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ORIGINAL ARTICLE

Occurrence mechanism and prediction of rocky land degradation in karst mountainous basins with the aid of GIS technology, a study case in Houzhai River Basin in southwestern China

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Abstract

Rocky desertification is a severe ecological issue threatening and constraining regional sustainable development in karst mountainous areas like Houzhai River Basin in southwestern China. The results indicate that slope gradient and altitude are closely associated with occurrence of rocky desertification in the study region and there are some significant correlations between rock outcrop and slope gradient ($r = 0.363$, $p < 0.001$) and between rock outcrop and altitude ($r = 0.0.336$, $p < 0.001$). Slope gradient and altitude are key factors contributing to rocky desertification in the studied basin. Therefore, special attention should be paid to sloping lands that have greater slope gradients or altitudes to prevent and control the rocky desertification in a karst mountainous basin as the Houzhai River Basin. Furthermore, it might be possible to predict the occurrence of rocky desertification using neural networks on the basis of geographical characteristics and human disturbance. The correlation coefficients between observed values and predicted values ranged from 0.728 to 0.905, with a mean value of 0.851 (ten times repeats). The present study also indicates that human disturbance has little effect on rocky desertification. However, further studies should be conducted to interpret the effects of agricultural activities on the occurrence of rocky desertification.

Keywords Rocky desertification · Rock outcrops · Slope gradient · Karst basin · Land use · Landform

Introduction

Rocky desertification is a type of land degradation that occurs globally, such as in the European Mediterranean basin, the Dinaric karst regions of the Balkans, and southwestern China (Yassoglou 2000; Yang et al. 2014). Soils play an essential role in securing food productivity, regulating the water cycle and maintaining biodiversity (Thomas et al. 2012; Kweon et al. 2013; Costantini et al. 2016). This process that transforms a karst area covered by vegetation and soil into a rocky landscape almost devoid of soil and vegetation under severe natural conditions or improper management and intense disturbance from human activities (Yuan 1997; Zhang et al. 2011a; Jiang et al. 2014; Cheng et al. 2017; You 2017). The rocky desertification process is characterized by bedrock exposure (rock outcrops) and soil erosion (Zhang et al. 2011b). Soil is a critical component of Earth systems and is important in the assessment of land quality (Martínez-Murillo and Ruiz-Sinoga 2007; Comino et al. 2016, 2017). For several decades, rocky desertification has usually been regarded as a severe ecological obstacle threatening and constraining regional sustainable development in karst areas, as it can cause many problems (include soil fertility loss, soil erosion, vegetation cover loss, plant species changes, and natural disaster occurrences). On one hand, rocky desertification can lead to many natural disasters (e.g., landslides, debris flow, droughts and floods) that affect the regional residents and hinder the development of the local society; on the other hand, local residents must find more resources (mainly available croplands) from the

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environment to satisfy the food requirement due to poor development of the local society. The process of rocky desertification then becomes accelerated. Therefore, the development of karst regions can become a vicious circle without proper management.

There are many factors contributing to the desertification process, such as climate change, hydrological and geographical conditions, and human development. Previous studies have reported that steep slope and precipitation are the basic driving forces that lead to soil erosion and the occurrence of rocky desertification in karst area (Xiong et al. 2009; Dai et al. 2017). Some researchers also claim that the proportion of rocky land desertification by human activities is up to 62.4%, and the contribution of natural factors is only 37.6% (Nong 2007; Liu et al. 2008). The rate and amount of soil erosion are also closely related to landform and land use/land cover regime (Wu et al. 2011). Depending on land use, human disturbance intensity varies significantly. In addition, land use directly determines plantation coverage (Yan and Cai 2015). However, some scientists hold the adverse idea and claim that human disturbance (mainly agricultural activities) can alleviate soil erosion and the occurrence of rocky desertification (Zhou et al. 2010). It is, therefore, of great importance to reveal the basic mechanism and factors of rocky desertification. Consequently, reasonable measures could be taken for preventing and controlling rocky desertification in karst regions.

Guizhou Province (24°37′–29°13′N, 103°36′–109°35′E) is located on the Yunnan-Guizhou plateau. The area is a typical karst landform in southwestern China. Due to high population density and a low degree of economic development, karst rocky desertification in this region has expanded at an overwhelming rate during the past few decades (Yue et al. 2012; Yang et al. 2014; Zhang et al. 2016). Similar to the other karst areas in southwestern China, the geological environment is sensitive and fragile (Zhang et al. 2011b; Guo et al. 2013; Fan et al. 2015). Due to the unique landform, physical characteristics (including slope, slope position, and soil thickness, among others) are very complex. In Guizhou Province, it is common to find soil erosion, landslides, mudflow, thin soil and bedrock loss, which lead to lost land productivity and to natural disasters in such a fragile ecological environment (Yang et al. 2011).

Since 2001, rocky desertification has attracted great attention from provincial and local governments. Billions of Chinese yuan (¥RMB) have been invested to prevent and control rocky desertification (Bai et al. 2013; Cheng et al. 2017). Some measures have been developed to detain and alleviate the rocky desertification process and even to restore the poor lands that have suffered severe rocky desertification. The main measures include the following: (a) artificial afforestation of poor lands and sealing off mountainous areas for restoration; (b) educating residents to enhance environmental awareness and to encourage public participation; (c) promoting scientific and systematic project engineering implementation; and (d) providing technological support and formulating regulations to supervise rocky desertification activities (Yue et al. 2012). At present, controlling rocky desertification in karst areas in Guizhou has been formally established as a national goal (Cheng et al. 2017).

The present study, therefore, attempted to study the followings: (a) rock outcrops (refers to the degree of rocky desertification) and land use status in the Houzhai River Basin using GIS technology; (b) relationships between rock outcrops and geographical characteristics (including slope gradient, slope position, slope aspect, and altitude) and the leading factors contributing to rocky desertification in a karst mountainous basin; (c) prediction of rocky desertification in karst river basin with geographical characteristics and human disturbance.

