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Rocky Desertification Risk Zone Delineation in Karst Plateau Area: A Case Study in Puding County, Guizhou Province

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Abstract: Karst rocky desertification is a geo-ecological problem in Southwest China. The rocky desertification risk zone delineation could be used as a guide for the regional and hierarchical rocky desertification management and prevention. We chose the middle and lower reaches of the Houzhai underground basin on the karst plateau in Puding County, Guizhou Province, China as the study area and selected land use type, elevation, slope, aspect, lithology and settlement buffer as the main driving factors of the rocky desertification. The potential risk of rocky desertification was quantified with the factor-weights union method and statistical analysis method. Five grades of rocky desertification risk were delineated based on Geographic Information System. The extremely low, low, moderate, high and extremely high rocky desertification risk zones accounted for 5.01%, 44.17%, 33.92%, 15.59% and 1.30%, respectively. As a whole, the rocky desertification risk level was moderate because the area of low and moderate rocky desertification risk zones occupied 78.09% of the study area. However, more than half of the area (about 50.81%) was predicted to have moderate rocky desertification risk and above, indicating that the study area was subject to rocky desertification. Rocky desertification risk was higher in the southeast and lower in the northwest of the study area. Distinct differences in the distribution of rocky desertification risk zones corresponding to different factors have been found.
Keywords: rocky desertification; rocky desertification risk zone; karst plateau; Guizhou Province

1 Introduction

Karst landforms are generally the result of mildly acidic water acting on soluble bedrock such as limestone or dolostone. The karst areas are characterized by high eco-sensibility, low environmental capacity, weak anti-jamming capacity and poor stability. It accounts for about 15% of the world′s land area, and is the home for about 17% of the world′s population (Yuan and Cai, 1988). Three large and continuous karst regions in the world are distributed in East Asia, the eastern part of North America and the middle and southern parts of Europe. Rocky desertification is the most serious geo-ecological problem in karst areas, which is a process of land degradation involving serious soil erosion, the extensive exposure of basement rocks, the drastic decrease of soil productivity and the appearance of a desert-like landscape (Wang *et al*., 2004). Karst rocky desertification has never occurred in the eastern part of North America and the middle and southern parts of Europe. Some researches on karst conducted in those areas mainly focused on hydrology (Majone *et al*., 2004) and karst evolution (Grovea and Meiman, 2005). East Asia karst region, as the largest one of the three karst regions, is a typical fragile ecological zone, and has the most intensive karstification. Southwest China is distributed in a karst plateau area in the central part of East Asia karst region (Lan *et al*., 2003), where karst rocky desertification is one of the most serious environment problems. The sustainable development in this area has been restricted, threatening people′s living conditions (Chinese Academy of Sciences, 2003). Much research has been done on the karst rocky desertification in Southwest China, including the definition (Wang *et al*., 2004), distribution (Chen *et al*., 2007), causes (Li *et al*., 2004; Su *et al*., 2006; Huang and Cai, 2007), ecological-environmental effects (Wang, 2003) and preventive strategies (Zhou, 2006; Su *et al*., 2006). According to

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the remote sensing investigation done by Huang *et al.* in 2006, the total karst rocky desertification area of Guizhou and Guangxi provinces in Southwest China has reached 50 000 km^2 and 47 000 km^2, respectively. And it is spreading at a rapid rate of 2 500 km^2/yr (Huang *et al.*, 2006), therefore, understanding the dynamic mechanism of rocky desertification has become critical.

Rocky desertification risk zones can be defined as regions prone to rocky desertification, which can spread easily to other regions. Rocky desertification risk zone delineation is a prerequisite for the analysis of the dynamic mechanism and is important for management and prevention of rocky desertification. Based on land use classification, rocky desertification risk zones could be delineated in combination with other karst environmental conditions, facilitating regional and hierarchical rocky desertification management and prevention, however, few studies exist on karst rocky desertification zone delineation (Zhou, 2006).

We selected the middle and lower reaches of Houzhai underground basin in Puding County of Guizhou Province as the study area, and assessed the karst rocky desertification risk using the rocky desertification risk index (RDRI) bsed on Geographic Information System (GIS). The objectives of the study were to better understand different levels of karst rocky desertification risk and to provide scientific references for local land managers and policy-makers.

