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Quantitative assessment of ecological assets in the world heritage karst sites based on remote sensing: with a special reference to South China Karst

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Abstract

The benefits provided by ecological assets play a crucial role in enhancing human well-being. However, there is a scarcity of viable methods for assessing their status. This study is grounded in Land Use and Land Cover Change (LUCC) and integrates both the quantity and quality aspects of these assets. Utilizing the ecological asset index (EQ and EQi), this study conducts a quantitative assessment of the assets in the Shibing karst and the Libo-Huanjiang karst heritage sites, while also qualitatively analyzing their influencing factors. The findings reveal that: (1) In the Shibing heritage site, forest and impervious surface assets exhibited an upward trend, whereas cropland and grassland experienced a decline; meanwhile, shrub and water body assets remained relatively stable. The total area of assets rated as excellent or good increased by 95.371 km^2, resulting in an EQ enhancement of 45.427. (2) Likewise, in the Libo-Huanjiang heritage site, forest and impervious surface assets demonstrated an upward trajectory, while shrub assets declined. Cropland, grassland, and water body assets experienced minimal variation. The total area of assets rated as excellent or good expanded by 168.227 km^2, resulting in an EQ enhancement of 80.806. (3) The execution of a series of ecological protection projects and management plans for heritage site conservation primarily accounts for the enhancement of regional assets. Notably, ecological resources, socio-economic conditions, human resources, and conservation management policies serve as pivotal drivers influencing the alterations in heritage site assets.

Keywords Ecological assets, Ecological assessment, Remote sensing, GRA, South China Karst

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Introduction

Ecological assets represent a fundamental component of natural resources, capable of furnishing humanity with ecological products and services [1]. They encompass ecosystems capable of providing benefits to humanity within specific spatiotemporal contexts. These include natural ecosystems such as forests, shrubs, grasslands, wetlands, and deserts, as well as human-made ecosystems like croplands and urban green spaces, all founded on natural ecological processes, and wild flora and fauna resources [2]. Serving as the cornerstone of ecological benefits, ecological assets are acknowledged in both domestic and international research for bestowing a diverse range of ecological benefits. These encompass the provisioning of material products, regulatory services, as well as aesthetic, educational, and cultural services [3–5]. Nevertheless, there is considerable divergence worldwide in the assessment of ecological benefits, encompassing evaluation criteria, indicators, methods, and outcomes [6, 7]. Hence, the initial step in evaluating ecological benefits involves assessing the ecological assets responsible for their provision. Internationally, scholars more commonly employ the term "natural capital" rather than "ecological assets," with research predominantly concentrated on the valuation of natural capital [4, 8]. In China, the conceptualization of ecological assets is marked by inconsistencies, resulting in variations in scope, methods, and outcomes of studies concerning its valuation. This situation elevates uncertainty and complexity in conducting assessments and making decisions. Physical quantity accounting can effectively mitigate this uncertainty by statistically quantifying the extent of ecosystems of varying quality grades, including forests, grasslands, wetlands, croplands, urban green spaces, as well as the diversity of wild flora and fauna species, thereby addressing both quantity and quality aspects [9].

World Heritage (WH) represent some of the most exceptional places on Earth owing to their outstanding natural or cultural value [10–12]. Karst World Heritage sites (KWHS) constitute a significant facet of the WH, garnering global attention [13, 14]. Presently, there exist 30 KWHS worldwide. These sites serve as crucial resources for regional tourism development, acting as essential brands for market expansion and boasting global appeal [15]. Owing to their distinctive geological environment and biodiversity, KWHS have fostered rich and distinctive ecological assets, furnishing diverse ecological services such as water supply, soil conservation, carbon storage, and landscape beautification, while also meeting crucial material and spiritual needs of humanity [16]. However, as natural geographical units with specific geological backgrounds, Karst landscapes are susceptible due to their lithological characteristics. The ecological environment of KWHS is delicate, with vulnerabilities primarily evident in soil, hydrology, vegetation, and human environments [17–19]. These environments demonstrate a high sensitivity to changes, low environmental carrying capacity, and limited resilience to disasters [20, 21]. Therefore, undertaking regular and systematic assessments of ecological assets in KWHS is of paramount importance to ensure their sustainability.

Karst landscapes are considered among the most outstanding scenic views globally [22], widely distributed in Central and Southern Europe, Eastern North America, and Eastern Asia, covering a total area of 22 million km^2 [23, 24]. China's karst regions occupy over one-third of the total national territory, primarily concentrated in the southern karst belt with the Guizhou Plateau as its core, covering a total area of 550,000 km^2 [25]. This region is renowned for its typical and diverse karst landscapes, mainly distributed in eight provinces and autonomous regions including Yunnan, Guizhou, Guangxi, Chongqing, Sichuan, Hunan, Hubei, and Guangdong. The diverse and complex karst landscapes in southern China have formed seven unique World Natural Heritage sites [26]. The KWHS in southern China belong to the tropical-subtropical monsoon type, characterized by typical and diverse landforms and biological ecological features unmatched by other regions. Phase I and Phase II of Southern China Karst were listed in the WH List according to criteria (vii) and (viii) of the WH Convention, respectively. Among them, Shibing, Libo-Huanjiang karst represents outstanding examples of KWHS in southern China [27, 28]. Conducting a comprehensive assessment of the ecological assets of these two KWHS can help comprehensively understand the changes in the ecological assets of the heritage sites and provide guidance for the protection and management planning of the heritage sites.

This study aims to evaluate the ecological assets of two KWHS in Southern China—Shibing and Libo-Huanjiang—utilizing remote sensing indicators. Initially, we quantified the quantity of each type of ecological asset. Subsequently, we assessed the quality of ecological assets within the study area. Lastly, we developed indices for various types of ecological assets (EQi) and a comprehensive ecological asset index (EQ) assessment indicator based on both quantity and quality information. This comprehensive approach unveils the characteristics, quantity, and quality status of ecological assets in Shibing and Libo-Huanjiang KWHS. It analyzes the dynamic changes over the past 22 years and explores factors influencing the changes in ecological assets. The aim is to provide a reference for the sustainable development, ecological compensation, and effectiveness assessment of ecological protection in Shibing and Libo-Huanjiang WH Sites, as well as to offer insights for evaluating the effectiveness of ecological protection in similar regions.

Study area and data sources

Study area

The southern karst landscapes of China collectively refer to a series of World Natural Heritage nomination projects submitted by the Chinese government to the WH Committee. The first batch of heritage sites included Yunnan Stone Forest Karst, Guizhou Libo Karst, and Chongqing Wulong Karst, which were successfully inscribed on the WH List in 2007. The second batch of nominated sites included Guangxi Guilin Karst, Guizhou Shibing Karst, Chongqing Jinfoshan Karst, and the expansion area of Guangxi Huanjiang Karst for the Libo Karst site, which were successfully inscribed on the WH List in 2014. As a typical region of tropical-subtropical karst landscapes, the southern karst landscapes of China exhibit unique structural systems and evolutionary sequences, unparalleled in global geomorphological value [29–31]. Therefore, the geomorphological characteristics and diversity of the southern KWHS in China are recognized as the best. Following the principles of typicity, representativeness, feasibility, and demonstrativeness, this study selected Shibing Karst and Libo-Huanjiang Karst as the research area (Fig. 1).

Shibing karst WH site

The Shibing karst is located in Shibing County, eastern Guizhou Province, situated on the transitional slope from the mountains of central Guizhou to the hills of western Hunan. Its geographic center lies between 108° 05′ 40″ E and 27° 10′ 16″ N (Fig. 2). The total area of this heritage site is 10,280 hm^2, with a buffer zone covering 18,015 hm^2. The terrain slopes from north to south, with most areas at elevations ranging from 600 to 1250 m, and an average elevation of 912 m. Shibing karst is located in a subtropical monsoon humid climate zone, characterized by mild spring, cool summer, and a spring-like climate throughout the year, with evenly distributed precipitation. The average annual temperature is 16 °C, and the annual rainfall is 1220 mm. The typical feature of Shibing karst is the subtropical karst landscape developed on pure, thick, and ancient limestone, forming spectacular cone-shaped peaks and valley karst landforms [32]. This demonstrates that, under specific natural geographical backgrounds and structural foundations, limestone can develop typical and spectacular karst landscapes. Shibing karst represents an outstanding example of limestone karst landscapes worldwide, filling the typological gap in China's southern karst heritage series. It adds unique value to "Southern China Karst" and holds extremely high global significance and representativeness.

