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# Identifying the Landscape Security Pattern in Karst Rocky Desertification Area Based on Ecosystem Services and Ecological Sensitivity: A Case Study of Guanling County, Guizhou Province

**Bin Ying, Ting Liu, Li Ke, Kangning Xiong *, Sensen Li, Ruonan Sun and Feihu Zhu**

School of Karst Science, Guizhou Normal University, Guiyang 550003, China; keli202303@163.com (L.K.)
* Correspondence: xiongkn@gznu.edu.cn

**Abstract:** Ecological environmental security in karst areas is an issue of global concern. Identifying the ecological landscape security pattern (ELSP) is key to promoting environmental protection and alleviating the land development and utilization impacts. Ecological sources (ESs) and ecological corridors (ECs) are important bases for constructing an ELSP. We used five influencing factors (land use type, digital elevation model (DEM), rocky desertification degree, normalized difference vegetation index (NDVI) and slope) to obtain the distribution of the importance and sensitivity values of ecosystem services in Guanling County, Guizhou Province. The probability of the connectivity index (PC) was calculated, and the ES was extracted by combining the importance of ecosystem services, ecological sensitivity, and landscape connectivity. According to the topographic and geomorphological characteristics of Guanling County, seven indicators of elevation, slope, landscape type, degree of stone desertification, distance from rivers, distance from settlements, and distance from roads were selected as resistance factors for the outward expansion of the ESs to calculate the comprehensive resistance surface of Guanling County. Based on the gravity model, an interaction matrix between 10 ESs was constructed, and the magnitude of the interaction forces between the source sites was quantitatively evaluated to distinguish the important ECs and general ECs. The study showed that the total length of the ECs in Guanling County was 509.78 km, and the core area of Guanling County was large, accounting for 65.73% of the ecological landscape area. By assessing the importance of ecosystem services, ecological sensitivity, and landscape connectivity, 10 ES and 45 EC were obtained based on ArcGIS10.8, which constituted the landscape security pattern of Guanling County by ESs and ECs. Suggestions were proposed for a planning layout that will benefit the ecological restoration of Guanling County and environmental protection of the karst region according to the study area characteristics.

**Keywords:** landscape security pattern; ecosystem services; sensitivity; landscape connectivity; Guanling County; Guizhou



**Citation:** Ying, B.; Liu, T.; Ke, L.; Xiong, K.; Li, S.; Sun, R.; Zhu, F. Identifying the Landscape Security Pattern in Karst Rocky Desertification Area Based on Ecosystem Services and Ecological Sensitivity: A Case Study of Guanling County, Guizhou Province. *Forests* **2023**, *14*, 613. https://doi.org/10.3390/f14030613

Academic Editor: José Aranha

Received: 7 February 2023
Revised: 8 March 2023
Accepted: 16 March 2023
Published: 19 March 2023



## 1. Introduction

With the acceleration of urbanization, frequent human activities have led to the fragmentation of ecosystems. Ecological security issues have increasingly become the focus of attention of experts and researchers at home and abroad. The construction of regional security patterns is an effective way to improve the ecological environment and achieve regional sustainable development. Yu (1995) [1] proposed the theory of landscape security patterns based on the landscape ecological planning method advocated by Forman [2]. This theory satisfied the theoretical requirements of the reasonable regulation of ecological processes in ecological security research and became an effective way to guide the theory and practice of landscape ecology spatial pattern-ecological process coupling [3]. Ecological security patterns focus on biodiversity conservation, landscape restoration, ecosystem service supply, etc. It is of great significance to analyze the interaction between key elements and ecological processes for ecological security such as ecosystem integrity, reasonable structure, and normal function [4]. At present, the theory of landscape security patterns has been widely used in empirical research. For example, Li et al. (2015), using Changzhou as an example, used the minimum cumulative resistance model (MCR) to construct the resistance surface, determine the quantity and pattern optimization of urban ecological land, and solve urban environmental problems [5]. Based on the distance cost analysis method, Su et al. (2016) constructed an urban regional composite ecological security pattern (ESP) to protect the survival and habitat security of important vegetation, wild animals, and human beings [6]. Liang et al. (2018) comprehensively analyzed the priority protection area and the minimum cost EC, established a more representative, connected, and efficient EC network system, and proposed a new framework for a protection area network composed of protection priority and EC [7]. Peng et al. (2018) evaluated the ecological land risk, quantified the value of ecological land, identified the ESs of Shenzhen, and constructed EC to provide a theoretical framework for the study of urban ecological security patterns [8]. A large number of ES and EC studies have also been carried out in karst areas [9–12]. However, the research on ELSPs has mainly focused on cities, watersheds, and other regions, and few in karst areas. The construction method of ELSP is divided into three steps: the selection of ESs, the construction of comprehensive resistance surfaces, and the extraction of ECs [13]. The traditional method is subjective when selecting the ESs and usually selects areas with the highest ecological values as the ES, which lacks a certain scientific rigor. Therefore, some researchers have introduced more scientific methods such as the importance of ecosystem services [14], morphological spatial pattern analysis (MSPA) [15], and landscape connectivity analysis to identify ES.

Ecosystem services are the direct or indirect contributions of ecosystems to human well-being. They reflect the human need for ecosystems and are the frontiers of ecological, geographic and economic research [16]. At present, ecosystem services have made many contributions to human development. Researchers at home and abroad have studied the function, quantitative evaluation, and ecosystem service flow of ecosystem services [17–19]. Ecological sensitivity is mainly used in ecological environmental protection and spatial planning. Researchers have also combined ecological sensitivity evaluation with spatial security patterns, making it an important indicator for the selection of ESs [20–22]. Ecosystem services and ecological sensitivity assessments have gradually been applied to the study of regional security patterns, but little attention has been given to ecological protection and ecological security pattern construction in karst areas.