2 Methodology

2.1 Study area

The selected karst plateau area (26°12′09″–26°17′36″N, 105°39′16″–105°47′54″E) is along the middle and lower reaches of Houzhai underground river, located in Puding County, Guizhou Province, China (Fig. 1). The study area covers an area of 61.98 km^2 and had a population of 29 821 in 2006. Puding has a northern subtropical wet monsoon climate. The mean annual temperature is 15.1ºC. The highest average monthly temperature is 23ºC in July, and the lowest is 5.2ºC in January. The mean annual precipitation is 1 374.3 mm, of which 83.6%–90.2% concentrates in May–October (Chen *et al.*, 2005). The region contains a full suite of karst landforms, including poljes, cockpits, towers and dolines. Topography of the study area is relatively high in the east and low in the west. The surface undulates lightly with an average slope of 6.9°. The average elevation is 1 291 m, with the highest elevation of 1 551 m and the lowest of 1 219 m. Yellow soil is the main soil type. There are various types of natural vegetation, dominated by evergreen broad-leaved forest and deciduous broad-leaved forest.

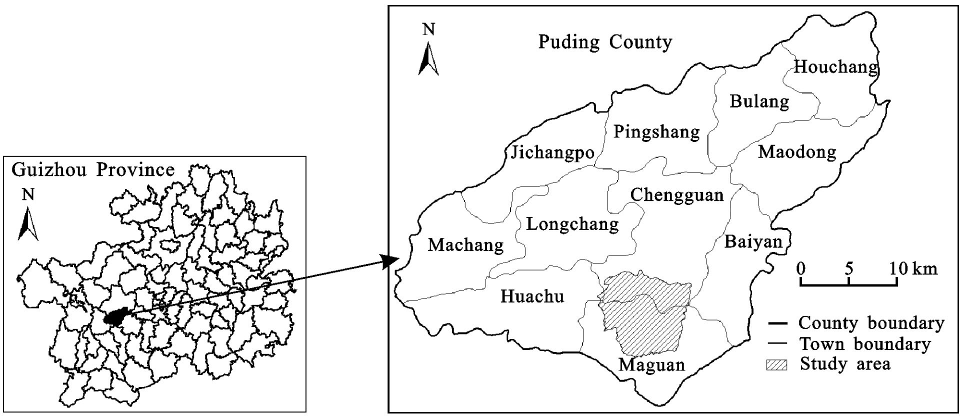

Fig. 1 Location sketch of study area

2.2 Selection of rocky desertification driving factors

2.2.1 Main driving factors

Although many factors drive rocky desertification (Li *et al.*, 2004; Su *et al.*, 2006; Huang and Cai, 2007), we chose land use type, elevation, slope, aspect, lithology and settlement buffer as the most important factors in this study, which were further divided into 38 classes (Table 1).

Land use is a key driving factor of rocky desertification because it represents human activities (Xiong *et al.*, 2008) and the degree of rocky desertification risk. Rocky desertification risk degree varies among land use types (Li *et al.*, 2006).

Topography is one of the most important natural factors that affect the occurrence and development of rocky desertification (Lu and Feng, 2002; Lan *et al.*, 2003). The main topographical parameters include elevation, slope and aspect in this paper. In karst areas, regions with different elevations have different rocky desertification sensitivities, that is, the relationship between the distribution of rocky desertification and elevation is close (Huang and Cai, 2007). In this study, the area with an elevation of 1300–1500 m shows high probability for rocky desertification because of favorable conditions for human activities. Aspect influences ground surface solar radiation receiving, and as a result, the rocky desertification occurrence and development possibilities differ with aspect. For example, south-facing slopes are more susceptible for desertification. Moreover, the steeper the slope, the more the surface soil and water loss, increasing the likely occurrence of rocky desertification (Huang and Cai, 2006).

