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ASSESSING SPATIAL-TEMPORAL EVOLUTION PROCESSES OF KARST ROCKY DESERTIFICATION LAND: INDICATIONS FOR RESTORATION STRATEGIES

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ABSTRACT

Karst rocky desertification (KRD) has become one of the most important eco-environmental problems in China. In order to put forward valid restoration strategies, the spatial-temporal KRD evolution processes were analyzed mathematically using 1:100 000 scale digital KRD distribution maps of Guizhou Province obtained from interpreting Landsat images from 1986, 1995, and 2000. The results showed that: (1) no obvious change took place in the total area of KRD land, but the mutual transformation of different types of KRD land was remarkable. (2) The change patterns of KRD land were classified into three types: simple mode, continuous mode, and reverted mode. (3) The total change rate of KRD land was 398·31 km^2 per year. (4) The higher the rank of KRD land is, the lower the change rate of KRD land will be. (5) Moderate KRD land had the fastest change frequency and was feasible to change to another type. On the whole, these indicated that the expansion of KRD had been brought under control because of the successful execution many ecological construction programmes. However, new KRD land appeared meanwhile owing to 'backward' eco-social development, and this should be clearly recognized. Copyright © 2011 John Wiley & Sons, Ltd.

KEY WORDS: karst rocky desertification; land use; restoration strategies; spatial analysis; GIS; Guizhou Province; PR China; Landsat imaging

INTRODUCTION

Karst rocky desertification (KRD) is a process of land degradation involving serious soil erosion, extensive exposure of underlying rocks, drastic decrease in soil productivity, and the appearance of a desert-like landscape (Wang *et al.*, 2004a). It is caused by unwise and over-intensive land use in a fragile karst geo-ecological environment (Wang *et al.*, 2004a; Bai *et al.*, 2005; Cao and Yuan, 2005; Li *et al.*, 2008). The first national monitoring results of KRD land in 2005, provided by the State Forestry Administration of China, showed that KRD land had reached 129 600 km^2 and the living space of 220 million residents had been threatened in South China. South China has a karst area of 451 000 km^2 much in Guizhou Province, Yunnan Province, Guangxi Zhuang Autonomous Region, Hunan Province, Hubei Province, Sichuan Province, Chongqing Municipalities, and Guangdong Province (Editorial Committee, 2008) (Figure 1). KRD not only has accelerated eco-environmental deterioration, such as soil erosion (Kirkby *et al.*, 2000), frequent occurrence of natural disasters and the degradation of the ecosystem (which in turn lead to the loss of land resources and non-arid zones) but also has exacerbated the poverty of the karst regions (Karst Research Group of the Institute of Geology, 1987; Yuan, 2001; Zhang *et al.*, 2001, 2002; Xiong *et al.*, 2002; Wang *et al.*, 2002, 2004a, 2004b; Bai *et al.*, 2006; Editorial Committee, 2008; Li *et al.*, 2008).

KRD has become one of the most important eco-environmental problems in China (Wang *et al.*, 2004a; Editorial Committee, 2008), and attracted the attention of Chinese central government. The 'National Economy and Social Development of the People's Republic of China in the Tenth Five-Year Plan' made it clear that there was a need to: "...to promote execution of the programme of comprehensively taming KRD in the karst regions of Guizhou Province, Guangxi Zhuang Autonomous Region and Yunnan Province." In the '11th Five-Year Plan' period (2006–2010), the National Reform and Development Commission had taken 100 karst counties[1] in South China as a pilot example and invested 3·0 billion Yuan RMB as special funds to conduct experiments on preventing and restoring KRD, and is considering investing further more money in all of 451 karst

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[1]Karst counties refer to those areas where the karst region covers an area of more than 30 per cent of the total land.

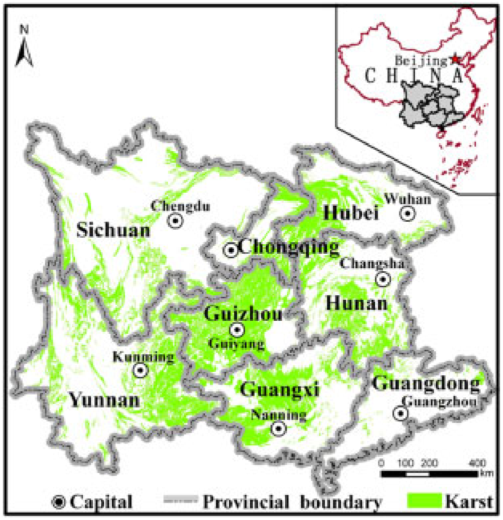


Figure 1. Map showing the distribution of karst regions in South China and the location of the study area. This figure is available in colour online at wileyonlinelibrary.com/journal/ldr

counties to carry out this duty. For example, in Guizhou Province alone an estimated 76 billion Yuan RMB needs to be invested to bring KRD under control according to the 'Plan of Prevention and Remedial Action against Karst Rocky Desertification in Guizhou Province' approved by the Guizhou Provincial authorities. The programme of comprehensively taming KRD has become the most important ecological management initiative in China at present time.