The term karst originates from the karst plateau of the former Yugoslavia, coupled with the atmosphere, hydrosphere, and biosphere to form the natural ecological environment of karst. It is widely distributed, accounting for 10% of the total Earth area [23,24]. The distribution of karst areas in China exceeds 1.24 million km$^2$, which is concentrated in Yunnan, Guizhou, Guangxi, etc., among which Guizhou karst has a continuous distribution and a wide area of carbonate rocks. Due to the lack of water and soil components in the ecological environment, the Guizhou karst area has low ecological capacity, poor environmental stability, and high sensitivity to variation, and is prone to disasters such as soil erosion, rocky desertification, drought, and flood. The special geomorphic conditions result in complex landforms and strong spatial heterogeneity in the karst areas. At present, the research into environmental governance and rocky desertification control in karst regions has achieved much success [25], and is mainly concentrated on the environment monitoring of karst [26–29], the spatial distribution of rocky desertification [30–32], the evolution process and patterns of rocky desertification [33–35], driving factor analysis [36–40], and rocky desertification control, etc. [41–43]. Guanling County in Guizhou Province is a typical karst landform area in China. With the acceleration of urbanization and the development of a large number of urban construction facilities, the originally fragile karst environment has been continuously affected by human activity and economic development, and the landscape pattern in the area has changed dramatically [44]. The vegetation coverage has been reduced, cave cracks have developed, water leakage has become serious, the terrain has become extremely fragmented, landscape connectivity has declined, and the ecological environment has become fragile [45]. It is of great significance for the sustainable development of the ecological environment in this karst region to construct a security pattern and optimize its spatial layout. This paper identifies the ecological source of Guanling County based on the importance of ecosystem services, ecological sensitivity, and landscape connectivity, and constructs a comprehensive resistance surface of the study area from the aspects of landscape, terrain, human interference, etc. ArcGIS spatial analysis was used to calculate the potential ecological corridor of Guanling County, and identified the important ecological corridor based on the gravity model to construct the landscape security pattern of Guanling County and provide effective scientific support for the planning and construction of the study area.

## 2. Materials and Methods

### *2.1. Overview of the Study Area*

Guanling County (Figure 1) is located in central Guizhou Province, the eastern ridge slope of the Yunnan-Guizhou Plateau to the south of the Guangxi hilly slope, within the city of Anshun, 105°15′~105°49′ E, 25°19′~26°05′ N, which is adjacent to Zhenning County, Zhenfeng County, Qinglong County, etc. The total area of the county is 1464 $km^2$. The terrain is high in the northwest and low in the southeast. The elevation is between 370 and 1850 m. The mountainous area accounts for 89% of the total area of the county, and the surface is rugged. The climate in the region is mainly a subtropical monsoon humid climate with sufficient heat, concentrated summer rainfall, and serious soil erosion. The mountains in the territory are part of the Wumeng Mountains. The landform types are complex and diverse. Carbonate rocks are widely distributed, and karst development is strong. Guanling County is a typical karst plateau mountainous area and the area of karst landforms encompasses 83.83% of the county. With socioeconomic development and the influence of human activities, the regional terrain is more fragmented, and the ecological environment has been seriously damaged.

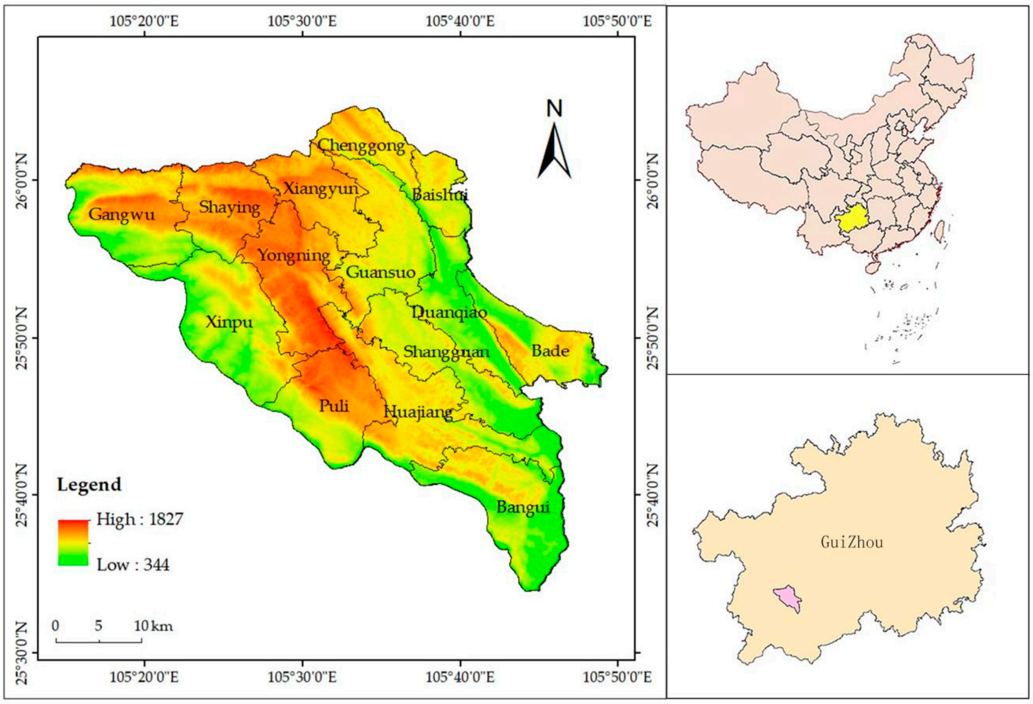


**Figure 1.** Geographical location map of Guanling County.

### 2.2. Data Sources

The basic data used in this study include land use data, digital elevation model (DEM) data, rocky desertification data, and normalized difference vegetation index (NDVI) data.

(1) Land use data: Derived from the results of the third national land survey (the third national land survey) in Guanling County, according to the land use classification system of the third national land survey (land use status classification GB/T21010-2017) [46]; the data are divided into seven categories.
(2) DEM data: Obtained from the Chinese Academy of Sciences Data Sharing Center (https://www.resdc.cn/), accessed on 17 May 2022, with a resolution of 30 m, and using ArcGIS10.8 surface analysis to extract the slope data.
(3) NDVI data: Obtained from the National Ecological Science Data Center (http://www.nesdc.org.cn/), accessed on 19 February 2022, with a resolution of 30 m.
(4) Rocky Desertification data: Rocky desertification data from Xiong et al. [47], and corrected by the visual interpretation of remote sensing and field survey observations.

### 2.3. Research Methods

#### 2.3.1. Importance and Sensitivity Analysis of Ecosystem Services

The ecosystem service value is the benefit to humankind from ecosystems [48–50]. The ecosystem service value per unit area of land use type was obtained according to the ecosystem service value evaluation research of Xie et al. (2008). (Table 1).

