

Human Driving Forces: Analysis of Rocky Desertification in Karst Region in Guanling County, Guizhou Province

WU Xiuqin¹, LIU Hongmeng², HUANG Xiulan², ZHOU Tao¹

(1. School of Soil and Water Conservation, Beijing Forestry University, Beijing 100083, China; 2. Key Laboratory for Environmental and Urban Sciences, Shenzhen Graduate School, Peking University, Shenzhen 518055, China)

Abstract: Karst rocky desertification is one of the major ecological and environmental problems that threaten the sustainable development of southwestern China. It is caused by irrational and intensive land-use patterns in karst geo-ecological environment. Therefore, it is vital to identify how human forces work on this degraded environment. Based on the soil erosion information in 2000 and remote sensing images of Guanling County collected in 2000 and 2007, four grades of karst rocky desertification data in 14 villages of Guanling County were extracted. Impacts of population, affluence, and other human forces on karst rocky desertification were analyzed using STIRPAT model. The results show that: 1) Factors of population and affluence had strong influence on karst rocky desertification. In the STIRPAT model analysis, the population and affluence coefficients were positive, indicating that the increase in population and affluence would lead to more serious desertification. 2) Factors of farmer correlated with karst rocky desertification negatively, especially the way of viewing the relationship between people and nature, and the level of knowledge about rocky desertification. Government behavior was not a significant factor in this analysis. 3) The findings provide evidence that STIRPAT model can be used to analyze the relationship between human driving forces and rocky desertification.

Keywords: karst rocky desertification; human driving forces; STIRPAT model; Guanling County, Guizhou Province

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1 Introduction

'Rocky desertification in southern China and sandy desertification in northern China' are two major environmental problems that restrict the sustainable development of China (Wang and Li, 2007). Karst rocky desertification is a typical land degradation, in which soil is seriously eroded, if not thoroughly eroded under irrational human impacts, leaving the bedrock widely exposed. As a result, the carrying capacity of land declines significantly, and the landscape becomes desert (Huang and Cai, 2007). Much domestic academic research on rocky desertification has been done with regard to its formation and evolution, including analyses of the forces driving desertification and the latter's ecological

and environmental effects, risk assessment, and integrated rehabilitation (Wu *et al.*, 2007). Of these, the analysis of the forces driving rocky desertification has been one of the central issues in desertification study. The karst landform provides the material background for rocky desertification. Therefore, many scholars in this field have spent much time studying the quantitative relationship between rocky desertification and natural factors, such as slope and geological conditions (Li *et al.*, 2006a; Su *et al.*, 2006; Xiao *et al.*, 2006; Zhou, 2006). Meanwhile, they have reached a consensus that human forces also play a vital role in the development of rocky desertification (Zhang and Hu, 2008).

There are some deficiencies in studies on the effects of human forces on karst rocky desertification. First,

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Corresponding author: WU Xiuqin. E-mail: wuxq@bjfu.edu.cn

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quantitative research is still lacking. Huang and Cai (2007) have pointed out that the evolutionary mechanism of karst rocky desertification should be strengthened at different spatial and temporal scales, especially in the study of the human forces that drive the phenomenon of rocky desertification and the identification of the contribution rate of natural and human factors. Second, the selection of the human driving forces is limited. Currently, the main human factors chosen for human-driving studies are usually economic and social factors, such as population density and per capita income. However, consciousness, behavior, and government policy indicators are rarely involved. Some researchers have pointed out that research on the causes of desertification should focus on the relationship between people and land, and regions on which these two factors interact (Li *et al.*, 2006b).

Studies on karst in abroad and domestic are almost simultaneous (Wang *et al.*, 2007), but the research on karst rocky desertification is rarely abroad (Zhang and Hu, 2008). The main reason might be that although the karst landforms is widely distributed across the world, the different natural basis (lithology, climate, *etc.*) and different human social conditions (population, economy, *etc.*) make the phenomenon of karst rocky desertification typical regionally different. Therefore, the karst rocky desertification in southwestern China is a distinct process of land degradation. In terms of the influence of human forces on karst ecosystem, the fact that the heavy deforestation in history and the widespread use of fire left a permanent imprint in karst ecosystem has been pointed out.