The effective measures for handling KRD at present in South China are presented mainly as follows (Editorial Committee, 2008): vegetation protection and construction, grassland construction and livestock husbandry development, water and land resources development and utilization, basic farmland construction, rural energy-source construction, relocation of the poverty-stricken residents, construction of scientific and technological support system, and so on. The core of these measures is to restore the ecologic system and to reduce the area of KRD land. Although the Chinese government had not yet taken it into consideration to handle KRD during the 20th century, karst regions in South China, lying in the upper reaches of the Yangtze River and Pearl River, acted as ecological shelters. Those shelters are important for economic development in the Yangtze River Delta and Pearl River Delta which are the two most economically developed areas in China. Work on ecological restoration has never been stopped in these regions, including the Yangtze River Shelter-Forest Project, the Pearl River Shelter-Forest Project, various water and soil conservation projects and poverty-alleviation projects, as well as some international support programmes. The analysis of dynamic changes in KRD land during the ecological construction over the past years is of important reference value for the present KRD restoration programmes.

Guizhou lies in the centre of karst regions in South China (Figure 1), and has the largest area of KRD land of any province (Editorial Committee, 1999), it is faced with the most serious and representative KRD problems. Using mathematical methods to analyze the historical data of KRD land distribution for 1986, 1995, and 2000, respectively, the authors take Guizhou Province as an example to help disclose the spatial-temporal KRD evolution processes in order to assess the influence of ecological construction and human activities on KRD.

STUDY AREA

Guzihou Province is located in southwestern China at approximately 24°37′-29°13′N and 103°36′-109°35′E. It covers an area of 176 000 km^2 (Figure 1). Carbonate rocks are widespread and account for 62 per cent of the total area of the Province (Wang *et al*., 2004b). In Guizhou Province, mountainous regions world-famous karst rock formations account for 92·5 per cent of the total area. The average altitude above sea-level is 1170 m. Most of the Province has a subtropical humid monsoon climate. The annual average temperature is 15°C, with a frost-free period of about 270 days a year. The rainfall per annum is 1100–1300 mm. Guizhou is a province which has the third biggest minority population and is one of the poorest provinces in China (Editorial Committee, 1999; Xiong *et al*., 2002).

MATERIALS AND METHODS

Materials

Landsat images taken in 1985, 1996, and 2000, respectively, were acquired from the depository of the Global Land Cover Facility (GLCF), the Chinese Data-Sharing Network of Earth System Science and Chinese Natural Resources Database. The corresponding 1:100 000 scale digital land use maps were provided by 'Environmental & Ecological Science Data Center for West China, National Natural Science Foundation of China.' The digital lithological data represent the earlier research results obtained by our research team (Wang *et al*., 2004b). Digital hydrogeology map, relief map, soil distribution map, as well as the practical investigation and population census data are from the Chinese Natural Resources Database.

Analytical Methods

According to the KRD classification criteria in 'A General Outline of Plan Program about Comprehensively Taming Karst Rocky Desertification (2006–2015)' issued by the

Table I. The classification criterion and characteristic code of KRD types

Classification and code of KRD type	Percentage of bare rock (per cent)	Distribution character of the exposed rock	Colour of the RS image
No KRD (NKRD)	<20	Star	Scarlet
Potential KRD (PKRD)	20–30	Star, Line	Shocking pink
Light KRD (LKRD)	31–50	Line	Pink
Moderate KRD (MKRD)	51–70	Line, Patch	Green in red
Severe KRD (SKRD)	71–90	Patch, Line	Gray in red
Extremely severe KRD (ESKRD)	>90	Patch	White, grey
No karst (NK)	Without considering KRD problems		

Note: Colour of the RS image displayed with Landsat TM bands 4, 3, and 2 (displayed as red, green, and blue).