**Table 1.** Ecosystem service value of land use types.

| Value of Ecosystem Services | Land Use Type | Importance of Ecological Services |
|---|---|---|
| 5 | Water body | Extremely important |
| 4 | Forestland and grassland | Highly important |
| 3 | Garden plot | Moderately Important |
| 2 | Cultivated land | Slightly important |
| 1 | Construction land and other land | Unimportant |

Ecological sensitivity is a comprehensive index used to evaluate the regional ecological environmental quality, land use rationality, and economic development. It is the basis of regional ecological environment planning and management [51]. This paper, combined with the principle of data availability and objectivity, chose five indicators (land use data, DEM, rocky desertification data, NDVI and slope) according to the current research [52] to evaluate the ecological sensitivity of the study area (Table 2).

**Table 2.** Ecological environment sensitivity the evaluation factor classifications and weights.

| Sensitivity Assignment | NDVI | DEM/m | Slope/° | Land Use Type | Rocky Desertification |
|---|---|---|---|---|---|
| 1 | ≤0.35 | ≤500 | ≤5 | Construction Land | Extremely strong rocky desertification |
| 3 | (0.35, 0.50] | (500, 800] | (5, 15] | Other land | Intense rocky desertification |
| 5 | (0.50, 0.65] | (800, 1100] | (15, 25] | Cultivated land | Moderate rocky desertification |
| 7 | (0.65, 0.75] | (1100, 1500] | (25, 35] | Grassland and Garden land | Mild rocky desertification |
| 9 | >0.75 | >1500 | >35 | Forestland and Water body | No rocky desertification |

#### 2.3.2. Landscape Connectivity Analysis

Landscape connectivity refers to the degree to which the landscape promotes or hinders movement between patches [53], which can be reflected by the size of the patches, the distance between similar patches, and the presence of corridors [54], and promotes the communication and exchange of species and biodiversity between patches. MSPA is an image processing method based on mathematical morphology principles such as corrosion, expansion, open operations, and closed operations to measure, identify, and segment raster images [55]. This method can suitably identify the important ecological patches in the study area and obtain seven kinds of landscape elements (core, edge, bridge, islet, perforation, loop and branch) for a clear spatial topological relationship between the target pixel set and the structural elements [56]. Based on the Guidos software, this paper examined the landscape structure of Guanling County by MSPA. The forestland, grassland, water area, cultivated land, and garden land in the seven types of land use in the study area were used as the foreground data, and the other types were used as the background data to extract the core areas. All values were binarized and imported into the Guidos Toolbox software for the MSPA analysis of the images using the eight-neighborhood analysis method.

Next, we used Conefor 2.6 software (available at http://www.conefor.org/ (accessed on 2 March 2023), as proposed by Saura and Torne (2009), to calculate the *dPC* of the core area. Finally, according to their *dPC* value from high to low, the patches were divided into four levels, and the importance pattern of the Guanling County landscape connectivity was finally obtained. The calculation formula of *dPC* is:

$$dPC = \frac{PC - PC_{i-remove}}{PC}$$

where $PC$ is the possible connectivity index of the whole landscape when all patches exist in the landscape and $PC_{i-remove}$ is the possible connectivity index value of the remaining patch composition landscape after removing patch $i$. The higher the *dPC* value, the higher the importance of the patch in landscape connectivity, and the more obvious its core position in the landscape. The calculation formula of $PC$ is:

$$PC = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} a_i \times a_j \times a_{ij}}{A_L^2}$$

where $n$ is the total number of habitat nodes in the landscape; $a_i$ and $a_j$ are the areas of plaque $i$ and plaque $j$, respectively; $A$ is the total area of the study area; and $a_{ij}$ is the maximum final connectivity of all paths between plaque $i$ and plaque $j$.

#### 2.3.3. Construction of Ecological Resistance Surface

The flow of matter and energy needs to overcome a certain resistance, and the resistance encountered in the outward diffusion of ESs constitutes the comprehensive resistance surface [57]. Based on previous studies [58,59], seven indicators were selected from landscape, topography, and human interference including the elevation, slope, landscape type, degree of stone desertification, distance from rivers, distance from settlements and distance from roads as the resistance factors for the outward expansion of ESs, and these resistance factors were assigned resistance values (from 1 to 9, where the higher the value, the higher the degree of resistance) in a hierarchy (Table 3). Using ArGIS10.8, these seven types of factors were superimposed by finding the mean value to obtain the comprehensive resistance surface of Guanling County.

#### 2.3.4. Construction of ELSP

The core steps of ecological security pattern construction include ecological source identification, ecological resistance surface construction, and key ecological corridor extraction. Among these, the ecological source is the starting point for the outward diffusion of species, which can promote the development of ecological processes and is the key area to ensure regional ecological security [60]. The identification of ESs in Guanling County is mainly based on the analysis of the importance of ecosystem services, ecological sensitivity, and landscape connectivity. ECs are corridors that can provide protection for biodiversity and prevent soil erosion and the loss of ecosystem services [61]. They are the pathways of material and energy flow in the region and key factors in maintaining ecological stability, ecological processes, and ecological function in the region [62]. According to the constructed comprehensive resistance surface, the ECs between the sources were extracted. Using the center point of the ESs as the ecological node, the minimum cost distance from each source to other ESs was calculated by the cost distance using the distance analysis tool in ArcGIS, and then the cost path was used to calculate the minimum cost path between the sources. Finally, the key EC in the study area, which were the channels with the smallest resistance value between the sources, were obtained. Based on the gravity model, we quantitatively evaluated the interaction between each ecological source and determined the importance of the potential corridor (the greater the interaction, the higher the importance of the corridor). The calculation formula of gravity model is as follows:

$$G_{ij} = \frac{N_i * N_j}{D_{ij}^2} = \frac{\frac{\ln s_i}{P_i} * \frac{\ln s_j}{P_j}}{\left(\frac{L_{ij}}{L_{max}}\right)^2} = \frac{L_{max}^2 * \ln(s_i) * \ln(s_j)}{L_{ij}^2 * P_i * P_j}$$

where $G_{ij}$ is the interaction force between source patches $i$ and $j$; $N_i$ and $N_j$ is the weight value of source patches, $D_{ij}$ is the potential corridor resistance value between source patches $i$ and $j$; $P_i$ and $P_j$ is the resistance value of source patches $i$ and $j$; $L_{ij}$ is the potential corridor resistance value from source patches $i$ to $j$; $L_{max}$ is the maximum resistance value of all potential corridors in the study area.

