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Comprehensive Evaluation of Eco-environmental Vulnerability in Rocky Desertification Region

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Abstract. Combined with GIS and remote sensing technology, according to the eco-environment characteristics of karst rocky desertification region, a complete ecological vulnerability evaluation index system was established. The ecological vulnerability of the research area was evaluated and analysed from three aspects, including natural environment background, population characteristics, human-land relationship, and the index weight was determined by entropy method and coefficient of variation method, and the comprehensive evaluation results were obtained by comprehensive index method. The results showed that more than 80% of the regions in the study area had reached the moderate vulnerability level, and nearly 1/6 of the regions were severely vulnerable areas, showing a significant increase in distribution from east to west. Ecological vulnerability shows a significant effect of human-land relationship. With the increase of vulnerability level, the proportion of desertification area increases significantly.

1. Introduction

In the past several decades, as the population and economy growth, a great decrease in the land resources area at a fast speed and a clear difference in land-use change among geographic regions^[1]. Significant amount of high quality cultivated land was converted into developed land, the surface morphology is completely destroyed, and land resources eco-environment vulnerability has been increased^[2-4]. The ecological problems of karst mountainous areas have a very important impact on local economy and ecology. The disordered exploitation and utilization of karst land by human aggravate its relative ecological fragility^[5]. Therefore, it is imperative to evaluate its ecological vulnerability, which provides corresponding technical and data support for the subsequent development, utilization, recovery and protection of resources.

In order to prevent the continuous deterioration of the eco-environment, it provides decision-making methods for the rehabilitation and reconstruction of the degraded eco-environment system, so as to realize the sustainable development and utilization of resources and environment.



2. Materials and Methods

2.1 Study area

Our study area is located in the southern Yunnan, which is one of the most important rocky desertification areas. It covered an area of 7.48 million km², the entire 30 counties in Yunnan province, China (Figure 1), situated at a latitude between 22°17' and 26°06', and a longitude between 101°52' and 108°56', representing the rocky desertification is the most concentrated area. The annual average temperature is 12.5°C, and average annual precipitation is 1500 mm. Total evaporation is 1200 mm per year, three times more than annual precipitations, and typical of the subtropical and tropical plateau monsoon climate. The soil parent material mainly consists of laterite and krasnozems.

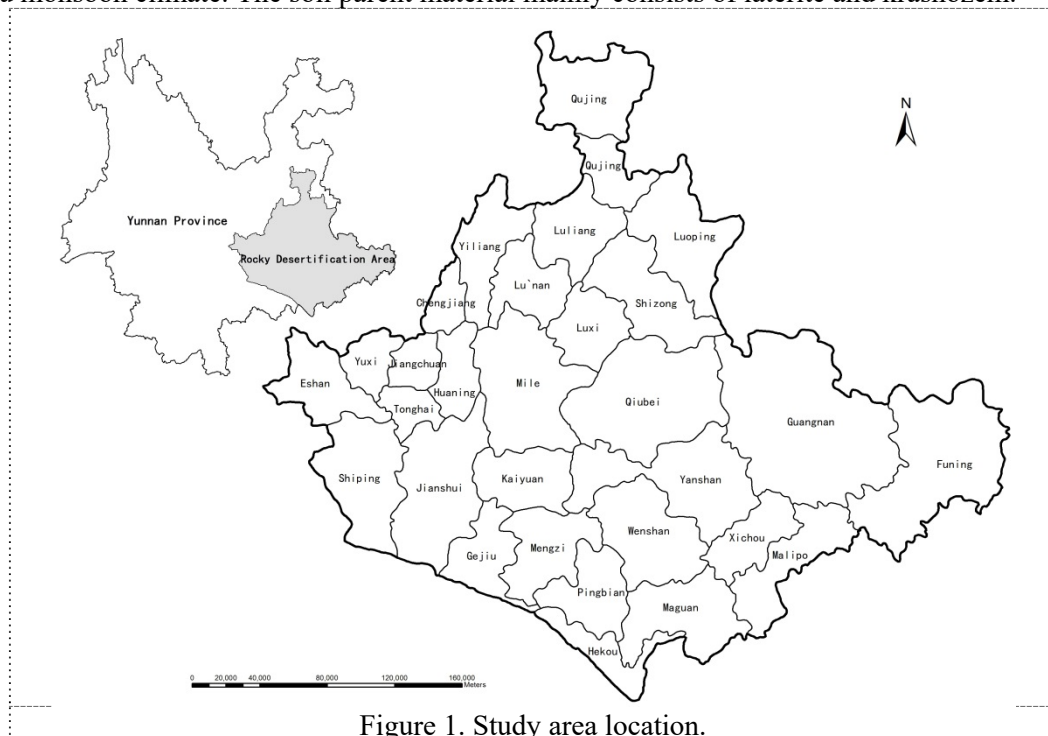


Figure 1. Study area location.

