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ORIGINAL ARTICLE

Spatial pattern of Karst rock desertification in the Middle of Guizhou Province, Southwestern China

Qiu-Hao Huang · Yun-Long Cai

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Abstract Karst rocky desertification is a typical type of land degradation in the Southwestern China. It has great ecological and economical implications for the local people. Landsat images from the middle of Guizhou Province collected in 1974, 1993 and 2001 were used for change detection of the pattern of Karst rocky desertification. The results show the following findings: (1) Desertification area expanded drastically in 27 years, at an increasing rate about 116.2 km^2/year. (2) High areas (900–1,500 m) are the most affected. (3) Areas with the slope <5° or >25° are also easily tend to be Karst rocky deserted. (4) The process of Karst rocky desertification is nearly irreversible. Few areas of Karst rocky desertification could be meliorated to non-desertification land. (5) Most of the degraded lands are located in the south and the central of the study region, and the meliorated land areas are sparsely located in the east and the west part of the region. All these findings would provide bases for the decision-making of the local government to improve the Karst rocky desertification

Keywords Land degradation · Karst rocky desertification · Temporal–spatial pattern · The Southwestern China

Q.-H. Huang · Y.-L. Cai (✉)
Department of Resources, Environment and Geography, Center for Land Study, Peking University, Laboratory for Earth Surface Processes, The Ministry of Education, Room 3355, YiFu Building 2, Beijing 100871, People's Republic of China
e-mail: caiyl@urban.pku.edu.cn

Introduction

Karst rocky desertification is a process in which soil is eroded seriously or even thoroughly, so that bedrock is exposed widespread, carrying capacity of land declines seriously, and at last, landscape appears similar to desert under violent human impacts on the vulnerable eco-geo-environment (Yuan 1993; Yang 1995; Cai 1997; Xiong 2002).

The Karst mountain region of the Southwester China is one of the largest Karst geomorphology distributing areas in the world (Yuan 1993). It is estimated that the Karst geomorphology covers about 620,000 km^2 in this region and the ecological environment is extremely fragile (Wang and Liu 2004). The region is also overpopulated and the social economy is laggard. So people have to over-exploit land for subsistence so as to lead to serious land degradation in the form of Karst rocky desertification. This issue has attracted widely attentions of the society. The Division of Geosciences, Chinese Academy of Sciences put forward suggestions of comprehensive melioration the Karst rocky desertification in 1994 and 2003 (Division of Geosciences, CAS 1994, 2003), and the central government also coordinate and organize different rehabilitation works for anti rocky desertification at different government levels (state, Province and county) and departments (such as agriculture, forestry and water conservancy departments) (Zhu 2001).

Much research has been done on the process of Karst rocky desertification including the ecological–environmental effects (Wang 2003), cause analysis (Wang and Li 2003; Zhang et al. 2001; Zhang et al. 1999) and integrated rehabilitation (Cai 1994; Cai and Meng 1999; Huang 2000). Yet to study the spatial pattern of Karst rocky desertification is still difficult due to lack of basic monitoring data.

This paper selects the middle of Guizhou Province in the Southwestern China as the study region, using the Landsat images in 1974, 1993 and 2001 respectively to assess the spatial pattern and its change of Karst rocky desertification. The objectives of this study are the following: (1) the identification of Karst rocky desertification trend in the middle of Guizhou Province; (2) the study of spatial correlation between karst rocky desertification pattern, elevation and slope; and (3) discrimination of different levels of Karst rocky desertification.

Data and methods

Study area

Middle of Guzihou Province is located in southwestern China at approximately 25°25′–26°34′N and 105°38′–107°21′E (Fig. 1). It covers about 12,400 km^2, of which Karst areas account for 80%. Climate is warm and moist with annual temperature ranging from 14 to 16°C. Terrain in this hilly Province has an average elevation of 1,100 m above sea level. Annual precipitation averages 1,200 mm, most part during the summer (June–September). Density of population is moderate with about 370 individuals by square kilometer. The main industries are agriculture and energy production (Cai 1990). This area was selected because it is the region that the most serious Karst rocky desertification has taken place. Studying the spatial pattern of Karst rocky desertification may help the local government to develop relevant regional development policies to improve the Karst rocky desertification.