Rocky desertification is obviously affected by lithological condition (Li *et al.*, 2003; Zeng and Wang, 2007). The degree of karst rocky desertification is strongly determined by the basement rock (Wang *et al.*, 2004). Compared with limestone, dolomite has a much lower degree of solution, more acid insoluble substances and a much stronger resistance to mechanical cracking force, thus, soil particles are easily formed and soil and water loss is less on dolomite. As a result, the degree of rocky desertification is lower on dolomite areas than on limestone areas (Zhou and Huang, 2003).

Settlement buffers can represent human activity accessibility and indirectly reflect the intensity of human disturbance. The closer the settlement, the more intense the disturbance from human activities (except geomantic forest, a legacy of history in China, which plays many important roles in village protection, ecological balance and scenic prettifying) and the higher the risk of rocky desertification. People engaged in agricultural production, who live mainly on land, constitute the major part of the county's total population (about 93.03%) in the study area. Consequently, rocky desertification is much more likely to occur.

2.2.2 Other driving factors

Climatic conditions (e.g., precipitation, temperature and sunshine) and social economic conditions (e.g., living standard and population density) can also affect the development of rocky desertification. However, because the size of the study area is small and climatic factors and population factors have negligible differences within this small spatial scale, those factors were considered background factors and were not analyzed in detail.

2.3 Data processing and analysis methods

Data processing and analysis include three steps: creating factorial maps, setting up rocky desertification risk index, and generating rocky desertification risk zone map (Fig. 2).

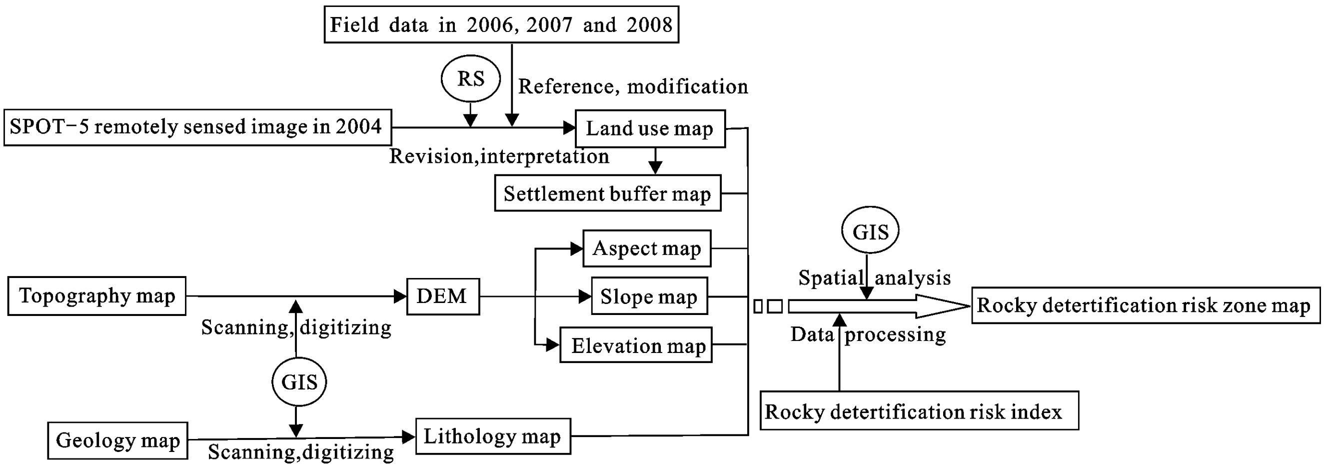

Fig. 2 Flow chart of rocky desertification risk zone delineation

2.3.1 Creating factorial maps

Factorial maps were generated for each rocky desertification factor, respectively. Topography maps with 1∶10 000 scale were scanned and rectified. Digital Elevation Map (DEM) was generated by the digitization of topographic maps. Aspect map, slope map and elevation map were then extracted from the DEM. SPOT-5 (the fifth satellite in the SPOT series, placed into orbit by an Ariane launcher) remote sensing image in 2004 was rectified using topography maps and DEM in remote sensing (RS) software. Based on this image, a digital land use map was created with visual interpretation. In addition, field data obtained in 2006, 2007 and 2008 from the study area was referenced to correct visual interpretation. A settlement buffer map (strips with a width of 200 m) was generated using the settlement map extracted from land-use map. Meanwhile, a geologic map of the study area was scanned and digitized to generate a lithology map in GIS software.