State Council of the People's Republic of China in 2008, the characteristics of different ranks of KRD are established (Table I, Figure 2). The classification criteria are more concrete than the previous ones (Wang *et al*., 2004b). The main difference lies in that the type of potential KRD (PKRD) is included in this paper, because many researchers and scholars found that PKRD is the key to assessing the KRD evolution processes, and also is the bridge to connect no KRD (NKRD) with KRD (Xiong *et al*., 2002; Bai *et al*., 2006; Editorial Committee, 2008; Li *et al*., 2008). 'The Communiqués about the Present Status of Rocky Desertification in Karst Regions' released by the State Forestry Administration of China in 2005 and the 'Plan Program about Comprehensively Taming Karst Rocky Desertification (2005–2050)' issued by the Guizhou Provincial authorities in 2007, both emphasized the importance of preventing PKRD. Therefore, PKRD is considered as one KRD type in this paper when discussing KRD spatial-temporal evolution processes.

Based on this classification scheme (Xiong *et al*., 2002; Bai *et al*., 2006) (Table I), in combination with the corresponding 1:100 000 scale digital land use maps, 1:200 000 scale digital hydrogeology map, relief map, and soil distribution map, the distribution maps of KRD land for 1986, 1995, and 2000 (Figure 3a, b, c) had been made by the human–computer interactive interpreting method (Burrough *et al*., 1992; Cheng, 1995; Eve *et al*., 1999; Antrop and Van Eetvelde, 2000; Alfredo *et al*., 2002; Bunkei *et al*., 2006) from the landsat images of Guizhou Province in the corresponding years. With MAPGIS® as the working platform, we produced overlapping digital distribution maps of KRD land in Guizhou Province for different years. The spatial-temporal evolution processes of different types of KRD land had been analyzed mathematically focusing on four aspects. First, how many change modes exist among mutual transformation of different types of KRD land? Second, what are the change range and direction of different types of KRD land? Third, what is the change rate of different types of KRD land? Finally, the change frequency should reflect mutual change intensities of different types of KRD land. The mathematical methods are described as follows.

Change Patterns of KRD Land

The change patterns can be divided into the following three main types: (1) simple change mode. It reflects a direct transformation from one specific type of KRD land to another. For example, NKRD land changes directly to MKRD land, leading to a decrease in the area of the former and an increase in the area of the latter, namely 'a → b' type. (2) Continuous change mode: it reflects a continuous transformation from a certain type of KRD land to another, and then to the third. For example, NKRD land changes to PKRD land first, and then to MKRD land. This is a multiple change pattern among different types of KRD land, namely 'a → b → c' type. (3) Reverted change mode: it reflects a transformation from a certain type of KRD land to another first, and then it reverts to the original type, namely 'a → b → a' type. For instance, when the project of ecological rehabilitation is executed in a certain region, LKRD land changes first to NKRD land due to closing hillsides to facilitate forestations or returning farmland to forest land, after the accomplishment of the project, because the living conditions of local residents had not been improved, reclamation resulted in the returning of NKRD land to LKRD land. Although such a change mode does not lead to the variation of the KRD land area, the influence of this evolution process on the local eco-environment cannot be ignored.

Assuming that $E(x)$, $N(x)$, and $T(x)$ are the spatial distribution functions of different types of KRD land in 1986, 1995, and 2000, respectively; the change modes discussed above could be expressed as:

$$\begin{cases} \text{Simple Change Mode}: \mathrm{L} = \mathrm{a} \rightarrow \mathrm{b} (H = 1, \quad J \neq 1 \quad \text{or} \quad H \neq 1, \quad J = 1) \\ \text{Continous Change Mode}: \mathrm{L} = \mathrm{a} \rightarrow \mathrm{b} \rightarrow \mathrm{c} (H \neq 1, \quad J \neq 1 \quad \text{or} \quad K \neq 1) \\ \text{Reverted Change Mode}: \mathrm{L} = \mathrm{a} \rightarrow \mathrm{b} \rightarrow \mathrm{a} (H \neq 1, \quad J \neq 1, \quad K = 1) \end{cases} \quad (1)$$

where L refers to the spatial-temporal evolution patterns of different types of KRD land during the period of time from 1986 to 2000; H, J, and K represent the ratios of $E(x)/N(x)$,

Figure 2. Photographs showing different classes of KRD landscape: (a) NKRD, (b) PKRD, (c) LKRD, (d) MKRD, (e) SKRD, (f) ESKRD, respectively. For the explanation of codes: NKRD, PKRD, LKRD, MKRD, SKRD, ESKRD see Table I. This figure is available in colour online at wileyonlinelibrary.com/journal/ldr

$N(x)/T(x)$, and $E(x)/T(x)$, respectively. In the case of $H = 1$, $J = 1$, and $K = 1$, it means that no change had taken place in the area of KRD land during 1986–1995, 1995–2000, and 1986–2000, respectively. On-the-other-hand, in the case of $H \neq 1$, $J \neq 1$, and $K \neq 1$, it means that changes had taken place in the area of KRD land during 1986–1995, 1995–2000, and 1986–2000, respectively.