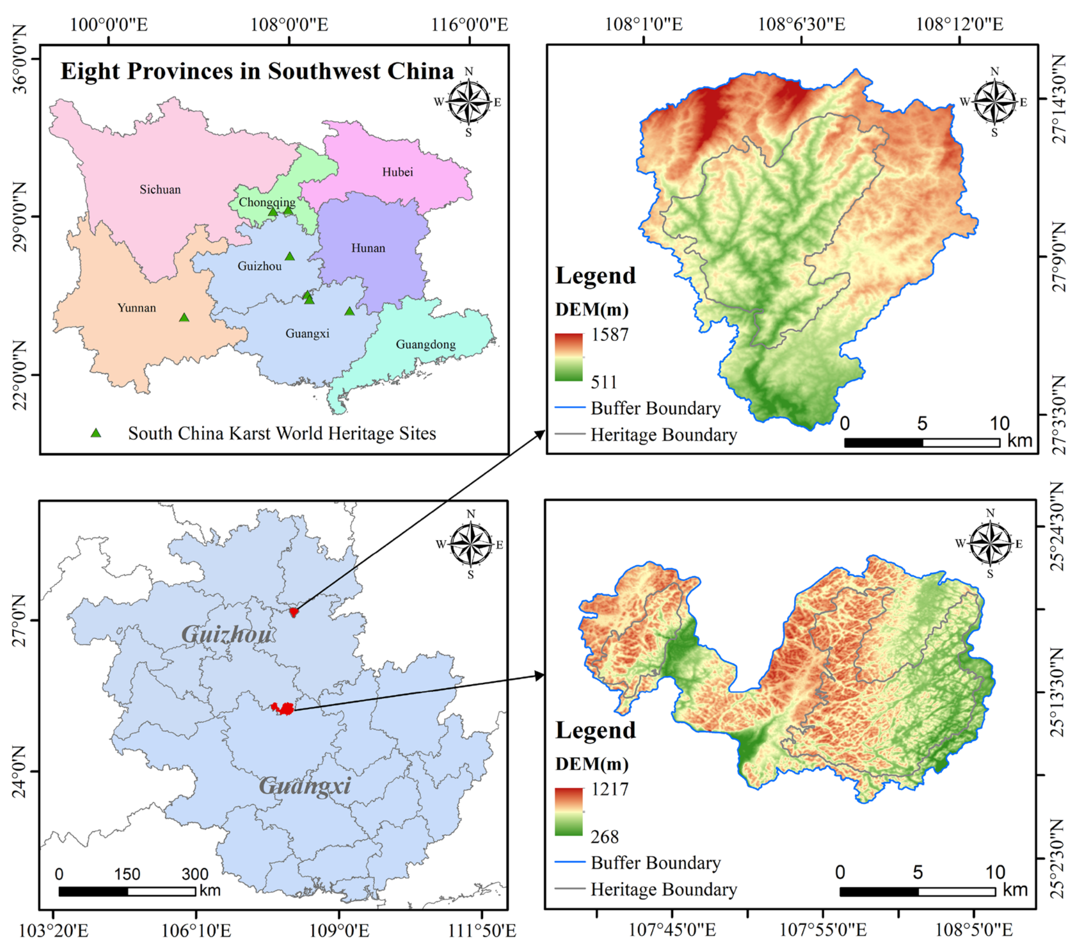

Figure. 1 Study area

Fig. 2 Shibing karst peculiar geological landscape

Libo-Huanjiang karst WH site

The Libo-Huanjiang karst is situated at the junction of Libo County in Qiannan Prefecture, Guizhou Province, and Huanjiang County in Hechi City, Guangxi Zhuang Autonomous Region. It mainly comprises the Daqikong and Xiaoqikong scenic areas in the Maolan National Nature Reserve and the Zhangjiang National Scenic Area, as well as the Mulun National Nature Reserve in Guangxi (Fig. 3). The total area of this heritage site is 36,647 hm^2, with the central coordinates ranging from 107° 58′ 30″ to 107° 59′ 40″ E and 25° 09′ 27″ to 25° 13′ 15″ N. The Libo-Huanjiang karst boasts diverse landforms, unique landscapes, complex and diverse habitats, rich biodiversity, and well-preserved vegetation. Its distinctive karst forest, rare on a global scale, forms the largest and best-preserved karst forest ecosystem globally, providing an excellent environment for biological growth and reproduction [33].

Research framework and data sources

Research framework

The physical quantity accounting of ecological assets mainly involves two aspects: quantity (area) and quality. In this study, we utilized ecosystem classification

Fig. 3 Rich and diverse ecological assets of Libo-Huanjiang karst

rules and analyzed remote sensing interpretation data to obtain the quantity of ecological assets. Meanwhile, the quality of different types of assets was assessed based on the Fraction of Vegetation Cover (FVC), categorized into five levels: excellent, good, moderate, poor, and inferior. With the assistance of ecological asset index indicators (EQ and EQi) that simultaneously reflect quantity and quality, we comprehensively evaluated and accounted for the physical quantity of ecological assets such as forests, shrub, grassland, and cropland. Finally, we discussed the driving factors influencing changes in ecological assets.

Data sources

In this study, Landsat TM/OLI remote sensing imagery data for four time periods (2000, 2007, 2014, and 2021) were employed, with a spatial resolution of 30 m and cloud cover less than 5%, ensuring high quality and accessibility. These image data were downloaded from the Geographic Spatial Data Cloud website (http://www.gscloud.cn). Preprocessing steps, including radiometric calibration, atmospheric correction, geometric correction, image mosaicking, and image alignment, were carried out using ENVI 5.3 and ARCGIS 10.2 software. The FVC data were based on the pixel binary model, considering that the Normalized Difference Vegetation Index (NDVI) value of a pixel is composed of information contributed by green vegetation and non-vegetated areas, obtained through inversion of MODIS imagery. MODIS-NDVI data were sourced from the Land Processes Distributed Active Archive Center (https://lpdaac.usgs.gov), and FVC data were obtained from the Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences (http://www.aircas.cas.cn/). The data for protection management planning were obtained from the planning documents and related materials of the Shibing and Libo-Huanjiang heritage sites. Grey Relational Analysis (GRA) data were primarily obtained through on-site questionnaire surveys of local residents, covering basic demographic information and factors influencing changes in ecological assets, with the latter constituting the core content of the questionnaire. The survey primarily focused on four aspects: ecological resources, socio-economic environment, conservation management policies, and human resources (Additional file 1).

Method

Quantity of ecological assets

In this study, the area of different types of ecological assets serves as a surrogate indicator to represent the quantity of ecological assets, derived from the ecosystem classification of remote sensing data. According to the national standard "Classification of Land Use Status" (GB/T 21010-2017), the remote sensing data of the heritage sites were classified into six land cover types: cropland, forest, shrub, grassland, water body, and impervious surfaces. Since water body and impervious surfaces do not contain green vegetation and constitute a very small proportion in both heritage sites, they were not included in the study of ecological asset quality and the ecological asset index.

Ecological asset quality

This study primarily focuses on the quality of cropland, forests, shrub, and grassland assets within the KWHS. FVC exhibits a significant positive correlation with ecosystem structure, composition, and species richness, making it a readily obtainable large-scale ecological parameter through remote sensing, suitable for evaluating the quality of ecological assets [34]. The study employs an interval method to categorize the quality of ecological assets into five levels: excellent, good, moderate, poor, and inferior, based on the differences in the quality of cropland, forests, shrub, and grassland assets [35]. The specific evaluation indicators and grading criteria are shown in Table 1.

The calculation method for the quality of ecological assets is:

$$NDVI = \frac{NIR - R}{NIR + R}, \tag{1}$$

where $NDVI$ is an abbreviation for Normalized Difference Vegetation Index, NIR stands for near-infrared band, and R stands for red band.

Table 1 Evaluation indicators and grading criteria for ecological asset quality

Ecological asset category	Ecological asset quality status level				
	Excellent (%)	Good (%)	Moderate (%)	Poor (%)	Inferior (%)
Cropland	≥ 85	70–85	50–70	25–50	< 25
Forest	≥ 85	70–85	50–70	25–50	< 25
Shrub	≥ 85	70–85	50–70	25–50	< 25
Grassland	≥ 85	70–85	50–70	25–50	< 25

$$FVC = \frac{NDVI - NDVI_{soil}}{NDVI_{veg} - NDVI_{soil}}, \quad (2)$$

Here, FVC denotes Fractional Vegetation Cover, $NDVI_{soil}$ is the NDVI value of pure bare soil pixels, and $NDVI_{veg}$ is the NDVI value of pure vegetation-covered pixels.