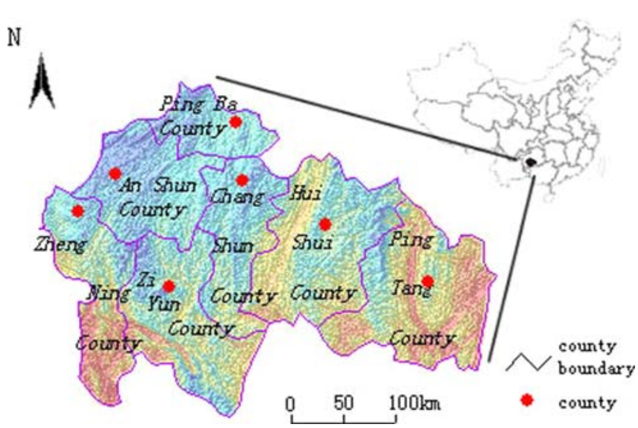

Fig. 1 Location of the study area

Biophysical factors for Karst rocky desertification classification

Xiong (2002) proposed that the Karst rocky desertification should be classified from four factors: percentage of vegetation (%), slope (°), percentage of bare rock (%) and average depth of top soil (cm). According to the factors, this paper classified the Karst rocky desertification into three levels, i.e., (1) slightly Karst rocky desertification; (2) moderately Karst rocky desertification; (3) severely Karst rocky desertification, and the threshold of each level are listed in Table 1. Image features of different levels of Karst rocky desertification studied by Yuang (1995) are also used, which is helpful for assess the Karst rocky desertification from RS image. Figure 2 shows the different levels of Karst rocky desertification.

Materials and data proceeding

Four kinds of data sources were used to setup the Karst rocky desertification maps: (1) three scenes of remote sensing imagery for the years 1974, 1993 and 2001 respectively; (2) land use maps of 1995 and 2000 with a scale of 25,000; (3) a common topographic base map of 1:100 000 scale of Guizhou Province; (4) digital elevation model (DEM) of Guizhou Province with the spatial resolution of 30 m. All these data are from Chinese Natural Resources Database (http://www.data.ac.cn/index.asp).

The remote sensing imageries were acquired in Jan 1st, 1974 (WRS1: Path137/Row42), Dec 27th, 1993 (WRS2: Path127/Row42), and Nov 23rd, 2001 (WRS2: Path127/Row42) by Landsat-1 (MSS), 5 (TM) and 7 (ETM +), respectively.

Table 1 Classification standard of Karst rocky desertification

	The standard of the Karst rocky desertification		
	Slightly	Moderately	Severely
Percentage of vegetation (%)	50–70	30–50	<30
Slope (°)	>18°	>22°	>25°
Percentage of bare rock (%)	>60	>70	>80
Average depth of top soil (cm)	<15	<10	<5
Color of the RS image[a]	Green in red	Gray in red	White, gray
Shape the RS image	Like star	Patch	Patch

Source: Xiong (2002) and Huang and Cai (2006a)

[a] Images displayed with Landsat TM bands 3, 4 and 5 (displayed as red, green and blue)