2.2 Evaluation index system

Under the guidance of person relations theory, according to the eco-environment change, evolution, to comprehensively consider the effect of the possible factors and optional factors of systematic, holistic and comparability, from natural environment background index, population characteristics index, index of relation between people and land class finally identified including 23 evaluation index system of evaluation index of eco-environment vulnerability (Table 1).

2.3 Research methods

2.3.1 Data standardization. Due to the different dimensions, orders of magnitude and properties of indicators, the original data need to be standardized to make the data comparable. The commonly used standardization methods include "extremum method", "averaging method", "efficiency coefficient method", "standardization treatment method", etc. In this paper, the method of range standardization is used to standardize the original data. When the larger the index value is, the more favorable the land use and eco-environment will be. When the smaller the index value is, the better the land use and eco-environment are, the negative index calculation formula is used to standardize the original data.

Table 1. Evaluation index system

| Index category | Index factor |
|--------------------------------|---|
| natural environment background | Carbonate outcrop area |
| | Mean altitude |
| | The terrain slope |
| | Surface fluctuation |
| | Average rainfall |
| | The average temperature |
| | Drainage density |
| | Surface runoff |
| | Vegetation coverage |
| | Rocky desertification area |
| Population characteristics | Soil type |
| | population density |
| | GDP per capita |
| | Per capita grain output |
| human-land relationship typ | Per capita arable land |
| | Land reclamation rate |
| | Soil erosion area index |
| | Soil erosion area index |
| | Degree of land use |
| | Degree of exploitation of mineral resources |
| | Road density |
| | Residential density |

The larger and better the positive index is, the following formula is used for standardization:

$$x'_{ij} = \frac{x_{ij} - \min(x_{ij})}{\max(x_{ij}) - \min(x_{ij})} \quad (1)$$

The smaller and better the negative index is, the following formula is used for standardization:

$$x'_{ij} = \frac{\max(x_{ij}) - x_{ij}}{\max(x_{ij}) - \min(x_{ij})} \quad (2)$$

2.3.2 Index weight determination. The weight of the index is to distinguish the reflection of each index to different important degrees of the evaluation system. Whether the weight is scientific and reasonable will directly affect the accuracy of the evaluation results. Therefore, how to determine the weight coefficient is one of the core problems of the evaluation. So far, there are two main methods to determine weights: subjective weighting method and objective weighting method. Subjective weighting method is a method for decision analysts to weight the subjective importance of various indicators based on their own experience. The more common methods include Delphi method (expert scoring method), binomial coefficient method, AHP method (analytic hierarchy process), etc. Objective weighting method is a method to determine the weight simply by using the objective information of index attributes and the fixed calculation method, including entropy method, complex correlation coefficient method and principal component analysis method. Considering that subjective weighting method is easy to be affected by researchers' subjective judgment and their own knowledge system and other factors and has great limitations, this paper chooses objective weighting method to calculate the weight value of water and soil resource utilization and eco-environment system indicators. Entropy method and coefficient of variation method were used to assign weight respectively, and then the average value of the two methods was taken to determine the weight value of each evaluation index in this paper.

Standardization of all index data is defined based on the following formula:

$$Y = \{y_{ij}\} m \times n \quad (3)$$

$$y_{ij} = \frac{x'_{ij}}{\sum x'_{ij}} \quad (4)$$

Calculate the entropy value of the evaluation index:

$$e_j = \frac{-1}{\ln m} \times \sum y_{ij} \ln y_{ij} \quad (5)$$

Calculate the difference coefficient of evaluation indexes:

$$g_i = 1 - e_i \quad (6)$$

Determine the weight of evaluation indicators:

$$w_j = \frac{g_i}{\sum g_i} \quad (7)$$

Table 2. Evaluation index weights

| Index category | Index factors | weights |
|--------------------------------|---|---------|
| natural environment background | Carbonate outcrop area | 0.0866 |
| | Mean altitude | 0.0432 |
| | The terrain slope | 0.0811 |
| | Surface fluctuation | 0.0334 |
| | Average rainfall | 0.0473 |
| | The average temperature | 0.0407 |
| | Drainage density | 0.0303 |
| | Surface runoff | 0.0507 |
| | Vegetation coverage | 0.0807 |
| | Rocky desertification area | 0.0314 |
| Population characteristics | Soil type | 0.0268 |
| | population density | 0.0459 |
| | GDP per capita | 0.0341 |
| | Per capita grain output | 0.0285 |
| | Per capita arable land | 0.0563 |
| human-land relationship typ | Land reclamation rate | 0.0874 |
| | Soil erosion area index | 0.0516 |
| | Soil erosion area index | 0.0434 |
| | Degree of land use | 0.0384 |
| | Degree of exploitation of mineral resources | 0.0321 |
| | Road density | 0.0314 |
| | Residential density | 0.0308 |

3. Data processing and research results

Regional eco-environment vulnerability assessment is a contains some of environment elements of the regional eco-environment vulnerability assessment, the environmental characteristic refers to it may encounter natural or man-made response characteristics of the stress sensitivity when ecological degradation than under the existing social economy and technology level can maintain the long-term usage and development of human beings, known as the vulnerability eco-environment. IN this evaluation, eco-environment vulnerability is divided into five levels: potential vulnerability, mild vulnerability, moderate vulnerability, severe vulnerability and extreme vulnerability (Table 3).

