Analysis of Temporal and Spatial Evolution of Rocky Desertification Sensitivity in Tongren, Guizhou Province

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Abstract. Based on the image data of Tongren in 1996, 2003, 2011 and 2017, spatial analysis and mathematical statistics were used to analyse the spatial and temporal evolution of the rocky desertification sensitivity in Tongren in the past 20 years. Combining the current status of rocky desertification sensitivity, grading sensitive regions and proposing corresponding treatment suggestions. The results showed that: (1) The sensitivity of rocky desertification in the western regions was relatively high. From 1996 to 2017, the slightly and moderately sensitive areas increased first and then decreased. It can be seen that low sensitivity regions has achieved remarkable improvement in recent years; while the areas of highly sensitive and extremely sensitive decreased first and then increased, whose regulation need to be strengthened. (2) The trend of rocky desertification sensitivity of some regions has improved while the others has deteriorated to some extent. The area of slight improvement and slight deterioration is the largest, which meant the governance is occurring while the destruction phenomenon still exists. The sensitive and insensitive conversion areas are small, while the different degree of sensitivity are relatively large. (3) The prevention and control of the karst regions in Tongren is divided into three levels, the area of level 1 to 3 is 5539.14km², 3450.89km² and 2879.37km² respectively, aim to each level we proposed corresponding measures to guide the restoration of rocky desertification in the southwest karst area.

1. Introduction

Rocky desertification refers to the problems of the destruction of the original fragile land caused by the unreasonable activities of human beings, and the exposure of bedrock is not conducive to crop growth. The karst regions in southwestern China are densely populated and the terrain is dangerous. The process of reclamation of steep slopes and irrational farming due to conflicts between people and land has caused serious soil erosion and rocky desertification. The impact of rocky desertification on agricultural returns has become an important factor restricting the socio-economic development of the regions. Rocky desertification sensitivity aims to clear the regions prone to rocky desertification under natural conditions and distribution of different levels. It helps to understand the current status of susceptibility to rocky desertification and its dynamic changes, and scientifically controls rock desertification.

In recent years, some domestic scholars began to explore the field of rocky desertification sensitivity, collected and quantified evaluation indicators from large-scale to small-scale to meet their research demands. Fan studied the sensitivity of rocky desertification in Southwest China, and selected...
lithology, land use, slope and annual precipitation as evaluation indicators. It was found that the sensitivity of rocky desertification in southwest karst regions was mainly mild and moderate. Xie\cite{5} selected the exposed regions, slope and vegetation coverage of carbonate rocks, evaluated the current status of rocky desertification sensitivity in Guizhou Province, and delineated the ecological protection red line for regions with extreme rocky desertification sensitivity. Xiong \cite{6} used GIS to evaluate the sensitivity of rocky desertification in Nanning City, and divided it into general sensitive regions, sensitive regions and extremely sensitive regions. At present, there are few research results about the dynamic change of rocky desertification sensitivity. Most of them took the levels of rocky desertification sensitivity as the object of dynamic change description \cite{7-15}, which couldn’t truly reflect the evolution of rocky desertification sensitivity to some extent and affect the results of dynamic analysis of rocky desertification.

Tongren located in the hinterland of Wuling Mountain, is the key target of national rocky desertification control and the key regions of poverty alleviation and development. Therefore, based on the remote sensing image of the study region, this paper identifies and evaluates the main influencing factors of rocky desertification sensitivity, generates the sensitivity distribution map of 1996, 2003, 2011 and 2017 respectively, analyzes the sensitivity transfer of different degrees through the transfer matrix, discovers the spatial and temporal evolution rule of rocky desertification sensitivity during the past 20 years, guides the restoration of ecological functions in key protected regions.

2. Overview of the study region
Tongren is located in the northeast of Guizhou, between 107°46′-109°25′E and 27°07′-29°05′N. It governs Bijiang, Wanshan, Jiangkou, Shiqian, Sinan, Dejiang, Yuping, Songtao, Yanhe and Yinjiang, with a total area of 18003km$^2$. The climate of Tongren is characterized by obvious monsoon climate and vertical difference. The annual average temperature is 13-17.5°C, and the annual average precipitation is 1110-1410mm. Due to the influence of parent rock, geology, altitude, climate and other factors, the soil types in Tongren are mainly yellow soil, lime soil, red soil, yellow brown soil and purple soil.