In 1971, the idea of IPAT equation was proposed. The impact (I) can be expressed as a product of three characteristics: the population size (P), its affluence or per-capita consumption (A), and the environmental damage (T) inflicted by the technologies. That is, $I = PAT$ (Ehrlich and Holdren, 1971; Daily and Ehrlich, 1992; Waggoner and Ausubel, 2002). However, the IPAT assumes that the changing ratio between human driving forces and environmental impact is the same. Thus, the IPAT equation is not very suitable for measuring the environmental impact of other human driving forces (Long *et al.*, 2006). To overcome this limitation, some scholars rebuilt some new types of this model. York *et al.* (2002) reformulated IPAT into a stochastic model, calling it STIRPAT for stochastic impact by regression on

population, affluence, and technology. Currently, the STIRPAT model is used mainly to analyze the influence of human driving forces on ecological footprint, water footprint, carbon dioxide emissions, energy consumption, and changes in the cultivated area (Xu and Cheng, 2005; Long *et al.*, 2006; Wang and He, 2008; Wang *et al.*, 2008; Sun and Xu, 2009). The present study uses the STIRPAT model to estimate the impact of human driving forces on the changes in karst rocky desertification.

In view of the practical significance of the present study on karst rocky desertification and the current deficiency in the research on karst rocky desertification, namely the absence of quantitative research and the limitation of the human driving factors, the present study attempts to make a quantitative analysis on the relationship between the human driving forces and rocky desertification using the STIRPAT model in the case study of Guanling County, Guizhou Province.

2 Materials and Methods

2.1 Study area

Guanling County (25°34'–26°05'N, 105°15'–105°49'E) is selected as the study area, which is located in the southwest of Anshun City, Guizhou Province, southwestern China (Fig. 1). The total area of the county is about 1466 km², of which the karst area accounts for more than 80%. The average elevation is about 1141 m. Humid subtropical monsoon climate is the main climate type in this region. Soil types are mainly yellow, red, and calcareous soils, of which the calcareous soil area accounts for 57.7% of the whole county.

In 2007, the population of Guanling was 324 800, of which the agricultural population accounts for 89.6%. The imbalance between the quantities of cultivated land resources and the number of agricultural population had resulted in a relatively tight contradiction between the local people and nature. To meet short-term survival needs, people have had to overexploit land, leading to serious land degradation in the form of karst rocky desertification.

2.2 Data sources

Land sat TM remote sensing images of Guanling collected in 2000 and 2007, and two corresponding land-use maps obtained from the local land department were used in the present study. The geometric correction

