applied sciences

MDPI

Article

Comparative Study on the Temporal and Spatial Evolution of the Ecosystem Service Value of Different Karst Landform Types: A Case Study in Guizhou Province, China

Qingping Lu [1,2], Cuiwei Zhao [1,*] and Huiyu Huang [1]

1 School of Geography and Environmental Science, Guizhou Normal University, Guiyang 550025, China
2 Guangxi Land and Resources Planning and Design Group Co., Ltd., Nanning 530022, China
* Correspondence: zhaocuiwei@sohu.com

Abstract: Paying attention to the ecosystem service value (ESV) of different karst landform types is of great benefit to the green, sustainable, and high-quality development of the ecological environment in Guizhou Province. Based on the eight-period China Land Cover Dataset (CLCD) from 1985 to 2020, we compared and analyzed the ecosystem service value and its temporal and spatial variation characteristics of different karst landforms with the equivalent factor method in the study. The results revealed that the overall ecological environment of Guizhou Province showed a tendency to improve. Over the past 35 years, the net increase in the ecosystem service value in Guizhou Province was USD 385 million, with the largest increase occurring from 2015 to 2020. The overall spatial distribution is characterized by continuous low values in the middle and concentrated high values in the surrounding areas. Some of the local ecological environment in Guizhou Province is still not well-preserved. The ecosystem service value in the pure-karst area has decreased by USD 122 million over the past 35 years, mainly in Dushan County and Libo County, Qiannan Prefecture. The semi-karst area has increased by USD 367 million, concentrated in the northern and central areas of Guizhou Province. The non-karst area increased by USD 140 million, mostly distributed in Pu'an County, Xingyi City, and Yanhe County. In terms of the ecosystem service value per unit area, the results were as follows: non-karst areas > pure-karst areas > semi-karst areas. The ecosystem service value of each geomorphological area varied with the elevation and slope, showing an inverted "V" trend, first increasing and then decreasing. The maximum ecosystem service value in the pure-karst and semi-karst areas was between 800 m and 1100 m above sea level, and the non-karst area was in the range of 500 m to 800 m. The maximum ecosystem service value in the non-karst areas and semi-karst areas was within the gradient of 15° to 25°, and the pure-karst area was between 6° and 15°. The forest contributed most to the ecosystem service value of each karst landform, followed by cropland, and finally shrubland and grassland. Guizhou Province should pay attention to the protection of forest and cropland ecosystems in terms of future land management, especially with regard to ecological construction in pure-karst landform areas.

Keywords: pure-karst; semi-karst; non-karst; ecosystem service value; Guizhou Province

Citation: Lu, Q.; Zhao, C.; Huang, H. Comparative Study on the Temporal and Spatial Evolution of the Ecosystem Service Value of Different Karst Landform Types: A Case Study in Guizhou Province, China. *Appl. Sci.* **2022**, *12*, 12801. https://doi.org/10.3390/app122412801

Academic Editor: Adriano Ribolini

Received: 2 October 2022
Accepted: 29 November 2022
Published: 13 December 2022

1. Introduction

Ecosystem service refers to the life support products and benefits that human beings receive directly or indirectly through the structure, process, and function of the ecosystem [1]. It provides an important link between the natural environment and human activities, and is also the basis of human survival and development [2]. With rapid socio-economic development and excessive human activities, the ecological equilibrium is seriously out of balance, which has led to the degradation of 60% of ecosystem services [3]. Human health, and regional and even global ecological security has been under threat. Hence, research into the ecosystem service value (ESV) has received much attention.

The value of ecosystem services can measure the potential contribution capacity of regional ecosystem services, usually represented in the form of money, which can incorporate environmental issues into socio-economic development decisions, and effectively assist regional spatial planning, ecological regulation, and ecological restoration [4–6]. The assessment principles and methods of ESV were proposed and practiced by Costanza et al. [7,8]. The Millennium Ecosystem Assessment (MA) project further promoted the research process [9], which also formulated a reference standard of ecosystem services quantification [10], making ESV a hot topic of discussion in the fields of ecology, economics, and geography [11–13]. Scholars believe that the history of ESV can be divided into four stages: qualitative description (before 1997), rapid development (1997–2005), diversified development (2005–2012), and comprehensive application (2012–present) [14]. The ideas and methods of research on ESV are constantly being innovated. In terms of research areas, the dynamic monitoring of the ESV from land such as watersheds and nature reserves to coastal and marine areas has been realized [15–18]. In terms of assessment objects, temporal and spatial pattern characteristics and influencing factors of ESV have been chiefly analyzed in croplands, woodlands, deserts, and wetlands [19–23]. Assessment methods are mainly the attempts of the market value method, carbon tax method, shadow engineering method, ESV coefficient method, travel cost method, and questionnaire survey method [24–29]. For example, Zhang et al. analyzed the spatial and temporal evolution of the ESV in the lower reaches of the Yellow River [30], and Liu et al. explored the gradient effect of ecosystem services in the transition zone of Beijing Bay [31]. At present, studies on the value of ecosystem services are not only numerous, but also all have good achievements, which can serve as a basic reference for the management and protection of the regional ecological environment. However, there have been few analyses comparing the evolution of spatial and temporal patterns of the ESV over long periods of time in different geomorphic regions from a spatial perspective.

Geomorphology is a component element of the natural geographical environment and a carrier of ecosystem services. Together, geomorphology and human beings have a comprehensive impact on the spatial and temporal patterns of ecosystem types and are closely related to the total and distribution of the ESV [32–34]. After a symposium on geomorphology and ecosystems held in Binghamton, USA concluded that integrating landform and ecosystem ecology is a key issue for future research [35], the study of the ESV of geomorphological types has become particularly important. However, current studies on different landform types have mostly focused on the evolution of vegetation cover [36], soil erosion characteristics, and land cover change [37,38], while research on the ESV of different landform types needs to be further developed, especially in the context of different karst landforms.

Due to its special geological background and hydrological structure in Guizhou Province [39], there is a fragile environmental ecosystem background with a wide distribution of pure carbonate rocks, impure carbonate rocks, and carbonate and non-carbonate rock interlayers [40], and the karst landform is strongly developed. With the deepening research, scholars have found that due to the internal geological differences in karst, under the action of external forces such as flowing water and gravity, the karst surface morphology, biological growth conditions, and land-use patterns will be different, leading to different ecosystem patterns in different regions [41], and ultimately affecting the space–time law of the ESV in karst landform areas. Existing studies on the value of ecosystem services mostly treat the whole study area as a pure-karst or non-karst landform type [42,43]. In addition, there is a lack of research differentiating and comparing the difference in ESV in karst landform areas, which means that the spatial–temporal evolution law of the ESV cannot be directly revealed in various karst landform areas. Therefore, in order to further clarify the internal differences in ESV in karst landform areas, we propose the use of Guizhou Province as the scope of research, and conducted the following main studies based on the division of different karst landform areas. First, we analyzed the characteristics of the spatial and temporal patterns of the ESV in Guizhou Province from 1985 to 2020. Second, we compared the spatial and temporal patterns of the ESV in different karst-landform-type areas. Finally, we explored the differences in the ESV across the topographic gradients in each karst landform area. While enriching the study of the ESV in karst ecologically fragile areas, we expect to provide references for differential refinement management and sustainable development of the grand ecological strategy in Guizhou Province.

2. Materials and Methods

2.1. Study Area

Guizhou Province is located in the hinterland of southwest China, in the northeastern part of the Yunnan–Guizhou Plateau. It is located between 103°36′–109°35′ E and 24°37′–29°13′ N. Its topography is low in the east and high in the west (Figure 1), with an east–west length of approximately 595 km and a north–south distance of approximately 509 km, with a total area of 176,167 km^2. There are six prefecture-level cities and three autonomous prefectures in Guizhou Province. Meanwhile, Guizhou Province, a fragile ecological area of rocky desertification in the mountains of southwest China, whose territory is interspersed with mountains, hills, canyons, and intermountain depressions, with rugged and broken surfaces, strongly developed karst landforms, and less enriched soils, is one of the three major karst sheet centers in the world [44]. Guizhou is responsible for building the ecological barriers of the Yangtze River and the Pearl River, and has been selected as a national ecological civilization pilot area in China, and is also an important connection point of the Yangtze River Economic Belt and the Belt and Road Initiative. Since the implementation of reform and opening up, and the development of western China, Guizhou has undergone rapid urbanization and industrialization, resulting in drastic changes in land use such as the desolation of arable land, the continuous increase in land for construction, soil erosion, and rock desertification. As its ecosystem is under great pressure, we need to carry out a quantitative assessment of the ESV, expecting to provide a basis for decision making in the construction of the ecological civilization in Guizhou.