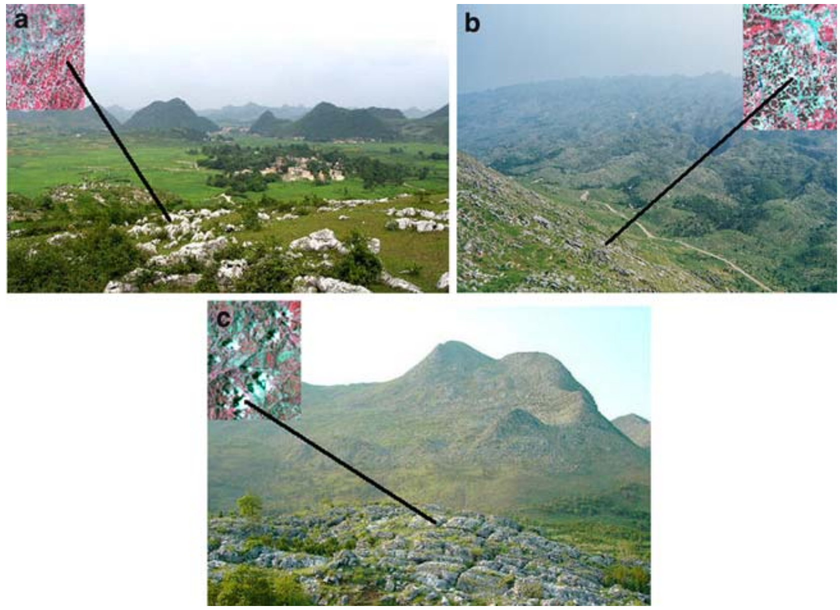

Fig. 2 Typical Karst rocky desertification in the middle of Guizhou Province. (In the corner are Landsat TM images with Landsat TM bands 3,4 and 5 displayed as *red*, *green* and *blue*.) **a** An example of slight degradation, patches of Karst rock are clearly visible. **b** An example of moderately degradation, bare Karst rock is widespread in the hillside. **c** An example of severe degradation, grass is sparsely distributed with a large proportion of Karst rock

Those images have different size of pixel, and then an intermediate size of pixels of 30 m was selected. Resampling imposed little distortion to Landsat-MSS data. In order to undertake comparative analysis among these images, images were georreferenced with the same control points for comparative reasons with Landsat TM images as reference. The number of ground control points (GCPs) used for registration varies by image, all the root mean square error (RMSE) of the registration process is less than a third of pixel (Table 2). Besides, topographic map of Guizhou Province, land use maps of 1995 and 2000 are also used in aiding precise rectification of remote sensing images and to correction of visual interpretation.

Then, all spatial data are unified to the following parameters:

Coordinate: Central Meridian: 105°; Standard Parallel 1: 25°; Standard Parallel 2: 47°;
Projection: Albers Equal Area Conic; Spheroid: WGS 1984; Datum: WGS 1984.

Table 2 Characteristics of image used in the study

	Image type	Number of GCPs for registration[a]	Geometric registration RMSE[b]
Jan 1st, 1974	MSS	20	±0.25
Dec 27th, 1993	TM	16	Master image
Nov 23rd, 2001	ETM+	20	±0.27

[a] Ground control points

[b] Root mean square error of *x*, *y* coordinates

Because different levels of karst rocky desertification show different features in remote sensing image (Table 1 and Fig. 2). Maps of karst rocky desertification in 1974, 1993 and 2001 was genereated by using supervised classifications of RS software. Finally, the classified classes in each image were grouped into eight land cover categories: farmland, forest, grassland, water body, build-up, slightly, moderately and severely karst rocky desertification. The classification accuracy is 85%, which is acceptable for this research. All the spatial analysis are done in ARCGIS environment. And software used in this study are PCI®9.1 and ARCGIS® 8.3.

Result and discussion

Karst rocky desertification expanded during 27 years according to remote sensing evalutions performed here (Fig. 3). Desertification area was about 1,401 km^2 in

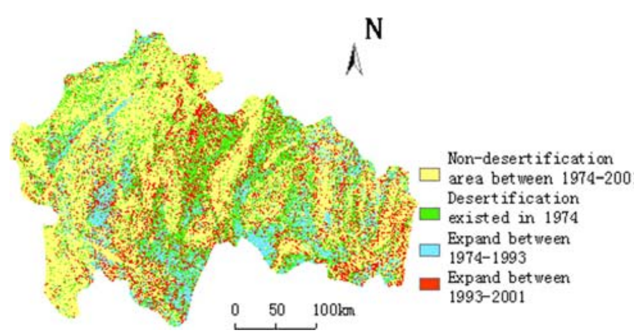

Fig. 3 The expanding Karst rocky desertification in the middle of Guizhou Province (1974–2001)

1974 (11% of the study area), it increased for 4,005 km^2 in 1993 (32%) and then it reached 4,538 km^2 in 2001 (37%), that means an average rate of 116 km^2/year (0.9%/year).

Table 3 reveals temporal change of land use types from 1974 to 2001. During this period areas of farmland, forest, grassland and water all decreased, while areas of build-up and Karst rocky desertification increased. Especially during 1974–1993, the increasing rates of Karst rocky desertification are quite high. Figure 4 is a map of Karst rocky desertification expansions from 1974 to 1993. The map shows that most of the farmland converted located in *Zi Yun County*, which is a typical agricultural county in the middle of Guizhou Province. The reason causing the fast desertification lies in the population pressure. Like other counties in the middle of Guizhou Province, the density of population of *Zi Yun County* is rather high, and the cultivated land per capita is only 0.06 ha (Huang et al. 2006). Even more the cultivated land productivity is extremely low (the average yield of grain is only about 2,265 kg/ha, much lower than the national average) and unable to meet the basic needs of materials and energy for life and production. Under the pressure of population growth, local people have to destroy forests and reclaim mountain lands in order to make a living. They also tend to cultivate steeper slopes, which lead to soil erosion and even Karst rocky desertification.