Materials and methods

Study region

Houzhai River Basin (26°10′–26°17′N, 105°41′–105°48′E) is located in the central part of Guizhou Province. The area is a typical mountainous karst landform on the Yun-Gui Plateau and it covers an area of 72 km^2. It is subtropical humid monsoon climate, and the mean annual temperature and mean annual precipitation are 15.1 °C and 1378.2 mm, respectively. The altitude of the study region ranged from 854.1 to 1628.6 m, with a mean value of 1310.7 m (variance is 4788.38). The main ecosystem types include montane elfin forest, coniferous and broad-leaved mixed forest, and evergreen broad-leaved forest. The parent materials of soils in the study region include dolomite rock, clay, marlite rock, arenaceous shale rock and carbonate rock. The eastern part mostly consists of a karst peak-cluster depression area, and the central and western parts are mostly lowlands and small hills interspersed with small hills or isolated mountains (Fig. 1). In this region, typical karst landforms lead to a high diversity of geographical characteristics, such as slope gradient, soil thickness, and slope position. A total of 92.78% of available flatlands (excluding construction land and watersheds) is used for cropland, and only 3.49% of flatlands are left for various forestland and grassland. The other 3.73% of flatlands consists of uncultivated land. A total of 42.13% of lands on mountains consists of cropland, and 44.95% of lands on mountains are left for various forestland and grassland. A total of 12.95% of lands on mountains consist of uncultivated land due to severe environmental conditions and poor geographical characteristics.

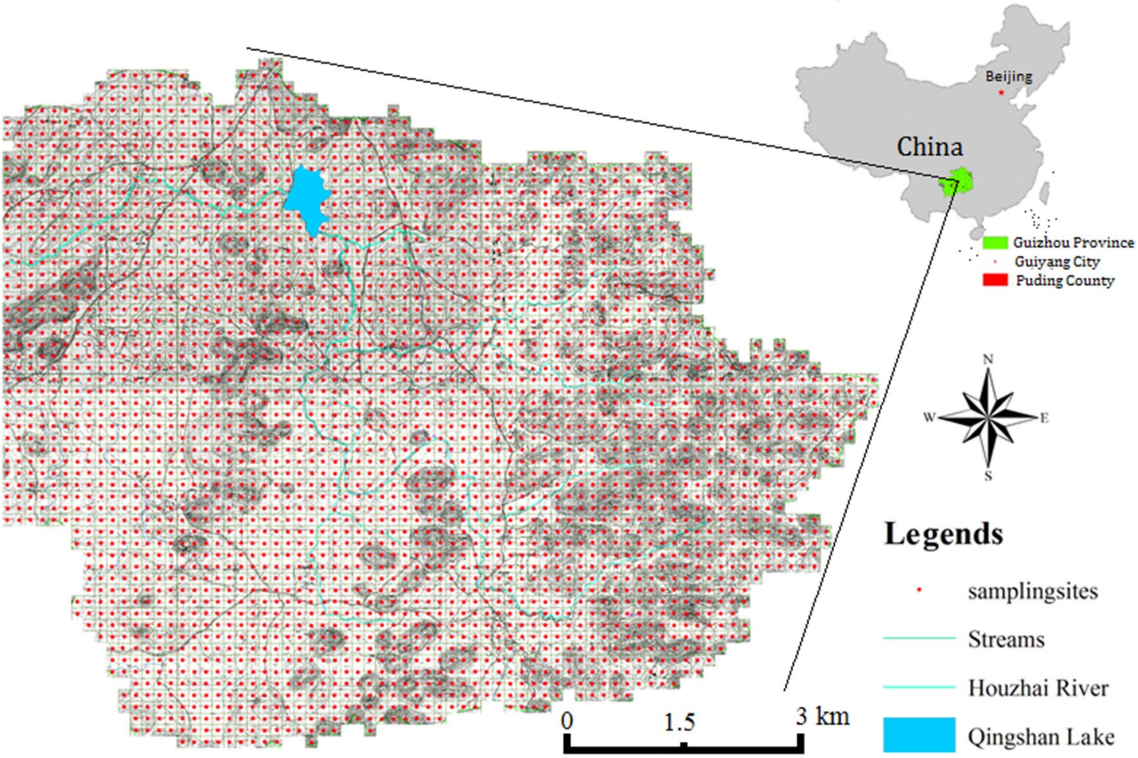

Fig. 1 Landform of the study region and the distribution of designed sampling sites

Soil sampling and field investigations

Sampling and investigation grids were designed on a relief map at a 150-m scale. From March 2013 to January 2015, soil samples and physical characteristics, including slope gradient, slope position, slope aspect, soil parent material, vegetation, altitude and rock outcrops, were sampled and measured at 2,755 designed grid points (Fig. 1; Table 1). A total of 22,057 soil samples were collected and stored in self-sealed plastic bags and returned to the laboratory where the soil samples were air dried, weighed and sieved to remove the gravel fraction (> 2 mm). The prepared samples were saved in zip-lock bags for the analysis of the organic matter (OM) content.

Analytical methods and statistical analysis

Information of altitude, longitude and latitude was collected using a global poisoning system (GPS) (UG801) from Beijing UniStrong Technology Corporation, and slope gradient, slope position, slope aspect, vegetation and parent materials of soils were obtained using a relief map and field investigations. Soil thickness was assessed using a T-shaped steel rod. Rock outcrops were measured by linear interception using tape. The total organic matter contents were determined by $K_2Cr_2O_7$ oxidation at 170–180 °C followed by titration with 0.10 mol L^{-1} $FeSO_4$ (Nelson and Sommers 1996; Wang et al. 2010).