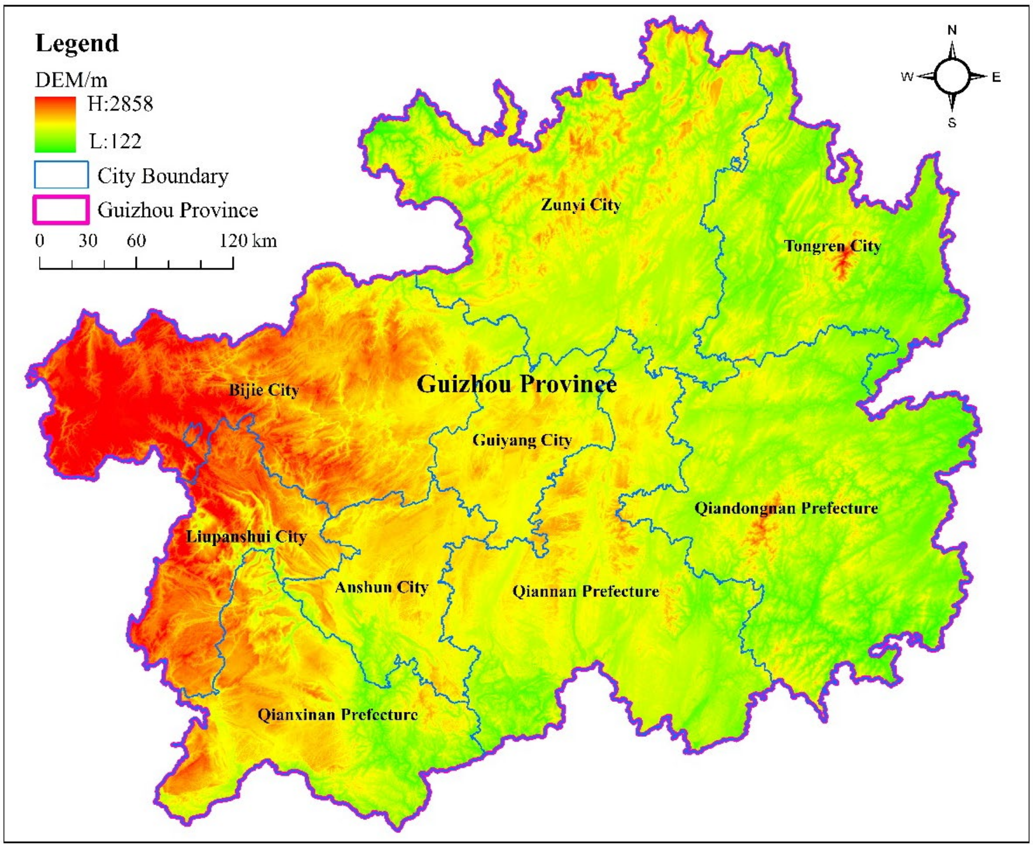

Figure 1. Location map of the study area.

2.2. Data Sources

2.2.1. Data Sources and Processing

The basic information required for the study are land-use data, lithology data, and DEM (Digital Elevation Model) data. The 1985–2020 land-use data are from the China Land Cover Dataset (CLCD) produced by Prof. Huang Xin's team in the School of Remote Sensing and Information Engineering, Wuhan University, and it is the first Google Earth Engine (GEE) platform to produce Landsat-derived high-resolution Chinese land cover data (30 m), which has an overall accuracy of 79.31%. Third-party tests have shown that the overall accuracy of CLCD is higher than datasets such as FROM_GLC and GlobeLand30, which are freely available via the Internet (https://doi.org/10.5281/zenodo.5210928 (accessed on 10 March 2022) [45]. The dataset divides the surface into nine categories: cropland, forest, shrubland, grassland, water, snow/ice, barren land, impervious land, and wetland. We obtained the land-use data of Guizhou Province from 1985 to 2020 using administrative boundary cropping. We found that there was no snow/ice category among them, and the wetland area was small and could be merged into water. The lithological data were obtained by scanning, correcting, and digitizing 1:200,000 maps of Guizhou Province. DEM data from the Japanese Earth observation ALOS satellite with a resolution of 12.5 m and a resampling of 30 m can be extracted using the ArcGIS spatial analysis tool (download available at https://search.asf.alaska.edu/ (accessed on 20 February 2021). All of the previously mentioned layers were defined as the WGS_1984 geographic coordinate system and Albers_Conic_Equal_Area projection coordinate system.

2.2.2. Classification of Karst Landforms

In his published book *Geomorphology*, J. Cvijic, a Yugoslavian scholar, classified the landform morphology of limestone into complete karst, semi-karst, and transitional karst [46]. An et al. found that between the complete karst and non-karst landform types, there are also "semi-karst" landform types that differ greatly from both landforms [47]. Hu et al. considered that semi-karst landforms are a transitional landform developed between impure carbonate rocks, carbonate rocks, and a non-carbonate rock interlayer [48]. Su et al. summarized the distribution characteristics of the three landform types [40]. Pure-karst landforms are strongly developed between pure carbonate rocks (e.g., continuous dolomite and continuous limestone, etc.), semi-karst landforms are mainly formed and enriched on impure carbonate rocks (e.g., interbedded tuff clastic rocks and interbedded dolomite clastic rocks, etc.), and non-karst landforms are closely related to non-carbonate rocks. Therefore, we conclude that the classification of karst landform types has mainly been based on lithology in the existing studies. In this paper, we agreed with the above viewpoints and divided Guizhou Province into three landform-type areas: pure-karst, semi-karst, and non-karst, based on the 1:200,000 lithological data (Figure 2). Among them, the pure-karst area accounted for 41.28%, the semi-karst area accounted for 20.09%, and the non-karst area accounted for 38.43%.

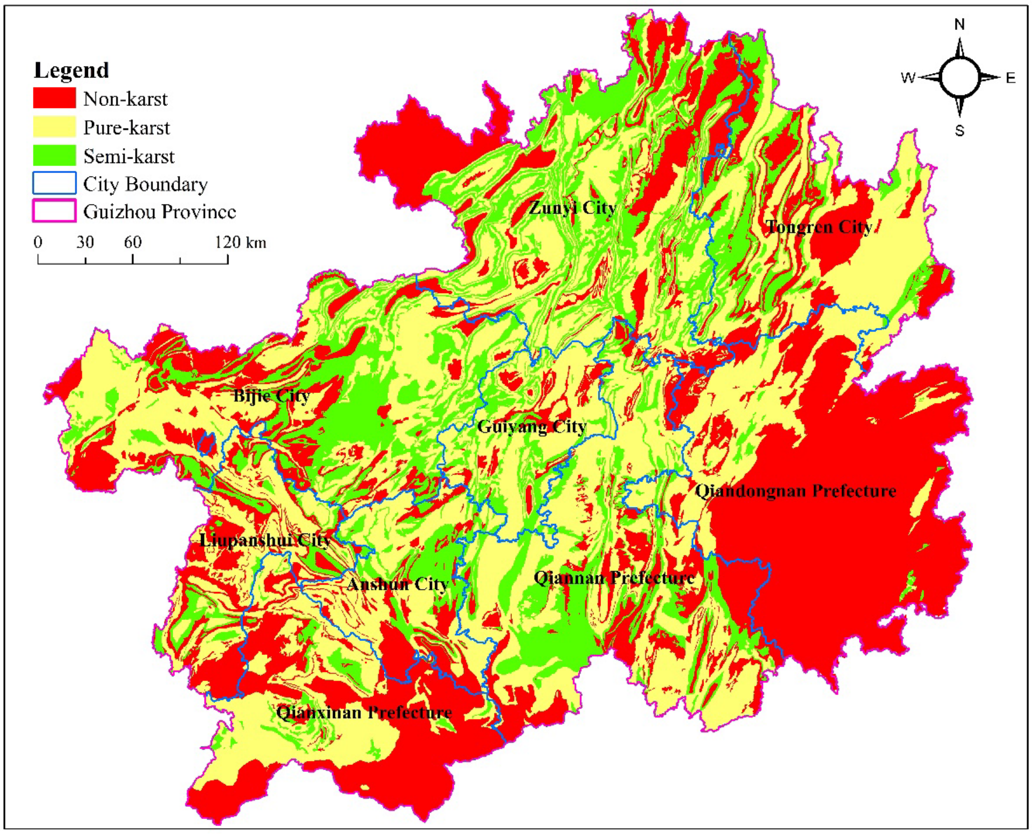

Figure 2. Spatial distribution pattern of the pure-karst, non-karst, and semi-karst landforms.

2.3. Method

2.3.1. ESV Assessment

Based on Costanza, Xie et al. classified Chinese ecosystems into four primary and 11 secondary service types, based on questionnaires from more than 200 Chinese ecologists, developed and revised the Chinese ESV equivalent table per unit area, and determined that the amount of economic value of one ecological service value equivalent factor was equal to 1/7 of the average grain yield market value in the study area. The value coefficients of ecosystem services per unit area for each region can be revised by using this method, which greatly improved the applicability of the method and made the method become the basis for assessing the value of ecosystem services for many scholars [49]. According to the principle and method of ESV assessment [50], first, we consulted the Statistical Yearbook of Guizhou Province and obtained the average grain yield of 3681.82 kg/hm^2 and the average grain price of 0.28 USD/kg. Second, we multiplied the grain yield per unit area and the average grain price, and then multiplied this by 1/7 to obtain the corrected economic value amount of 1 ESV equivalent factor in Guizhou Province as 147.61 kg/hm^2. Finally, 147.61 USD/hm^2 was multiplied by the unit area ESV equivalents to obtain the table of unit area ESV equivalent coefficients for land-use types in Guizhou Province (Table 1). Among them, the impervious area had no contribution to the ESV, and its coefficient was assigned as 0 [51]. The ESV assessment formula is as follows:

$$ESV = \sum_{i=1}^{n} (S_i \times VC_i) \quad (1)$$

$$ESV_m = \sum_{i=1}^{n} (S_i \times VC_{mi}) \quad (2)$$

Table 1. Coefficient of ESV per unit area in Guizhou Province (USD/hm^2).