**Table 3.** Ecological resistance surface evaluation system.

| Resistance Value | Distance from River/m | Distance from the Settlement/m | Distance from Road/m | Degree of Stone Desertification | Landscape Type | Elevation/m | Slope/° |
|---|---|---|---|---|---|---|---|
| 1 | ≤500 | >1000 | ≤1000 | No rocky desertification | Forestland and Water body | ≤500 | ≤5 |
| 3 | (500, 1000] | (1000, 800] | (500, 1000] | Mild rocky desertification | Grassland and Garden land | (500, 800] | (5, 10] |
| 5 | (1000, 1500] | (800, 500] | (200, 500] | Moderate rocky desertification | Cultivated land | (800, 1100] | (10, 15] |
| 7 | (1500, 2000] | (200, 500] | (100, 200] | Intense rocky desertification | Other land | (1100, 1500] | (15, 25] |
| 9 | >2000 | ≤200 | ≤100 | Extremely strong rocky desertification | Cultivated land | >1500 | >25 |

## 3. Results and Analysis

### *3.1. Land Use Analysis of Guanling County*

According to the land use distribution in Guanling County (Figure 2), the largest area was that of cultivated land at 404.34 km$^2$, accounting for 27.94% of the total area; the forestland area was 345.48 km$^2$, accounting for 23.87% of the total area; the grassland area was 246.31 km$^2$, accounting for 17.02% of the total area; the garden land area was 16.38 km$^2$, accounting for 1.13% of the total area; the water body area was the smallest, at only 15.73 km$^2$, accounting for 1.09% of the total area; and the construction land area was 42.31 km$^2$, accounting for 2.92% of the total area. The area of bare land and other land was 376.50 km$^2$, accounting for 26.02% of the total area. There was more cultivated land, bare land, and other land in Guanling County (Table 4), and the ecological environment was poor. Forest protection and the Grain for Green Project are recommended. The water area was relatively small, and thus water resource protection should be improved.

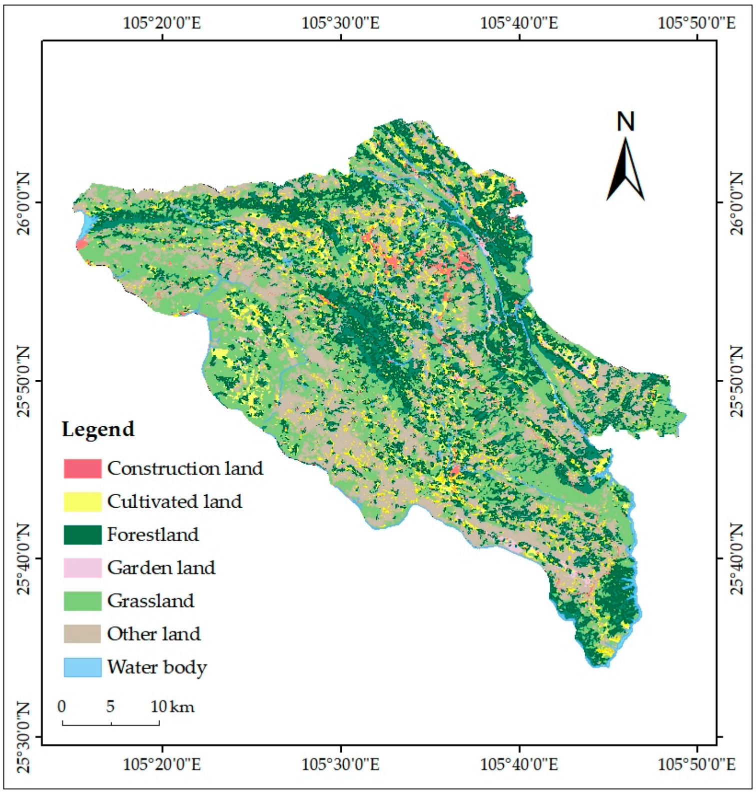


**Figure 2.** Guanling County land use distribution map.

**Table 4.** Areas of various land use types in Guanling County.

| Land Use Types | Area ($km^2$) | Proportion (%) |
|---|---|---|
| Forestland | 345.48 | 23.87 |
| Grassland | 246.31 | 17.02 |
| Garden land | 16.38 | 1.13 |
| Water body | 15.73 | 1.09 |
| Cultivated land | 404.34 | 27.94 |
| Construction land | 42.31 | 2.92 |
| Other land | 376.50 | 26.02 |

### *3.2. Analysis of Importance and Ecological Sensitivity of Ecosystem Services*

The importance of ecosystem services can be calculated for different ecosystems to analyze regional differentiation rules and clarify the important areas of ecosystem services. According to research on the evaluation of ecosystem service value by Xie et al. (2008), water areas, forestlands and grasslands, garden lands, cultivated lands, and construction lands were assigned an importance value of 5, 4, 3, 2, and 1, respectively (where the higher the value, the higher the value of the ecosystem services). Then, a distribution map of the importance of ecosystem services in Guanling County (Figure 3) was obtained. The area of extremely important and important areas of ecosystem service value was 607.38 km$^2$, accounting for 41.98% of the total area of the county.

Ecological environmental sensitivity is an important factor restricting urban development. The more sensitive the ecological environment, the more likely environmental problems are to occur in the area. Through the superposition of ecological sensitivity evaluation factors, the ecological sensitivity evaluation results were obtained. The natural breakpoint method was used to divide the ecological sensitivity into five grades: insensitive, mildly sensitive, moderately sensitive, highly sensitive, and extremely sensitive (Figure 4). The highly sensitive and extremely sensitive area of Guanling County was 526.5 km$^2$, accounting for 36.37% of the total area of the county, mainly in the northwest, central, east, and south; the insensitive area was 53.5 km$^2$, accounting for 3.70% of the total area of the county, mainly distributed in the western and southern fringes of the study area. The ecological environment of Guanling County is relatively fragile.

