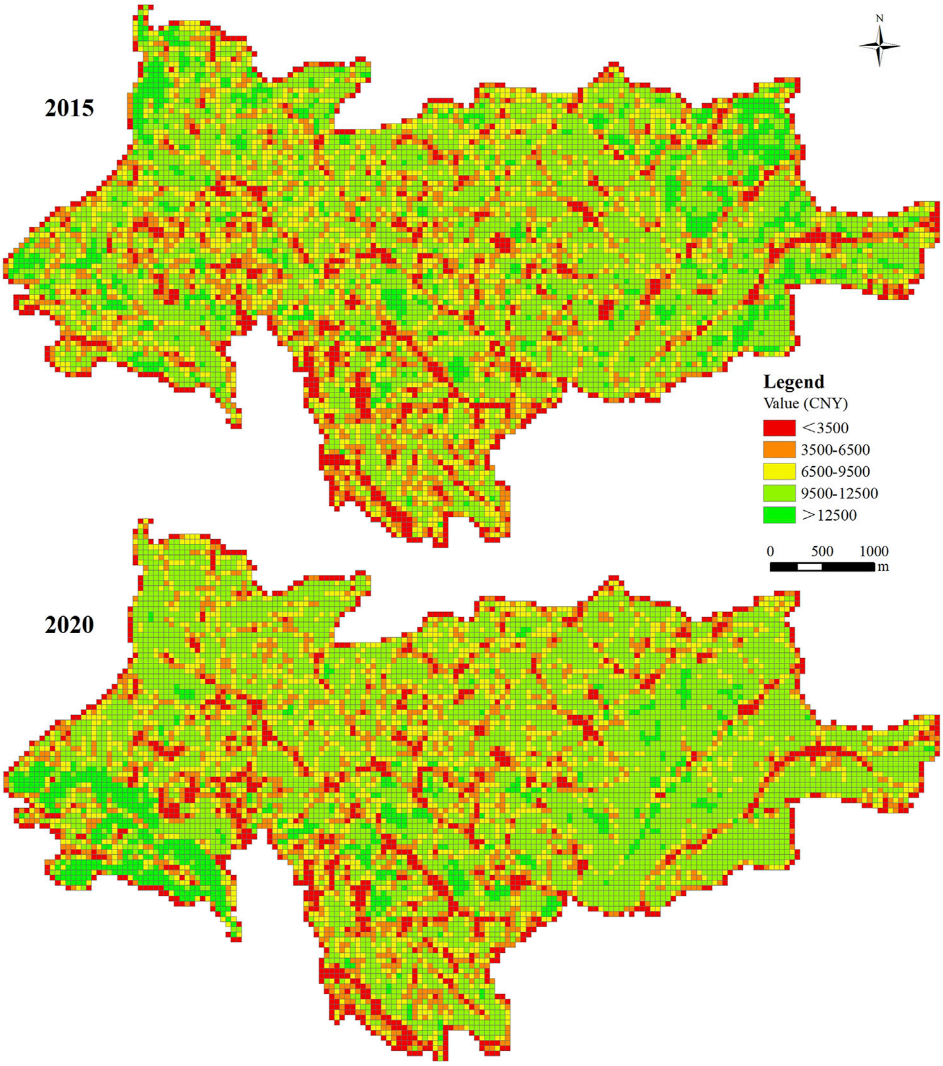

FIGURE 5
Spatial distribution of ecosystem service values.