Prediction of rocky desertification occurrence with artificial neural networks

To present a clearer picture regarding the importance of different factors on the occurrence of rocky desertification, artificial neural networks (ANNs) were employed. ANNs are a major artificial intelligence approach derived from the operation of biological neurons. It is based on a collection of connected units called artificial neurons. Each connection between artificial neurons can transmit a signal from one to another (Rumelhart et al. 1986; Basheer and Hajmeer 2000). The ANNs can solve multivariate non-linear problems with a suitable amount of data and an appropriate training algorithm (Zhang and Pan 2014; López et al. 2017; Fan et al. 2017). For example, Fan et al. use ANNs to predict removal of Cd(II) by nZVI/rGO on with pH, contact time and operating temperature. In their study, pH, contact time and operating temperature are independent factors, and removal of Cd(II) by *n*ZVI/*r*GO is a dependent factor. In this study, soil organic matter, altitude, slope gradient, slope position, slope aspect, soil thickness and human disturbance were independent factors, and rock outcrop was a dependent factor. Before

Table 1 Information of soil profiles and soil samples collected from different land uses

Land use	Total profiles	Collect season	Number of soil profiles	Number of soil samples
Paddy fields	400	Dry (June–November)	0	0
		Wet (December–May)	400	4128
Flat cropland	1217	Dry (June–November)	877	8084
		Wet (December–May)	340	2885
Sloping cropland	148	Dry (June–November)	107	744
		Wet (December–May)	41	357
Grassland	127	Dry (June–November)	91	721
		Wet (December–May)	36	218
Uncultivated land	396	Dry (June–November)	256	1519
		Wet (December–May)	140	844
Shrub grassland	71	Dry (June–November)	58	268
		Wet (December–May)	13	62
Shrub land	172	Dry (June–November)	117	525
		Wet (December–May)	55	307
Arbor-shrub mixed forestland	55	Dry (June–November)	38	232
		Wet (December–May)	17	96
Arbor forestland	169	Dry (June–November)	127	817
		Wet (December–May)	42	250

prediction, non-numerical information was transformed into numerical information. The detailed information of network and model is listed in Tables 2 and 3. Lands on mountains were divided into five groups based on slope position information (bottom land, foot slopes, back slopes, shoulder slopes and summits). Lands on different slope aspect were divided into four groups based on sunshine intensity (Group 1: 0° ≤ slope aspect ≤ 45° and 315° ≤ slope aspect ≤ 360°; Group 2: 225° ≤ slope aspect ≤ 315°; Group 3: 45° ≤ slope aspect ≤ 135°; Group 4: 135° ≤ slope aspect ≤ 225°). Lands with different human disturbance were divided into 5 groups (Group 1: all forestlands; Group 2: uncultivated lands; Group 3: abandon croplands; Group 4: grasslands; and Group 5:

Table 2 Detailed information of network

Layers	Items	Information
	Factors	
Input layer	1	Slope position
	2	Slope aspect
	3	Slope gradient
	4	Altitude
	5	Human disturbance
	6	Soil thickness
	7	Soil organic matter
	Number of units[a]	878
Hidden layer(s)	Number of hidden layers	1
	Number of units in hidden layer 1[a]	16
	Activation function	Hyperbolic tangent
Output layer	Dependent variables	
	1	Rock outcrops
	Number of units	1
	Rescaling method for scale dependents	Standardized
	Activation function	Identity
	Error function	Sum of Squares

[a] Excluding the bias unit

Table 3 Detailed information of model

Treatment	Items	Information
Training	Sum of squares error	22.274
	Relative error	0.094
	Stopping rule used	1 Consecutive step(s) with no decrease in error[a]
	Training time	00:00:47.891
Testing	Sum of squares error	11.671
	Relative error	0.257

Dependent variable: rock outcrops

The SSE and RE of testing data were obtained by the predicted values of testing sample based on the obtained model

[a] Error computations are based on the testing sample

croplands). Then, 60% of total data sets were assigned randomly by a computer for training and the remaining data sets were used for testing.

Statistical analysis was carried out with Microsoft Excel 2003, SPSS 18.0, Origin 6.1. A geographic information system (GIS) is a system designed to capture, store, manipulate, analyze, manage, and present spatial or geographic data. In this study, ArcMap 10.3 was used to study spatial information of rocky desertification and land use in the Houzhai River Basin.

Results

Rocky desertification and land use

Rocky desertification status was divided into six degradation classes (Table 4). With GIS technology, spatial information of rocky desertification of studied basin is presented in Fig. 2a. It is found that rocky desertification of the Houzhai River Basin is closely associated with landform. As shown in Fig. 1, the landform of the eastern part of the studied basin is mostly karst peak-cluster depression area. Rocky desertification occurred mostly in the eastern and northern parts of study region. Rocky desertification also occurred in the central and western parts mostly on isolated mountains. Obviously, rocky desertification occurred in this basin primarily on mountains. The areas of rocky desertification to a light degree, moderate degree, high degree, and extremely high degree were 7.81 km^2, 4.50 km^2, 1.87 km^2 and 0.25 km^2, respectively.

To analyze the relationships between land use and rocky desertification occurrence, land use in the study region was classified as paddy field, flat cropland, sloping cropland, grassland, uncultivated land (covered with poor wild grass), shrub grassland, shrub land, arbor–shrub mixed forestland and arbor forestland on the basis of human disturbance intensity and plantation coverage (Fig. 2b). Geographical characteristics including rock outcrops, slope gradient and soil thickness of different land use are listed in Table 5. Paddy fields are the least degraded lands in the study region. These lands have low rock outcrops, small slope gradients and high soil thickness. The most valuable aspect of these lands is that they are adjacent to water resources (streams), which is of great importance for irrigation. Paddy fields are mainly distributed in the northern, central and southern parts of the present basin. The flat croplands are also of high soil quality following paddy fields. The mean values of rock outcrops, slope gradients and soil thickness soil organic matter were 9.19%, 6.06° and 71.43 cm, respectively. The mean soil thickness of grassland is 56.03 cm, which is similar to that of sloping cropland (56.16 cm). However, the mean rock outcrop of grassland is much greater than that of sloping cropland. In addition, soil organic matter levels in cropland soils are significantly lower than those in other use land soils. It is believe that this difference mostly resulted from the divergence of vegetation coverage and human disturbance. First, vegetation coverage and human disturbance determine the quality and quantity of organic matter incorporated into the soil (Hansen et al. 2004; Lal 2009); second, human disturbance influences the degradation rate of land by changing the soil environment (Persson and Stadenberg 2010). Uncultivated land, shrub grassland, shrub land, arbor–shrub mixed forestland and arbor forestland are, generally, of poor soil quality. For these lands, the mean value of rock outcrop was greater than 20%, the mean value of slope gradients was greater than 15°, and the mean value of soil thickness was lower than 45 cm. However, the contents of soil organic matter in these lands