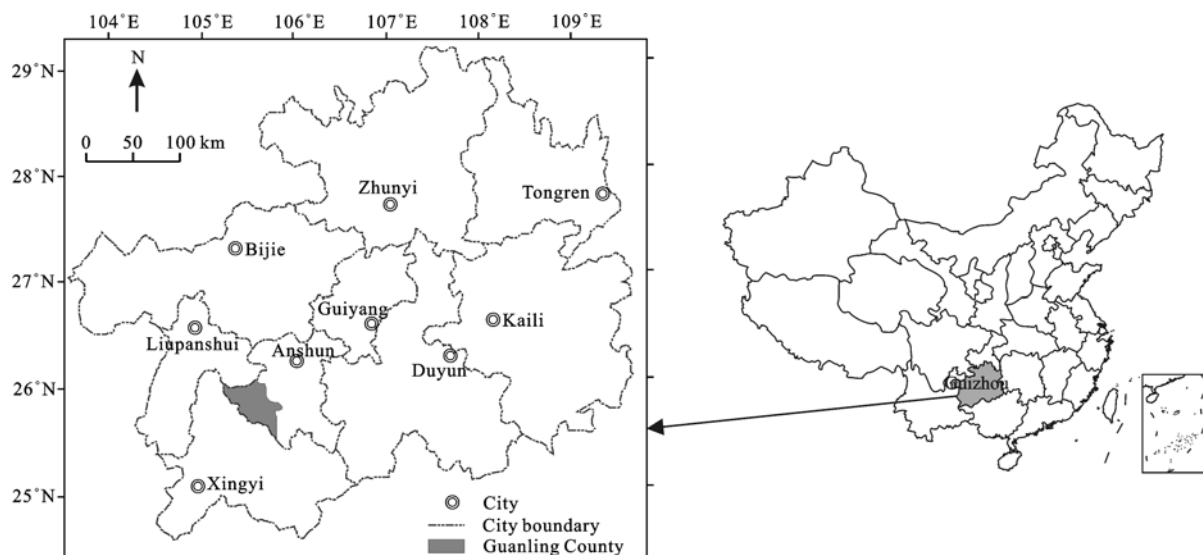


Fig. 1 Location of study area

of the remote sensing images had been completed, and both the remote sensing data and land-use maps are in Albers map projection. In addition, soil data maps, geological maps, administrative maps, climate data, and other environmental data were collected from the local land department, water department, and the meteorological bureau. A database of human driving forces was established based on 360 farmers' questionnaires; socioeconomic statistical data were collected from the local statistic bureau in the field investigation in 2009.

2.3 Methods

2.3.1 Extraction of rocky-desertification information

First, Landsat TM images in 2007 were radio metrically and geometrically corrected. Thus, the 2007 land-use maps were obtained with the information of vegetation coverage. Then, referencing to the data on soil erosion in the study area and field research in 2000, the classification system was built (Table 1), hence extracting information on the desertification in 14 towns in Guanling County.

2.3.2 Model

The specification of the STIRPAT model is:

$$I_i = aP_i^b A_i^c T_i^d e \quad (1)$$

where, the constant a scales the model; b , c , and d are the exponents of P , A and T , respectively, which must be estimated; e is the error term; I_i represents the environment impact of observational unit i which means the grade of karst rocky desertification; P_i represents the driving factor of population of observational unit i ; A_i represents the affluence factor of observational unit i ; T_i is the driving factor of technology of observational unit i . Equation (1) is essentially a multivariate nonlinear model. To test the impact of human factors on the environment, Equation (1) can be transformed into logarithmic form, which is the Equation (2) showed as follows:

$$\ln(I) = a + b \ln(P) + c \ln(A) + d \ln(T) + e \quad (2)$$

where, a and e are the log of a and the log of e from Equation (1), respectively. We drop the subscript i to reduce clutter in the equation. The meanings of I , P , A

Table 1 Evaluation grade of karst rocky desertification

Grade	Vegetation coverage (%)	Soil erosion	Land use type
Mild	>50	Mild	Natural forest, plantation of trees and shrubs, and secondary grassland
Moderate	50–20	Moderate	Medium-coverage shrub grassland and forest land
Severe	<20	Severe	Low-coverage grassland and sparse forest
Non-rocky	>80	Slight	Others

and T are the same with those in Equation (1) and this situation also applies to the Equation (3) and Equation (4).

In the STIRPAT model, T is included in the error term, rather than estimated separately, making it consistent with the IPAT model, where T is solved to balance I , P , and A . These modifications yield the following Equation (3):

$$\ln(I) = a + b \ln(P) + c \ln(A) + e \quad (3)$$

If there are a number of integrated T factors which can be measured, they can be decomposed into T_1, T_2, \dots, T_n ; thus the Equation (4) can be resulted from the equations (1) and (2) as the following:

$$\ln(I) = a + b \ln(P) + c \ln(A) + d \ln(T_1) + f \ln(T_2) + e \quad (4)$$

Models (1)–(8) in 3.2 are all based on equations (2)–(4).