Figure 1. Location map of study district
3. Data source and research methods

3.1. Data source
The data mainly includes Tongren administrative area map, digital elevation model data (30M resolution), karst data from Karst data center (http://www.karstdata.cn/), 1:1 million soil type data from resource and environment science data center of Chinese Academy of Sciences (http://www.resdc.cn/), landsat5 TM image in 1996, 2003 and 2011 and landsat8 OLI in 2017 remote sensing image from USGS data center (https://earthexplorer.usgs.gov/).

3.2. Classification of rocky desertification sensitivity
According to National Ecological Protection Red Line—Technical Guide for Delineating Ecological Function Red Line (Trial) [17] and reference [18], relying on the natural conditions, lithology, slope, vegetation coverage and soil type were selected as the classification indexes of rocky desertification sensitivity. In accordance with Ecological Function Zoning Technical Specifications [19], the sensitivity degree of rocky desertification in the study regions was divided into insensitive, slightly sensitive, moderately sensitive, highly sensitive and extremely sensitive. Evaluation indexes and classification criteria are shown in Table 1.

### Table 1. The evaluation indexes of rocky desertification sensitivity

| Evaluation indexes | Insensitive | Slightly sensitive | Moderately sensitive | Highly sensitive | Extremely sensitive |
|--------------------|-------------|--------------------|---------------------|-----------------|-------------------|
| Lithology          | Non-karst   | karst              | karst               | karst           | karst             |
| Slope              | ≤5°         | 5°~15°             | 16°~25°             | 26°~35°         | >35°              |
| Vegetation coverage| ≥70%        | 50°~70%            | 30°~50%             | 20°~30%         | <20%              |
| Soil type          | irrigation soil | mountain soil | lime (rock) | yellow soil,yellow soil | purple soil |

3.3. Information extraction of rocky desertification sensitivity
Among them, lithology is the main factor to evaluate the of rocky desertification sensitivity. The karst is the distribution of karst landform, and the non-karst landform is not the sensitive regions of rocky desertification [20]. The karst area is 11869.4km², accounting for 66% of the entire study region. The karst landform distribution is shown in Figure 2. The slope is extracted from the DEM. The slope is greater than 25°, which may lead to highly sensitive and extremely sensitive [21]. Soil erosion directly affects the degree of loss, which leads to rocky desertification. Yellow soil accounts for 57% of the total soil area of the study region and is very sensitive to soil erosion. Based on the soil type distribution map (Figure 4) and graded according to the degree of possible rocky desertification sensitivity [22]. The classification of slope is shown in Figure 3. VFC is calculated by formula (1), and the vegetation coverage classification map (Figure 5) is obtained according to the possible degree of rocky desertification sensitivity [23].

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VFC = \frac{(NDVI_{soil} - NDVI_{\text{min}})}{(NDVI_{\text{max}} - NDVI_{soil})}
\]  

Where: NDVI_{soil} is the NDVI minimum and NDVI_{max} is the NDVI maximum in the image.
Figure 2. Distribution of Karst landform

Figure 3. Classification of slope

Figure 4. Distribution of soil types

Figure 5. The classification of vegetation cover

4. Result and analysis

4.1. Temporal and spatial evolution of rocky desertification sensitivity

The area of insensitive area of rocky desertification is the largest, and the overall area of sensitive intensity is highly sensitive > moderately sensitive > slightly sensitive > extremely sensitive. The process of spatio-temporal evolution of rocky desertification is not only a deduction in time series, but also a conceptual expression in space [25,26]. From the interpretation of time series in 20 years, the sensitive area of slight and moderate rocky desertification increased first and then decreased, from 6306.59km² in 1996 to 6718.19km² in 2003, and then decreased to 6372.8km², 5884.64km² in 2011 and 2017; while the sensitive area of high and extreme rocky desertification decreased first and then increased, from 5366.51km² in 1996 to 4930.59km² in 2003, and then increased to 5322.88km², 5787.69km² in 2011 and 2017. From the perspective of the expression of the spatial concept, statistical analysis of the regions shows that there is a significant spatial difference in the sensitivity level of rocky desertification. Except a few sensitive regions of rocky desertification in the east, most of them belong to insensitive regions, while the highly and extremely sensitive regions mainly distribute in the west. There are three types of evolution in the sensitive regions of rocky desertification: (1) Increase first and then decrease, mainly including Songtao and Dejiang; (2) Reduce first then increase then decrease, mainly including Wanshan, Yanhe, Yinjiang, Yuping, Jiangkou and Bijiang, among them, the overall trend of Wanshan, Yuping, Jiangkou, and Bijiang shows a decrease in the area of rocky desertification, while the riverside and the Yinjiang show an increasing trend; (3) Reduce first and then increase, mainly including Shiqian and Sinan. The distribution of land with different sensitivity levels is extremely fragmented, and it is difficult to prevent and control. The situation of local rocky desertification control is still severe and repetitive.
Figure 6. Rocky desertification sensitivity map of Tongren during 1996-2017