Ecosystem Services		Cropland	Forest	Shrubland	Grassland	Water	Barren Land
Provisioning services	Food production	144.29	42.81	28.05	56.09	118.09	0.00
	Raw material production	47.60	97.42	63.47	82.66	33.95	0.00
	Water resource provision	−94.84	50.19	32.47	45.76	1223.67	0.00
Regulating services	Gas regulation	115.13	320.31	208.13	290.79	113.66	2.95
	Climate regulation	60.89	959.45	624.38	769.04	338.02	0.00
	Environment purification	17.34	284.88	188.94	253.89	819.22	14.76
	Water regulation	130.26	699.66	494.49	563.86	15,091.44	4.43
Supporting services	Soil conservation	114.40	391.16	253.89	354.26	137.28	2.95
	Nutrient cycle maintenance	20.30	29.52	19.19	26.57	10.33	0.00
	Biodiversity maintenance	22.14	355.74	231.74	321.79	376.40	2.95
Cultural services	Aesthetic landform supply	9.96	156.46	101.85	141.70	278.98	1.48

In this formula, ESV denotes the total value of the ecosystem services (USD); S_i is the area of the class i land-use type (hm^2); VC_i is the ESV coefficient of class i land-use type (USD/hm^2); ESV_m represents the value of item m ecosystem service type (USD); and VC_{mi} is the value coefficient of the item m ecosystem service type of class i land-use type (USD/hm^2).

2.3.2. Extraction of Terrain Feature Data

Elevation and slope data were obtained by DEM extraction and divided into six grades. The slope classification was based on the work of Wang etc. [27], and the elevation classification was mainly based on the work of Feng and Tan, etc. [52,53]. The results are shown in Table 2.

Table 2. Elevation and slope grading standards.

Classification	Elevation (m)	Area Proportion (%)	Slope (°)	Area Proportion (%)
I	≤500	6.18	≤6	10.43
II	(500~800]	21.87	(6~15]	29.99
III	(800~1100]	29.43	(15~25]	33.19
IV	(1100~1400]	22.85	(25~35]	18.20
V	(1400~1700]	9.67	(35~45]	6.32
VI	>1700	9.99	>45	1.87

3. Results

3.1. Study of the ESV in Guizhou Province

3.1.1. Time Series Changes in the ESV in Guizhou Province

According to Formulas (1) and (2), combined with Table 1, the ESV of land-use types in Guizhou Province from 1985 to 2020 (Table 3) and the ecosystem services function value (Figure 2) were calculated.

Table 3. Land-use type ESV, 1985–2020 (unit: USD million).

Year	Cropland	Forest	Shrubland	Grassland	Water	Barren Land	Total ESV
1985	3336.70	35,096.13	2302.89	1439.75	572.43	0.00	42,747.91
1990	3345.62	35,335.18	2074.76	1478.10	588.42	0.00	42,822.08
1995	3394.50	35,913.16	1737.04	1149.51	669.89	0.00	42,864.11
2000	3405.01	35,638.92	1842.42	1159.57	789.28	0.00	42,835.20
2005	3562.80	34,884.21	1830.91	1013.05	804.52	0.00	42,095.49
2010	3598.08	35,068.48	1628.81	845.77	1064.16	0.00	42,205.29
2015	3619.06	35,398.99	1334.50	723.38	1197.32	0.00	42,273.25
2020	3452.19	36,612.32	1113.09	687.27	1268.39	0.01	43,133.26

As can be seen from Table 3, from 1985 to 2020, the ESV in Guizhou Province increased from USD 42.748 billion to USD 43.133 billion, a net increase of USD 385 million or 0.9%, showing a trend of first increasing, then decreasing, then increasing. The ESV increased the most between 2015 and 2020, with an increase of 2.03%, indicating that the overall trend in the ESV in Guizhou Province is improving. Forests contributed the most to the ESV in Guizhou Province, accounting for more than 80% in all eight periods, followed by cropland with a contribution rate of 7% to 9%, and finally shrubland and grassland. The trend in each ecosystem type was that the ESV in shrubland and grassland decreased, while the ESV in cropland, forest, and water increased, and the contribution tended to increase continuously. Water and forest had the fastest average annual growth rates of 3.47% and 0.12%, respectively. However, because the area of water was much smaller than the forest area, the ESV growth contribution was lower than for the forest. Over the 35 year period, the area of forest increased by 4.23% and its ecosystem value increase was 3.93 times higher than the total ESV increase, indicating that the forest change was the main cause of the ecosystem value change in Guizhou.

In terms of the value of the different ecosystem service types (Figure 3), the largest proportion of each period was accounted for by regulating and supporting services, which were above 66% and 22%. The value of the provisioning and regulating service types increased, while the value of the supporting and cultural service types decreased. The value of the provisioning services type increased by USD 43 million, with the highest increase of USD 21 million being attributed to water provision in particular. The value of the regulating service types increased by USD 402 million, especially the hydrological regulating service type, which had the largest increase at USD 497 million. The remaining three services decreased by USD 95 million. The supporting service and cultural service types decreased in value by USD 51 and USD 8 million, respectively, with the largest decrease occurring among the supporting services in the value of the biodiversity service type, with an average annual decrease of 5.5%.

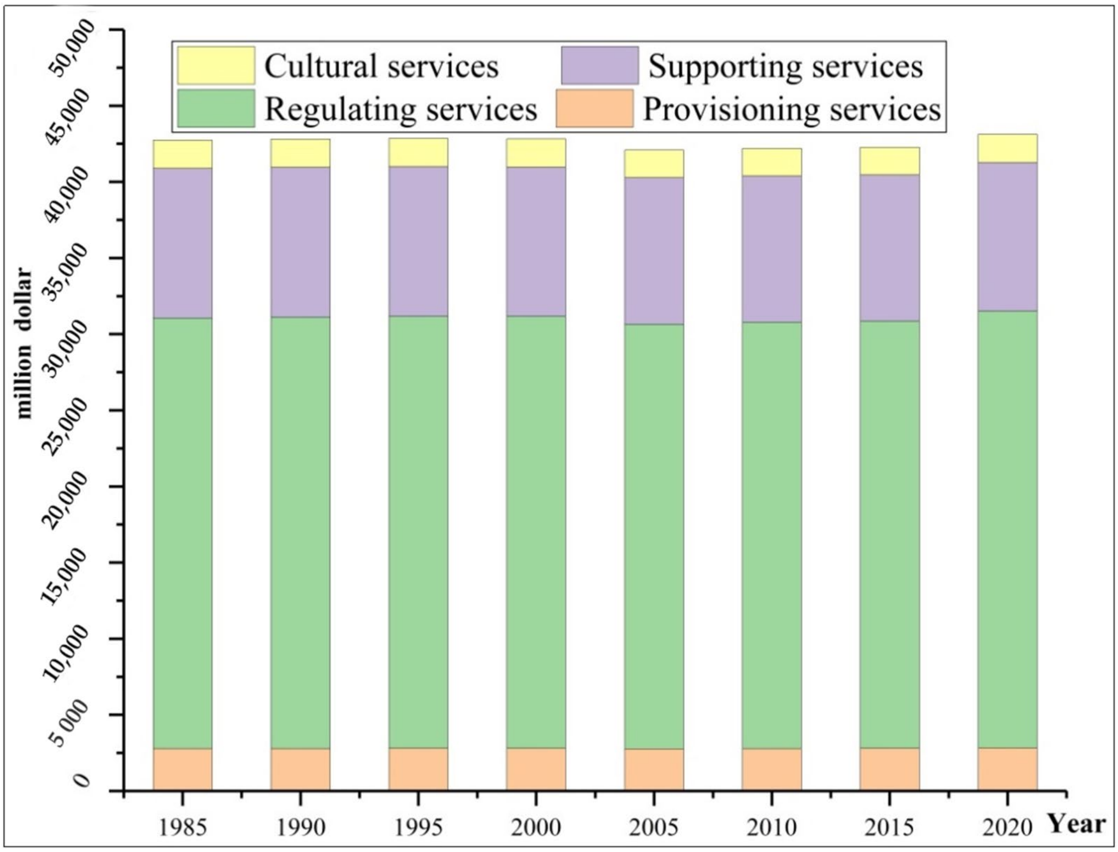

Figure 3. The value of each ecosystem service type.

3.1.2. Spatial Changes in the ESV in Guizhou Province

Based on the land-use layer of Guizhou Province from 1985 to 2020, the ESV was linked to it to spatialize the ESV of Guizhou (Figure 4).