Ecological asset index

To accurately reflect the changes in the physical quantity of ecological assets and facilitate comparisons between different regions, this study established an Ecological Asset Index to comprehensively evaluate and account for the physical quantity of assets such as cropland, forests, shrub, and grassland in KWHS, considering both quantity and quality factors [36]. Specifically, we multiplied the area of ecological assets at different quality levels (excellent, good, moderate, poor, and inferior) by their respective quality weighting factors. Then, we compared this product with the ratio of the total area of the asset type to the highest quality weighting factor, obtaining the ecological asset quality index. Meanwhile, we normalized the ratio of ecological asset area to the total land area of China to obtain the ecological asset area index. Finally, we multiplied the quality index by the area index to obtain the comprehensive index of ecological assets.

$$\mathrm{EQ} = \frac{\sum_{i=1}^{4}\sum_{j=1}^{5}\left(EA_{ij} \times j\right)}{\left(\sum_{i=1}^{4} EA_i \times 5\right)} \times \frac{\sum_{i=1}^{4} EA_i}{9600000} \times 10^7, \quad (3)$$

$$EQi = \frac{\sum_{j=1}^{5}\left(EA_{ij} \times j\right)}{(EA_i \times 5)} \times \frac{EA_i}{9600000} \times 10^7, \quad (4)$$

where EQ is the ecological asset composite index; EQi is the ecological asset composite index of category i; i is the type of ecological asset; j is the ecological asset quality grade index, i.e., grade 1–5; EA_{ij} is the area of ecological asset grade j in category i; EA_i is the area of ecological assets in category i; and 9,600,000 is the official data of China's national land area in km^2; "$\times 10^7$" is to make the range of values of the calculation results between 1000.0 and 0.1, which is convenient for later application.

Grey relational analysis

GRA is a specific statistical technique used to assess the degree of relationship between main factors and subfactors within a system [37]. Through GRA, it is possible to identify the primary and secondary factors causing changes in the system's development and quantitatively compare and analyze the dynamic development trends of the system [38]. Compared to traditional statistical analysis methods such as regression analysis, analysis of variance, principal component analysis, etc., the GRA method is suitable for various sample sizes and sample regularities. It involves minimal computational complexity and avoids inconsistencies between quantitative results and qualitative analysis, thereby addressing the limitations of using mathematical statistical methods for system analysis [39]. The data for this study were derived from a questionnaire survey, characterized by insufficient information and a small sample size, making the GRA method suitable for identifying key factors influencing the ecological assets of KWHS. The following are the calculation steps of the GRA method for extracting key factors from the survey questionnaire:

(1) First, we establish the evaluation index system based on the investigation purpose, and compute it using the following formula:

$$\boldsymbol{X_i^T} = \left[\boldsymbol{x_i(1), x_i(2), x_i(3), \ldots, x_i(m)}\right]. \quad (5)$$

In this formula, X_i represents the score set of the i-th surveyed object, (S) represents the score of the i-th subject on the S-th factor, $i = 1, 2, 3, \ldots, n$, $S = 1, 2, 3, \ldots, m$, and T denotes the transpose matrix.

(2) The reference sequence serves as an ideal comparative benchmark, formed by the optimal (or worst) values of each index, to construct a reference data column, or other reference values selected based on the survey objectives. The calculation formula remains as follows:

$$\boldsymbol{X_0^T} = [\boldsymbol{x_0(1), x_0(2), x_0(3), \ldots, x_0(m)}]. \quad (6)$$

(3) When computing the difference sequence, calculate the absolute difference between the index sequence (comparison sequence) of each evaluation object and the corresponding elements of the reference sequence. The calculation formula remains as follows:

$$\left| X_0(S) - X_i(S) \right|, \ \mathrm{i} = 1, 2, 3, \ldots, \mathrm{n}; \ \mathrm{S} = 1, 2, 3, \ldots, \mathrm{m} \left|. \right. \quad (7)$$

(4) Determine the formulas for the minimum and maximum differences between two levels as follows:

$$\min_{i=1}^{n}\min_{S=1}^{m} |\boldsymbol{X_0(S) - X_i(S)}| \quad \mathop{Max}_{i=1}^{n}\mathop{Max}_{S=1}^{m} |\boldsymbol{X_0(S) - X_i(S)}|. \quad (8)$$

(5) Calculate the correlation coefficient between each comparison sequence and the corresponding elements of the reference sequence using the following formula:

$$\mathbf{R}[X_0(S),X_i(S)]=\left[\min_{i=1}^{n}\min_{S=1}^{m}|X_0(S)-X_i(S)|+V\mathop{Max}_{i=1}^{n}\mathop{Max}_{S=1}^{m}|X_0(S)-X_i(S)|\right]\bigg/\left[|X_0(S)-X_i(S)|+V\mathop{Max}_{i=1}^{n}\mathop{Max}_{S=1}^{m}|X_0(S)-X_i(S)|\right]. \quad (9)$$

In this formula, R[$X_0(S),Xi(S)$] is the correlation coefficient of the i-th observed object on the S-th factor. If the optimal value is used as the reference sequence, the greater R[$X_0(S),X_i(S)$], the stronger the correlation. V is the resolution coefficient, with a range between (0, 1). A smaller V indicates a greater difference between correlation coefficients, stronger discrimination ability, and is typically set to 0.5.

(6) The score for each factor is computed based on the weighted average of correlation coefficients, aiming to gauge the correlation between each assessment subject and the reference sequence. The higher the correlation, the more prominent the factor's importance. Below is the calculation formula:

$$\mathbf{R}(S)=\sum_{i=1}^{n}Z_i\mathbf{R}[X_0(S),X_i(S)]. \quad (10)$$

In this formula, R(S) is the relevance of the S-th factor, Z_i is the weight of the i-th observed object.

Indicator system construction

The ecological assets of KWHS are influenced by various factors, stemming from both internal and external sources. However, further in-depth research and empirical testing are necessary to understand the mechanisms and impacts of these influencing factors. Considering the availability and representativeness of indicator data, we referred to relevant research findings [40, 41] and combined them with the actual conditions of the study area to select 23 factors from four aspects: ecological resources, socio-economic environment, human resources, and conservation management policies. Employing the maximum value of each indicator as the comparative sequential indicator (Table 2), a scoring questionnaire was developed to identify key factors using the GRA formula.

Results

Ecological asset characteristics

The Shibing and Libo-Huanjiang KWHS boast unique geological landscapes and favorable climatic conditions,

Table 2 Selection of impact factors on ecological assets

Impact factors	Dimensions of impact factors	Indicator of impact factors
Internal impact factors	Ecological resources (A)	Unique geological and landscape resources (A1)
		Biodiversity of ecosystems (A2)
		Cultural resources (A3)
		Characteristic tourist resources (A4)
		Characteristic ecological product resources (A5)
		Ecological environment suitability (A6)
	Social-economic environment (B)	Residents' income level (B1)
		Infrastructure construction (B2)
		Sales of ecological products (B3)
		Branding of ecological products (B4)
		Economic benefits of ecological products (B5)
External impact factors	Conservation management policies (C)	Government encouragement and support (C1)
		Ecological compensation (C2)
		Product policy support (C3)
		Industrial reform (C4)
		Skills training (C5)
		Support for heritage site management (C6)
	Human resources (D)	Residents' skill level (D1)
		Residents' overall quality (D2)
		Management personnel capacity of heritage sites (D3)
		Skills of scenic area staff (D4)
		Technical guidance talent related to ecological product supply (D5)
		Leadership capacity of village committees/resident committees (D6)

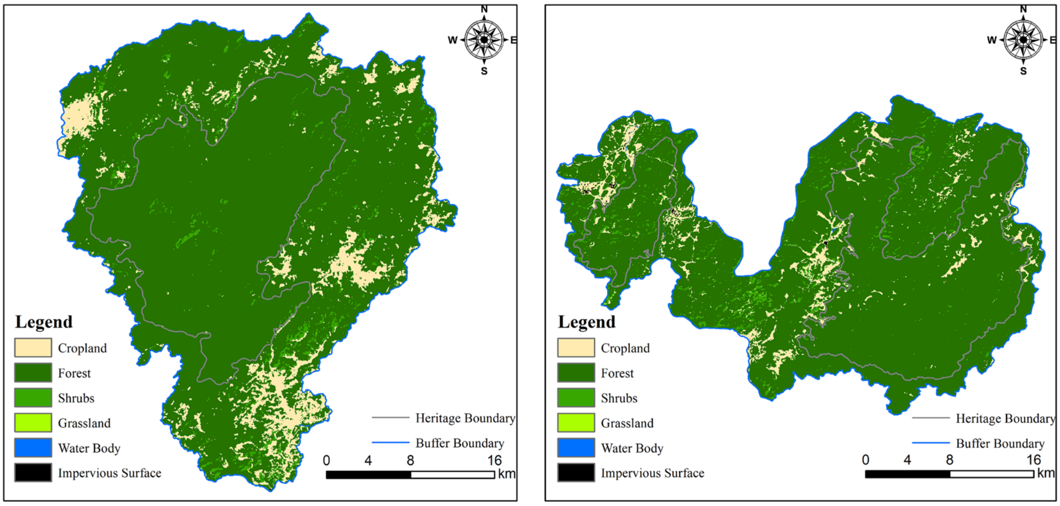

Figure4 Distribution of ecological assets (left Shibing karst, right Libo-Huanjiang karst)

Table 3 Percentage of number of ecological assets

Types of ecological assets	Shibing karst		Libo-Huanjiang karst	
	Area (km^2)	Proportion (%)	Area (km^2)	Proportion (%)
Cropland	24.077	8.51	49.244	6.05
Forest	252.652	89.31	732.417	89.98
Shrub	5.984	2.12	30.708	3.77
Grassland	0.043	0.02	0.228	0.03
Water body	0.029	0.01	0.385	0.05
Impervious surface	0.117	0.04	1.008	0.12

nurturing a diverse range of ecological assets, including forests, cropland, shrub, grassland, and water bodies. These ecological assets exhibit characteristics such as typical geological landform development, exceptionally high aesthetic value, and rich biodiversity.