Table 2. Area and proportion of rocky desertification sensitivity in different grades

| Rocky desertification sensitivity |Insensitive| Slightly sensitive | Moderately sensitive | Highly sensitive | Extremely sensitive |
|----------------------------------|-----------|-------------------|---------------------|-----------------|-------------------|
| Area/km²                         |           |                   |                     |                 |                   |
| 1996                             | 6165.40   | 1576.41           | 4730.18             | 5123.71         | 242.80            |
| Proportion/%                     | 34.56     | 8.84              | 26.52               | 28.72           | 1.36              |
| 2003                             | 6189.71   | 1944.25           | 4773.94             | 4703.85         | 226.74            |
| Proportion/%                     | 34.70     | 10.90             | 26.76               | 26.37           | 1.27              |
| 2011                             | 6142.82   | 1868.10           | 4504.70             | 5056.98         | 265.90            |
| Proportion/%                     | 34.44     | 10.47             | 25.25               | 28.35           | 1.49              |
| 2017                             | 6162.41   | 1723.27           | 4161.37             | 5448.75         | 338.94            |
| Proportion/%                     | 34.55     | 9.66              | 23.33               | 30.55           | 1.90              |

4.2. Evolution direction of rocky desertification sensitivity

4.2.1. Overall evolution direction

Table 3. The area of the evolution direction of the rocky desertification sensitivity

| Year   | Extreme improvement | Slight improvement | No change | Slight deterioration | Severe deterioration |
|--------|---------------------|--------------------|-----------|----------------------|----------------------|
| 1996-2003 | 240.84         | 1852.14           | 14333.33  | 1358.98              | 53.20                |
| 2003-2011 | 177.38         | 1673.48           | 13596.60  | 2162.04              | 228.99               |
| 2011-2017 | 262.00         | 1942.95           | 12803.90  | 2518.96              | 294.83               |
| 1996-2017 | 315.64         | 2063.18           | 12662.08  | 2504.19              | 277.55               |

The rocky desertification sensitivity in each year was divided into five grades: extreme improvement, slight improvement, no change, slight deterioration and severe deterioration. Slight improvement refers to the evolution of rocky desertification sensitivity to lower sensitivity in the vicinity, such as the transition from moderately sensitive to slightly sensitive; extreme improvement refers to the transition from rocky desertification sensitivity to the lower sensitivity, such as the transition from moderately sensitive to insensitive; slight deterioration refers to the transition from rocky desertification sensitivity to higher sensitivity in the vicinity, such as the transition from moderately sensitive to highly sensitive; severe deterioration refers to the transition of rocky desertification sensitivity to higher sensitivity, such as the transition from insensitive to highly sensitive.

It can be seen from the Table 3 that from 1996 to 2017, the area of no change was the largest (12662.08km²), followed by slight improvement and slight deterioration, and extreme improvement and severe deterioration were the least. During 1996-2003, the sensitivity of rocky desertification improved (11.73%) more than deteriorated (7.92%), the population growth was stable, and the overall trend of rocky desertification became better; in 2003-2011, the improvement (10.38%) less than deteriorated (13.4%), and the deteriorated areas were mainly distributed in the East. Affected by the continuous drought in 2006, the vegetation coverage was greatly reduced, and the sensitivity of rocky desertification was slightly sensitive and moderately sensitive, which has become highly sensitive and extremely...
sensitive; from 2011 to 2017, the improvement ratio (12.37%) is less than the deterioration ratio (15.79%), and both the improvement regions and the deterioration regions have increased. On one hand, the five-year action plan for Tongren’s rocky desertification control issued in 2010 has attracted attention to the problem of rocky desertification. At the same time, with the acceleration of urbanization, the decline of agricultural population, and ecological environment management projects, the sensitivity of rocky desertification has been greatly improved. On the other hand, the rapid economic development led to a certain rebound of rocky desertification after 2012.