Change Direction and Range of KRD Land

The following transfer matrix model was adopted to describe the change tendency and range of different types of KRD land during the spatial-temporal evolution processes of KRD land:

$$\mathbf{M} = \begin{bmatrix} S_{11} & S_{12} & \dots & S_{1n} \\ S_{21} & S_{22} & \dots & S_{2n} \\ \dots & \dots & \dots & \dots \\ S_{n1} & S_{n2} & \dots & S_{nn} \end{bmatrix} \quad (2)$$

where **M** refers to the conversion matrix of different types of KRD land in Guizhou Province during the period of time between 1986–2000; S_{nn} refers to the change area (km^2)

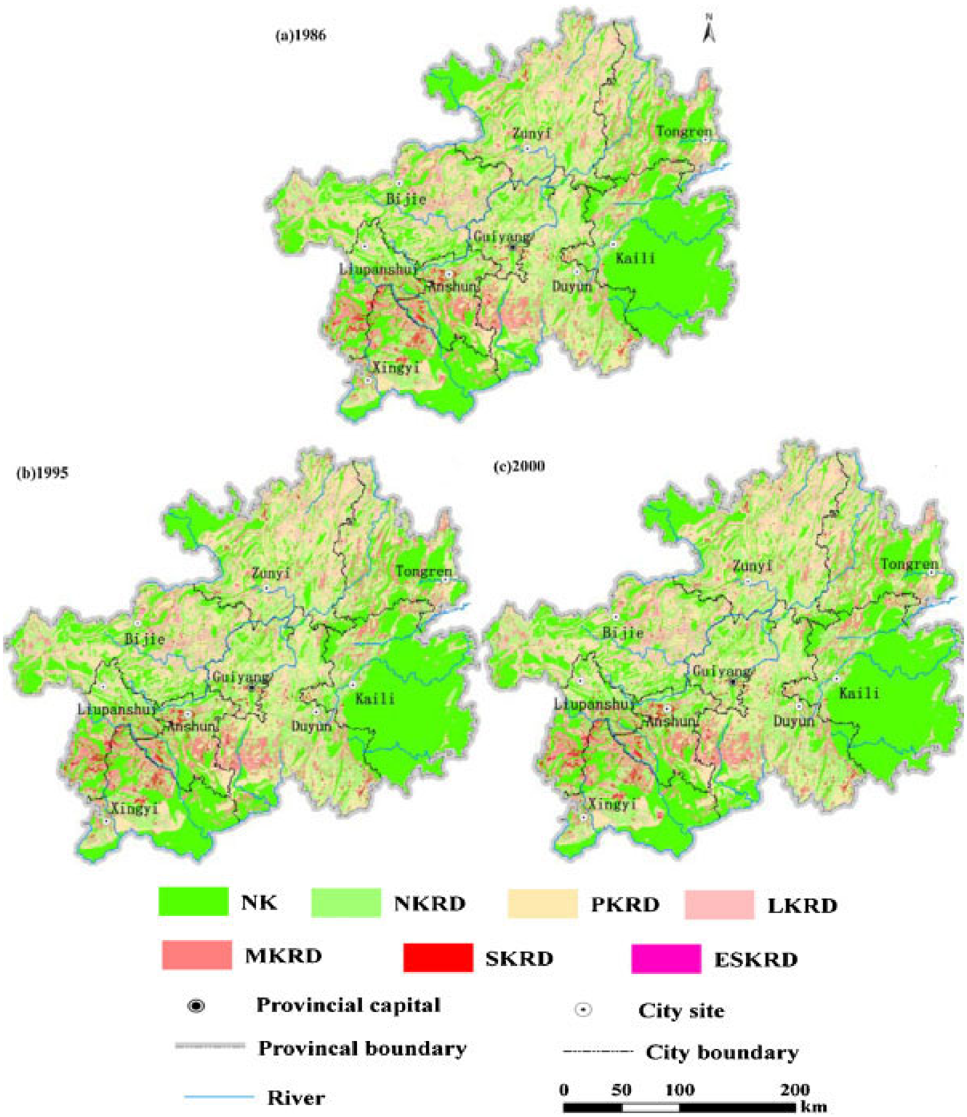


Figure 3. Map showing the distribution of KRD land in Guizhou Province in 1986 (a), 1995 (b), and 2000 (c), respectively. For the explanation of codes: NKRD, PKRD, LKRD, MKRD, SKRD, ESKRD, and NK see Table I. This figure is available in colour online at wileyonlinelibrary.com/journal/ldr

from a certain type of KRD land to another during the research periods; n refers to the amount of a certain type of KRD land which was involved in calculation.