Quantitative characteristics of ecological assets

From the distribution of areas (Fig. 4, Table 3), it can be observed that forests dominate the ecological assets in both the Shibing and Libo-Huanjiang WH sites. The total area of the Shibing site is approximately 283 km^2, with forests accounting for 89.31%, cropland covering 24.077 km^2 (8.51%), shrub occupying 2.12%, and grassland covering merely 0.02%. Water bodies and impervious surfaces have negligible areas, each accounting for less than 0.05%. Similarly, in the Libo-Huanjiang site, ecological assets are predominantly forested. With a total area of 814 km^2, forests cover 732.417 km^2 (89.98%), cropland occupies 49.244 km^2 (6.05%), and impervious surfaces are slightly higher than Shibing at 0.12%. Shrub,

Table 4 Quality of ecological assets in the Shibing karst 2021

Quality grade	Types of ecological assets			
	Cropland	Forest	Shrub	Grassland
Excellent				
Area (km^2)	1.018	122.113	1.147	0.031
Proportion (%)	2.51%	51.89%	25.02%	3.99%
Good				
Area (km^2)	2.896	72.87	1.337	0.046
Proportion (%)	7.15%	30.97%	29.16%	5.99%
Moderate				
Area (km^2)	6.897	27.676	1.11	0.134
Proportion (%)	17.03%	11.76%	24.2%	17.50%
Poor				
Area (km^2)	9.505	9.015	0.79	0.13
Proportion (%)	23.47%	3.83%	17.23%	16.95%
Inferior				
Area (km^2)	20.184	3.651	0.201	0.160
Proportion (%)	49.84%	1.55%	4.38%	55.56%

grassland, and water bodies account for 3.77%, 0.03% and 0.05%, respectively.

Ecological asset quality characteristics

The ecological asset quality characteristics of the Shibing and Libo-Huanjiang WH sites exhibit significant two-tier differentiations. Specifically, in the Shibing site (Table 4), the quality of forests and shrub is predominantly excellent and good, while cropland and grassland are mainly of poor and inferior quality. For cropland assets, poor and inferior quality levels account for 49.84% and 23.47%, respectively. More than half of the shrub are of good quality or higher, with 54.18% rated as such, significantly higher than those rated below poor at 21.61%. Grassland quality is generally poor, with a high proportion of inferior quality at 55.56%. Similarly, in the Libo-Huanjiang site (Table 5), the ecological asset quality characteristics are similar to those of the Shibing site. Overall, forest quality is relatively good, with levels rated as good or higher reaching 74.18%. However, grassland quality is generally poor, with a high proportion of inferior quality reaching 90.65%.

Table 5 Quality of ecological assets in the Libo-Huanjiang karst 2021

Quality grade	Types of ecological assets			
	Cropland	Forest	Shrub	Grassland
Excellent				
Area (km^2)	0.847	261.302	1.036	0.001
Proportion (%)	1.76%	35.67%	3.63%	0.74%
Good				
Area (km^2)	1.786	282.094	3.870	0.001
Proportion (%)	3.71%	38.51%	13.54%	0.46%
Moderate				
Area (km^2)	4.269	137.572	10.043	0.006
Proportion (%)	8.86%	18.78%	35.15%	3.39%
Poor				
Area (km^2)	6.588	33.719	8.484	0.008
Proportion (%)	13.68%	4.60%	29.70%	4.75%
Inferior				
Area (km^2)	34.681	17.915	5.136	0.160
Proportion (%)	72.00%	2.45%	17.98%	90.65%

Characteristics of the ecological asset index

In 2021, the EQ for the Shibing KWHS was 225.606 (Fig. 5). Among them, forests, as the primary asset of the Shibing site, had the highest index, reaching 205.985. The EQi for cropland was 15.95, while for shrub and grassland, they were relatively lower at 3.374 and 0.297, respectively. Similarly, in 2021, the EQ for the Libo-Huanjiang KWHS was 641.269. Among them, forests had the highest EQi, reaching 611.032. The EQi for cropland and shrub were 15.009 and 15.186, respectively. However, the EQi for grassland was extremely low, at only 0.043.

Changes in ecological assets

Since 2000, the ecological asset patterns of the Shibing and Libo-Huanjiang WH sites have remained relatively stable, with minimal changes in their spatial distribution. However, there has been a significant improvement in the overall quality of ecological assets, and the ecological asset indices have shown a steady upward trend. This indicates that in recent years, effective measures have been taken to protect and improve the ecological environment of these two heritage sites.

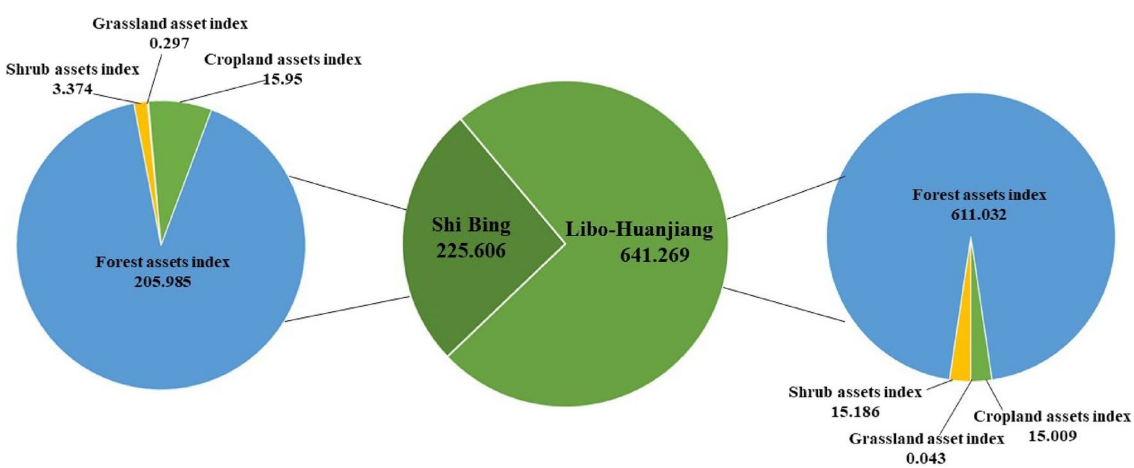

Fig. 5 The Shibing, Libo-Huanjiang karst ecological asset index

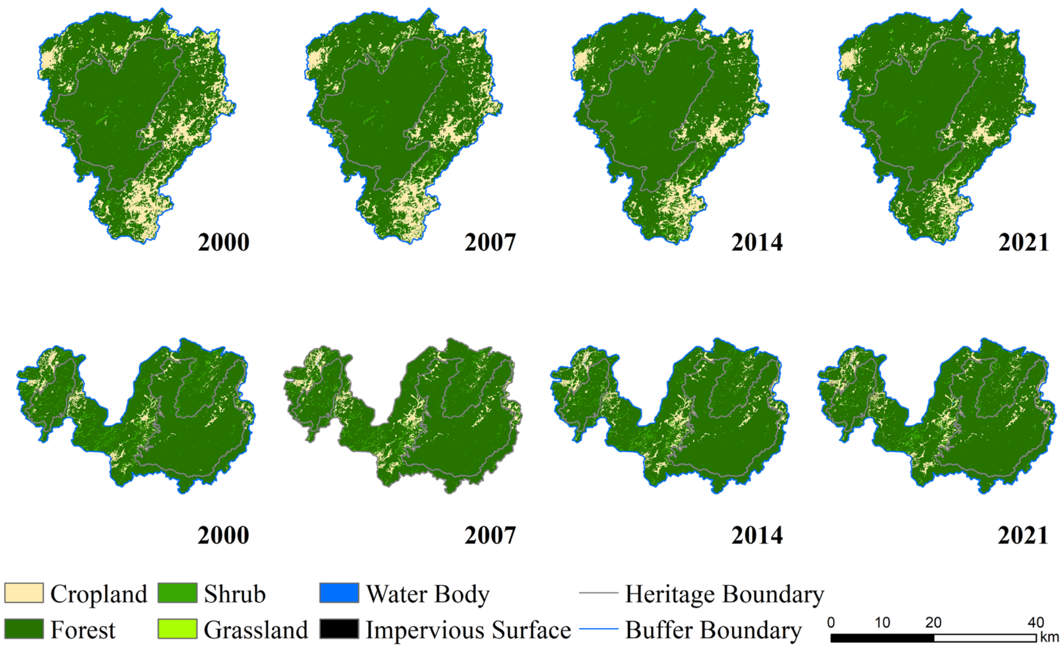

Fig. 6 Overall changes in ecological asset area (upper Shibing karst, lower Libo-Huanjiang karst)