Table 4 Classification of rocky desertification degradation

Classes	Rocky desertification status	Rock outcrop
I	No risk of rocky desertification	Rock outcrop < 20%
II	Latent risk of rocky desertification	20% ≤ rock outcrop < 30%
III	Rocky desertification to a light degree	30% ≤ rock outcrop < 50%
IV	Rocky desertification to a moderate degree	50% ≤ rock outcrop < 70%
V	Rocky desertification to a high degree	70% ≤ rock outcrop 90%
VI	Rocky desertification to an extremely high degree	90% ≤ rock outcrop

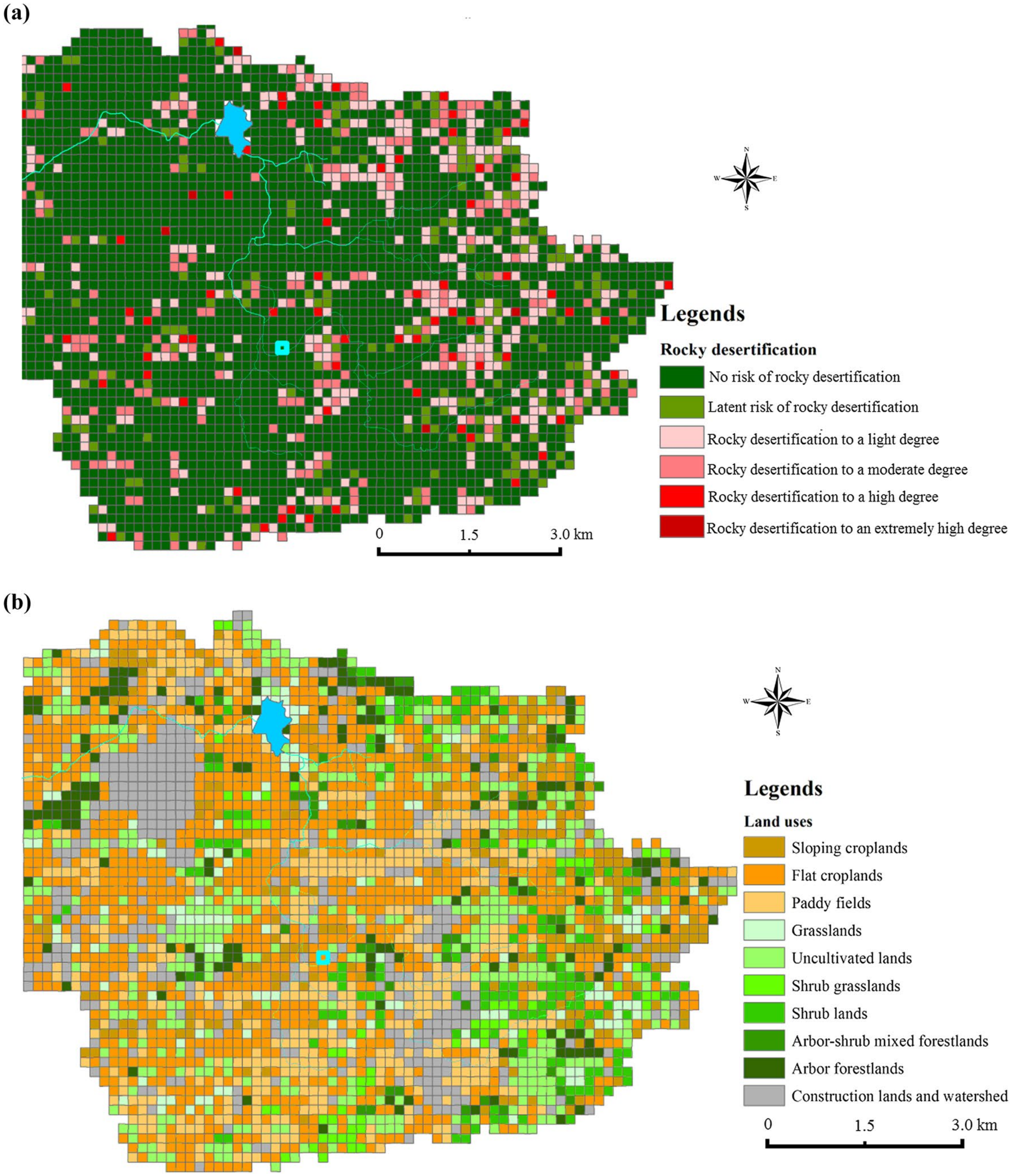

Fig. 2 Rocky desertification status (**a**) and land uses **b** in the Houzhai River Basin

are much higher than those in croplands (paddy fields, flat croplands and sloping croplands) and grasslands.

As shown in Table 5, all mean values of rock outcrops of grasslands, uncultivated lands and forestlands were greater than 20% which is greater than that of croplands including paddy fields, flat croplands and slopping croplands. Most of previous studies focus on rock outcrops and soil erosion of croplands and little of literature concern about the rock outcrops and soil erosion of forestland in study region (Li et al. 2016; Dai et al. 2017).

Relationships among slope gradient, rock outcrop and soil thickness

A significant positive correlation was observed between slope gradients and rock outcrops, as the Pearson correlation

Table 5 Geographical characteristics and soil organic matter of different land uses

Land use	Number of sampling sites	Area (km^2)	Rock outcrops (%)	Slope gradients (°)	Soil thickness (cm)	Soil organic matter (%)
Paddy field	400	9.00	1.93 ± 0.47A	0.00 ± 0.00A	83.91 ± 1.18E	3.74 ± 0.06AB
Flat cropland	1217	27.38	9.19 ± 0.49B	6.06 ± 0.32B	71.43 ± 0.88D	3.40 ± 0.04A
Sloping cropland	148	3.33	17.20 ± 1.65C	18.15 ± 1.26C	56.16 ± 2.52C	3.46 ± 0.11A
Grassland	127	2.86	21.65 ± 2.14C	8.84 ± 1.46B	56.03 ± 2.73C	4.30 ± 0.20B
Uncultivated land	396	8.91	29.92 ± 1.31D	17.97 ± 1.03C	42.00 ± 1.33B	5.60 ± 0.15C
Shrub grassland	71	1.60	34.80 ± 2.70E	35.36 ± 3.09E	30.07 ± 2.01A	6.49 ± 0.35D
Shrub land	172	3.87	26.74 ± 1.65D	30.98 ± 1.46E	31.75 ± 1.60A	6.90 ± 0.22D
Arbor–shrub mixed forestland	55	1.24	22.71 ± 3.46CD	23.15 ± 3.32D	41.39 ± 4.16B	6.89 ± 0.47D
Arbor forestland	169	3.80	26.86 ± 2.02D	15.08 ± 1.45C	44.94 ± 2.34B	5.58 ± 0.22C