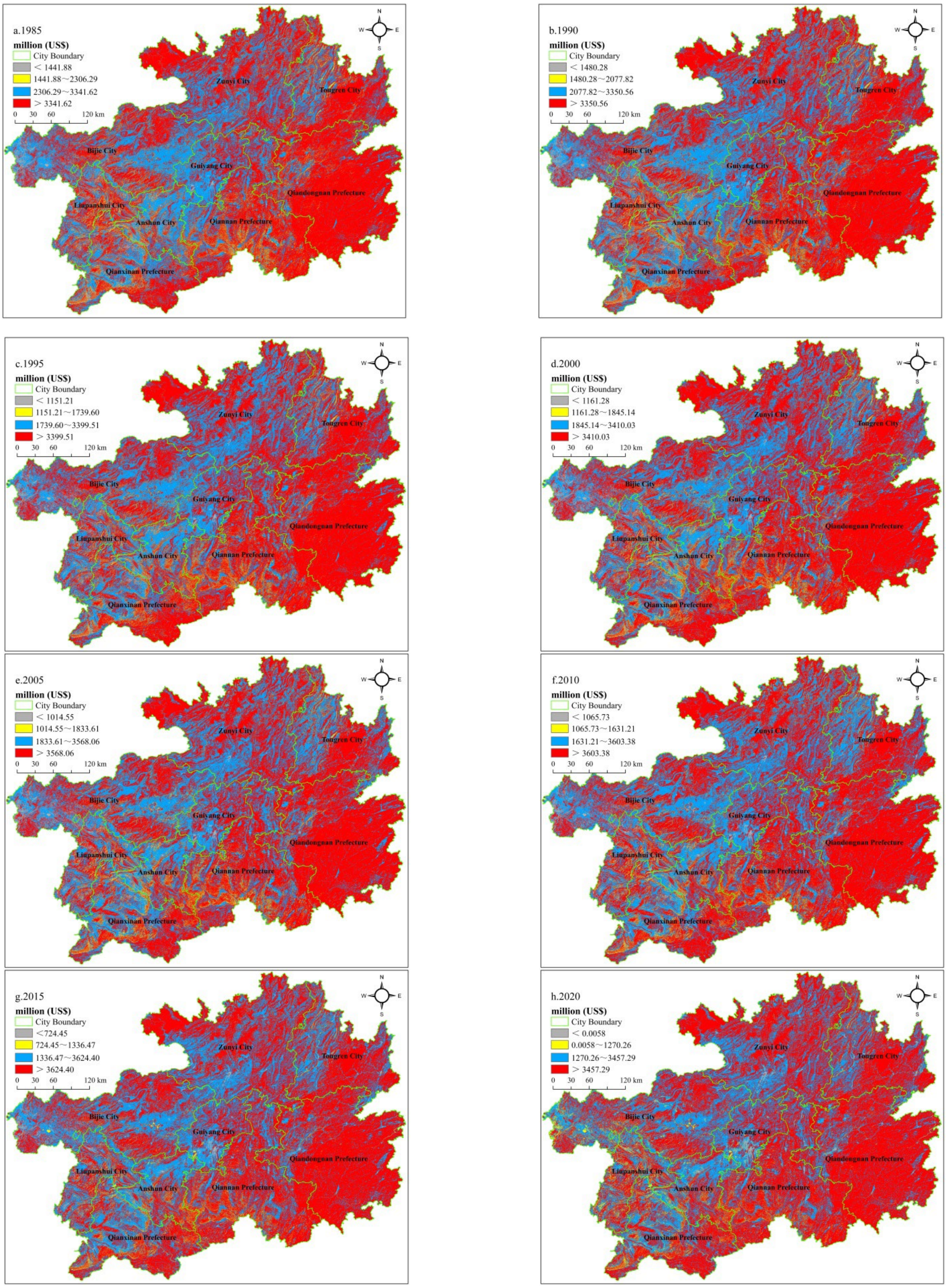

Figure 4. The spatial pattern of ESV in Guizhou Province from 1985 to 2020. Note: In the figure, (**a**) is 1985, (**b**) is 1990, (**c**) is 1995, (**d**) is 2000, (**e**) is 2005, (**f**) is 2010, (**g**) is 2015, (**h**) is 2020.

From Figure 4, it can be seen that the ESV in Guizhou Province showed an overall distribution characteristic of low in the middle, and high in the surrounding areas, especially in the east and southeast, as most of the forest in Guizhou Province is distributed in these areas. There was also a small concentrated distribution in the north, mainly provided by the bamboo forest in Chishui City, with the reputation of being the bamboo town in China. According to statistics, from 2000 to 2020, the area of bamboo forest in Chishui City increased by more than 50,000 hectares, accounting for more than 28% of the area of Chishui City. The central ESV contiguous low value area was concentrated in Anshun City and Guiyang City, because the Guiyang and Anshun areas are flatter, with more intense human activities and have more arable land distributed there. Meanwhile, there were also a few contiguous ESV in Weining County, Bijie City, in the west. This is mainly because Weining County, the second most populous county in Guizhou Province, focused on agricultural development with agricultural land accounting for approximately 89% of the county area [54], while the forest and grassland areas, the main contributors to the ESV, were less distributed. The distribution of the ESV in other regions was more scattered and fragmented.

3.2. Evolution Characteristics of the ESV in Different Landform Types

3.2.1. Temporal and Spatial Variation in the ESV in Different Landform Types

Formula (1) was used to calculate the ESV of different karst areas (Table 4). At the same time, due to the different areas of each landform type, the ESV per unit area was used for comparative analysis (Figure 5).

Table 4. Total ESV of different karst landform types, 1985–2020 (unit: USD million).

Landform Type	1985	1990	1995	2000	2005	2010	2015	2020
Pure-karst	16,813.80	16,843.23	16,788.89	16,718.96	16,433.59	16,348.35	16,328.07	16,691.97
Semi-karst	7457.10	7435.42	7430.28	7473.36	7404.59	7397.36	7527.33	7824.02
Non-karst	18,477.01	18,543.43	18,644.94	18,642.87	18,257.30	18,459.58	18,417.84	18,617.27

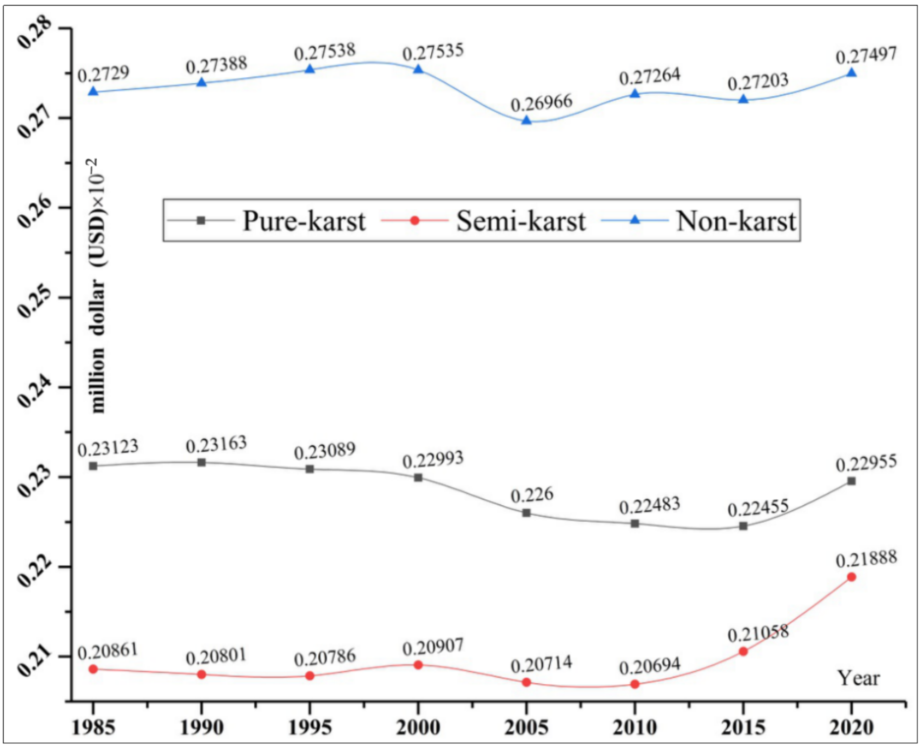

Figure 5. ESV per unit area in different karst landform types from 1985 to 2020.

As can be seen from Table 4, the total ESV in each period in the past 35 years was as follows: non-karst areas > pure-karst areas > semi-karst areas.

The total ESV in the pure-karst areas was USD 16.814 billion in 1985 and USD 16.692 billion in 2020, a decline of USD 122 million over the past 35 years, with an average annual decline of USD 4 million, or a reduction rate of 0.72%. From 2000 to 2005, the ESV declined the fastest, with an average annual decrease of USD 57 million. From 2015 to 2020, the ESV increased the fastest with an average annual increase of USD 73 million. The total ESV increased to varying degrees in the semi-karst and non-karst areas. The total ESV increased by USD 367 million in the semi-karst area, with an average annual increase of more than USD 0.01 billion. From 2000 to 2005, the ESV declined the fastest, with an average annual decrease of USD 14 million. From 2015 to 2020, the ESV increased the fastest at USD 59 million/year. The total ESV in the non-karst area increased by USD 140 million, and an average annual increase of USD 4 million, with a growth rate accounting for approximately 0.76%, comparable to the rate of decrease in the pure-karst area. The fastest rate of decrease and the fastest rate of increase in the non-karst areas were in the same time period as the pure-karst and semi-karst areas. From 2000 to 2005, the ESV decreased at an average annual rate of USD 77 million, while from 2015 to 2020, the ESV increased at an average annual rate of USD 40 million.