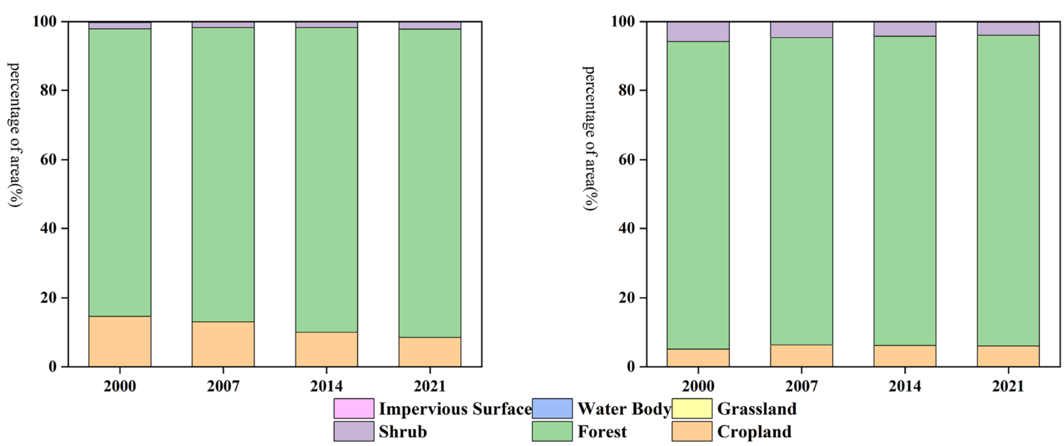

Fig. 7 Changes in the proportion of ecological asset areas by type (left Shibing karst, right Libo-Huanjiang karst)

Changes in ecological asset area

Between 2000 and 2021 (Figs. 6 and 7), the forest and impervious surface areas in the Shibing heritage site showed an increasing trend, while cropland and grassland exhibited a decreasing trend. The areas of shrubbery and water body remained relatively stable. Specifically, the forest area experienced a significant increase, expanding by 17.111 km^2, representing a growth rate of 6.05%. Cropland, on the other hand, significantly decreased by 17.195 km^2, marking a decline of 6.08%. The areas of shrubbery and water body remained almost unchanged, fluctuating from 5.229 km^2 and 0.027 km^2 in 2000 to 5.984 km^2 and 0.029 km^2 in 2021, respectively. The area of grassland saw a slight decrease by 0.27%, while the impervious surface area slightly increased by 0.03%. Meanwhile, in the Libo-Huanjiang heritage site, the forest and impervious surface areas also showed an increasing trend, while the shrubbery area decreased. The areas of cropland, grassland, and water body remained relatively stable. The forest area experienced a noticeable increase, expanding by 7.413 km^2, representing a growth rate of 0.91%. However, the shrubbery area significantly decreased by

15.905 km^2, marking a decline of 1.96%. The areas of cropland, grassland, and water body changed slightly from 41.638 km^2, 0.461 km^2, and 0.223 km^2 in 2000 to 49.244 km^2, 0.228 km^2, and 0.385 km^2 in 2021, respectively. The impervious surface area also saw a slight increase, growing by 0.11%.

Changes in the quality of ecological assets

Over the past 22 years, the overall quality of assets in the Shibing and Libo-Huanjiang KWHS has shown an upward trend (Fig. 8). Specifically, in the Shibing heritage site, the area of excellent and good assets increased by 95.371 km^2, representing a growth rate of 33.66%, while the area of poor and inferior assets decreased by 56.75 km^2. In the Libo-Huanjiang heritage site, the area

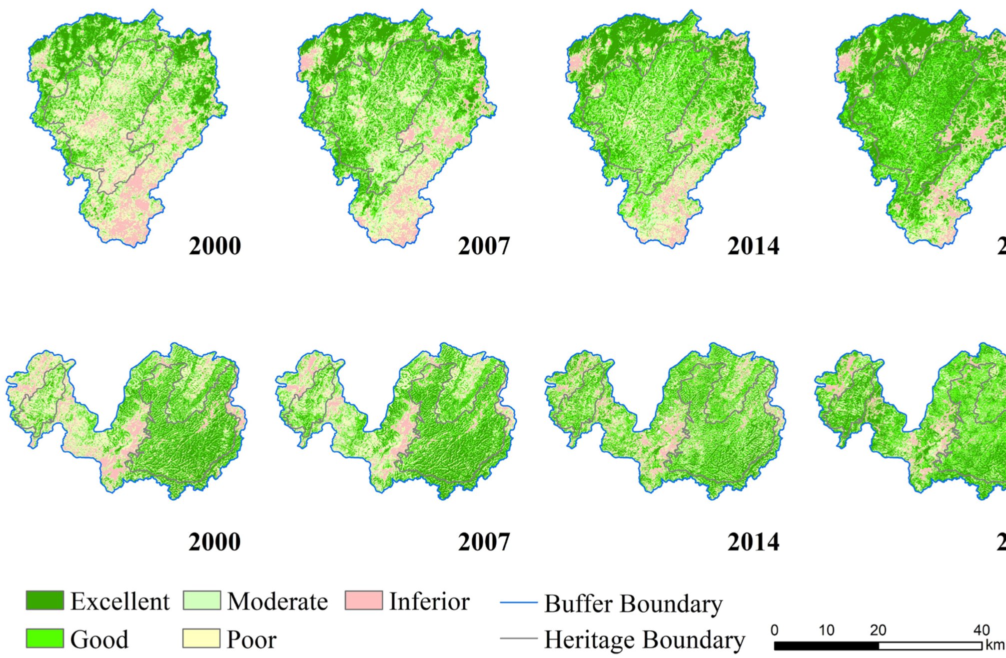

Fig. 8 Overall changes in ecological asset quality (upper Shibing karst, lower Libo -Huanjiang karst)

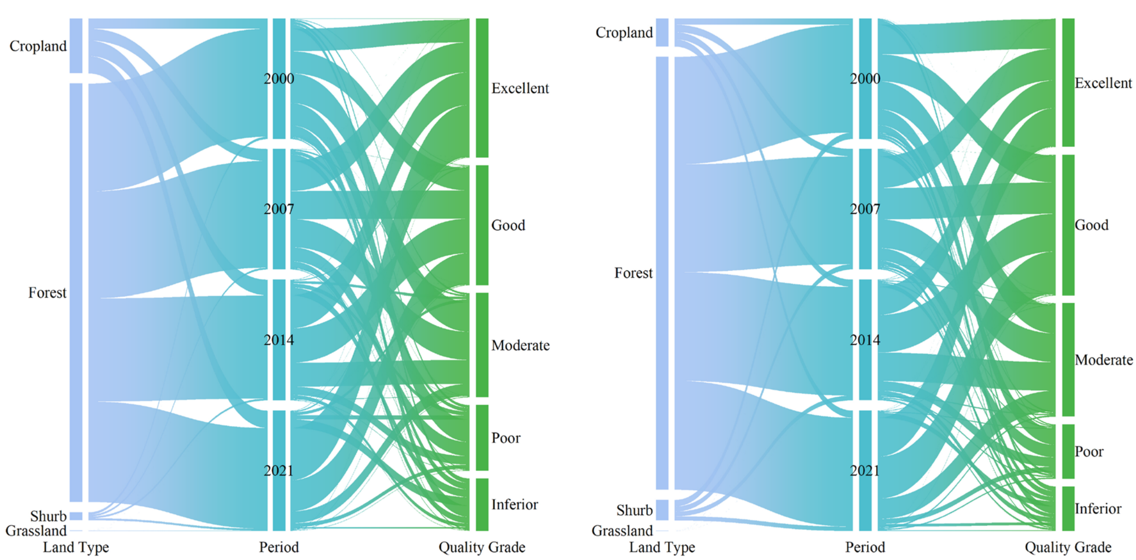

Fig. 9 Changes in the quality of various types of ecological assets (left Shibing karst, right Libo- Huanjiang karst)

of excellent and good assets increased by 168.227 km^2, with a growth rate of 20.64%, while the area of poor and inferior assets decreased by 121.1 km^2. Within the assets of the Shibing heritage site (Fig. 9), the quality of forests showed a significant improvement, with the areas of excellent and good grades increasing by 31.09% and 10.43% respectively, while the areas of medium, poor, and inferior grades all decreased. The quality of shrubbery continued to improve, with the area of grades good and above increasing by 48.11%. The quality of cropland remained relatively stable, mainly dominated by poor grade. Although the overall quality of grassland was relatively poor, there was also a trend towards improvement in grades excellent, good, and medium. In the assets of the Libo-Huanjiang heritage site, the quality of forests continued to improve, with the area of grades good and above increasing from 52.46 to 74.18%. The quality of shrubbery showed an overall increasing trend, shifting from poor and inferior grades towards medium grade. The quality of cropland and grassland remained relatively stable, mainly dominated by poor grade.