value equivalents of this study are in line with the actual situation and have a high degree of credibility. The total value of village ecosystem services increased by CNY 63.45 × 10^4 during the KDC period, a change that came mainly from the contribution of the expansion of forested and orchard landscapes in the ecosystem. These expansions have enhanced the ecosystem's ecological, productive, and living functions. The value of provision services, regulating services, cultural services, and supporting services increased significantly, primarily regulating services. However, there are trade-offs between services in different landscapes. Due to the reduction in arable and grassland landscapes, a large amount of the value of services is offset in the trade-off process, resulting in an unremarkable increase in the total value of services and a lack of supply capacity for ecosystem services in karst desertification control villages. Secondly, the value of the services generated by the forest landscape is more theoretical. It has yet to be translated into real economic terms. For farmers, developing eco-industries such as orchards can bring more direct economic benefits than eco-forests. At the same time, orchards outperform arable land in providing support services, provisioning services, regulating services, and cultural services, except food production. As an essential measure in the management of karst desertification, eco-industry development has achieved some success in ecological restoration. However, the limitations of the fragmented karst landscape have prevented the development of a large-scale eco-industry. As a result, the value of regulating services generated by the forest landscape remains an essential component of the value of ecosystem services in villages. This value does not provide farmers with tangible economic benefits, and the green hills are not transformed into golden mountains. Due to the lack of mechanisms, platforms, and policy support for the value transformation of village ecosystem services in KDC, the ecological assets of village ecosystems still need to be revitalized. The supply capacity of village ecosystem services is at a low level.

4.3 The TPI provides a spatial reference for enhancing the value of village ecosystem services

Existing studies have more often analyzed and elaborated spatially on ecosystem services with the help of orientation. This approach only

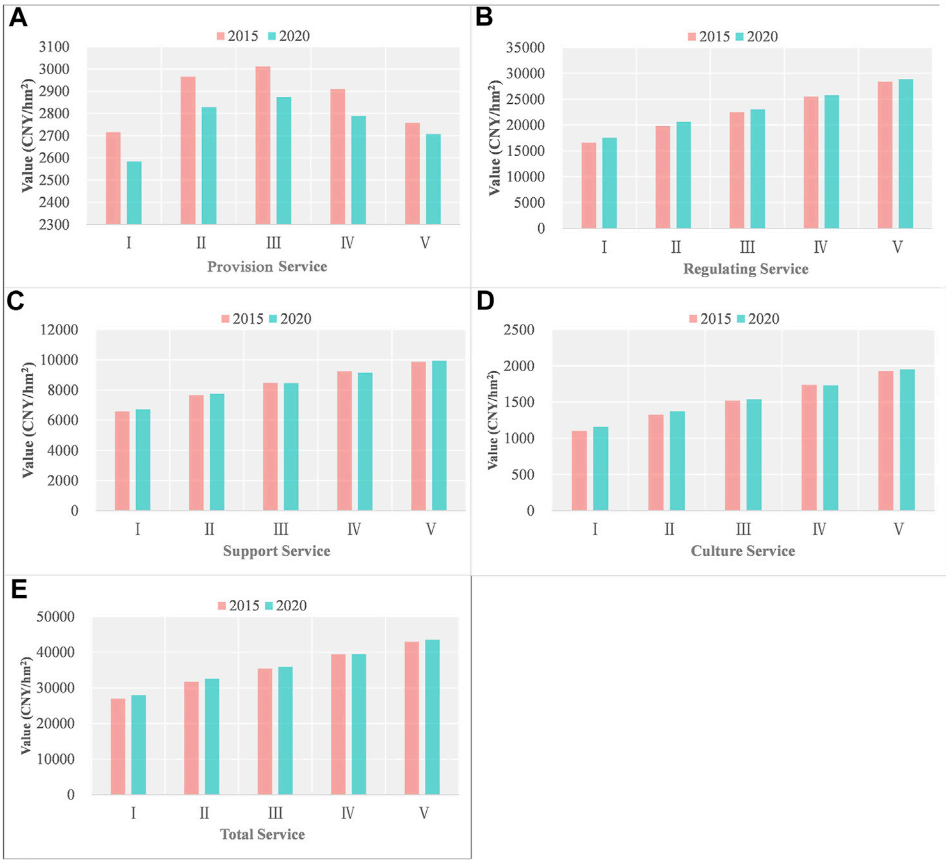

FIGURE 6
Distribution of the value of different ecosystem services at different TPI levels. In this combination diagram: **(A)** this panel is the value of provision services; **(B)** this panel is the value of regulation services; **(C)** this panel is the value of support services; **(D)** this panel is the value of culture services; and **(E)** this panel is the value of total services.