From the ESV per unit area in different karst-landform-type areas (Figure 5), the results were as follows: non-karst areas > pure-karst areas > semi-karst areas. The ESV per unit area in all three landform areas showed an increasing trend, with a downward trend from 2000 to 2005. The reason for this is that, after 2000, with the implementation of the Western Development Strategy and the increasing level of urbanization and industrialization in Guizhou Province as well as the concentration of the rural population in the cities, the urbanization rate increased by nearly 3 percentage points, and the area of construction land expanded, resulting in a decrease in the area of ecological land, which negatively affected the value of regional ecosystem services [55]. With the introduction of the "Opinions of Guizhou Provincial People's Government on Improving the Grain for Green Policy (Qianfufa [2007] No. 35)" in 2007 and the "Work Plan of Combining Forest and Grass for the New Round of Grain for Green Project in Guizhou Province" in 2016, and the enhancement of human awareness of ecological environmental protection, the forest coverage rate of Guizhou Province reached 61.51% in 2020, and the ESV per unit area increased year by year.

Among the ESV of land-use types in each karst-landform-type area, the contribution of the cropland, forest, barren land, and water ESV increased slightly in the pure-karst area. Only shrubland and grassland showed a decreasing trend in the ESV, and the combined decrease in both (USD 1.059 billion) was higher than the combined decrease in the first four (USD 937 million). The decline was due to the decrease of 432,307.60 hm^2 in shrubland and grassland in the pure-karst area. In total, 296,676 hm^2 of grassland was converted to forest, mainly in Dushan County, Huishui County, and Libo County in Qiannan Prefecture, and forest was the main contributor to the ESV in Guizhou Province. In addition, 98,380.20 hm^2 of grassland was converted to forest, which mainly occurred in Weining County in Bijie City, Panzhou City in Liupanshui City, and Xinyi City in Qianyinan Prefecture. As a result, the area of forest in the pure-karst area increased, and the proportion of the forest ESV increased further, from 77.29% in 1985 to 81.74%. The ESV of cropland, shrubland, and grassland declined in the semi-karst area, while the ESV of other land-use types maintained an increasing trend. Shrubland, in particular, had the largest decrease, reaching USD 251 million, a decrease of 57.23%. This was followed by grassland, with a decline of USD 141 million or 56.23%. Cropland had a relatively small decline of USD 40 million. The percentage of ESV in cropland declined from 12.80% in 1985 to 11.69% in 2020. Over the past 35 years, the forest in the ESV increased by USD 666 million, mainly in the northern and central regions of Guizhou Province such as Suiyang County and Zheng'an County in Zunyi City, Qianxi City, and Zhijin County in Bijie City. The contribution of the ESV of forest areas increased from 75.05% to 80.04% in the beginning. The added value of the ESV in water was USD 132 million, which was sporadically distributed in areas such as

Qingzhen City, Sinan County, and Weining County. The ESV of shrubland and grassland in the non-karst area decreased by USD 492 million, with both categories decreasing by more than half, at 50.23% and 59.02%, respectively. The decline was due to the conversion of 73.53% of the shrubland in the non-karst area into forest with the implementation of the policy of hillclosing afforestation and ecological environmental protection, mainly in the regions of Pu'an County, Xinyi City, and Yanhe County. Approximately 90% of the properties of the original grassland also changed. A total of 56.29% of the grassland was transformed into forest and 34.65% was transformed into cropland, and this transformation was concentrated in the western edge in Guizhou Province (Xinyi City, Weining County, and Pu'an County). The ESV of water and forest areas showed an upward trend, with a combined increase of USD 576 million over the past 35 years, mainly because the large cropland areas in Wangmu County, Zhengfeng County, and Ziyun County, located in the non-karst areas, were converted to forest. Meanwhile, the ESV in forest areas accounted for more than 89% of the total ESV during the same period, and the ESV in water increased from 0.83% to 2.74%. The rise in the water ESV was inextricably linked to the fact that Guizhou Province has spent three years building water transportation infrastructure, which had a significant impact, resulting in a significant increase in water.

3.2.2. ESV Terrain Effect in Different Landform Areas

Elevation Effects of the ESV Changes

With the increase in elevation, the total ESV of the three landform type areas over the past 35 years showed the trend of first increasing and then decreasing (Figure 6), and the change over time was small.

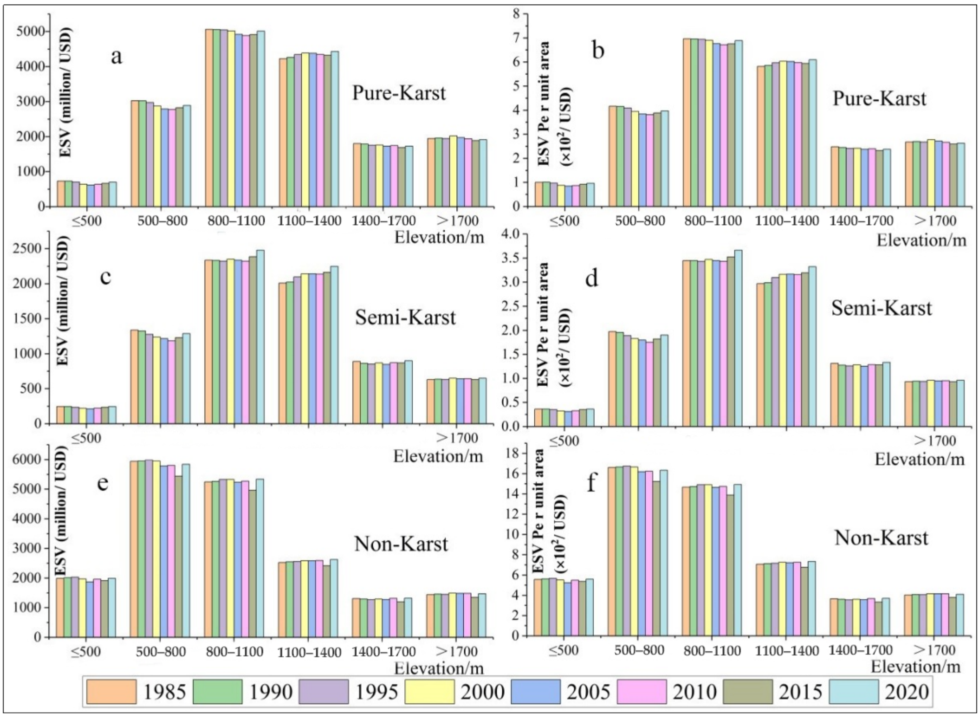

Figure 6. Elevation effect of the ESV in different landform areas from 1985 to 2020. Note: (**a**,**c**,**e**) in the figure represents the total ESV of the pure-karst, the semi-karst, and the non-karst areas, respectively, in each elevation gradient. (**b**,**d**,**f**) represents the ESV per unit area of the pure-karst, the semi-karst, and the non-karst areas, respectively, in each elevation gradient.

The maximum ESV in the pure-karst and semi-karst areas was between 800 and 1100 m, accounting for 30% and 31% of the total ESV, respectively, and the minimum was within 500 m, accounting for less than 5%. The maximum ESV in non-karst areas was between 500 m and 800 m, accounting for 31.42–32.18% in the 35 year period, and the minimum was between 1400 m and 1700 m, accounting for approximately 7%. When the elevation was above 800 m, the total ESV of the non-karst area decreased rapidly, below that of the pure-karst area by approximately 50%; however, it was always higher than that of the semi-karst area. This is mainly related to the topography of Guizhou Province, which is high in the west and low in the east. Non-karst areas are mostly distributed in areas with an elevation lower than 800 m at the edge of Guizhou Province such as Qiandongnan Prefecture and Chishui City (the forest in non-karst area accounts for approximately 11.40% of the total area of the province), while pure-karst and non-karst areas are mainly on the plateau above 800 m. In addition, within the elevation of 1100 m to 1400 m, although the order of the total size of the areas was as follows: pure-karst > semi-karst > non-karst, the pure-karst area was dominated by cropland and forest, which accounted for 50% and 46% of the area of cropland and forest in the pure-karst area, and the non-karst area was dominated by forest and shrubland, which accounted for 32% and 18% of the non-karst area, respectively. In the semi-karst area, cropland is dominant, accounting for approximately 34% of the cropland area in each period, while the forest area only accounted for approximately 21%. The contribution of the ESV of cropland was less than that of the forest area, resulting in the non-karst area being smaller than that of the semi-karst area, but its ESV was larger than that of the semi-karst area.

In terms of the elevation gradient of the ESV per unit area in the three landform types, the change trend in the ESV per unit area in the three landform types generally showed a first increasing, then decreasing trend, and the transition zone of the maximum and minimum was the same as that of the total ESV. However, when the elevation was above 1100 m, the area of cropland, forest, shrubland, and grassland in the non-karst area increased to different degrees with the elevation, which made the ESV in the non-karst area increase, and the ESV per unit area increased accordingly. In contrast, the area of cropland and forest in the semi-karst area and pure-karst area gradually decreased with the elevation increase, and the total ESV in the semi-karst area and pure-karst area decreased.

Slope Effect of the ESV Change

It can be seen from Figure 7 that the ESV in the non-karst area varied significantly with the slope, showing a law of first increasing and then decreasing with an inverted V-shaped trend. This was followed by the semi-karst area, and the pure-karst area had less variation. The ESV of the three landform type areas in different slope ranges showed relatively little change over time.