Mean ± standard errors

Within columns, values followed by the same capital letter (A–E) are not significantly different ($p < 0.05$) between different land uses

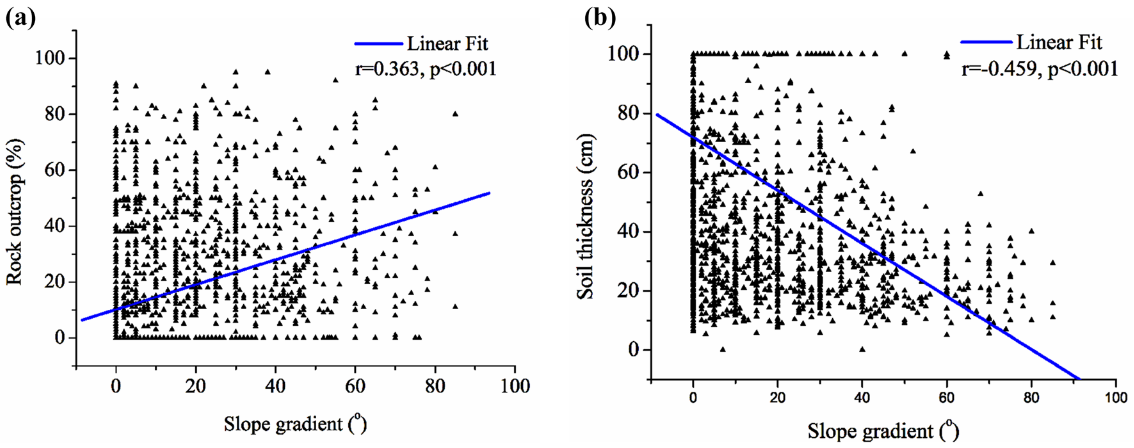

Fig. 3 Effects slope gradient on rock outcrop and soil thickness (**a** relationship between slope gradient and rock outcrop; **b** relationship between slope gradient and soil thickness)

coefficients was 0.363 ($p < 0.001$) (Fig. 3). A significant negative correlation was also observed between slope gradients and soil thickness ($r = -0.459$; $p < 0.001$). Along with increased slope gradient, rock outcrop increased and soil thickness decreased. Therefore, it is believed that slope gradient is a critical factor in soil loss and contributes to the occurrence of rock desertification.

To reveal the potential effects of slope gradient on land use (human disturbance), a comparison between sloping croplands and the other use sloping lands (including grasslands, uncultivated lands, shrub grasslands, shrub lands, arbor–shrub mixed forestlands and arbor forestlands) regarding slope gradient, rock outcrop and soil thickness (Fig. 4) was conducted. For sloping cropland, there was no correlation between slope gradients and rock outcrops ($r = -0.008$, $p > 0.05$), while significant correlations were observed between slope gradients and soil thicknesses ($r = -0.196$, $p < 0.001$) and between rock outcrops and soil thicknesses ($r = -0.417$, $p < 0.001$). In contrast, significant correlations were observed between slope gradients and rock outcrops ($r = 0.196$, $p < 0.001$), and between slope gradients and soil thicknesses ($r = -0.355$, $p < 0.001$), and between rock outcrops and soil thicknesses ($r = -0.388$, $p < 0.001$) regarding the other use sloping lands.

First, the rock outcrops of sloping croplands did not increase with increasing slope gradients, but few decreased; the rock outcrops of the other use sloping lands increased with increasing slope gradients. Second, the soil thicknesses of sloping croplands decreased with increasing slope gradients as the other use sloping lands, but the Pearson correlation coefficient between the soil thicknesses and slope gradients of sloping cropland was much lower than that of the other use sloping lands (absolute value). Third, the rock outcrops of both sloping croplands and the other use