All maps had different pixel sizes, therefore we selected an intermediate pixel size of 2.5 m. All spatial data were unified to the same standard projection.

2.3.2 Setting up rocky desertification risk index

To create a rocky desertification risk index we assigned weights to each driving factor with regard to their rocky desertification sensitivities. Although all driving factors were considered to be sensitive to rocky desertification, different driving factors had different sensitivities. Assigned weights could be flexible depending on the actual situation of the study area. Applying as much objectivity as possible, we proposed some weights based on expert experience and our knowledge of the study area. The maximum weight assigned to a driving factor was 0.2, low enough to avoid underestimation of other significant driving factors. Land use, slope and lithology were considered as the determinant factors for rocky desertification development and were assigned the highest weight of 0.2. The remaining rocky driving factors were assigned weights of 0.15 (aspect and settlement buffer) and 0.1 (elevation). Within a driving factor, different classes were ranked according to their rocky desertification contribution. Multiplying the weight by the rank, we calculated the rocky desertification sensitivity for each class (Table 1).

Based on the rocky desertification sensitivity of driving factors, rocky desertification risk index (*RDRI*) can be calculated by Equation (1):

$$RDRI = \sum_{i=1}^{6} W_i X_j \tag{1}$$

where W_i is the weight of rocky desertification driving factor i (i=1, 2, …, 6); and X_j is the rank of class j in driving factor i, which changes along with rocky desertification driving factors.

2.3.3 Generating rocky desertifacation risk zone map

By overlapping land use map, aspect map, slope map, elevation map, lithology map and settlement buffer map, we created a comprehensive map. Based on this map and *RDRI*, the rocky desertification risk zone map was generated.

All spatial data were analyzed in GIS environment, and softwares used in this study were ERDAS IMAGINE 8.6 and ARCGIS 9.0.

Table 1 Weights of driving factors, ranks of classes and their rocky desertification sensitivity (RDS)

Code	Factor and weight	Class	Rank	RDS
1	Land use Type (0.2)	Paddy field	3	0.60
		Dry land	4	0.80
		Grassland	7	1.40
		Sparse forest	5	1.00
		Shrub forest	6	1.20
		Forest	1	0.20
		Build-up land	2	0.40
		Water body	0	0.00
		Bare soil	8	1.60
		Bare rock	9	1.80
2	Elevation (0.1)	<1250 m	4	0.40
		1250–1300 m	3	0.30
		1300–1350 m	5	0.50
		1350–1400 m	6	0.60
		1400–1450 m	8	0.80
		1450–1500 m	7	0.70
		1500–1550 m	2	0.20
		>1550 m	1	0.10
3	Slope (0.2)	Gently sloping (0°–3°)	1	0.20
		Very moderately sloping (3°–5°)	2	0.40
		Moderately sloping (5°–8°)	3	0.60
		Middle sloping (8°–15°)	4	0.80
		Strongly sloping (15°–25°)	5	1.00
		Steep (25°–35°)	6	1.20
		Sharp (>35°)	7	1.40
4	Aspect (0.15)	No aspect (0°)		
		Shaded aspect (337.5°–67.5°)	0	0.00
		Semi-shaded aspect (292.5°–337.5°,	1	0.15
		67.5°–112.5°)	2	0.30
		Semi-sunny aspect (247.5°–292.5°,	3	0.45
		112.5°–157.5°)	4	0.60
		Sunny aspect (157.5°–247.5°)		
5	Lithology (0.2)	Dolomite	1	0.20
		Limestone	2	0.40
6	Settlement buffer (0.15)	<200 m	6	0.90
		200–400 m	5	0.75
		400–600 m	4	0.60
		600–800 m	3	0.45
		800–1000 m	2	0.30
		1000–1200 m	1	0.15

3 Results

3.1 Classification of main rocky desertification factors

Main rocky desertification factorial maps include land use, elevation, slope, aspect, lithology and settlement buffer (Fig. 3). Land use types of the study area were divided into 10 classes: paddy field, dry land, grassland, sparse forest, shrub forest, forest, build-up land, water body, bare soil and bare rock (Fig. 3a). Elevation was divided into eight ranges with 50-m intervals (Fig. 3b). The slope classification map was created by a seven-grade classification system (Tang and Song, 2006) (Fig. 3c) and the aspect classification map was created by a five-grade classification system (Fig. 3d) (Xie *et al.*, 2007). All rocks in the study are carbonate, including two subtypes, dolomite and limestone (Fig. 3e). The settlement buffer map shows distances from settlement ranging from 0 to 1 200 m (Fig. 3f).