The maximum ESV in the non-karst and semi-karst areas was in the range of 15° to 25°, accounting for approximately 37% and 34% of the total ESV of this landform-type area. The maximum pure-karst area ESV ranged from 6° to 15°, accounting for approximately 24% in each period. The minimum values of the three landform areas were all in the slope greater than 45°, and the proportion of the ESV in each period was significantly different. The proportion of the ESV in all periods was approximately 55% in the pure-karst area, followed by approximately 28% in the non-karst area, and approximately 15% in the semi-karst area. The ESV in the non-karst and semi-karst areas decreased above 25° of the slope, and their ESV per unit area also showed a similar change pattern. The reason for the decline is that the non-karst and semi-karst areas cumulatively accounted for 69.05% and 77.16% of their respective total areas in the range of 0° to 25°. The forested area of the non-karst area increased from 2% in the 0° to 6° range to 28% in the 15° to 25° range, and the semi-karst area increased from 2% to 18%. Cropland also showed the same trend, but the proportion was lower than that of the forest areas. In spite of the Grain for Green Policy, the area of each landform type greater than 25° was small, leading to the characteristics of the ESV in non-karst and semi-karst areas first increasing and then decreasing with the slope change. The total ESV and ESV per unit area of pure-karst area were the lowest among the three landforms, except for ranges less than or equal to 6°. The reason for this is that, in the less than or equal to 6° slope, the pure-karst area was 973,586 hm^2. Although this was twice as large as the non-karst and semi-karst areas, the main contributors to the ESV were forest and cropland areas, accounting for only approximately 2% and 9%, respectively, which led to a slightly higher total ESV than for the non-karst and semi-karst areas, while its value per unit area remained low.

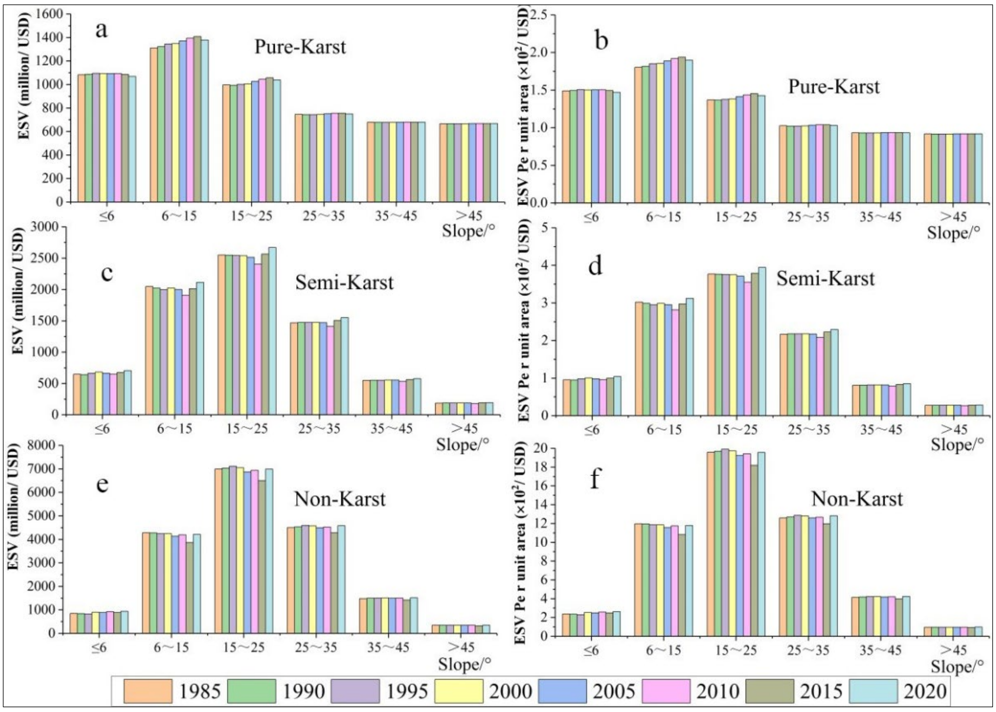

Figure 7. Slope effect of ESV in different landform areas from 1985 to 2020. Note: (**a**,**c**,**e**) in the figure represents the total ESV of the pure-karst, the semi-karst, and the non-karst areas, respectively, in each slope gradient. (**b**,**d**,**f**) represents the ESV per unit area of the pure-karst, the semi-karst, and the non-karst areas, respectively, in each slope gradient.

4. Discussion

4.1. General Law of ESV Changes in Karst Landforms

The change trend in the elevation and slope of the ESV in the three landform types was "first ascending and then descending". From the perspective of elevation, the value of the ecosystem service will be affected by the law of vertical zonal differentiation, that is, after reaching a certain elevation, the temperature gradually decreases, the growth of vegetation is limited, and the succession of forest to shrubland and unused land occurs. In terms of slope, the area with a gentle slope is the concentrated place of human activities. With an increase in slope, human activities gradually decrease, the land-use structure is mainly forest and grass land, and the value of the ecosystem services increases. In general, when a certain slope and elevation are reached, the growth of vegetation is gradually inhibited, and the value of the ecosystem services decreases [56].

In either a pure-karst area, a non-karst area, or a semi-karst area, forest is the main contributor to the ESV, followed by cropland and, finally, shrubland and grassland. Changes in the area of forest, grassland, and cropland can increase or decrease the total regional ESV. Therefore, adjusting the land-use structure and pattern can directly affect the regional ESV, which is closely related to the policy of returning farmland to forest or grassland and of relocation to alleviate poverty in different places in Guizhou Province. Under the influence of the Grain for Green Policy and relocating to other places to alleviate poverty, cropland with a slope greater than 25° was strictly reverted to forest or wilderness, and the population continued to gather in the low terrain niche. This can alleviate the contradiction between human and land in such an ecologically fragile area, and allow forest, shrubland, and grassland to dominate in areas with a high slope.

4.2. The Variation in ESV in Different Landform Areas

In terms of the same elevation position, the ESV per unit area was as follows: non-karst areas > pure-karst areas > semi-karst areas. The main reason for this is that the soil layer in the non-karst area is thick, which can meet the needs for growth of the various land vegetation. The purity of the soluble carbonate rock in pure-karst areas is high. During the soil forming process, the rock is weathered and dissolved in water, which makes is difficult for it to remain in place. The soil formed is thin, and the hydrothermal conditions and the vegetation growth environment is poor. The degree of dissolution in the semi-karst area is relatively light compared with that in the pure-karst area, and the soil that can meet the needs of plant growth can still be left in the landform development. However, due to strong human activities, the water and soil loss is intensified, and the ESV per unit area in semi-karst areas is the lowest.

The ESV per unit area in non-karst areas > pure-karst areas > semi-karst areas for the same slope. The reason for this is that under the influence of the typical calcareous environment of karst, elements such as potassium, iodine, and sodium required for plant growth are quite scarce in the pure-karst area, which is extremely restrictive to plant growth. At the same time, the soluble salt content in pure-karst areas is high, the slope increases, the soil, water, and nutrient run-off happens more easily, resulting in rock desertification, and "underground water rolling flow, surface water as expensive as oil" is a true portrayal of the area [57]. In contrast, compared with the pure-karst areas, semi-karst and non-karst areas tend to have thicker soil layers with good water and fertility retention. The conditions of soil and water in non-karst areas are better than those in semi-karst areas, resulting in continuous soil cover and denser natural vegetation growth [49].

The combined effects of human activities on land use through various socio-economic activities have caused changes in land-use patterns and structures, which affect the spatial and temporal distribution and changes in the regional ESV. Over the past 35 years, the population in Guizhou Province has increased by 8,843,300 people. The agglomeration effect of economic development has caused people to leave the countryside to increase their income, and has promoted the process of industrialization and urbanization. The urbanization rate increased from 9.3% in 1979 to 53.15% in 2020, resulting in dramatic changes in the land properties of each karst-landform-type area. The most obvious was the rapid increase in impervious land areas. For example, the impervious land in semi-karst areas increased by 353.03%, 94.79% of which is from cropland, with a decrease of USD 14 million in the cropland ESV. The impervious land in the non-karst areas increased by 287.54%, of which, 90.61% was provided by cropland, and the cropland ESV decreased by USD 10 million. The impervious land in the pure-karst area increased by 62,990.37 hm^2, of which, 91.24% was cropland, and the cropland ESV decreased by USD 34 million. Meanwhile, the increase in the impervious land area directly led to serious encroachment on ecological land; in addition, the decrease in the forest ESV in all periods of the three landform areas was more than USD 5 million.

4.3. Research Features and Enlightenment

We used the equivalent factor method to link the ESV with different landform types and terrain gradients to compare and highlight the spatial and temporal variation characteristics of the ESV in each karst-landform-type area and its terrain gradients. First, this paper can reflect the great value that different karst landform ecosystems bring to humans and arouse public attention toward karst landform ecosystems. Second, this paper also reflects the shift in human understanding of the services provided by karst ecosystems from "unpaid" to "paid" [58]. Finally, this paper quantifies the effect of regional ecological conservation. However, the study still has some shortcomings. First, the ESV coefficient of paddy fields and drylands was not calculated separately in the estimation of the ESV, which may be slightly low. Second, this study only carried out the study on the ESV of different karst landform areas at the macro-level, and did not take into account the ecological process and ecological demand of specific areas. Future studies should be based on the natural environment, social economy, and other perspectives of each karst geomorphic area to explore the ESV of different karst geomorphic areas from the supply–demand balance level. This will promote the rational allocation of land resources and ecological restoration in karst areas. In general, from 1985 to 2020, the ESV in Guizhou Province increased by USD 385 million, and its ecological environment showed a tendency to improve, mainly due to the increase in forest areas, indicating that the policies in Guizhou Province such as the Grain for Green Policy and hillclosing afforestation are effective in improving the ecological environment. However, from the perspective of different karst landform types, the ESV in the pure-karst areas decreased by USD 122 million, the semi-karst areas increased by USD 367 million, and the non-karst areas increased by USD 140 million. Some local ecological environments in Guizhou Province are still not well-preserved.