4.2.2. Evolution transfer matrix

Table 4. The transfer probability matrix of various rocky desertification types

| Year       | Type          | Insensitive | Slightly sensitive | Moderately sensitive | Highly sensitive | Extremely sensitive |
|------------|---------------|-------------|--------------------|----------------------|-----------------|---------------------|
| 1996-2017  | Insensitive   | 22.60       | 17.79              | 10.77                | 1.10            | 0.25                |
|            | Slightly sensitive | 20.36       | 711.43             | 219.01               | 0.50            | 0.80                |
|            | Moderately sensitive | 28.68       | 796.12             | 1608.86              | 28.38           | 0.00                |
|            | Highly sensitive  | 0.24        | 279.50             | 1158.99              | 161.30          | 0.00                |
|            | Extremely sensitive | 0.00        | 0.41               | 6.80                 | 87.70           | 0.00                |

In order to better reflect the evolution process of rocky desertification sensitivity, the transfer matrix of rocky desertification sensitivity in different research periods was established to quantitatively study the transfer trend of rocky desertification sensitivity in different degrees [24]. From table 4, it can be seen that from 1996 to 2017, the insensitive regions were mainly transformed into the slightly sensitive and moderately sensitive regions, with an area of 20.36 km² and 28.68 km². The area from sensitive area to insensitive area is 52.25 km². The results showed a trend of improvement, but it was difficult to achieve a leap forward improvement from the highly sensitive and extremely sensitive regions to insensitive, while the slightly sensitive and moderately sensitive regions were relatively easy to change into the insensitive regions.

4.3. Classification and suggestion of rocky desertification control

Through the possibility of occurrence of rocky desertification sensitivity in 2017 and the dynamic evolution regions in 1996-2017, the classification prevention and control regions were divided into three levels: level 1 contains limit regions, level 2 contains supervision regions and level 3 contains prevention regions [27]. Division principle can be seen in Table 5.

Table 5. Standard for the Prevention and Control of rocky

| Type   | Division principle (Just satisfy one of them) |
|--------|----------------------------------------------|
| Level 1| (1) Highly sensitive regions, extremely sensitive regions; (2) The rocky desertification sensitivity change regions is severe deterioration. |
| Level 2| (1) Moderately sensitive regions; (2) The rocky desertification sensitivity change regions is slight deterioration. |
| Level 3| (1) Remaining regions |

According to the grading standards in Table 5 and the priority order of level 1, level 2 and level 3, Figure 7 was obtained. It showed that the area of level 1 was 5539.14 km². The regions of this level has been seriously damaged, and the ecological recovery capacity was weak. It needs to increase the capacity of human interference, and vigorously implement measures such as closing hills for forests and returning farmland to forests; the area of level 2 was 3450.89 km². For regions where rocky desertification was likely to occur, the supervision was mainly supplemented by governance to realize ecology and economy go hand in hand; the area of level 3 was 2879.37 km², including other parts in the sensitive regions except for level 1 and level 2. The possibility of sensitivity was relatively low, and publicity and prevention were the main factors.
5. Conclusion

Based on the Landsat remote sensing image data of Tongren in 1996, 2003, 2011 and 2017, through RS and GIS technology and mathematical statistics methods, the rocky desertification sensitivity was extracted, and its temporal and spatial characteristics and internal transfer characteristics were quantitatively studied. At the same time, the classification and suggestions of rocky desertification control were preliminarily discussed. The main conclusions are as follows:

(1) From the perspective of temporal and spatial evolution of sensitivity to rocky desertification, the area of slightly sensitive regions and moderately sensitive regions increased first and then decreased; the area of highly sensitive regions and extremely sensitive regions decreased first and then increased. In terms of spatial distribution, the sensitivity in the west was more serious than that in the east, among which Dejiang and Yanhe were the most serious in the northwest.

(2) In terms of the evolution direction of rocky desertification sensitivity, the area of slight improvement and slight deterioration was the largest. Therefore, measures must be taken to prevent the insensitive regions from turning into the sensitive regions, and to control the regions that have formed the sensitive regions of rocky desertification, so as to make them gradually develop into benign regions.

(3) The prevention and control classification of rocky desertification is a prospective work. In order to enhance the accuracy of governance and provide basis for reasonable policy-making. Combining the current situation and evolution characteristics, the study regions can be divided into three levels. Among them, level 1 area was 5539.14km², level 2 area was 3450.89km² and level 3 area was 2879.37km².

In recent years, Tongren has proposed a green land development path, and comprehensively implemented rock desertification control projects, mainly returning farmland to forests and grasslands, and curbing rocky desertification. The vegetation conditions have improved and the sensitivity of rocky desertification has improved year by year, which indicates that rocky desertification Sensitivity was affected by the artificial-natural duality. This study only considers lithology, slope, vegetation coverage, and soil as evaluation indicators. It didn’t consider the interference of human activities, so further analysis and discussion are needed in the future.

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