Table 3. Evaluation results levels

| levels | Vulnerability degrees |
|-------------------------|-----------------------|
| Potential Vulnerability | 0.80-1.00 |
| Mild Vulnerability | 0.60-0.80 |
| Moderate Vulnerability | 0.40-0.60 |
| Severe Vulnerability | 0.20-0.40 |
| Extreme Vulnerability | 0.00-0.20 |

According to the score and weight of each index, the eco-environment vulnerability value of the counties in southeast Yunnan was calculated. According to the comprehensive evaluation results and the principle of maximum membership, the eco-environment vulnerability degree of 30 karst counties was graded (Figure 2, Table 4). According to the division results, there are 4 extremely vulnerable counties, 4 severely vulnerable counties, 8 moderately vulnerable counties, 7 mildly vulnerable counties and 7 generally vulnerable counties in the 30 counties in the region.

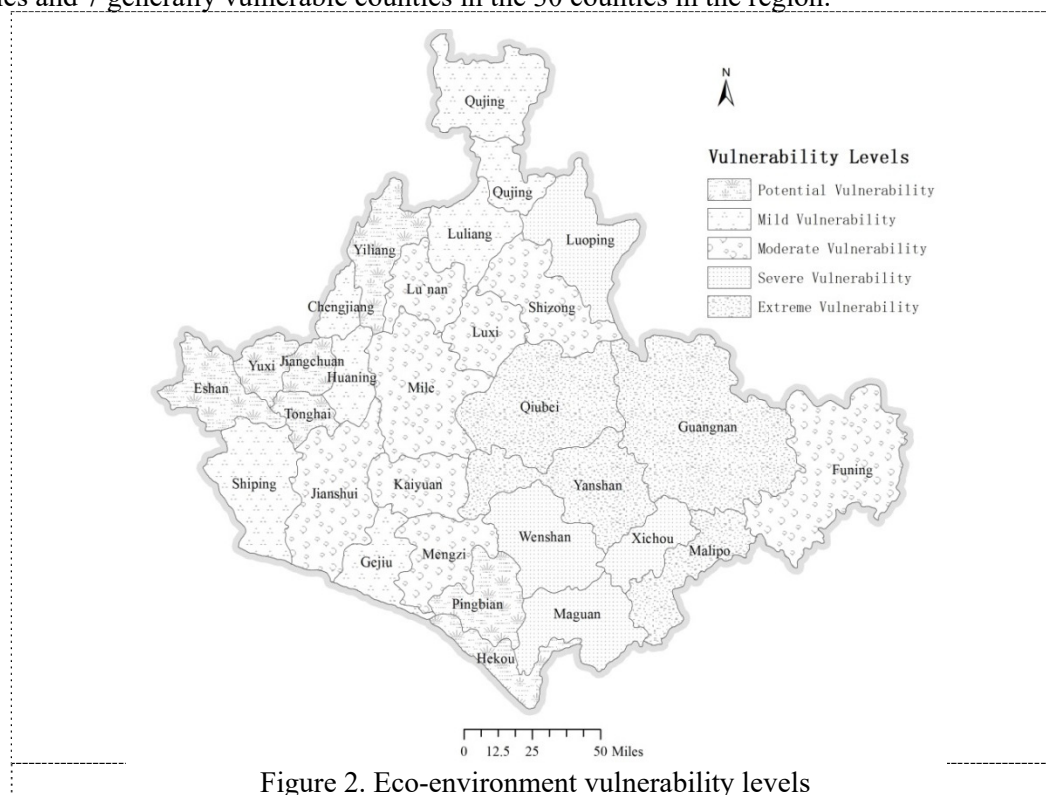


Figure 2. Eco-environment vulnerability levels

Table 4. Evaluation results of Karst vulnerability eco-environment

| levels | Vulnerability areas include counties (cities, districts) | Characteristics |
|-------------------------|--|--|
| Potential Vulnerability | Tonghai, Jiangchuan, Hongta, Eshan, Yiliang, Hekou, Pingbian | The surface vegetation covers well and is less affected by human activities |
| Mild Vulnerability | Huaning, Gejiu, Chengjiang, Zhanyi, Qilin, Luliang, Shi ping | Mountainous and forested areas are vast, forests have a good capacity to conserve water, and they are rich in water, heat and land resources |
| Moderate Vulnerability | Funing, shizong, luxi, maitreya, kaiyuan, jianshui, mengzi, shilin | Terrain is complex, forest water conservation capacity is poor, easy to occur soil erosion |
| Severe | Wenshan, ma guan, xichou, | Mountainous and Rocky Mountains have large areas, |