Changes in ecological asset index

Between 2000 and 2021 (Fig. 10), the EQ of both the Shibing and Libo-Huanjiang heritage sites has shown a continuous upward trend due to the improvement in asset quality. Specifically, the EQ of the Shibing Heritage Site increased from 180.179 to 225.606. In terms of EQi, the EQi of cropland, forests, shrubbery, and grassland all exhibited an upward trend, increasing by 6.547, 37.329, 1.261, and 0.289 respectively. Similarly, the EQ of the Libo-Huanjiang heritage site increased from 560.463 to 641.269. In terms of EQi, the EQi of cropland and forests showed an increasing trend, with increases of 4.35 and 80.065 respectively. However, the EQi of shrubbery and grassland showed a decreasing trend, with decreases of 3.572 and 0.037 respectively. These data reflect the improvement in ecological asset quality and the steady growth of the ecological asset index in these two heritage sites over the past several years.

Exploration of influencing factors

Through an analysis of the characteristics and changes in the quantity, quality, and index of ecological assets in the Shibing and Libo-Huanjiang KWHS, it is found that the ecological asset characteristics and changes in both sites exhibit similarities. The quantity of their main asset, forests, is increasing, and the overall quality of ecological assets is improving, with EQ showing a continuous growth trend. However, the quality of cropland and grassland in both sites is poor, while shrubbery shows a trend of improvement. An analysis of the transfer of ecological assets in the heritage sites from 2000 to 2021 (Fig. 11) further reveals that in the Shibing heritage site, the main asset transfer is from cropland to forests, while in the Libo-Huanjiang heritage site, the main transfer is from shrubbery to forests. These changes are direct results of the enhancement of ecological assets in the heritage sites. The main reasons for these changes include a series of ecological protection measures implemented by the

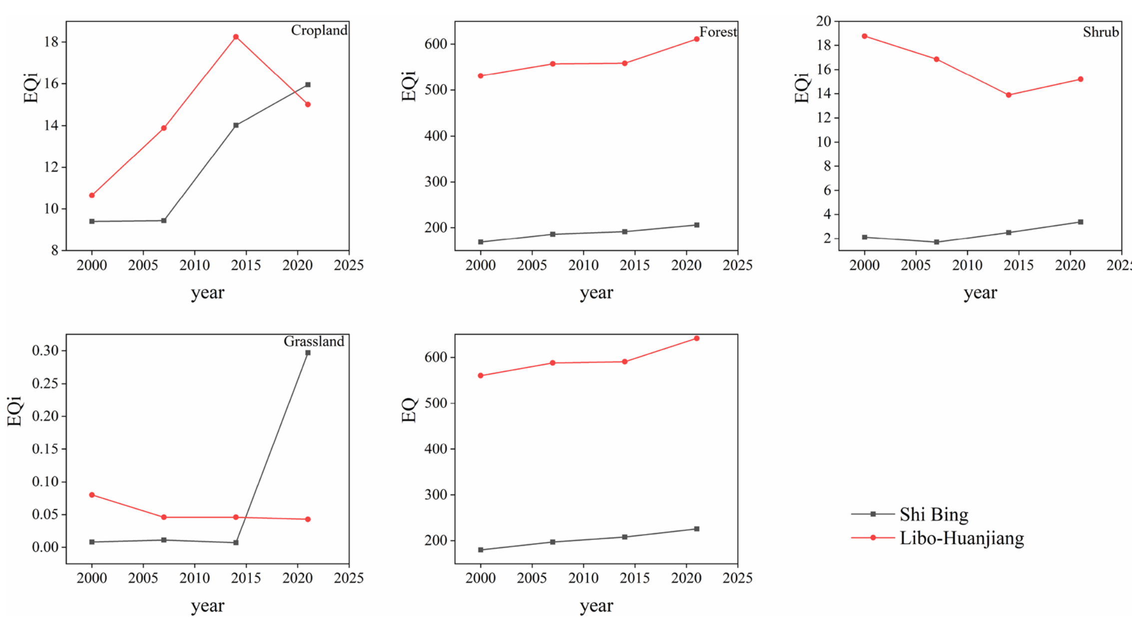

Fig. 10 Changes in ecological asset index

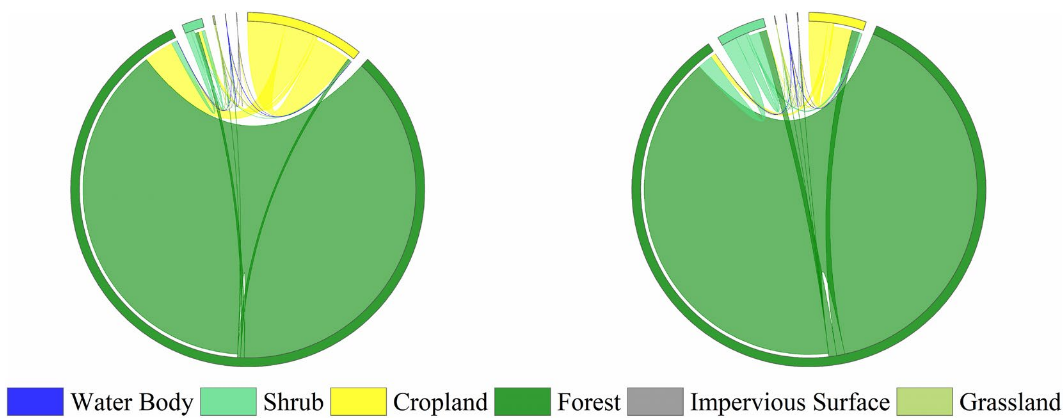

Fig. 11 Land transfer changes from 2000 to 2021 (left Shibing karst, right Libo-Huanjiang karst)

Table 6 Ecological protection measures

Ecological conservation measures	Effects
Retiring cultivated land for reforestation	Encourages farmers to retire cultivated land for reforestation, improving soil quality and the ecosystem
Ecological compensation	Levies environmental taxes on polluters to encourage eco-friendly behaviors
Ecological red lines	Establishes ecological protection boundaries and strengthens ecological protection oversight
Construction of ecological civilization	Promotes the development of ecological civilization, fostering green growth and environmental awareness
Ecological restoration	Restores damaged ecosystems by reviving the functions and stability of natural ecological systems, enhancing ecological quality
"Carbon peaking" and "carbon neutrality" commitment	Commits to achieving carbon neutrality by 2060, promoting greenhouse gas emissions reduction and renewable energy development
National forestry resource protection and sustainable development plan	Promotes the protection and sustainable utilization of forest resources, mitigating deforestation and land degradation
"Green waters and mountains are gold and silver" policy	Emphasizes ecological protection to drive sustainable economic growth through environmental conservation
Improvement of natural ecosystem quality	Comprehensively enhances the functionality and quality of important ecological safety barriers, advancing the sustainable utilization and circulation of ecosystems
Establishment of the ecological civilization pilot area system	Accelerates the refinement of ecological civilization performance evaluation and accountability systems, the establishment of ecological environmental protection regulations and standards, and the development of public interest litigation and law enforcement judicial systems

national and local governments, as well as conservation management plans for each heritage site. These measures have played a crucial role in protecting and enhancing the ecological assets of the heritage sites.

Ecological protection measures

Since the twentieth century, China has implemented a series of ecological conservation measures (Table 6). These measures aim to maintain the stability and diversity of ecosystems, reduce ecosystem vulnerability, and thereby improve the quality of ecological assets. The ecological services provided by ecosystems, such as water supply, air purification, food production, etc., are influenced by ecological conservation, becoming more reliable and sustainable, and helping to meet human needs. Therefore, with the implementation of numerous ecological conservation measures, the ecological assets of heritage sites have also been correspondingly enhanced.