In the future, Guizhou Province should pay attention to the following:

(1) Development plans should be formulated in strict accordance with the principle of ecological priority and green development, and green GDP should be incorporated into the performance assessment system of government officials.
(2) The ecological environment construction and protection of pure-karst landscape areas should be strengthened.
(3) The ecological land area and layout of the pure-karst and semi-karst areas should be reasonably increased within an altitude less than or equal to 500 m.
(4) In areas with slopes greater than 25°, all three geomorphic areas should strictly implement the Grain for Green policy.

5. Conclusions

Based on the eight-period China Land Cover Dataset (CLCD) from 1985 to 2020, we compared and analyzed the spatial and temporal variation characteristics of the ESV in different karst areas according to the actual distribution of different karst landform types in Guizhou Province. We drew four conclusions from the results.

First, in terms of time series, the ESV in Guizhou Province increased from USD 42.748 billion in 1985 to USD 43.133 billion in 2020, showing a trend of first increasing, then decreasing, then increasing, with the largest increase occurring from 2015 to 2020. Spatially, the ESV in Guizhou Province showed an overall distribution characteristic of being low in the middle, and high in the surrounding areas, especially in the east and southeast, which have been concentrated areas of a high ESV. In contrast, central Anshun City and Guiyang City are contiguous areas with a low ESV.

Second, the total ESV in pure-karst areas has decreased by USD 122 million over the past 35 years, mainly in Dushan County and Libo County of Qiannan Prefecture. The ESV in semi-karst areas increased by USD 367 million, mainly in the northern and central regions in Guizhou Province such as Suiyang County of Zunyi City and Zhijin County of Bijie City. The ESV in non-karst areas increased by USD 140 million, mostly in Pu'an County, Xingyi City, and Yanhe County. The ESV per unit area was as follows: non-karst areas > pure-karst areas > semi-karst areas, and they all showed an upward trend.

Third, the terrain effect of the ESV in the three landform-type areas showed an inverted "V" trend that first increased and then decreased with the change in elevation and slope. The maximum ESV in the pure-karst and semi-karst areas was between 800 and 1100 m above sea level, and the minimum ESV was less than 500 m. The maximum ESV in the non-karst area was between 500 and 800 m and the minimum was in the range of 1400 to 1700 m. The maximum ESV in the non-karst and semi-karst areas was in the range of a 15° to 25° slope, and the maximum in the pure-karst areas was between 6° and 15°.

Finally, although the ecological environment of Guizhou Province is improving on the whole, the ecological environment is still not well-preserved in some areas. In terms of future land management, attention should be paid to the protection of forest areas, cropland, and other ecosystems, especially to strengthen the ecological environment construction in pure-karst landform areas.

Author Contributions: Q.L. and C.Z. designed and developed the research idea. Q.L. and H.H. collected and processed data. Q.L. wrote the manuscript. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the University Humanities and Social Sciences Research Project of Guizhou Province (2020SSD003).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: We would like to thank Huang Xin's team for providing the basic data for the study. We sincerely thank each reviewer for pointing out the shortcomings of the article and the direction for the revision of the article.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Bera, B.; Bhattacharjee, S.; Sengupta, N.; Shit, P.K.; Adhikary, P.P.; Sengupta, D.; Saha, S. Significant reduction of carbon stocks and changes of ecosystem service valuation of Indian Sundarban. *Sci. Rep.* **2022**, *12*, 7809. [CrossRef] [PubMed]
2. Li, J.H.; Gao, M.X. Spatiotemporal evolution and correlation analysis of ecosystem service values and ecological risk in Binzhou. *Acta Ecol. Sin.* **2019**, *39*, 7815–7827.
3. Li, B.Y.; Chen, N.C.; Wang, Y.C.; Wang, W. Spatio-temporal quantification of the trade-offs and synergies among ecosystem services based on grid-cells: A case study of Guanzhong Basin, NW China. *Ecol. Indic.* **2018**, *94*, 246–253. [CrossRef]
4. Liu, Z.T.; Wang, S.J.; Fang, C.L. Spatiotemporal evolution and influencing mechanism of ecosystem service value in the Guangdong-Hong Kong-Macao Greater Bay Area. *Acta Geogr. Sin.* **2021**, *76*, 2797–2813.
5. Su, M.N.; Peng, B.R. Integrating values of ecosystem services into decision making in coastal management in Xiamen. *Ocean. Coast. Manag.* **2018**, *207*, 104590. [CrossRef]
6. Ho, H.L.; Nguyen, T.H.D.; Vo, T.T.; Yoshihisa, S. An analytical approach in accounting for social values of ecosystem services in a Ramsar site: A case study in the Mekong Delta, Vietnam. *Ecol. Indic.* **2018**, *89*, 118–129.
7. Costanza, R.; D'Arge, R.; de Groot, R.; Farber, S.; Grasso, M.; Hannon, B.; Limburg, K.; Naeem, S.; O'neill, R.V.; Paruelo, J.; et al. The value of the world's ecosystem services and natural capital. *Nature* **1997**, *387*, 253–260. [CrossRef]
8. Hindsley, P.; Yoskowitz, D. Global change—Local values: Assessing tradeoffs for coastal ecosystem services in the face of sea level rise. *Glob. Environ. Change* **2018**, *61*, 102039. [CrossRef]
9. Deng, Y.J.; Hou, M.Y.; Xie, Y.F.; Gao, Q.; Yao, S.B.; Gong, Z.W.; Lu, Y.N.; Jia, L.; Li, Y.Y. Impact of the Grain for Green Project on the temporal and spatial evolution of ecosystem service value in northern Shaanxi. *Acta Ecol. Sin.* **2020**, *40*, 6597–6612.
10. Zhou, W.H.; Shi, Y.H.; Pan, L.; Fu, T.; Zheng, L.Y. Evaluation of Final Service Value of Donghu Lake Wetland Ecosystem in Wuhan City in 2017. *Wetl. Sci.* **2019**, *17*, 318–323.
11. Fang, L.L.; Xu, D.H.; Wang, L.C.; Niu, Z.G.; Zhang, M. The study of ecosystem services and the comparison of trade-off and synergy in Yangtze River Basin and Yellow River Basin. *Geogr. Res.* **2021**, *40*, 821–838.
12. Huang, M.Y.; Fang, B.; Yue, W.Z.; Feng, S.R. Spatial differentiation of ecosystem service values and its geographical detection in Chaohu Basin during 1995–2017. *Geogr. Res.* **2019**, *38*, 2790–2803.
13. Zheng, Z.M.; Fu, B.J.; Hu, H.T.; Sun, G. A method to identify the variable ecosystem services relationship across time: A case study on Yanhe Basin, China. *Landsc. Ecol.* **2014**, *29*, 1689–1696. [CrossRef]
14. Yin, N.; Wang, S.; Liu, Y.X. Ecosystem service value assessment: Research progress and prospects. *Chin. J. Ecol.* **2021**, *40*, 233–244.
15. Bhaskar, S.; Ye, Q.H.; Nitesh, K. Assessment of Ecosystem Services Value Based on Land Use and Land Cover Changes in the Transboundary Karnali River Basin, Central Himalayas. *Sustainability* **2019**, *11*, 318311.
16. Sannigrahi, S.; Chakraborti, S.; Joshi, P.K.; Keesstra, S.; Paul, S.K.; Jha, S.; Dang, K.B. Ecosystem service value assessment of a natural reserve region for strengthening protection and conservation. *J. Environ. Manag.* **2019**, *244*, 208–227. [CrossRef]
17. Friess, D.A.; Yando, E.S.; Wong, L.; Bhatia, N. Indicators of scientific value: An under-recognised ecosystem service of coastal and marine habitats. *Ecol. Indic.* **2020**, *113*, 106255. [CrossRef]
18. Sun, C.Z.; Wang, Y.Y.; Zou, W. The marine ecosystem services values for China based on the emergy analysis method. *Ocean. Coast. Manag.* **2018**, *161*, 66–73. [CrossRef]
19. Ke, X.L.; Zhou, Q.S.; Zuo, C.C.; Tang, L.P.; Turner, A. Spatial impact of cropland supplement policy on regional ecosystem services under urban expansion circumstance: A case study of Hubei Province, China. *J. Land Use Sci.* **2020**, *15*, 673–689. [CrossRef]
20. Estoque, R.C.; Myint, S.W.; Wang, C.Y.; Ishtiaque, A.; Aung, T.T.; Emerton, L.; Ooba, M.; Hijioka, Y.; Mon, M.S.; Wang, Z.; et al. Assessing environmental impacts and change in Myanmar's mangrove ecosystem service value due to deforestation (2000–2014). *Glob. Change Biol.* **2018**, *24*, 5391–5410. [CrossRef]
21. Wen, L.; Song, J.; Zhang, H.C.; Zhang, X.F.; Wang, F.G.; Ha, S.N.; Wang, L.X. Dynamics of ecosystem service value in Ulan buh Desert from 1990 to 2018. *J. Arid. Land Resour. Environ.* **2020**, *34*, 57–64.