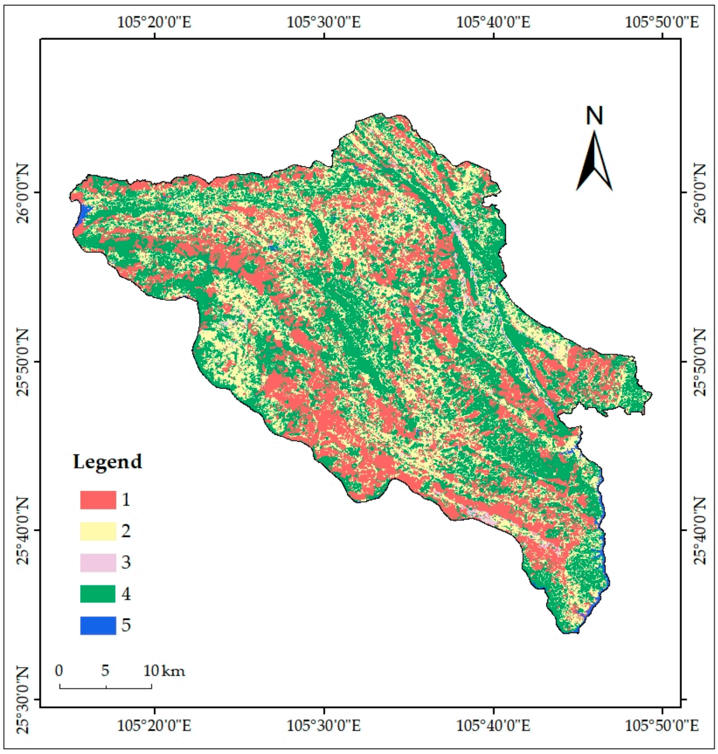


**Figure 3.** Importance distribution map of ecosystem services in Guanling County.

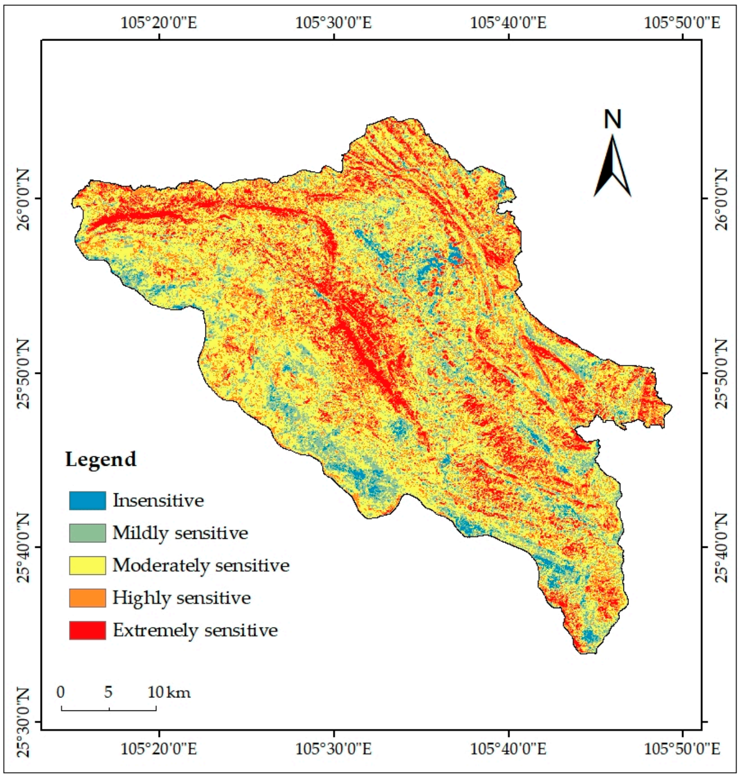


**Figure 4.** Ecological sensitivity distribution map of Guanling County.

### *3.3. Analysis of Landscape Connectivity and Landscape Types in Guanling County*

There are many indicators used to measure landscape connectivity. The integral index of connectivity (IIC) and probability of connectivity (PC) proposed by Pascual-Hortal and Saura (2006) can evaluate landscape connectivity more effectively than other indicators [63]. Both the IIC and PC are landscape connectivity evaluation indices based on graph theory, but the PC has more advantages and is more rational than the IIC index [64]. *Guidos* software was used to analyze the landscape structure of Guanling County by MSPA, and the core patches of Guanling County were extracted. Combined with Conefor 2.6 software, the *dPC* index value of each patch was calculated. According to the level of *dPC*, the landscape connectivity of Guanling County was divided into four levels: extremely high, high, medium, and low. In the landscape type of Guanling County (Figure 5), the core area was an important species habitat, with an area of 608.61 km$^2$, accounting for 65.73% of the ecological landscape area, and was widely distributed. The loop area had a certain buffer effect on species migration, covering an area of 70.59 km$^2$, accounting for 7.62% of the ecological landscape area. The islet area was the smallest and was the supplementary part of the core area. This area was only 11.71 km$^2$, accounting for 1.30% of the ecological landscape area. The perforation distribution in the study area was relatively uniform, with an area of 45.15 km$^2$, accounting for 4.88% of the ecological landscape area. The edge area was the external boundary of the core area, with an area of 120.06 km$^2$, accounting for 12.97% of the ecological landscape area. The connecting bridge, with an area of 31.30 km$^2$, accounting for 3.39% of the ecological landscape area, had a certain effect on the communication between species. The area of the branch line was 38.53 km$^2$, accounting for 4.16% of the ecological landscape (Table 5).