According to the STIRPAT model, index system of factor requirements, field research results, and human driving forces were constructed (Table 2). The practical number of the total population of each town was selected as the population factor. The choice of affluence factor was based on the economic structure of the study area. The main industry of Guanling is agriculture; thus, the per capita cultivated land was chosen as the affluence factor. In the STIRPAT model, T stands for technology, but more for the residual (York *et al.*, 2003). The present study specified T as farmer factor and government regulation factor, turning the 'quantified T factors' into a sense of progress in farmers' awareness and the administrations of government, which explored the impact of farmers' behaviors, awareness, and the regulation of government on desertification.

Table 2 Index system of human forces

First-level indicator		Secondary-level indicator
P	Population	Population
A	Affluence	Per capita cultivated land
		View of human-land relationship
T_1	Farmer factor	Farmers' field behavior
		Understanding of rocky desertification
T_2	Government regulation factor	Government behavior

The factors for farmer and government regulation were derived from face-to-face interviews based on a structured questionnaire for farmers, which took place in late July 2009, and lasted for 21 days. The survey ques-

tionnaires were distributed in 138 administrative villages of Guanling County and 360 valid questionnaires were screened for use in the bellowed-studies. Each questionnaire contained 56 questions related to the following aspects: 1) demographic characteristics; 2) farmers' field behavior and land conservation measures; 3) farmers' economic, cultural, and health standards; 4) farmers' awareness of issues on rocky desertification; and 5) farmers' view of human-land relationship and their concept of birth. Questionnaire results were extracted with experts scoring, and analyzed using SPSS 17.0.

Farmer-factor includes three secondary factors: farmers' concept of human-land relationship, farmers' field behavior, and their understanding of rocky desertification. They are all non-quantifiable variables; in order to quantify the answers and count into the model, they were classified into three levels as follows: one point for Level 1, five points for Level 2, and ten points for Level 3. Level 1 means that the answers are not reasonable, level 2 presents more reasonable answers than those of Level 1, and the Level 3 stands for the most reasonable answers. The weight of secondary factors was determined using the Delphi Method, eight experts in a related study area, and the final score of farmer-factor was obtained through weighted sum (Table 3).

The government-regulation factor was focused on government behaviors, including the government's technical guidance for farmers' field behavior and the accessibility of farmers' feedback channels. The extraction method was identical to that of the farmer factor (Table 3).

Table 3 Weights of factors of farmer and government regulation

Secondary factors		Weight
Farmer factor	View of human-land relationship	0.35
	Farmers' field behavior	0.35
	Understanding of rocky desertification	0.3
Government regulation factor	Government behavior	1

3 Results

3.1 Analysis of current situation of karst rocky desertification

Through statistical analysis, the total rocky desertification area of Guanling County was found to be 91 738. 39 ha

in 2007, accounting for 62.58% of the total area of Guanling. The mild rocky desertification area was 9168.95 ha, accounting for 6.25% of the total county area. The moderate rocky desertification area was 50 045 ha, the largest in all grades of land desertification in the area, accounting for 34.14% of the total county area. Severe rocky desertification area was 32 524.77 ha, accounting for 22.19% of the county area (Table 4). The results showed that the situation of rocky desertification in Guanling County was relatively serious.

Table 4 Area of Karst rocky desertification of Guanling County in 2007

Grade of rocky desertification	Area (ha)	Percentage (%)
Non-rocky	54861.61	37.42
Mild	9168.95	6.25
Moderate	50044.67	34.14
Severe	32524.77	22.19
Total rocky area	91738.39	62.58
Total area	146600.00	100.00

Figure 2 shows that non-desertification patches were mainly distributed in Xinpu, Gangwu, as well as the southeast of Bade Town. The mild rocky desertification area was mainly distributed in Gangwu, Duanqiao, and Xinpu. Moderate desertification was mainly distributed in eastern and central Guanling. The area of moderate desertification was the largest in Huajiang, followed by Bangui. Severe desertification was mainly distributed in western and central Guanling County, with the area in Puli being the largest, followed by Xinpu, Gangwu, and Yongning (Fig. 2 and Fig. 3).