Distribution of Karst rocky desertification in different elevation

It is also important to study the relationship between distribution of Karst rocky desertification and elevation. Table 4 shows the Karst rocky desertification expansion in different elevation between 1974 and 2001. From the table, the area with elevation between 900–1,500 m is the most fragile area that Karst rocky desertification taken place. In 1974, Karst rocky desertification distributed in this area accounts for

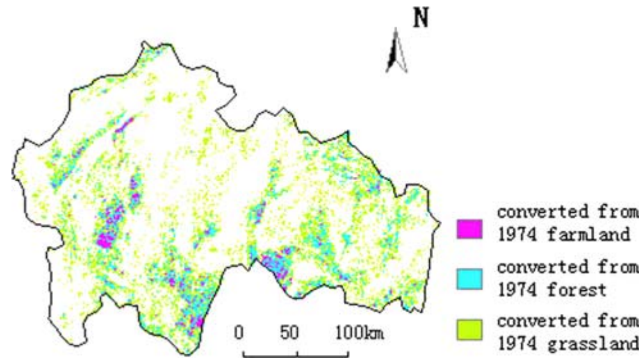

Fig. 4 Karst rocky desertification expansions from 1974 to 1993

11.3% of the total area, while in 1993 the ratio is 30.4%, and in 2001 the ratio changes to 33.4%. In nearly 27 years the Karst rocky desertification expanded about 2,698.3 km^2. Therefore this area is the key area to monitoring and mitigating the Karst rocky desertification. Besides, the area between 600–900 m is also an area worthy of attention. The change rates of this area in two time periods are quite high.

The relationship between Karst rocky desertification distribution and slope

Slope is one of the main factors resulting in topsoil erosion. In Karst mountain area southwest China, areas with slope >15° are not suitable for farming because it would accelerate soil erosion, which would change the farmland into barren soil. The central government also promulgate decrees that farmland with slope >25° must be changed into forest or grassland to protect topsoil, and areas with the slope <5° is nearly suitable for all kinds of land use (Huang and Cai 2006b). Therefore the intervals for slope are designed according to unique terrain and suitability of land use and the slope are classified into four levels to highlight the threshold of 5°, 15° and 25°. With the increase of the gradient, the topsoil is unstable and tends to be

Table 3 Temporal change of land use types in middle of Guizhou Province (1974–2001) (unit: km^2)

	1974	1993	2001	Annual change rate 1974–1993 (%)	Annual change rate 1993–2001 (%)
Farmland	1450.8	1128.4	868	–1.17	–2.88
Forest	4253.2	3273.6	2,976	–1.21	–1.14
Grassland	4600.4	3323.2	2,852	–1.46	–1.77
Water	37.2	24.8	24.8	–1.75	0.00
Build-up	657.2	756.4	1,116	0.79	5.94
Slightly desertification	669.6	1,736	2033.6	8.38	2.14
Moderately desertification	607.6	1711.2	1773.2	9.56	0.45
Severely desertification	124	446.4	756.4	13.68	8.68

Table 4 Distribution of Karst rocky desertification in different elevations (unit: km^2)

	1974	1993	2001	1974–1993 change	1993–2001 change
<600 (m)	1.21 (km^2) (0.01%)	3.41 (0.03%)	9.35 (0.08%)	2.2 (181.82%)	5.94 (174.19%)
600–900	70.66 (0.57%)	177.94 (1.44%)	355.54 (2.87%)	107.28 (151.83%)	177.6 (99.81%)
900–1,200	743.81 (6.00%)	1708.1 (13.77%)	1970.83 (15.89%)	(129.64%) 964.29	262.73 (5.38%)
1,200–1,500	653.14(5.27%)	2067.54 (16.67%)	2124.25 (17.13%)	1414.4 (216.55%)	56.71 (2.74%)
<1,500	19.53 (0.16%)	42.34 (0.34%)	53.56 (0.43%)	22.81 (116.79%)	11.22 (26.50%)

Table 5 Distribution of Karst rocky desertification in different slope (unit: km^2)