elucidates the spatial distribution characteristics of ecosystem services in this one location, does not reveal the universal characteristics of similar study areas, and lacks guidance. The TPI can reflect spatial characteristics well. The spatial significance can be uncovered by using it to elaborate on the spatial characteristics of ecosystem services. The nature of the spatial distribution of ecosystem services can be revealed to dissect the spatial distribution characteristics of village ecosystem services in the study area and extend the result to other areas of the same type. The village ecosystems in this study show different characteristics of change in service value at different TPI gradients. The value of provision services shows an inverted U-shaped distribution as TPI rises, peaking at gradient III, a feature inconsistent with findings in other karst regions (Han et al., 2020; Zhou et al., 2021). The value of regulation, support, cultural, and comprehensive services increase with TPI, a trend consistent with Han's findings (Han et al., 2020). The value of provisioning services per unit area is low on very high and shallow TPI gradients, making this area a potential for ecosystem provisioning service value enhancement. The higher the TPI, the lower the human activity, the higher the value of regulating services, supporting services, cultural services, and comprehensive services exhibited at the highest TPI gradient, and the lower the value of ecosystem services at the low TPI gradient. Thus, the low TPI gradient is a significant potential area for ecosystem service value enhancement, providing a topographic spatial reference for village ecosystem service value enhancement in the karst plateau mountains.

4.4 Limitations

There are some possible limitations to this study. Firstly, the land use data in this paper were obtained by interpreting remote sensing imagery. This method can only identify two-dimensional space. However, tree forests, shrublands, and grasslands may co-exist in three-dimensional space. Only tree forests can be identified if this situation exists, and information on shrublands and grasslands will be lost, leading to an underestimation of the value of village ecosystem services. The future of remote sensing interpretation should be a breakthrough in three dimensions. Secondly, the research context of this paper is the karst plateau mountains and targets village ecosystems with potential-light KDC. Due to the high heterogeneity of karst areas, the findings of this study may be more applicable to village ecosystems with characteristics consistent with this paper. Future research on

KDC in village ecosystems should be increased, especially comparative studies between different village ecosystems.

5 Conclusion

Based on dynamic changes in LULC, this paper investigates the landscape pattern and EVS of potential-light KDC village ecosystems in the karst plateau mountains using the land use matrix method, the landscape pattern index, the TPI, and the modified value equivalents. It bridges the gaps in the field at village scales, in rural environments, and in the context of KDC, and provides a reference about KDC for research on ES. Based on the findings and discussions, we conclude the following. Firstly, during the period of KDC, the vegetation types of the village ecosystems in the karst plateau mountains with potential mild KDC are in positive succession, and the land use is dominated by woodland, or-chard, and construction land, while the area of dry land and grassland shows a decreasing trend. The dominance of shrubland is gradually increasing. The shape of the orchard and construction land types tends to be more complex, while the shape of woodland, grassland, and cropland tend to be more regular. The shape of the landscape also tends to be regular and clustered. Landscape spread and connectivity are increasing, while fragmentation and SHID is decreasing. Secondly, the value of regulation and cultural services has increased over the 5 years, with regulation services making the most significant contribution. However, landscape change has led to a trade-off between services, with a downward trend in the value of provisioning and support services. The supply capacity of village ecosystem services is inadequate due to the offsetting services generated. The total value of ES in KDC villages increased by only CNY63.45 × 10^4, and the value of services was not effectively transformed economically. Thirdly, the value of ecosystem services exhibited different characteristics of variation across topographic space. As TPI increases, the value of provisioning services follows an inverted U-shape, with the remaining services increasing as TPI increases. Furthermore, the value of ecosystem services has a more significant potential to increase on the gradient of low TPI.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

Conceptualization, KX, and QW; methodology, JZ; software, HX, and SS; formal analysis, QW; investigation, JZ, HX, and SS; data curation, HX; writing-original draft preparation, QW; writing-review and editing, KX, QW; visualization, QW; supervision, JZ; project administration, QW; funding acquisition, KX All authors have read and agreed to the published version of the manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenvs.2023.1020331/full#supplementary-material

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