3.2 Analysis of human driving forces on karst rocky desertification

Based on STIRPAT equations (2)–(4), the two basic factors, population and affluence, were analyzed firstly,

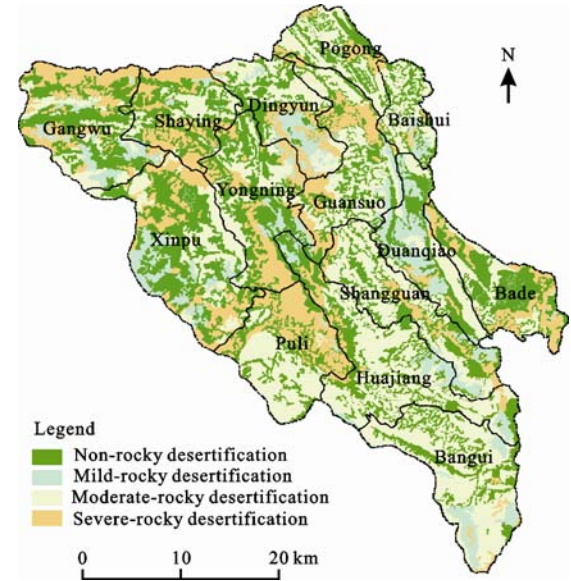


Fig. 2 Distribution of rocky desertification in Guanling County

then the *T* factor (farmer and government regulation) was added to the model. The models (1)–(8) were re-sulted from the analysis procedure.

3.2.1 Effects of different human driving forces

By identifying the total area of rocky desertification in 14 towns as the dependent variable, Model (1) was obtained to analyze the effects of population and affluence on rocky desertification. The model parameters are shown in Table 5.

Population and per capita cultivated land were used in Model (1) as human factors to analyze the human impacts on rocky desertification. In Model (1), when the population factor changed to the positive direction for 1% while the other factors remained constant, the corresponding environmental pressure would increase 0.812%. One percent increase in the per capita cultivated land will lead to a 0.879% increase in environmental pressure. The results of Model (1) showed that the total area of rocky desertification had increased

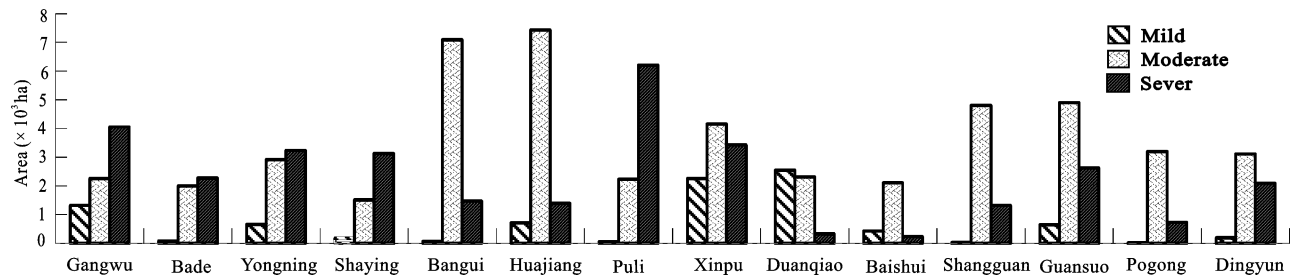


Fig. 3 Rocky desertification area of each town in Guanling County

Table 5 Models (1)–(5)