Heritage site protection and management plan

Since being inscribed on the WH List, both the Shibing and Libo-Huanjiang sites have strictly adhered to

Table 7 Conservation and management plan for the Shibing karst (2013–2030)

Measures	Implementation period
Implement unified planning for the construction of tourist facilities within the heritage site, ensuring coordination in specifications, scale, and overall appearance with the natural landscape; simultaneously, rectify buildings that disturb the natural landscape of the heritage site, restoring the visual landscape	Near-term
Strengthen environmental management and control in the heritage site and surrounding communities, raise residents' and tourists' environmental awareness, and prevent the natural beauty of the nominated site from being affected by environmental issues	Long-term
Strengthen early warning and prevention of natural disasters within the heritage site, protecting the vegetation landscape in the nominated area	Long-term
Enhance the protection of various landscape types within the heritage site and their corresponding individual geological and geomorphological structures, preserving the integrity of the natural landscape structure and its natural beauty in the nominated area	Long-term
Enhance the protection of columnar peak clusters and ridgeline mountains within the nominated area, avoiding human-induced damage that affects the landscape structure and natural beauty of the heritage site's local area	Medium-term
In the selection of tourist facility sites, avoid as much as possible the rare species communities and their habitats and key corridors, preventing construction activities from causing irreversible damage to the flora and fauna resources and their habitats	Long-term
The heritage site should collaborate and consult with the local fire department to promptly develop forest fire prevention and extinguishing plans applicable to the heritage site, ensuring timely response in the event of a fire and protecting rare and endangered species	Near-term

Table 8 The Libo-Huanjiang karst protection and management plan (2008–2020)

Project name	Implementation period	Project scale	Estimated investment (10,000/RMB)
1. Experimental base			
(1) Establish a database of rare and endangered plants	Medium-term	1 set	100
(2) Experimental base for the hydrological effects of karst forests in Libo	Long-term	20 ha	200
(3) Rare and endangered plant garden	Medium-term	20 ha	200
2. Vegetation greening			
(1) Retire cultivated land for reforestation	Near-term, medium-term	480 ha	2200
(2) Afforestation in closed-off areas	Near-term, medium-term, long-term	12,000 ha	1300
(3) Responsible forest land	Near-term, medium-term, long-term	16,666 ha	1625
(4) Greening and beautification	Near-term	600 mu	120
(5) Wetland construction	Near-term	500 mu	260
3. Fire prevention facilities			
(1) Xiaoqikong Fire Command Center	Near-term	500 square meters	50
(2) Establishment of heritage site fire brigade	Near-term, medium-term, long-term	20 personnel	260
(3) Fire equipment storage room	Near-term	300 square meters	30
(4) Fire equipment	Near-term	4 sets	40
(5) Forest fire trucks	Near-term	5 vehicles	250
(6) Fire observation towers	Near-term	10 towers	150
(7) Firewater pools and pipelines	Near-term	4 sets	400
(8) Ecological protective forest belts	Long-term		1000
(9) Aircraft firefighting	Long-term	1 time	100

The approximate exchange rate of Chinese RMB to US dollars is around 6.5 to 6.8 RMB per US dollar

the international guidelines of the Convention Concerning the Protection of the World Cultural and Natural Heritage as well as relevant laws and regulations of China. These two heritage sites have conscientiously

Table 9 Scores for each influencing factor

Impact factors	Dimensions of impact factors	Indicator of impact factors	Score	Rankings
Internal impact factors	Ecological resources (A)	Unique geological and landscape resources (A1)	0.706	10
		Biodiversity of ecosystems (A2)	0.753	4
		Cultural resources (A3)	0.780	2
		Characteristic tourist resources (A4)	0.710	8
		Characteristic ecological product resources (A5)	0.682	13
		Ecological environment suitability (A6)	0.687	12
	Social-economic environment (B)	Residents' income level (B1)	0.629	21
		Infrastructure construction (B2)	0.690	11
		Sales of ecological products (B3)	0.935	1
		Branding of ecological products (B4)	0.648	18
		Economic benefits of ecological products (B5)	0.624	23
External impact factors	Conservation management policies (C)	Government encouragement and support (C1)	0.742	6
		Ecological compensation (C2)	0.707	9
		Product policy support (C3)	0.658	15
		Industrial reform (C4)	0.646	19
		Skills training (C5)	0.625	22
		Support for heritage site management (C6)	0.730	7
	Human resources (D)	Residents' skill level (D1)	0.746	5
		Residents' overall quality (D2)	0.648	17
		Management personnel capacity of heritage sites (D3)	0.761	3
		Skills of scenic area staff (D4)	0.638	20
		Technical guidance talent related to ecological product supply (D5)	0.655	16
		Leadership capacity of village committees/resident committees (D6)	0.668	14

fulfilled their obligations and commitments, continuously strengthened the interdisciplinary theoretical research on WH, improved the level of protection and management, and intensified efforts in planning protection and lawful protection of the heritage sites. Both the Shibing and Libo-Huanjiang sites have issued recent, mid-term, and long-term protection management plans successively (Tables 7 and 8). The implementation of these protection management plans is a direct cause of the enhancement of ecological assets in the heritage sites.

GRA driving factors

According to the calculation steps of grey relational analysis, we obtained scores for 23 influencing factors, ranging from 0.6 to 1.0 (Table 9). Among them, the score for ecological product sales is the highest, while the score for the economic efficiency of ecological products is the lowest. The rankings of all influencing factors are as follows: B3 (0.935) > A3 (0.780) > D3 (0.761) > A2 (0.753) > D1 (0.746) > C1 (0.742) > C6 (0.730) > A4 (0.710) > C2 (0.707) > A1 (0.706) > B2 (0.690) > A6 (0.687) > A5 (0.682) > D6 (0.668) > C3 (0.658) > D5 (0.655) > D2 (0.648) > B4 (0.648) > C4 (0.646) > D4 (0.638) > B1

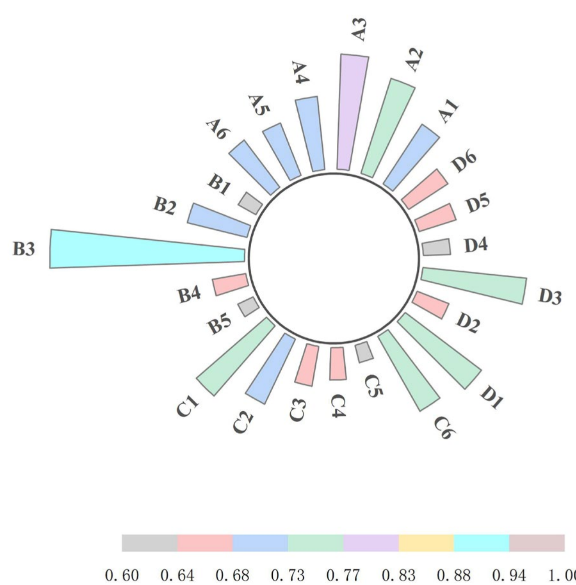

Fig. 12 Ranking of indicators of impact factors

Fig. 13 Indicator scores for each of the internal impact factors

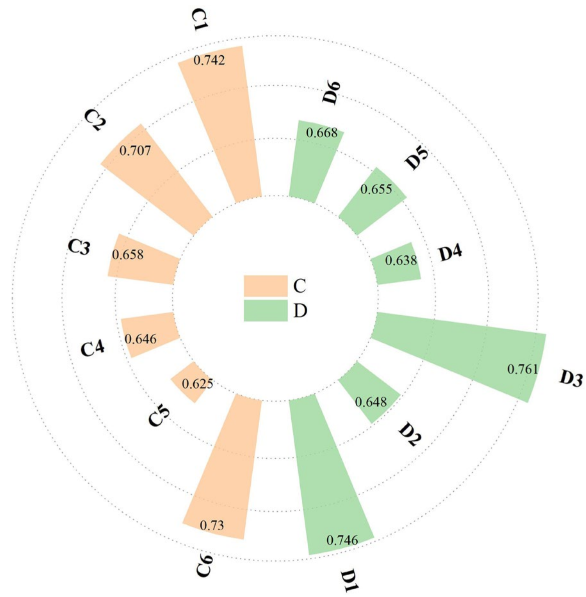

Fig. 14 Indicator scores for external influences

(0.629) > C5 (0.625) > B5 (0.624) (Fig. 12). These scores and rankings provide us with an intuitive understanding of the importance of each influencing factor, which helps us better understand and explain the changes in ecological assets and their influencing factors.

Drawing from the identification of key factors impacting ecological assets, we categorize the driving forces into internal and external domains. Across four dimensions—ecological resources (A), socio-economic environment (B), conservation management policies (C), and human resources (D)—we delve into the driving mechanisms behind ecological asset development in KWHS. Within the internal driving forces (Fig. 13), the spectrum of influencing factors related to ecological resources spans from 0.6 to 0.8, with the highest score reaching 0.780 and the lowest 0.682. Notably, cultural resources (0.780) and ecosystem diversity (0.753) emerge as pivotal driving factors. As for the factors within the socio-economic environment, the scores range from 0.6 to 1.0, with the pinnacle being 0.935 and the nadir 0.624. Remarkably, the sale of ecological products (0.935) stands out as the primary driving factor in this domain.

Examining the external driving forces (Fig. 14), the scores attributed to influencing factors of conservation management policies vary between 0.6 to 0.8, with a peak of 0.742 and a trough of 0.625. Noteworthy driving factors encompass government encouragement and support (0.742), backing for heritage site management (0.730), and ecological compensation (0.707). Similarly, the scores related to influencing factors of human resources span from 0.6 to 0.8, with a zenith of 0.761 and a nadir of 0.638. Of significance are the capabilities of heritage site management personnel (0.761) and the proficiency levels of residents (0.746) as primary driving factors. These findings offer deeper insights into the evolution of ecological assets, facilitating the formulation of effective conservation and management strategies.