	1974	1993	2001	1974–1993 change	1993–2001 change
<5°	256.71 (2.07%)	1116.3 (9.13%)	1135.89 (11.39%)	859.59 (334.85%)	19.59 (1.75%)
5–15°	362.45 (2.92%)	813.43 (6.56%)	933.35 (7.53%)	450.98 (124.43%)	119.92 (14.74%)
15–25°	127.1 (1.02%)	434 (3.50%)	484.31 (3.91%)	306.9 (241.46%)	50.31 (11.59%)
>25°	649.15 (5.24%)	1481.59 (11.95%)	1713.72 (13.82%)	832.44 (128.24%)	232.13 (15.67%)

eroded by runoff, which lead to Karst rocky desertification finally. Table 5 shows that most of Karst rocky desertification are located in areas with slope <5° or >25°. It is easy to understand that areas with slope >25° have few of vegetation to conserve soil and water. As to area with slope <5°, one of the explanations is that the plain terrain are suitable for agricultural use, such as grazing or farming. But due to overuse of these lands, the irrational land use accelerates the process of the topsoil erosion.

The characteristic of conversion of different levels of Karst rocky desertification.

Table 6 shows the conversion of different levels of Karst rocky desertification from 1974 to 2001. It suggests that the process of Karst rocky desertification is nearly irreversible. Once the land degraded, few of Karst rocky desertification could be converted to non-desertification land. Figure 5 is a map showing land degradation during 1974–2001. It indicates that in south and central region the land degraded, and the meliorated land areas are sparsely located in the east and west part of region. The map also prove the land degradation is the main trend during 1974 to 2001.

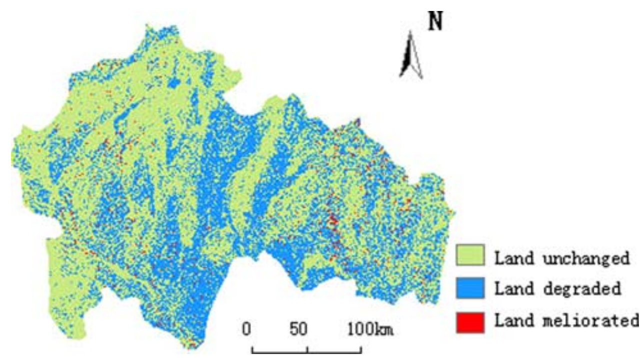

Fig. 5 The map of land degradation between 1974 and 2001

Table 6 Desertification levels transition proportion (%) (1974–1993–2001)

		Slightly (%)	Moderately (%)	Severely (%)	Non-desertification (%)
		1993			
1974	Slightly	33.05	37.87	29.06	0.02
	Moderately	30.42	45.00	24.33	0.25
	Severely	12.29	33.80	53.89	0.02
	Non-desertification	11.65	7.32	3.36	77.67
		2001			
1993	Slightly	60.32	17.36	18.56	3.76
	Moderately	32.35	29.48	34.89	3.28
	Severely	2.73	0.39	96.22	0.65
	Non-desertification	6.28	3.52	3.28	87.0
		2001			
1974	Slightly	30.27	46.17	20.41	3.15
	Moderately	12.39	49.90	34.82	2.89
	Severely	14.95	21.90	61.87	1.28
	Non-desertification	14.12	8.73	5.40	71.75

Conclusion

From temporal–spatial analysis of Karst rocky desertification pattern in the middle of Guizhou Province, China, the characteristic of Karst rocky desertification are summarized as follows:

1. The Karst rocky desertification in the study area still gets worse, and the spatial extent of desertification has drastically expanded from 1974 to 2001, at an increasing rate about 116.2 km^2/year.
2. High areas (900–1,500 m) are the most affected areas.
3. Areas with slope $<5°$ or $>25°$ are also tend to Karst rocky desertification.
4. The process of Karst rocky desertification is nearly irreversible. Few of Karst rocky desertification could be meliorated to non-desertification land.
5. Most of the degraded lands are located in the south and the central of the study region, and the meliorated land areas are sparsely located in the east and the west part of the region.

All these findings have profound implications on how to mitigate Karst rocky desertification in the study area. Lastly, this study indicated that the combination of RS and GIS techniques is generally an effective means to monitor Karst rocky desertification like middle of Guozhou Province, which is a rugged region difficult for field survey.

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