The transfer matrix between 1986 and 2000 had been acquired by adding the transfer matrix between 1986 and 1995 obtained through overlapping Figure 3a with Figure 3b to the transfer matrix between 1995 and 2000 obtained through overlapping Figure 3b with Figure 3c.

Change Rate of KRD Land

The change rate (V) is defined as the ratio of the change area (ΔS_i) of a certain type of KRD land to time (T) during which the transformation of KRD type happened, and its unit is $km^2 a^{-1}$.

$$V = \Delta S_i / T \tag{3}$$

ΔS_i was obtained by using the established transfer matrix of different types of KRD land in Section 3.2.2.

Change Frequency of KRD Land

For a certain type of KRD land I, the change frequency (unit: per cent a^{-1}) is defined as:

$$f = (\Delta S_i / S_i) \times T^{-1} \times 100\% = V / S_i \times 100\% \tag{4}$$

where ΔS_i refers to the change area of a certain type of KRD land (unit: km^2); S_i refers to the area of the same type of

KRD land at the initial stage of evolution process (unit: km^2); T refers to the research period (unit: a); and V is the change rate as described in Section 3.2.3.

RESULTS AND ANALYSIS

General Change Characteristics of KRD Land

As shown in Figure 3a, b, and c, KRD land is concentrated in southern, southwestern and western Guizhou Province, and covers over 35 per cent of the total area of karst regions in Guizhou Province. The total area of KRD land was nearly 38 830 km^2 in 1986, 38 563 km^2 in 1995, and 38 903 km^2 in 2000, respectively (Table II). Of the total area, >60 per cent is for LKRD land, >33 per cent for MKRD land, <6 per cent for SKRD land, and <1 per cent for ESKRD land. MKRD, SKRD, and ESKRD land occurs in a scattered, mosaic pattern throughout the regions of LKRD land (Figure 3).

Evidently, from 1986 to 2000 the total area of KRD land had not varied significantly in consideration of the fact that the net change area of KRD land only increased to 73·31 km^2 and that of PKRD land had decreased to 271·21 km^2 (Table II). It does not mean that during these periods no great change had taken place in the respective distribution area of different types of KRD land. The total change area of KRD land in Guizhou Province had reached 6506·10 km^2, from 1986 to 2000 (Figure 4), demonstrating that except for a land of 198·21 km^2, which had changed from KRD to NKRD, a land as large as 6307·89 km^2 was involved in mutual transformation of different types of KRD land, accounting for 98·87 per cent of the total change area.

Spatial-temporal Evolution Processes of KRD Land

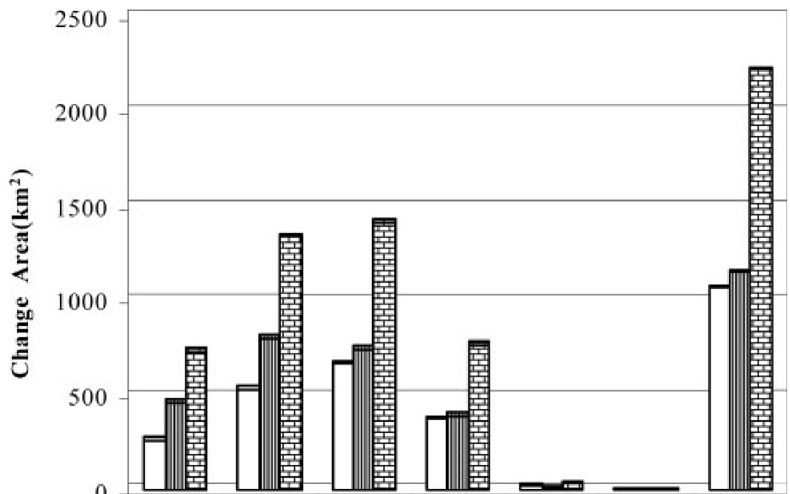
According to the criteria of Equation (1), the proportions of different change modes were figured out through the analysis of spatial relationship on the MAPGIS® platform (Figure 5). The percentage of continuous change mode is largest, accounting for 80·09 per cent, followed by simple change mode, accounting for 18·67 per cent, and reverted change mode is smallest, accounting for 1·24 per cent. This demonstrates that the continuous change mode is prevailing and the mutual transformation of different types of KRD land is extremely remarkable in the spatial-temporal evolution processes of KRD land in Guizhou Province during the periods of time from 1986 to 2000.