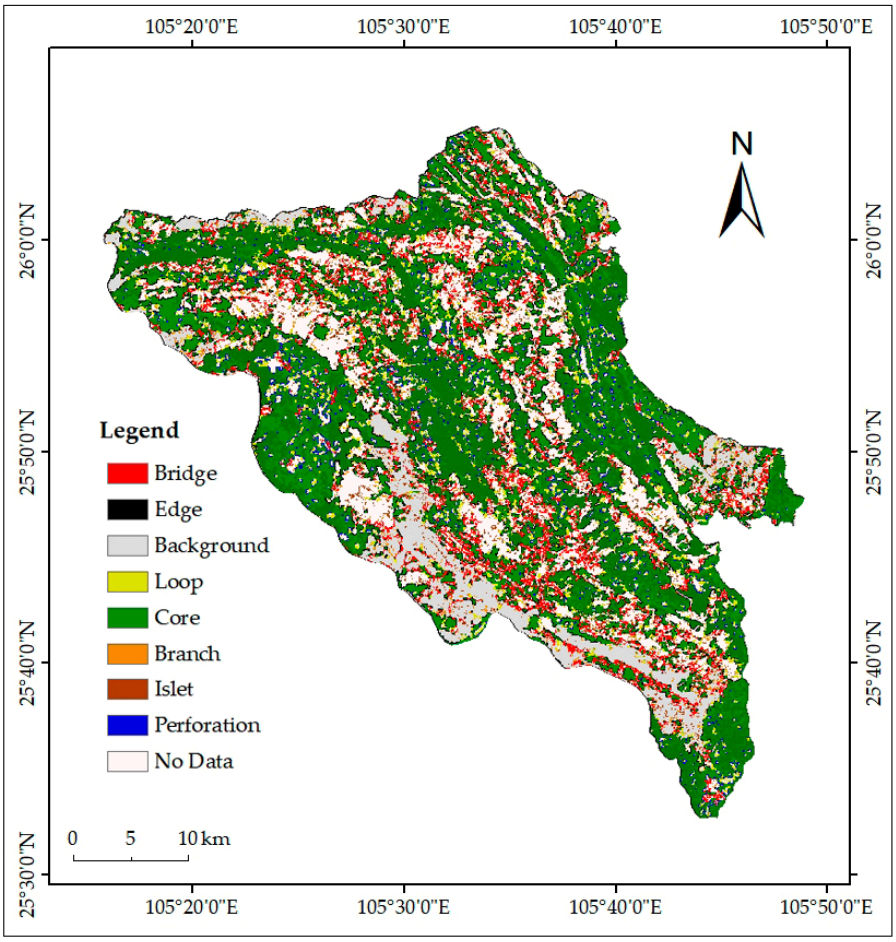


**Figure 5.** MSPA landscape type map of Guanling County.

**Table 5.** Landscape types in Guanling County.

| Landscape Type | Area ($km^2$) | Proportion of Total Area of Ecological Landscape (%) |
|---|---|---|
| Core | 608.61 | 65.73 |
| Islet | 11.71 | 1.26 |
| Perforation | 45.15 | 4.88 |
| Edge | 120.06 | 12.97 |
| Loop | 70.59 | 7.62 |
| Bridge | 31.30 | 3.38 |
| Branch | 38.53 | 4.16 |

In the analysis of landscape connectivity in Guanling County (Figure 6), the area of very high and highly connected patches was 518.26 $km^2$, accounting for 35.82% of the total area, mainly in the central, western, and eastern parts of the study area. The area of medium and low connectivity patches was 929.04 $km^2$, accounting for 64.20% of the total area, mainly distributed in the northern and southern regions of the study area, with a relatively large area and wide distribution. The landscape patches in Guanling County are relatively fragmented, and the connectivity between the landscapes is poor, which is mainly related to the special topography of the karst region.

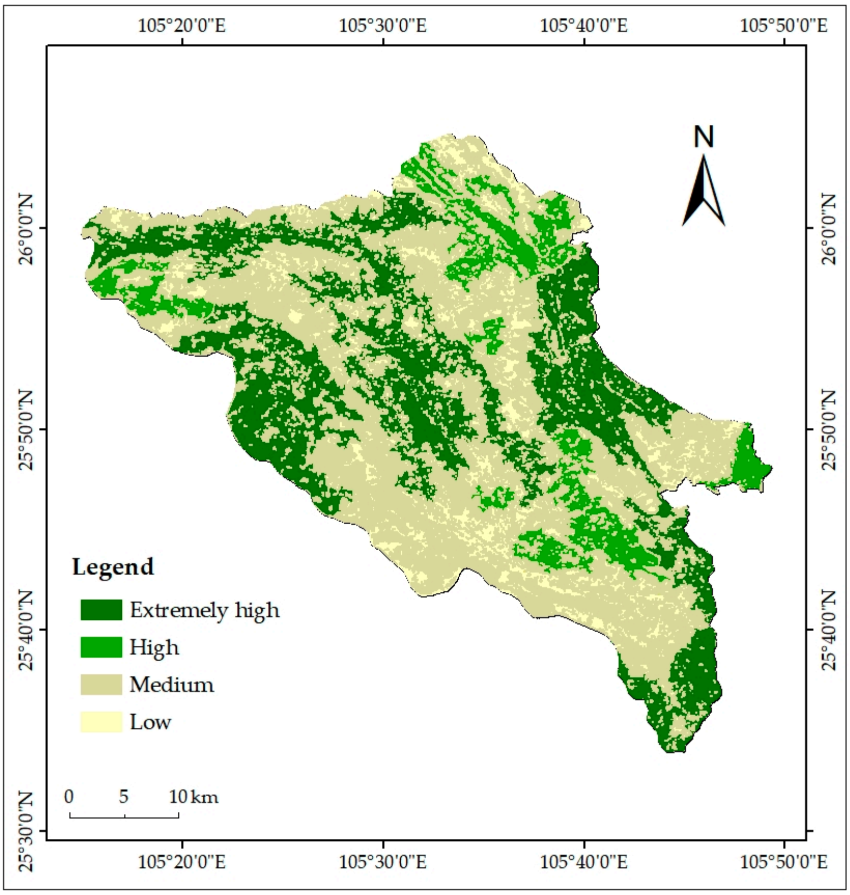


**Figure 6.** Guanling County landscape connectivity distribution map.

*3.4. Comprehensive Resistance Surface and ES*

We used the reclassification tool in ArcGIS10.8 to derive the resistance surface of seven single factors, and then superimposed these seven types of factors to find the mean value to obtain the comprehensive resistance surface distribution map of Guanling County (Figure 7). The results show that there is a high resistance area mainly located in the north, central, and south of Guanling County, and the patches in this area are fragmented and the landscape connectivity is poor. The low resistance areas are mainly located in the western and southern fringes, where the landscape connectivity is relatively good and mainly consists of woodlands and grasslands. The selection of ES sites was based on the analysis of ecosystem service importance, ecological sensitivity, and landscape connectivity in Guanling County, and the ecosystem service importance, ecological sensitivity, and landscape connectivity were divided into four levels: very high, high, medium and low, respectively. Patches with two levels, very high and high after overlaid analysis with ArcGIS, were selected as ecological source sites. Finally, 10 ESs were obtained, with an area of 387.48 $km^2$, accounting for 26.78% of the total area. As far as the landscape components are concerned, the source sites were mainly woodlands, waters, and grasslands, and the ecological values of construction land and bare land were relatively low, mostly non-source sites. In terms of distribution area, the southwest region of Guanling County had less distribution, while the central, western, and eastern regions had more distribution. The distribution of ESs was fragmented, and there were many fine patches in the area, with poor inter-patch connectivity and high landscape fragmentation, which is very unfavorable for species dispersal.