	Model 1 (1)	Model (2)	Model (3)	Model (4)	Model (5)
Constant	10.132 (3.686 ^{***})	9.870 (3.321 ^{***})	14.064 (6.842 ^{***})	12.053 (4.788 ^{**})	10.083 (3.470 ^{***})
Population	0.812 (2.880 ^{**})	0.808 (2.742 ^{**})	0.883 (4.761 ^{***})	0.886 (3.622 ^{***})	0.809 (2.726 ^{***})
Per capita cultivated land	0.879 (2.578 ^{**})	0.815 (2.019 [*])	0.989 (4.395 ^{***})	0.717 (2.374 ^{***})	0.854 (2.094 ^{**})
Farmers' field behavior		0.176 (1.087 [*])			
Concept of human-land relationship			−2.50 (−3.959 ^{***})		
Understanding of rocky desertification				−1.574 (−2.211 ^{**})	
Government regulation factor					0.064 (not evident)
R^2	0.460	0.466	0.790	0.637	0.461
F	4.688	2.911	12.517	5.861	2.852
N	14	14	14	14	14

Notes: The number in brackets is the t test; *, **, *** is significant at the 0.1, 0.05, and 0.01 level, respectively

correspondingly with the population growth and the rise in per capita cultivated land. The goodness of fit of Model (1) was 0.460, which was not high, showing that the population factor and affluence factor could only explain 46% of all environmental pressures as measured by the area of rocky desertification.

Using the Equation (2), three secondary farmer factors were analyzed separately.

On the basis of Model (1), taking farmers' field behavior as farmer factor, Model (2) was developed. Farmers' field behavior, which is one of the secondary farmer factors, was added into Model (2). In Model (2), the equation's goodness was 46.6%, which was almost equal to that of Model (1). It showed that the three factors: population, per capita cultivated land, and farmers' field behavior could explain 46.6% of all the environmental pressures measured by rocky desertification area of the region. The coefficients of population and per capita arable land were 0.808 and 0.815, respectively, indicating that, under the same conditions, 1% increase in population and per capita arable land would lead to an increase in environmental pressure by 0.808% and 0.815%, respectively. The coefficient of farmers' field behavior factor was 0.176, indicating that farmers' field behavior, which was measured in the present study, did not have a significant relationship with the degree of the rocky desertification in the region. This finding was not similar to people's understanding, but it could be explained by the practical survey. Our survey results showed that the farmers' field behavior in Guanling did not vary too much, that is, their behaviors, such as plowing habits, were almost the same on a county wide scale.

Population, affluence, and the farmers' concept of human-land relationship were used in Model (3). The farmers' concept of human-land relationship has to do with the farmers' view of nature and how to treat it, and whether human beings could in fact change the nature. The goodness of fit in Model (3) was 79.0% and the regression coefficients were significant ($p < 0.01$), indicating that population, per capita arable land, and farmers' concept of human-land relationship could explain 79.0% of the environmental pressure measured by the area of rocky desertification. The coefficient of farmers' concept of human-land relationship was −2.50, which showed that, under a no-other-change condition, one percent increase in this factor would lead to a 2.5% reduction in environmental stress. The more scientific and more advanced the farmers' concept of human-land relationship, the lower the degree of rocky desertification. Regions where farmers could not reasonably understand the relationship between human activity and nature suffered more serious degrees of desertification. The results show that improving farmers' understanding of nature vis-à-vis human activity has a major impact on decreasing rocky desertification.

Population, affluence, and the farmers' understanding of rocky desertification were selected in Model (4). The farmers' understanding of rocky desertification had to do with whether they were aware of the environmental phenomenon or had thought about what has caused it. In Model (4), the goodness of fit was 63.7%, and the regression coefficient was significant ($p < 0.05$), which indicated that population, per capita arable land, and farmers' understanding of rocky desertification could explain 63.7% of the total environmental pressure

measured by the area of rocky desertification. The regression coefficients of population and per capita arable land stayed close to that of Model (3), indicating the stability of the simulation. The coefficient of the farmers' understanding of rocky desertification was -1.574 , showing that a 1% increase in farmers' understanding of rocky desertification would release 1.574% of environmental pressure. The development of rocky desertification and the farmers' understanding of the environmental phenomenon interacted with each other. However, in the regions where the desertification degree was relatively the same, the better the farmers' understanding of desertification, the lower the degree of desertification.