According to Equation (2), the calculated results for the change direction and range of different types of KRD land are given in Table III. It is obvious that there exist two evolution trends: from low- to high-rank KRD types forwardly and from high- to low-rank KRD types inversely. The forward evolution trend occurred mainly in the NKRD land transformation series, including that from NKRD to PKRD land, NKRD to LKRD land and NKRD to MKRD land, with the change area of 1765 km^2, accounting for 60 per cent of the total change area involved in this series. The inverse evolution trend occurred mainly in the LKRD and MKRD land transformation series, including that from LKRD to NKRD land and LKRD to PKRD land, and MKRD to NKRD land, MKRD to PKRD land and MKRD to LKRD, with the change in area of 952·74 and 932·01 km^2, both accounting for 31 per cent of the total change area involved in this series. As for the PKRD land transformation series, two evolution trends were involved and the change area was nearly equal to each other. The forward transformation area from PKRD to LKRD land and PKRD to MKRD land reached 889·67 km^2, accounting for 30 per cent of the total change area. On the other hand, the inverse transformation area from PKRD to NKRD land reached 1045·77 km^2, accounting for 34 per cent of the total change area. To sum up, from 1986 to 2000 the change area of KRD land involved in the inverse evolution processes reached 3042 km^2, slightly higher than that of 2932 km^2 in the forward evolution processes. Nearly equal coexistence of the forward and inverse KRD land evolution processes reflects the actual situation in Guizhou Province. Although a large number of ecological rehabilitation projects had been executed during the period of time from 1986 to 2000, the ecological status did not show any sign of improvement. Because of its backwardness in economic development in China the inappropriate human activities that have induced KRD still exist in Guizhou at present (Wang *et al.*, 2004a). However, it is interesting to note that KRD land has not further

Table II. Area and proportion of different KRD types in karst areas of Guizhou Province (1986–2000)

Types of KRD land		NKRD land	PKRD land	LKRD land	MKRD land	SKRD land	ESKRD land	KRD land
1986	Area (km^2)	38 527·42	32 089·88	23 618·23	13 001·4	2191·04	19·13	38 829·80
	Proportion (per cent)	35·20	29·32	21·58	11·88	2·00	0·02	35·48
1995	Area (km^2)	38 260·66	32 623·36	22 950·51	13 378·79	2214·66	19·12	38 563·08
	Proportion (per cent)	34·96	29·81	20·97	12·22	2·02	0·02	35·23
2000	Area (km^2)	38 725·33	31 818·67	23 695·15	12 985·68	2203·02	19·26	38 903·11
	Proportion (per cent)	35·38	29·07	21·65	11·86	2·01	0·02	35·55

Note: For explanation of codes: NKRD, PKRD, LKRD, MKRD, SKRD, and ESKRD see Table I. The areas of KRD land equal to summing of areas of LKRD, MKRD, SKRD, and ESKRD land.



	NKRD Land	PKRD Land	LKRD Land	MKRD Land	SKRD Land	ESKRD Land	KRD Land
□ 1986-1995	266.75	533.48	667.72	377.39	23.62	0.01	1068.74
▥ 1995-2000	464.66	804.69	744.64	393.11	11.64	0.13	1149.62
⊞ 1986-2000	731.41	1338.17	1412.36	770.50	35.26	0.14	2218.26

Figure 4. Changes in area of different types of KRD land in the karst regions of Guizhou Province (1986–2000). For the explanation of codes: NKRD, PKRD, LKRD, MKRD, SKRD, and ESKRD, see Table I.

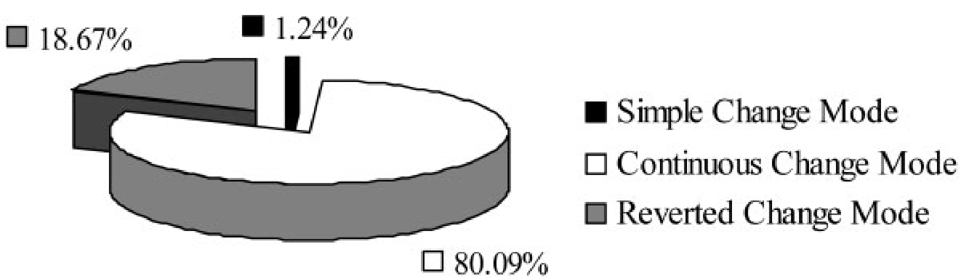


Figure 5. The proportions of different evolution patterns for KRD types in Guizhou (1986–2000).

expanded, implying that KRD has been brought under control basically, and significant effects have been achieved in ecological rehabilitation.