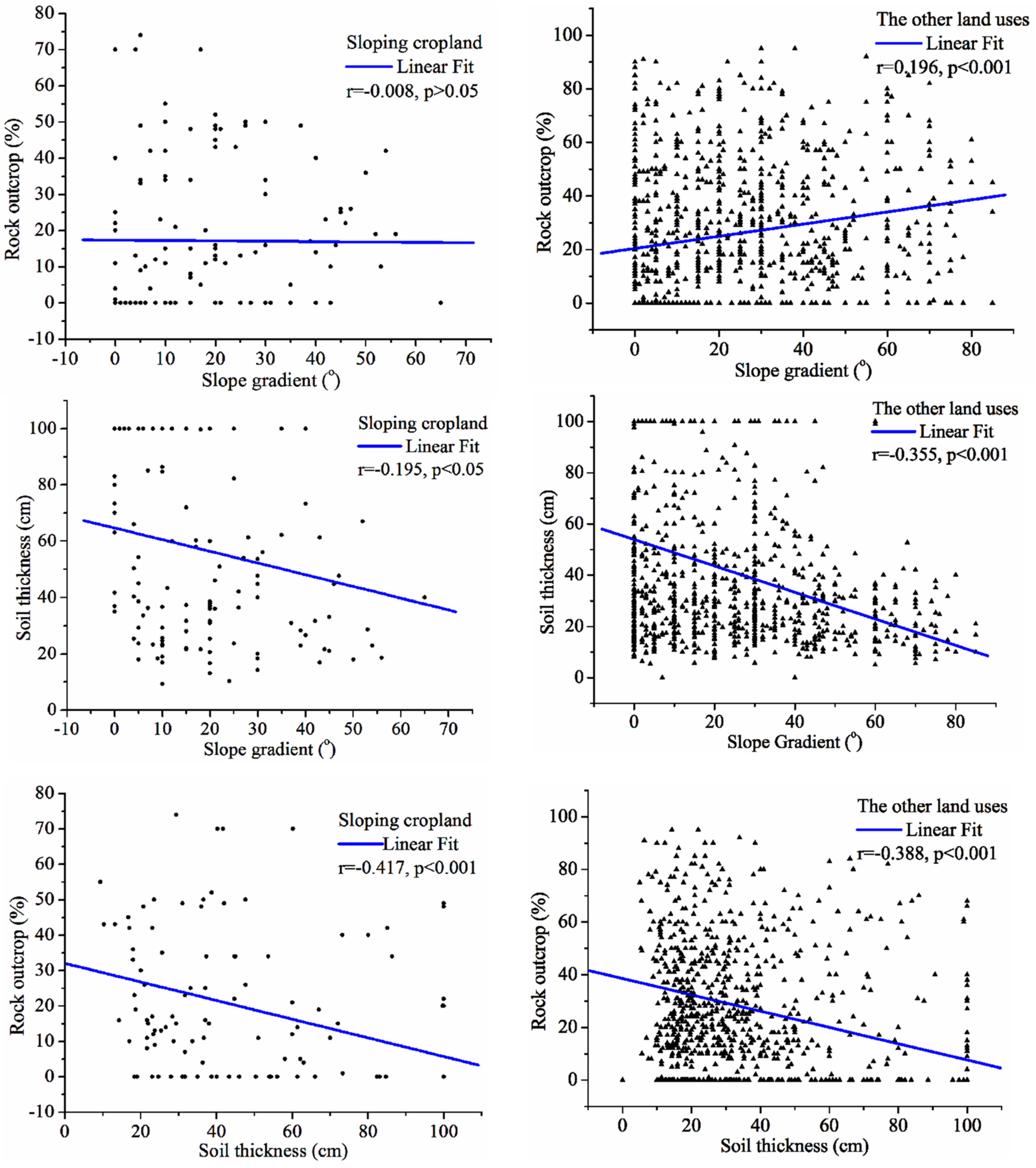

Fig. 4 Comparison between sloping cropland and other land uses regarding slope gradient, rock outcrop and soil thickness

sloping lands decreased with increasing soil thicknesses, but the Pearson correlation coefficient between the soil thicknesses and outcrops of sloping croplands was slightly greater than that of the other use sloping lands (absolute value). All of these probably indicate that sloping croplands has lower rock outcrops and greater soil thickness than the other use sloping lands do. It is believed that rock outcrop and soil thickness are critical factors in the choice of sloping croplands rather than slope gradient, and slope gradient was closely associated with the occurrence of soil loss and rocky desertification.

Relationships among slope position, rock outcrop and soil thickness

In this study, lands on mountains were divided into five groups based on the slope position information (bottom land, foot slopes, back slopes, shoulder slopes and summits). As shown in Table 6, slope positions mostly led to variation in slope gradient and soil thickness. From bottom land to shoulder slopes, slope gradient increased from 10.92 ± 0.562° to 34.50 ± 1.774°, and the soil thickness decreased from 61.82 ± 1.16 to 35.73 ± 2.12 cm. On the

Table 6 Effects of slope position on rock outcrops and soil thickness

Slope position	N	Proportion (%)	Slope gradient (°)	Rock outcrop (%)	Soil thickness (cm)
Bottom land	679	39.05	10.92 ± 0.562A	16.15 ± 1.22A	61.82 ± 1.16D
Foot slope	513	29.50	19.53 ± 1.167B	22.76 ± 2.08B	50.23 ± 2.16C
Back slope	209	12.02	27.12 ± 0.899C	27.13 ± 1.56C	43.25 ± 1.14B
Shoulder slope	172	9.89	34.50 ± 1.774D	27.36 ± 2.11C	35.73 ± 2.12A
Summit	166	9.55	11.80 ± 1.517A	27.55 ± 2.93C	49.72 ± 2.45C

Means and standard errors

Within columns, values followed by the same capital letter (A–D) are not significantly different ($p < 0.05$) between slope positions

summit parts, the slope gradient decreased to 11.80 ± 1.517°, and the soil thickness increased to 49.72 ± 2.45 cm. The statistical results also indicate that slope gradient and soil thickness are closely associated with slope position, and no significant correlation exists between rock outcrop and slope position. As shown in Table 7, the mean values of the slope gradients and rock outcrops of sloping cropland were lower than those of the other use sloping lands at each slope position, and the mean values of the soil thicknesses of sloping croplands were greater than those of the other use sloping lands at each slope position.

Relationships among slope aspect, rock outcrop and soil thickness

China is on the northern hemisphere of the earth. The intensity of sunshine on slopes follows the order: slopes facing south (135°–225°) > slopes facing east (45°–135°) > slopes facing west (225°–315°) > slopes facing north (315°–360° and 0°–45°). Discrepancies exist between different slope aspects concerning cropland proportion, slope gradient, rock outcrop and soil thickness of both sloping croplands and the other use sloping lands (Table 8). However, no statistical significance was observed among different slope aspects of both sloping cropland and the other use sloping land, except for soil thickness. It is worth noting that all the mean values of the slope gradients and rock outcrops of the sloping cropland of different slope aspects were lower than those of the other use sloping land; in contract, the mean values of the soil thickness of the sloping cropland of different slope aspects were greater than those of the other use sloping land regarding different slope aspects. These results probably indicate that slope aspect is not an important factor that contributes to land choice for croplands, although there is some variation within the cropland proportion of different slope aspects. Again, the results indicated that rock outcrops and soil thickness are critical factors in determining land arrangement for sloping croplands, and slope aspect has little contribution to occurrence of rocky desertification.

Relationships among altitude, rock outcrop and soil thickness

In the studied basin, altitude was closely associated with slope gradient ($r = 0.392$, $p < 0.001$), rock outcrop ($r = 0.336$, $p < 0.001$) and soil thickness ($r = -0.479$, $p < 0.001$) (Table 9). It is worth noting that there was no correlation between altitudes and slope gradients of sloping croplands.