22. Zhang, M.; Dilinuer, A.J. Evaluation of ecosystem service value of constructed wetland on the west bank of the Bosten Lake. *Trans. Oceanol. Limnol.* **2021**, *43*, 169–174.
23. Pan, N.H.; Guan, Q.Y.; Wang, Q.Z.; Sun, Y.F.; Li, H.C.; Ma, Y.R. Spatial Differentiation and Driving Mechanisms in Ecosystem Service Value of Arid Region: A case study in the middle and lower reaches of Shule River Basin, NW China. *J. Clean. Prod.* **2021**, *319*, 128718. [CrossRef]
24. Guo, H.Y.; Wang, Y.R.; Lu, Q.; Zhou, J.X.; Wei, Q.Z. Assessment on the eco-service value in karst rocky desert: A case study in Jinsha County. *Carsologica Sin.* **2013**, *32*, 211–217, 224.
25. Zhou, B.H.; Cao, J.J.; Zhu, C.P.; Jin, B. Valuation of wetland ecosystem services along the Yangtze River in Anqing, Anhui Province. *Geogr. Res.* **2011**, *30*, 2296–2304.
26. Han, P.; Si, J.; Wang, Y.G. Contrastive Analysis of Valuation Methods of Ecosystem Services Value: A Case Study of Zhifanggou Watershed in a Hilly and Gully Region of Loess Plateau. *J. Basic Sci. Eng.* **2009**, *17*, 102–112.
27. Luo, G.J.; Wang, S.J.; Li, Y.B.; Bai, X.Y. Spatio-temporal dynamics and ecological service function assessment of slope farmland in Karst areas of Guizhou province, China. *Trans. Chin. Soc. Agric. Eng.* **2014**, *30*, 233–243.
28. Zhao, N.; Wang, H.; Zhong, J.Q.; Sun, D.Q. Assessment of Recreational and Cultural Ecosystem Services Value of Islands. *Land* **2022**, *11*, 205. [CrossRef]
29. Petway, J.R.; Lin, Y.P.; Wunderlich, R.F. A Place-Based Approach to Agricultural Nonmaterial Intangible Cultural Ecosystem Service Values. *Sustainability* **2020**, *12*, 699. [CrossRef]
30. Zhang, P.Y.; Geng, W.L.; Yang, D.; Li, Y.Y.; Zhang, Y.; Qin, M.Z. Spatial-temporal evolution of land use and ecosystem service value in the Lower Reaches of the Yellow River Region. *Trans. Chin. Soc. Agric. Eng.* **2020**, *36*, 277–288.
31. Liu, X.N.; Liu, C.L.; Chen, L.; Pei, X.; Qiao, Q. Gradient effects and ecological zoning of ecosystem services in transition zone of Beijing Bay. *Trans. Chin. Soc. Agric. Eng.* **2020**, *36*, 276–285.
32. Chen, Y.; Li, J.F.; Xu, J. The Impact of Socio-economic Factors on Ecological Service Value in Hubei Province: A Geographically Weighted Regression Approach. *China Land Sci.* **2015**, *29*, 89–96.
33. Zeng, J.; Li, J.F.; Yao, X.W. Spatio-temporal dynamics of ecosystem service value in Wuhan Urban Agglomeration. *Chin. J. Appl. Ecol.* **2014**, *25*, 883–891.
34. Swanson, F.J.; Zhang, L.F. Effects of landform on ecosystem model and function. *Prog. Geogr.* **1990**, *1*, 6–10.
35. Wang, B.X.; Cheng, W.M.; Song, K.Y.; Li, H. Preliminary study on eco-geomorphology research dynamic: The interdisciplinary science of geomorphology and ecosystem ecology. *Acta Ecol. Sin.* **2022**, *42*, 1–15.
36. Pang, G.W. Vegetation Coverage in Different Landforms of Shaanxi Province: Spatial and Temporal Variations and Influencing Factors. *J. Yangtze River Sci. Res. Inst.* **2021**, *38*, 51–58.
37. Wang, H.; Gao, J.B.; Hou, W.J. Quantitative attribution analysis of soil erosion in different geomorphological types in karst areas. *J. Geogr. Sci.* **2019**, *29*, 271–286. [CrossRef]
38. He, W.C.; Zhao, S.M.; Cheng, W.M. Analysis of land cover change on basic geomorphic types in Shanxi Province. *J. Geo-Inf. Sci.* **2016**, *18*, 210–219.
39. Song, X.W.; Gao, Y.; Wen, X.F.; Guo, D.L.; Yu, G.D.; He, N.P.; Zhang, J.Z. Carbon sequestration potential and its eco-service function in the karst area, China. *J. Geogr. Sci.* **2017**, *27*, 967–980. [CrossRef]
40. Su, Q.J.; An, Y.L.; Ma, S.B.; Zhao, Y.; An, J.K.; An, H.F. Landscape ecological quality of different lithological regions in karst Mountains: A case study in the Luodian county of Guizhou Province. *Carsologica Sin.* **2017**, *36*, 454–462.
41. Han, H.Q.; Su, Z.H. Research progress and prospects of karst ecosystem services. *Carsologica Sin.* **2017**, *36*, 352–358.
42. Feng, Q.; Zhou, Z.F.; Chen, Q.; Zhu, C.L. Spatial-temporal evolution research of ecosystem service value in ecologically vulnerable karst regions under the Perspective of poverty Alleviation relocation. *Acta Ecol. Sin.* **2022**, *42*, 1–10.
43. He, X. Study on the evolution of ecological security in Karst area based on the threshold of ecosystem services. *Sci. Geogr. Sin.* **2021**, *9*, 2021–2030.
44. Xue, B.; Xiao, X.; Li, C.H.; Li, J.Z. A spatial analysis based evaluation of forestry ecosystem service value in Guizhou province. *J. Guizhou Norm. Univ. (Nat. Sci.)* **2019**, *37*, 37–44.
45. Hu, F.; An, Y.L.; Xu, J. Preliminary discussion on concept and landscape features of "Semi-Karst": A case study of Guizhou province. *Geogr. Res.* **2015**, *34*, 1569–1580.
46. Li, Y.H. The evolution of implication of karst and its environmental protection. *Carsologica Sin.* **2000**, *3*, 64–71.
47. An, Y.L.; Lv, T.; Xiong, K.N.; Zhou, Z.F. The study to karst-desertification in Guizhou with "3S". In Proceedings of the 1st Symposium of Chinese Soil and Water Conservation Monitoring, Guangzhou, China, 19–20 December 2001.
48. Yang, J.; Huang, X. The 30 m annual land cover dataset and its dynamics in China from 1990 to 2019. *Earth Syst. Sci. Data* **2021**, *13*, 3907–3925. [CrossRef]
49. Xie, G.D.; Lu, C.X.; Leng, Y.F.; Zheng, D.; Li, S.C. Ecological assets valuation of the Tibetan Plateau. *J. Nat. Resour.* **2003**, *3*, 189–196.
50. Jiang, H.; Wu, Q. Ecological Service Value Evaluation and Temporal-Spatial Evolution Characteristics in Jiangsu Province Based on LUCC. *Resour. Environ. Yangtze Basin* **2021**, *30*, 2712–2725.
51. Wu, C.Y.; Chen, B.W.; Huang, X.J.; Wei, Y.H.D. Effect of land-use change and optimization on the ecosystem service values of Jiangsu province, China. *Ecol. Indic.* **2020**, *117*, 106507. [CrossRef]
52. Feng, Z.M.; Tang, Y.; Yang, Y.Z.; Zhang, D. The Relief Degree of Land Surface in China and Its Correlation with Population Distribution. *Acta Geogr. Sin.* **2007**, *10*, 1073–1082.

53. Tan, W.Y.; Zhou, Z.F.; Zhu, C.L.; Ma, G.X. Topographic Relief and Its Influence on Soil Erosion Sensitivity in Karst Mountain Area—Taking Libo County, Guizhou Province as an Example. *Bull. Soil Water Conserv.* **2019**, *39*, 77–83.
54. Wei, Y.; Li, R.T.; Ma, X.E. Research on cultivated land protection and sustainable utilization in karst ecologically fragile region: A Case study of Weining County. *Rural. Econ. Sci.-Technol.* **2016**, *27*, 7–9.
55. Li, X.D. Dynamic relationship and coordination degree between urbanization level and cultivated land area in Guizhou. *Popul. Soc.* **2011**, *27*, 64–69.
56. Pan, H.L.; Li, M.H.; Cai, X.H.; Wu, J.; Du, Z.; Liu, X.L. Responses of growth and ecophysiology of plants to altitude. *Ecol. Environ. Sci.* **2009**, *18*, 722–730.
57. Ma, S.B.; An, Y.L.; Yang, G.B. Analysis of Vegetable NDVI Variation on Various Lithology in Karst Area Based on GIS. *Res. Soil Water Conserv.* **2017**, *24*, 202–206+212.
58. Anonymous. The Connotation, Evaluation and its significance of Ecological Services. In Proceedings of the Second Advanced Seminar on Ecological Compensation Mechanism Construction and Policy Design, Urumqi, China, 29 July 2008.