| | | | |
|-----------------------|---------------------------|---------|---|
| Vulnerability | luo ping | | uneven rainfall distribution, less land suitable for crop growth and unbalanced natural resources and socio-economic development |
| Extreme Vulnerability | Guangnan, Yanshan, Malipo | Qiubei, | The natural environment is severely affected by human activities, with steep mountain slopes, wide karst distribution, poor land, poor agricultural production conditions, serious vegetation damage and slow economic growth |

As it can be seen from Figure 2, from the perspective of spatial distribution, the extremely vulnerability eco-environment and its intensity are mainly concentrated in areas such as Guangnan county, Yanshan county, Malipo county, Wenshan city and Maguan county of Wenshan and Honghe states, which all belong to areas with serious rocky desertification. On the one hand, the degree of social and economic development is relatively slow, and the ecological sensitivity is relatively high. At the same time, this region has a high population density, is a gathering place of ethnic minorities in Yunnan province, a small per capita arable land area, a large demand for construction land, and a strong economic driving force for unreasonable land development and utilization, which are the main reasons for the vulnerability eco-environment. Eco-environment moderate vulnerability areas are mainly distributed in Funing, division, stone forest and other regions, mountain and big stone mountain area, these areas rainfall distribution, suitable for crop growth of the land area of less, natural resources and unbalanced social and economic development, eco-environment vulnerability and mild vulnerable area mainly concentrated in the sea, Jiangchuan county, Hongta, Eshan, appropriate is good, estuary region, because of the low carbonate area percentage, and relatively high forest coverage, the eco-environment in a relatively stable state.

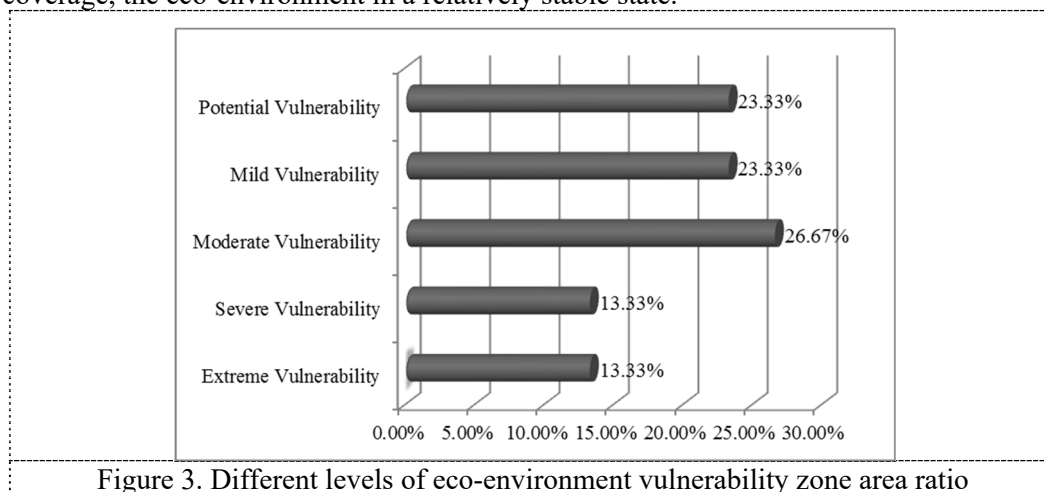


Figure 3. Different levels of eco-environment vulnerability zone area ratio

4. Conclusion

The ecological and environmental vulnerability assessment results of 30 karst counties (cities and districts) in southeast Yunnan showed that there were 4 extremely vulnerable counties, 4 severely vulnerable counties, 8 moderately vulnerable counties and 7 mildly vulnerable counties, showing a situation of small at both ends and large in the middle. The eco-environment vulnerability of karst region in southeast Yunnan reflects the comprehensive effect of special natural factors and human activities. Due to the many and complex factors affecting the eco-environment and the difficulty of karst vulnerability environment governance, the evaluation results were comprehensively analysed and combined with the principle of regional conjugation to summarize the characteristics of karst rocky desertification eco-environment vulnerability areas in southeast Yunnan, which were mainly reflected in the following aspects: (1) thin soil layer, low fertility, lack of arable land and small environmental capacity; (2) obvious soil erosion and serious soil erosion; (3) the phenomenon of rocky desertification is

serious and the trend of rocky mountain desertification is intensified;(4)dual spatial structure, easy to form a series of vulnerability environmental problems such as drought and waterlogging.

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