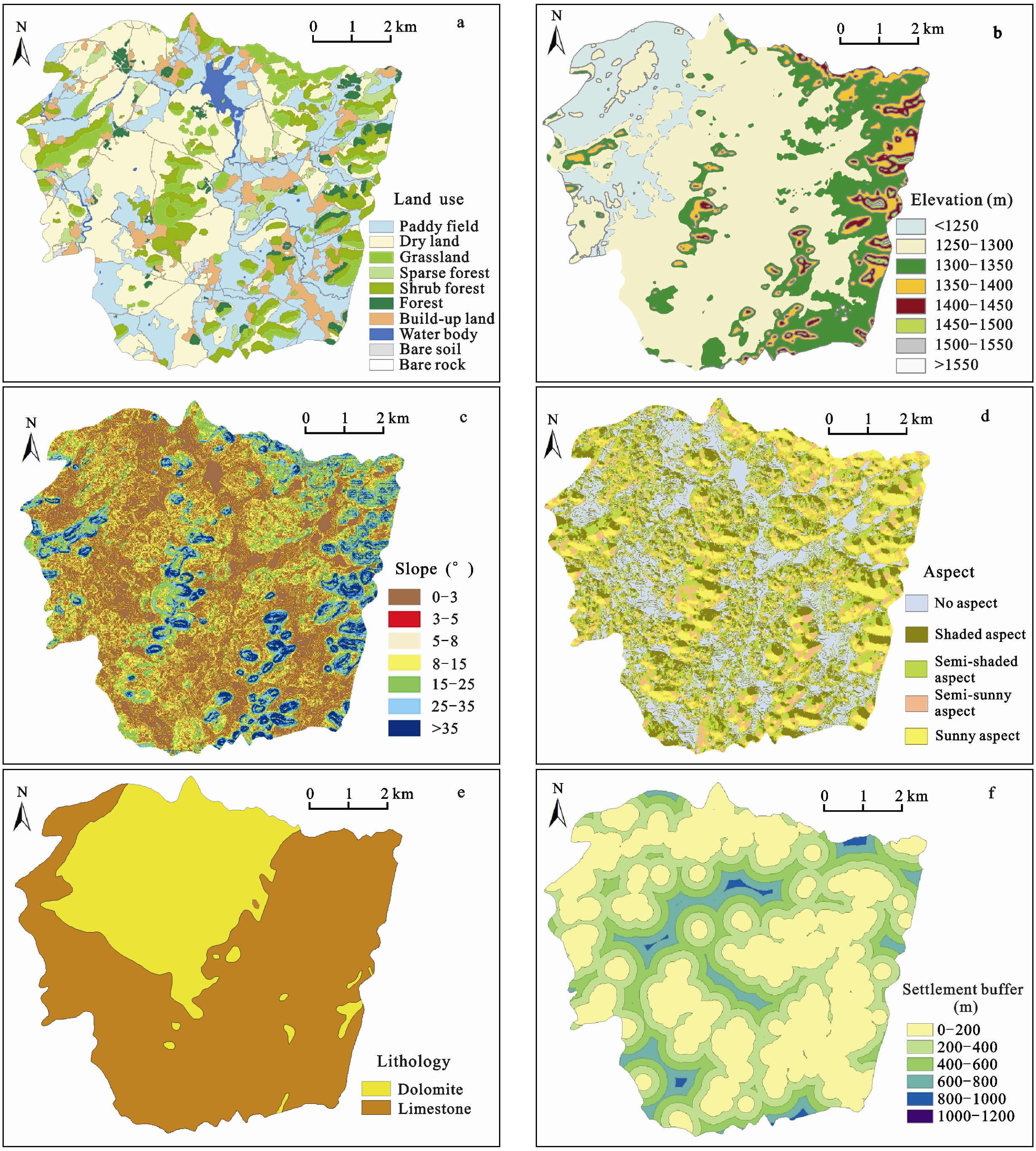

Fig. 3 Classes of main rocky desertification factors of land use type (a), elevation (b), slope (c), aspect (d), lithology (e), and settlement buffer zone (f)