According to Equation (3), the calculated change rates of different types of KRD land are shown in Figure 6. The highest change rate of PKRD land is measured at $131{\cdot}02\,km^2\,a^{-1}$, followed by NKRD land with a change rate of $120{\cdot}66\,km^2\,a^{-1}$, the others are listed as in descending order: LKRD, MKRD, SKRD, and ESKRD land. The change rate of different types of KRD land is inversely proportional to its degree of degradation, e.g., the higher the rank of KRD land is, the lower the change rate of KRD land will be. It means that the low-rank KRD land is unstable and feasible to change to high-rank KRD land. On the other hand, the high-rank KRD land, for example SKRD land with a change rate of $7{\cdot}3\,km^2\,a^{-1}$, nearly 20-times lower than that of PKRD land, was postulated to be in a stable state and unlikely to change any more within 20 years.

According to Equation (4), the calculated change frequencies of different types of KRD land are shown in Figure 7. The fastest change frequency of MKRD land reached 0·48 per cent a^{-1}, followed by PKRD land with a change frequency of 0·41 per cent a^{-1}, indicating that changes in MKRD and PKRD land use are most intense and dynamic. From the ecologic viewpoints, both MKRD and PKRD land are the ecotone between the best (NKRD) and the worst (SKRD and ESKRD) ecosystems. The ecotone is fragile, sensitive, and variable, and it is the most frequent

Table III. Conversion matrix of different KRD type land in Guizhou Province between 1986 and 2000 (unit km^2)

	Types of KRD land	NKRD land	PKRD land	LKRD land	MKRD land	SKRD land	ESKRD land
1986–1995	NKRD		659·04	128·86	289·23	26·02	0·07
	PKRD	335·09		85·38	236·8	11·74	0·03
	LKRD	352·47	409·57		127·91	29·49	0·23
	MKRD	129·8	122·94	30·25		1·6	0·01
	SKRD	18·98	10·81	7·41	8·02		0·01
	ESKRD	0·08	0·19	0·05	0·02	0·02	
1995–2000	NKRD		216·41	347·87	123·6	18·69	0·13
	PKRD	710·68		458	109·5	17·92	0·21
	LKRD	128·76	61·95		29·23	7·9	0·1
	MKRD	307·13	204·52	137·37		8·03	0·02
	SKRD	24·83	8·61	29·1	1·64		0·02
	ESKRD	0·06	0·03	0·23	0·01		0·01
1986–2000	NKRD	0	875·45	476·73	412·83	44·71	0·19
	PKRD	1045·77	0	543·38	346·29	29·66	0·24
	LKRD	481·22	471·52	0	157·14	37·39	0·33
	MKRD	436·93	327·46	167·62	0	9·64	0·03
	SKRD	43·81	19·43	36·51	9·66	0	0·03
	ESKRD	0·14	0·22	0·28	0·03	0·02	0·01

Note: For explanation of codes: NKRD, PKRD, LKRD, MKRD, SKRD, and ESKRD, see Table I.

place of material cycle, and energy conversion and information transfer between two ecosystems. As viewed from the KRD evolution processes, the continuous change mode is prevailing, with MKRD and PKRD as the middle transition to connect high- and low-rank degradation. However, as the middle transition like PKRD and MKRD, the change frequency of LKRD land is only 0·32 per cent a^{-1}. It is implied that the change frequency of KRD land is not only related to human activities, but also to other factors. Further research in this aspect is needed. The change frequencies of SKRD, ESKRD, and NKRD are lowest (Figure 7), indicating that the best or worst ecological systems are most stable, which is in consistency with the traditional characteristics of the ecosystem stability.