Table 7 Effects of slope position on the rock outcrops and soil thickness of sloping croplands and the other use sloping lands

Sloping land	Slope position	N	Proportion (%)	Slope gradients (°)	Rock outcrop (%)	Soil thickness (cm)
Sloping croplands	Bottom land	469	26.97	6.38 ± 1.65A	14.64 ± 2.45B	61.06 ± 4.20B
	Foot slope	332	19.09	26.64 ± 3.58C	20.35 ± 5.09C	53.37 ± 6.78AB
	Back slope	96	5.52	24.76 ± 2.44BC	24.73 ± 3.39C	45.50 ± 3.94A
	Shoulder slope	132	7.59	22.70 ± 6.06B	13.73 ± 5.27B	55.09 ± 11.46AB
	Summit	98	5.64	6.75 ± 3.20A	2.00 ± 2.00A	52.25 ± 19.38AB
The other use sloping lands	Bottom land	210	12.08	15.30 ± 1.23A	25.46 ± 1.61A	46.61 ± 2.01C
	Foot slope	181	10.41	27.38 ± 1.97B	34.28 ± 2.97B	36.82 ± 2.58B
	Back slope	113	6.50	31.51 ± 1.18B	31.02 ± 1.47B	34.89 ± 1.32B
	Shoulder slope	40	2.30	39.08 ± 2.05C	31.04 ± 2.07B	27.01 ± 1.68A
	Summit	68	3.91	16.28 ± 2.51A	36.85 ± 3.37B	34.15 ± 3.01B

Mean ± standard errors

Within columns, values followed by the same capital letter (A–C) are not significantly different ($p < 0.05$) between slope positions

Table 8 Effects of slope aspect on the rock outcrops and soil thickness levels of sloping cropland and other land uses

	Slope aspects	*N*	Proportion (%)	Slope gradient (°)	Rock outcrops (%)	Soil thickness (cm)
Sloping croplands	Slopes facing south	162	39.71	20.08 ± 3.09A	16.13 ± 3.13A	51.34 ± 6.41A
	Slopes facing east	143	54.62	23.13 ± 2.46A	11.03 ± 3.23A	70.06 ± 5.92B
	Slopes facing west	165	47.69	18.72 ± 2.27A	21.10 ± 4.66A	51.79 ± 5.40A
	Slopes facing north	401	55.39	22.80 ± 2.64A	19.75 ± 3.25A	46.39 ± 4.27A
The other use sloping lands	Slopes facing south	246	60.29	27.96 ± 1.29A	39.75 ± 1.62A	35.84 ± 1.61A
	Slopes facing east	118	45.38	25.42 ± 1.87A	28.15 ± 2.17A	34.87 ± 2.22A
	Slopes facing west	181	52.31	28.07 ± 1.43A	29.87 ± 1.68A	40.59 ± 1.83B
	Slopes facing north	323	44.61	27.63 ± 1.36A	27.30 ± 1.47A	40.11 ± 1.67AB

Mean ± standard errors

Within columns, values followed by the same capital letter (A–B) are not significantly different ($p < 0.05$) between slope positions

Table 9 Pearson correlations among altitude, slope gradient, rock outcrops and soil thickness

Lands	Altitude	Slope gradient	Rock outcrops	Soil thickness
Total lands ($N = 1739$)				
Altitude	1			
Slope gradient	0.392** $p = 0.000$	1		
Rock outcrops	0.336** $p = 0.000$	0.303** $p = 0.000$	1	
Soil thickness	−0.479** $p = 0.000$	−0.510** $p = 0.000$	−0.550** $p = 0.000$	1
Sloping croplands ($N = 871$)				
Altitude	1			
Slope gradient	0.042 $p = 0.676$	1		
Rock outcrops	0.214* $p = 0.032$	0.008 $p = 0.805$	1	
Soil thickness	−0.485** $p = 0.000$	−0.195* $p = 0.043$	−0.417** $p = 0.000$	1
The other use sloping lands ($N = 868$)				
Altitude	1			
Slope gradient	0.382** $p = 0.000$	1		
Rock outcrops	0.244** $p = 0.000$	0.120** $p = 0.008$	1	
Soil thickness	−0.438** $p = 0.000$	−0.476** $p = 0.000$	−0.446** $p = 0.000$	1

It is well known that lands at higher altitude are always poor conditions for plant growth. However, lands at higher altitudes are also chosen for food production due to the shortage of cropland.

Importance of different factors on the prediction of rocky desertification occurrence

Using ANNs prediction analysis with soil organic matter, altitude, slope gradient, slope position, slope aspect, soil thickness and human disturbance as factors, the linear correlation coefficients between predicted values and observed values ranged from 0.728 to 0.905, with a mean value of 0.851 (ten times repeats). Table 3 presents the model of one repeat. The sum of squares error and relative error of testing data was 9.4% and 25.7%, respectively. These results indicate that this method might be feasible way for predicting the occurrence of rocky desertification based on the geographical characteristics and human disturbance (Figs. 5, 6). The normalized importance of factors under study follows the

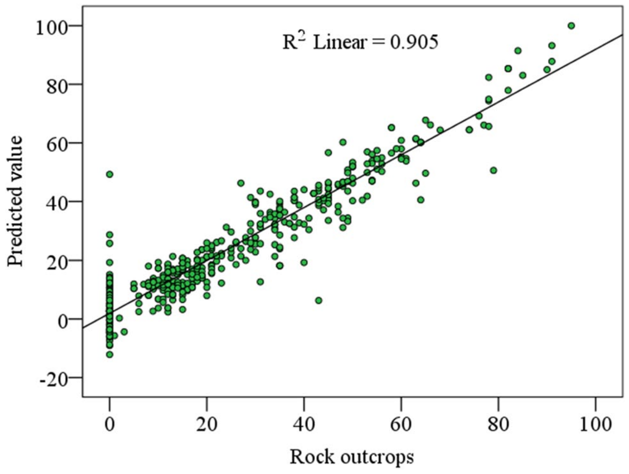

Fig. 5 Relationship between the observed values and predicted values of rock outcrops