3.2 Zonation of rocky desertification risk

Rocky desertification risk levels reflect the possible occurrence and spreading risk of rocky desertification. The resulting *RDRI* data of the study area were grouped by discrete intervals of 1. As a result, the study area was divided into five levels of rocky desertification risk (Table 2). As a whole, the rocky desertification risk level was moderate, because about 78.09% of the study area was in low and moderate rocky desertification risk zones. About half of the area (about 50.81%), however, belonged to moderate or more serious desertification risk, indicating that the study area was prone to rocky desertification and require effective prevention measures.

Table 2 Classification of rocky desertification risk zones

Level	Area (km^2)	Proportion (%)
Extremely low (1≤*RDRI*≤2)	3.11	5.01
Low (2<*RDRI*≤3)	27.38	44.17
Moderate (3<*RDRI*≤4)	21.02	33.92
High (4<*RDRI*≤5)	9.66	15.59
Extremely high (*RDRI*>5)	0.81	1.30

3.3 Spatial distribution of rocky desertification risk zones

The rocky desertification risk zone map shows that, in general, the rocky desertification risk was higher in the southeast and lower in the northwest of the study area (Fig. 4). The extremely low rocky desertification risk zones were mainly distributed in the northwest; low and moderate zones were distributed across the study area; and high and extremely high zones were mainly distributed near the margin of the study area, especially along the southeastern margin, probably because those areas had more serious human disturbance and more vulnerable geological environment (mainly limestone bedrock).

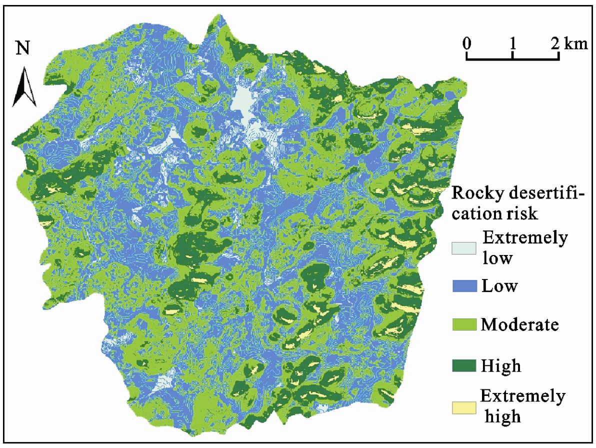

Fig. 4 Classification of rocky desertification risk zones of study area

4 Discussion and Conclusions

The RDRI approach used here is a useful and comprehensive tool to delineate rocky desertification risk zones. The importance of the driving factors of rocky desertification varies from area to area (Li *et al*., 2004; Su *et al*., 2006; Huang and Cai, 2007). One of the most important driving factors is human activity, but unregulated human activities often complicate the precise prediction of rocky desertification. The assignment of suitable weights of driving factors and ranks of classes therefore requires the support from expert decision and a deep knowledge of the study area under analysis. Better understanding of the study area results in more precise zone delineation.

The most important driving factors of rocky desertification in this study were land use types, elevation, slope, aspect, lithology and settlement buffer. The results indicated that extremely low, low, moderate, high and extremely high rocky desertification risk zones accounted for 5.01%, 44.17%, 33.92%, 15.59% and 1.30%, respectively. The rocky desertification risk was high in the southeast and low in the northwest. Rocky desertification risk zone delineation is essential to land managers for effective rocky desertification management and reasonable land-use planning, and also provides a basis for evaluation and prediction of rocky desertification. Hence, this approach can be seen as a flexible tool that can be adapted to different conditions of study areas in rocky desertification risk zone delineation.

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