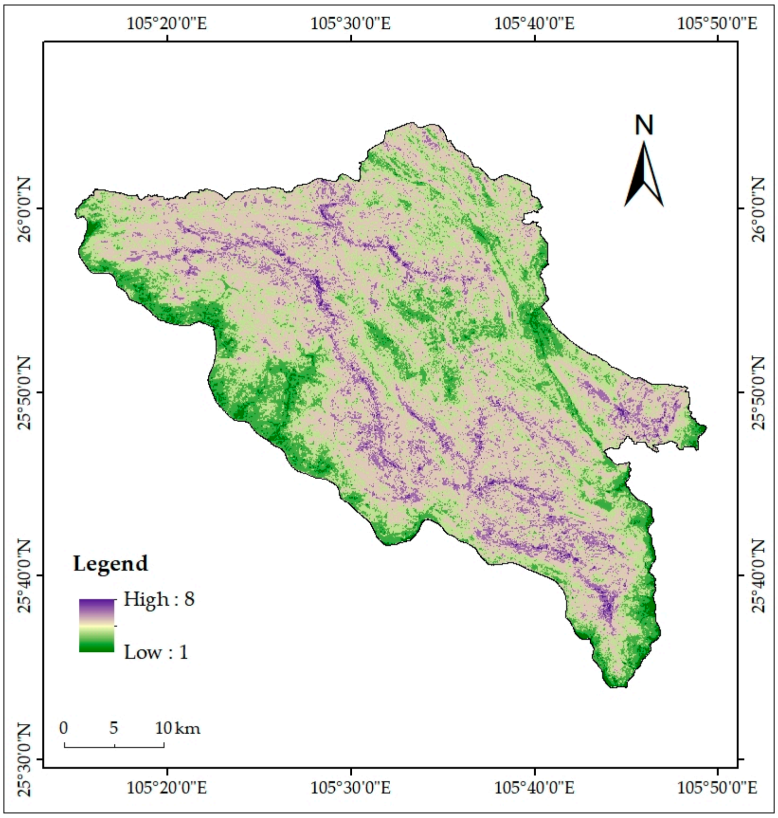


**Figure 7.** Guanling County comprehensive resistance surface distribution map.

### 3.5. EC Identification and ELSP Construction

EC are the links between each ecological source and the pathways of material flow, allowing species to avoid disturbance during migration [65]. According to the results of the ecological source distribution, using the distance analysis tool in ArcGIS10.8, combined with the comprehensive resistance surface of the study area, the minimum consumption distance between the ecological source points in the study area was calculated, and a total of 45 EC were obtained. The total length of the EC was 509.78 km, the maximum resistance value was 2.06 and the minimum resistance value was 0.23. Twenty of these ECs had resistance values above 1. Based on the gravity model, the interaction matrix between the 10 ecological source sites was constructed (Table 6), which could quantitatively evaluate the magnitude of the interaction between the source sites and discern the importance of potential ECs, and the corridors with interaction forces greater than 10 were identified as important ECs, while the rest were general ECs. The interaction between source 6 and source 8 was the largest with 168.1243, which indicates that the material exchange and transportation between the two sources were more convenient and less costly. The interaction between source 3 and 9 was the smallest at 2.2473, which indicates that the exchange between the two sources requires a higher cost distance and a higher difficulty factor for material exchange and transportation. The ELSP is mainly composed of ecological nodes and EC. Under certain social, economic development and ecological protection conditions, this pattern plays an important role in the regional ecosystem. The ELSP of Guanling County is composed of ESs and ECs (Figure 8).

**Table 6.** Interaction matrix between sources based on gravity model calculations.

| Number of Source | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 23.556 | 4.1539 | 4.7667 | 4.765 | 8.9556 | 7.954 | 9.5467 | 43.4106 | 19.5628 |
| 2 | | 0 | 7.0123 | 8.5573 | 4.9466 | 24.6238 | 24.6462 | 21.9493 | 6.4892 | 23.4465 |
| 3 | | | 0 | 22.3342 | 17.3254 | 16.2479 | 32.0352 | 10.4792 | 2.2473 | 4.4374 |
| 4 | | | | 0 | 19.6368 | 12.927 | 32.9607 | 8.1683 | 2.2863 | 3.911 |
| 5 | | | | | 0 | 10.362 | 16.8525 | 7.2889 | 2.4914 | 3.4039 |
| 6 | | | | | | 0 | 78.5538 | 168.1243 | 3.9237 | 17.3001 |
| 7 | | | | | | | 0 | 30.9580 | 3.5073 | 9.6917 |
| 8 | | | | | | | | 0 | 5.3442 | 39.4447 |
| 9 | | | | | | | | | 0 | 9.4984 |
| 10 | | | | | | | | | | |