Discussion

Currently, scholars from China and other countries have begun to assess the value of natural resources and their impact on human well-being [42]. As research on sustainable development mechanisms deepens, issues such as the valuation of natural resources, estimation of ecological assets, and ecosystem services have attracted widespread attention from researchers worldwide [43]. Scholars have conducted long-term and systematic research on the quantification of ecosystem service values [44]. However, the accuracy and objectivity of ecological asset assessment are often affected by limitations in research methods such as indicator quantification, value conversion, and systematic evaluation index systems [45, 46]. With the widespread application of remote sensing and geographic information systems technology, research on ecological asset assessment at different scales is increasing [47, 48]. However, most of these studies focus on examining the spatial distribution and temporal change patterns of ecological assets. Moreover, global changes, climate warming, and human activities have become dominant factors influencing the evolution pattern of regional ecological assets. The ecological environment in karst areas is fragile, and hydrogeological development is unique, making the assessment of ecological assets challenging. In practice, ecological asset assessment has rarely been applied in KWHS.

In this study, we effectively assess the ecological assets of the heritage sites by integrating data on the quantity and quality of ecological assets and using the ecological asset index. Compared to traditional field survey methods used to identify land use types, vegetation coverage, and community structural complexity [49, 50], index-based approaches using remote sensing can provide timely and efficient assessment methods. Nevertheless, most studies rarely comprehensively evaluate the ecological assets of the study area based on changes in area, quality, and index [51, 52]. Moreover, they only use single indicators for assessment, which may not be systematic and comprehensive enough. Additionally, previous research has mainly focused on remote sensing at large spatial scales, failing to eliminate the influence of spatial heterogeneity on the assessment of ecological asset quality [47, 53]. One of the strengths of this study is the comprehensive analysis of the quantity, quality, and change characteristics of ecological assets in the heritage sites, followed by the analysis of the ecological asset composite index, leading to a more comprehensive assessment of ecological assets. Secondly, the study area is located in the KWHS in southern China, where the natural environment is similar, helping to eliminate the influence of natural factors on the assessment of ecological assets. Third, by selecting two representative KWHS in southern China, we more fully demonstrate the changes in ecological assets in these areas. Finally, we have developed dimensionless indices to assess the status and changes of ecological assets, which, by comparing the current state of regional ecological assets with their original state, help managers identify the degree of degradation and restoration potential of different ecosystems. In this study, the EQ for the Shibing heritage site in 2021 was 225.606, and for the Libo-Huanjiang heritage site, it was 641.269. This indicates significant enhancement of ecological assets in both heritage sites since 2000.

The EQ and EQi, through dimensionless processing, effectively integrate quantity and quality, providing a method to assess the comprehensive status of ecological assets. For both heritage sites, from 2000 to 2021, there has been an increase in forest area (Fig. 6), improvement in forest quality (Fig. 8), and an increase in the EQi for forests, indicating an enhancement in forest ecological assets (Fig. 10). This result is consistent with previous studies, indicating a significant improvement in forest vegetation coverage and ecosystem services in recent years [54, 55]. Furthermore, this study explores the reasons for changes in ecological assets. According to the research, the EQ and main EQi of the two study areas have been increasing (Fig. 10). Through the exploration of influencing factors and extensive data collection, it is found that since the late twentieth century and the inscription of the study areas on the WH List, governments at all levels, managers, and local indigenous people have devoted significant manpower, material resources, and financial resources to focused protection efforts. The implementation of a series of ecological conservation measures and heritage site protection management plans is the main reason for the improvement in ecological assets in the heritage sites, indirectly confirming the effectiveness of the research findings. However, changes in ecological assets are not solely the result of a single factor but are influenced by a combination of internal and external factors [56, 57]. Hence, questionnaire survey data are analyzed using GRA. Based on the previous analysis of influencing factors, these factors have different impacts on the changes in ecological assets of KWHS. Internally, the main driving forces are cultural resources, the richness and diversity of ecosystems, distinctive tourism resources, and the sale of ecological products (Fig. 13). Externally, the main driving forces are government encouragement and support, ecological compensation, support for heritage site management, residents' skill levels, and the capacity of heritage site management personnel (Fig. 14). These driving mechanisms are interrelated and interact, forming a diverse, comprehensive, and complex system driving changes in ecological assets. This study analyzes the driving mechanisms of the development and changes in ecological assets of KWHS from four dimensions: ecological resources, socio-economic environment, conservation management policies, and human resources. The study also found that compared to other regions, the improvement in the ecological asset status of KWHS is more significant [58, 59]. This may be due to the high level of attention and support from conservation management policies, resulting in less human-induced damage to their ecological assets and thus more obvious improvement. Considering that ecological assets are the basis for the supply of ecological products, this improvement indirectly reflects the enhancement of the ecological product supply capacity of KWHS [60]. This improvement will bring more abundant ecological benefits to the karst regions of southern China.

This study assumes that the weight of ecological assets in terms of both quantity and quality is equal, yet their importance may not necessarily be equivalent. Instead, it is contingent upon environmental factors and constraints of ecological processes [61]. Future attention needs to be directed towards the influence of weight assignment on the assessment outcomes of ecological assets.

Furthermore, EQ and EQi fail to address the impact of landscape pattern changes on ecological assets. However, the composition of spatial structure influences the transmission of materials and energy across different patches, rendering such information essential for studying the status of ecological assets. With the advancement of remote sensing data, a multi-scale, multi-source monitoring approach for assessing the ecological environment quality of heritage sites has emerged, ranging from large-scale satellite remote sensing to medium-scale unmanned aerial vehicle surveillance and small-scale ground monitoring stations. This paper also employs a comprehensive analysis method incorporating multiple perspectives and factors to qualitatively analyze the influencing factors of ecological assets, and quantitatively assesses the degree of influence of each factor. By combining qualitative and quantitative methods and considering the joint effects of internal and external factors, a driving mechanism for the formation of ecological assets has been constructed. However, the thorough analysis of the balance/synergy between each factor and ecological assets is yet to be accomplished. Key factors constraining the variation of ecological assets vary by region. In future ecological asset assessment and monitoring, unmanned aerial vehicle surveillance and ground monitoring stations should be fully taken into account, and region-specific integrated sky-ground systems should be maximized to provide effective solutions for the conservation and sustainable development of KWHS.

Conclusion

This study integrates information on the quantity and quality of ecological assets, introducing two ecological asset indices, EQ and EQi. Through analyzing the characteristics of ecological assets, accounting for quantity and quality, calculating ecological asset indices in Shibing and Libo-Huanjiang KWHS, their current status, variations, and influencing factors are revealed. The following conclusions are drawn:

1. The quantity of ecological assets in Shibing and Libo-Huanjiang heritage sites is primarily composed of forests, accounting for 89.31% and 89.98%, respectively, while the proportions of cropland, shrubs, grassland, water body, and impervious surfaces are relatively small.
2. The quality of ecological assets in both sites exhibits similarity, showing a two-tier differentiation. Forests and shrubs are predominantly of excellent, good, and moderate quality, while cropland and grassland are mainly of poor and inferior quality. Overall, the quality of ecological assets in both sites has significantly improved.
3. From 2000 to 2021, EQ in Shibing heritage site increased from 180.179 to 225.606, and EQ in Libo-Huanjiang heritage site rose from 560.463 to 641.269. In EQi, the order of importance for Shibing Karst is forests > cropland > shrubs > grassland, while for Libo-Huanjiang Karst it is forests > shrubs > cropland > grassland.
4. Since the beginning of the twenty-first century and the listing of the study area as a World Natural Heritage site, governments at all levels, managers, and local indigenous peoples have focused on the protection of the heritage sites, investing significant manpower, material resources, and financial resources. The development and changes in ecological assets of KWHS are the result of the comprehensive effects of internal and external factors. Four aspects—ecological resources (0.719), socio-economic environment (0.705), human resources (0.686), and conservation management policies (0.685)—are crucial for promoting the positive changes in ecological assets.

Abbreviations

OUV	Outstanding Universal Value
EQi	Various types of ecological asset indices
EQ	Comprehensive ecological asset indices
FVC	Fraction of vegetation cover
NDVI	Normalized Difference Vegetation Index
LUCC	Land use and cover change
GRA	Grey relational analysis
WH	World heritage
KWHS	Karst world heritage sites

Supplementary Information

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Additional file 1. Questionnaire design and field research.

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Author contributions

Conceptualization: KX, QL; methodology: QL, HX; data collection and analysis: JW, YC, JY, HX; writing—original draft: QL; writing—review and editing: JB, QL, KX; supervision: HX, KX; funding acquisition: KX, LG. All authors read and approved the final manuscript.

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Availability of data and materials
Datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Competing interests
The authors declare that they have no competing interests.

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