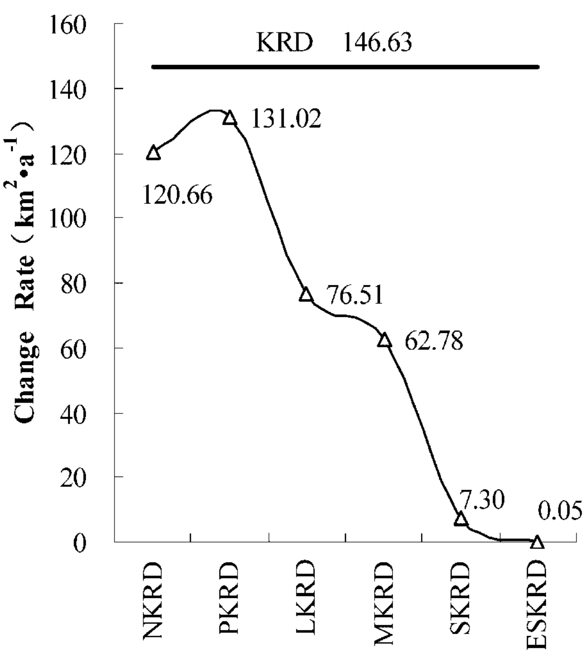


Figure 6. The change rates of different types of KRD land in Guizhou (1986–2000). The black solid line refers to the accumulative change rates of the four ranks of KRD land from slight to extremely severe. For the explanations of codes: NKRD, PKRD, LKRD, MKRD, SKRD, and ESKRD, see Table I.

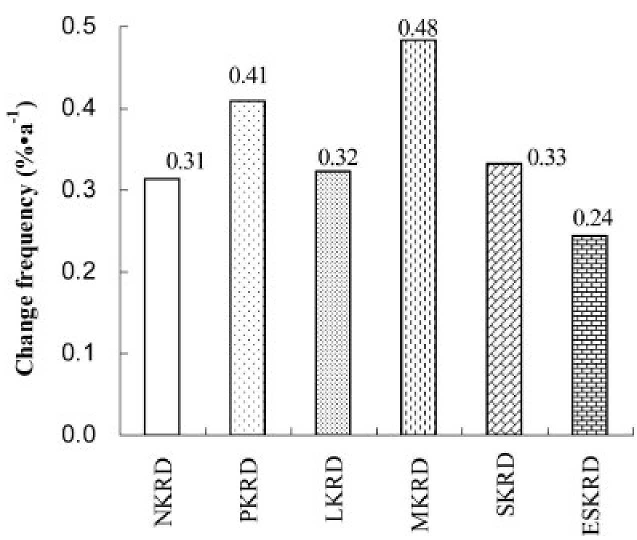


Figure 7. The change frequencies of different types of KRD land in Guizhou Province (1986–2000). For the explanations of codes: NKRD, PKRD, LKRD, MKRD, SKRD, and ESKRD, see Table I.

CONSEQUENCES FOR KRD REHABILITATION

KRD land rehabilitation is very urgent and necessary. However, it is not enough to analysis only static state of KRD. Only through assessing the dynamic changes of KRD land can the scientific and effective rehabilitation measures be made. A set of analytical methods to assess the spatial-temporal KRD evolution processes was created in this paper. Continuous monitoring KRD changes needs detect and analysis the change pattern, change range and direction, change rate, and change frequency of KRD land. At present, some rehabilitation measures have been taken where KRD is serious, and their effects need to be evaluated by the method created in this paper. For example, in Beipanjiang River and Panxian County, a number of prevention and control measures have been taken, and it is easy to determine rehabilitation effects by assessing the proportion and change rate of reverted change model. According to the findings in this article, some suggestions to KRD land rehabilitation can be put forward as follows.

According to the characteristics of the continuous change mode prevailed in the spatial-temporal KRD land change patterns, KRD rehabilitation cannot be accomplished overnight. The process of KRD forward evolution includes a series of stages: woodland → scrub → grassland → pioneer weed species → barren exposure, so, KRD rehabilitation measures are also promoting strictly in accordance with the ecological succession step by step. In the areas where KRD is strong, pioneer plants should be introduced first, and then consider introduction of trees and other plants when pioneer plants have improved soil fertility conditions and reached certain coverage.

According to the characteristics of equal coexistence of KRD forward and inverse evolution processes and high change frequency of PKRD land, it is necessary to consider integration of prevention measures with rehabilitation measures, in order to guarantee the effects of the latter. Meanwhile, KRD rehabilitation should link with the adjustment of industrial structure in rural areas to increase people's income, promote their living level, develop eco-industries in light of local conditions, ease Human–Land conflict and completely change any wrong lifestyles.

According to the characteristics of negative relationship between change rates of KRD land with KRD rank, practice of KRD rehabilitation should be concentrated in the regions where KRD is not strong. ESKRD and SKRD land, with more than 70 per cent rock exposure, are the typical land which is difficult to use and lost the farm value almost, and are very difficult to recovery in the short term. Comparing with ESKRD and SKRD land, LKRD and MKRD land are easy to be controlled. Because there exists discontinuous soil widely in rock crevices and fractures in those areas, if we restrict irrational human activities and take effective measures to deal with, the evolution trend of those areas would direct to PKRD and NKRD land. Considering further the highest change frequency of MKRD, therefore, MKRD land should be as 'core' in KRD rehabilitation.

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