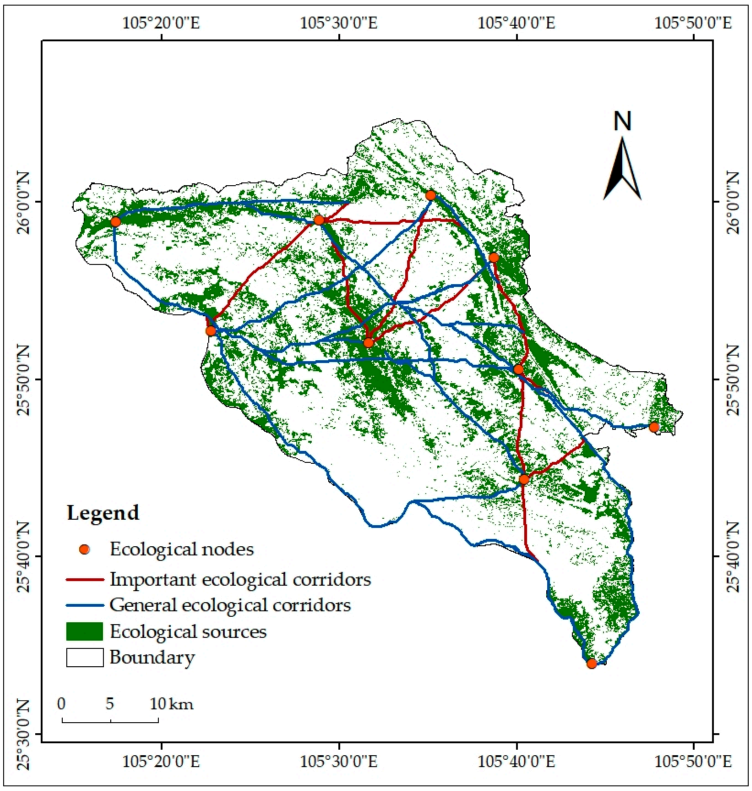


**Figure 8.** Landscape security pattern layout of Guanling County.

## 3.6. Discussion

This study combined ecosystem service values and landscape connectivity to determine the ESs, which is more scientific than previous methods and avoids the subjective selection of ESs. According to the particular topography and geomorphology in the study area and considering the influence of various factors on regional development, the five evaluation factors of rocky desertification degree, land use, NDVI, DEM, and slope were selected to analyze the sensitivity of the study area. The selection of indicators takes into account the geomorphological characteristics of the karst region, which provides a more scientific basis for the construction of the comprehensive resistance surface and the extraction of EC in the study area.

According to the results from this research, we suggest that the protection of the core source area should first be strengthened in the process of ecological land use planning. The ES is a key part of the region. The ecological source area in Guanling County is small, with a low proportion and scattered distribution, which is very unfavorable for the exchange of materials in the region. Therefore, it should be protected in the landscape planning process and development, and construction should be prohibited. Second, ECs should be established, native species should be used as much as possible, and corresponding widths should be set according to the source distribution and the topographic and geomorphic characteristics of the study area to promote species migration and minimize artificial facilities. An organic combination of the ECs identified in this study and the original corridor to form an EC system can improve landscape connectivity between patches. In corridor planning, the potential corridors identified in this study can be organically combined with the original corridors; important ECs can be built in combination with the current corridors to enhance the connectivity between the corridors and the source sites; the construction of general ECs can be combined with some scattered fragmented patches using the existing spatial pattern to increase the connectivity between the source sites. Third, we should focus on the restoration of landscape patches. The general landscape of Guanling County is relatively fragmented. In the planning process, we should focus on the reconstruction and restoration of landscape patches with poor patch connectivity and high ecologically sensitive areas to minimize human interference.

## 4. Conclusions

This research selected five factors of land use type, DEM, slope, NDVI, and rocky desertification to analyze the ecological sensitivity of Guanling County in Guizhou Province with ArcGIS10.8 software. Through the superposition of various factors, the distribution status of the ecological sensitivity of Guanling County was obtained. Based on the natural breakpoint method, the calculation results were divided into five grades: insensitive, mildly sensitive, moderately sensitive, highly sensitive, and extremely sensitive, and the distributions of seven landscape types (core, islet, perforation, branch, bridge, edge, loop) in the study area were identified. The core area was the main landscape in the study area and an important habitat for species. The total core area was 608.61 km$^2$, accounting for 65.73% of the ecological landscape area, with a wide distribution range. Using Conefor 2.6 software, the *dPC* index value of each patch was calculated, and the distribution of landscape connectivity in Guanling County was obtained and divided into four grades: extremely high, high, medium, and low. The results showed that the very high and high connectivity patches in Guanling County had an area of 518.26 km$^2$, accounting for 35.82% of the total area, and were mainly distributed in the central, western, and eastern parts of the study area; the medium and low connectivity patches had an area of 929.04 km$^2$, accounting for 64.20% of the total area, and were mainly distributed in the northern and southern parts of the study area, with a relatively large area share and wide distribution. The landscape fragmentation of Guanling County was serious, and the connectivity was poor. According to the overlay of ecosystem service importance, ecological sensitivity, and landscape connectivity in Guanling County, 10 ESs were obtained with an area of 387.48 km$^2$, accounting for 26.78% of the total area of the county. Using the distance analysis tool in ArcGIS10.8, combined with the comprehensive resistance surface of the study area, the minimum consumption distance between each ecological source point was calculated, and a total of 45 ECs were obtained. The maximum resistance value was

2.06 and the minimum resistance value was 0.23, among which 20 ECs had resistance values over 1. Based on the gravity model, the interaction matrix between 10 ESs was constructed to quantitatively evaluate the magnitude of the interaction forces between the source sites and identify the important EC and general EC in Guanling County. Together, ESs and ECs constitute the ELSP of Guanling County. In the southwest part of the study area, the connectivity of landscape patches was relatively poor, the distribution of ES was limited, and the sensitivity was high. In future planning and construction efforts, we should focus on the ecological protection of this area and reduce human interference. However, there were still shortcomings in this study: the study of EC in the study area was mainly based on the minimum cost distance, the width of the corridor was determined by many factors together, influenced by topography, climate change, etc. In this study, the article did not study the width of the corridor in detail because we were limited by the data acquisition and, at the same time, there was not enough time to conduct detailed experiments. The width of the corridor has an important impact on the ecological function of the landscape [66]. Future research will address these inadequacies to improve the scientific accuracy of the study.

**Author Contributions:** Conceptualization, B.Y. and T.L.; methodology, B.Y. and T.L.; software, T.L. and L.K.; validation, B.Y., T.L. and L.K.; formal analysis, B.Y. and T.L.; investigation, T L., S.L. and R.S.; resources, B.Y. and K.X.; data curation, T.L. and L.K.; writing—original draft preparation, B.Y. and T.L.; writing—review and editing, B.Y. and F.Z.; project administration, B.Y.; funding acquisition, B.Y. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research was funded by the National Natural Science Foundation of China (42261056, 42061028); the Key Science and Technology Program of Guizhou Provence: Poverty alleviation model and technology demonstration for eco-industries derivated from the karst desertification control (No. 5411 2017 Qiankehe Pingtai Rencai); the Oversea Expertise Introduction Program for Discipline Innovation of China: Overseas expertise introduction center for South China Karst eco-environment discipline innovation (No. D17016).

**Data Availability Statement:** Data supporting this study can be obtained from the Chinese Academy of Sciences Data Sharing Center (https://www.resdc.cn/, accessed on 17 May 2022) and the National Ecological Science Data Center (http://www.nesdc.org.cn/, accessed on 19 February 2022).

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

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