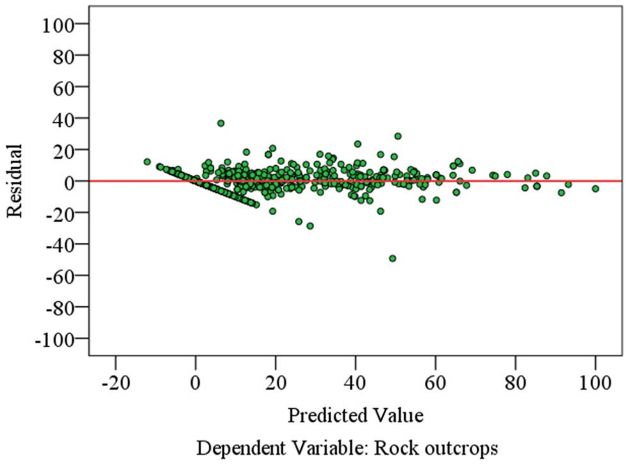

Fig. 6 Residual of predicted values of rock outcrops

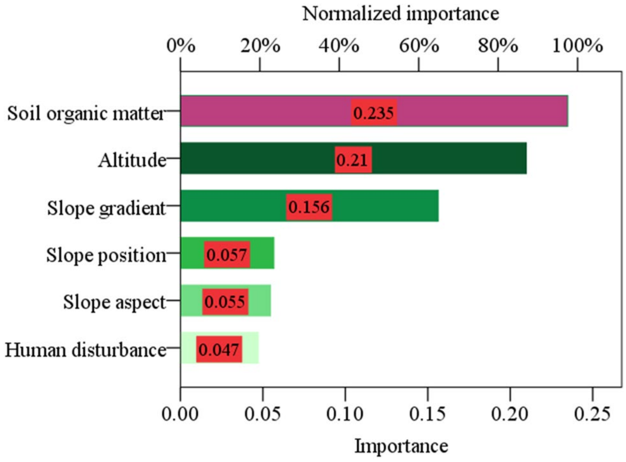

Fig. 7 The importance of different factors from ANNs prediction analysis

order: soil organic matter > altitude > slope gradient > sloe position > slope aspect > human disturbance (Fig. 7).

Discussion

Factors affecting rocky desertification and land use

Rocky desertification in study region is a serious problem. Slope gradient and altitude are both critical factors leading to soil loss and rocky desertification. With greater slope gradient, soils are easily lost due to surface runoff, resulting in the occurrence of rocky desertification. Along with increasing altitude, the environment becomes more severe, including greater slope gradients and lower soil thickness. Then, plantations become increasingly poorer. Therefore, lands at higher altitude have lower soil conversation ability. Previous studies claim that human activity is the main driving force for initiation and development of rocky desertification (Su et al. 2006; Trac et al. 2007; Liu et al. 2008; Tang et al. 2016; Dai et al. 2017). However, the present study did not find any evidence that human disturbance (agricultural activities) contributes to rocky desertification as rock outcrops of sloping cropland were generally lower than those of the other use sloping lands. However, this result does not indicate that human disturbance (agricultural activities) has no effect on the occurrence of rocky desertification in the study area, as only better sloping lands (lower slope gradient, lower rock outcrops and greater soil thickness) were selected for croplands. Furthermore, to prevent soil erosion, croplands owners usually take some measures to protect soils. This might be one of the reasons why the soil thicknesses of sloping croplands are greater than those of the other use sloping lands in the Houzhai River Basin. We believe that it is necessary to establish a long-term (decades to centuries) tracking study of the rock outcrops of specific croplands to reveal the effects of human disturbance on rocky desertification in karst mountainous basins, such as the studied Basin.

Based on the present study, the contradiction between human needs and cropland shortage is still a severe problem in the present Basin. Landform is the primary factor contributing to the occurrence of rocky desertification and land use in studied area. Slope gradient, rock outcrop and soil thickness are governing factors in the consideration of whether lands on mountains should be chosen for croplands. Lands with smaller slope gradient, lower rock outcrop and thicker soil thickness were managed for croplands. Otherwise, lands were left and become different forestlands, grasslands and wasteland under the work of natural succession. In contrast, slope aspect presents no significance in this consideration. Lands of poor quality (taller rock outcrop, greater slope gradient and thinner soil thickness) are left and become grassland, uncultivated land, shrub grassland, shrub land and arbor forestland under the work of natural succession. In addition, a shortage of cropland still exists. To prevent soil erosion, cropland owners usually take some measures to protect soils (Zhou et al. 2010; Xu et al. 2013). The common applied measures include building retaining walls (building walls with stones at the edge of sloping cropland) and improving drainage status (digging drainage trenches to regulate surface runoff to avoid flow through sloping croplands). Therefore, human disturbance (mainly agricultural activities), probably, presents some contribution in prevention and control of rocky desertification occurrence.

Prediction of the occurrence of rocky desertification

Although the normalized importance value of soil organic matter reached 0.235, which is greater than those of the other factors under study, soil organic matter is not a critical factor that contributes to occurrence of rocky desertification. The difference in soil organic matter is primarily caused by land use (refers to vegetation coverage and human disturbance), and rock outcrop is one of the critical factors in determining land use. Therefore, the close relationship between soil organic matter and rock outcrops mainly result from human disturbance. In other words, increase in rock outcrop might lead to increase in soil organic matter contents. The results from ANNs analysis are in strong agreement with the Pearson correlation analysis. All of them indicate that altitude and slope gradient are leading factors that contribute to the occurrence of rocky desertification in the studied basin. In actuality, the altitude level directly determines the level of slope gradient and cover vegetation to some extent. Therefore, the primary factor contributing to the occurrence of rocky desertification is slope gradient. Human disturbance presented little effects on the occurrence of rocky desertification.

Conclusions

On the basis of field investigation and results from laboratory analysis, it was found that spatial characteristic of rock outcrop in Houzhai River Basin is closely associated with landform, and rock outcrop and soil thickness are key factors in management of land use in this region. Slope gradient and altitude are the primary factors leading to the occurrence of rocky desertification in studied basin. Slope position and slope aspect have little effect on the occurrence of rocky desertification in the study area. ANNs are a feasible method for the prediction of rocky desertification occurrence with geographical factors and human disturbance. It is worthy noting that the present study indicates that human disturbance (agricultural activities) presents little contribution to the occurrence of rocky desertification which is inconsistent with reported literature.

In summary, special attention should be paid to slope gradient and altitude in consideration of prevent and control rocky desertification in a karst mountainous basin. To reveal the effects of human disturbance on rocky desertification, it is necessary to perform a long-term tracking study of the rock outcrops of specific croplands.

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