Population, affluence, and the government-regulation factor were selected in Model (5). The regression coefficients of these factors were significant ($p < 0.05$), except for the coefficient of government-regulation factor. The goodness of fit of Model (5) reached 46.1%, which was only 0.1% higher than that of Model (4). This result indicated that the newly added government-regulation factor could not explain much of the environmental stress in the region. The regression coefficient of government-regulation factor was 0.064. This showed that the government-regulation factor, especially technical guidance and the degree of accessibility of feedback channels, which were measured in the present study, did not have a significant correlation with rocky desertification. The direct actor of the government regulation was the government, with the farmers as objects. Although under some certain conditions government regulation impacted farmers, this was not so significant as to be the main driving force in the formation and development of rocky desertification.

3.2.2 Impacts of population, affluence, and integrative-farmer factor on different levels of rocky desertification

Considering the results of models (1)–(5), population,

affluence, and integrative-farmer factor were used in models (6)–(8) to analyze the relationship between different degrees of rocky desertification and human driving forces (Table 6). To be sure, the phenomenon of rocky desertification is a developing process. At different development stages, a similar driving factor can play different roles. Mild rocky desertification area was used in Model (6) to represent environmental pressure. Moderate rocky desertification area was used in Model (7) to represent environmental pressure. Environmental pressure in Model (8) was characterized by the area of severe rocky desertification.

In Model (6), the farmer factor was the most significant contributor to mild desertification in mild rocky desertification regions. These areas had relatively good natural conditions, thus enhancements in the farmer factor could greatly improve the status of rocky desertification.

In Model (7), for moderate rocky desertification regions, the most significant driving factor was population, followed by affluence. This finding indicated that in the process of rocky desertification, the key factors were population and per capita arable land. The increase in population and per capita arable land area could bring more direct pressure to bear on the land system. The increase in arable land area meant the loss of natural vegetation, increasing the risk of erosion and accelerating the process of land degradation.

In Model (8), the most significant factor for severe desertification was that of per capita arable land area, which indicated that in the degradation process from moderate to heavy rocky desertification, per capita arable land area played a vital role. Combined with the field research results, in the severe desertification regions, the overexploitation of land was rather severe, as shown by the large area of sloping farmland. To meet survival requirements, farmers have had to expand the

Table 6 Models (6)–(8)

	Model (6)	Model (7)	Model (8)
Constant	36.328 (3.008**)	7.945 (1.772*)	13.881 (not evident)
Population	0.415 (not evident)	0.863 (2.543**)	0.897 (not evident)
Affluence	-0.139 (not evident)	2.518 (2.068*)	5.749 (2.375**)
Farmer factor	-14.742 (-3.189**)	-0.587 (not evident)	-3.114 (not evident)
R^2	0.549	0.481	0.409
F	3.645	2.780	2.079
N	14	14	14

Notes: The number in brackets is the t test; *, **, *** are significant at the 0.1, 0.05, and 0.01 level, respectively

farmland area instead of increasing the low yield. When farming in the plains did not meet production demands, exploiting the sloping farmlands became the only choice. Land with a slope higher than 25° was unsuitable for agriculture, as it was more vulnerable to erosion, thus facilitating a more rapid process of land degradation that would be more difficult to reverse. When land degradation reached a certain level, farmers usually abandoned these sites. Farmers would then exploit new sloping land. This behavioral pattern has become a vicious cycle that has resulted in intensified land degradation and the formation of rocky desertification.

The goodness of fit of models (6)–(8) showed a decreasing trend at 0.549, 0.481 and 0.409, indicating that the more serious the degree of rocky desertification, the more complex the driving forces.

4 Discussion and Conclusions

4.1 Discussion

4.1.1 *Attempt of STIRPAT conceptual model*

STIRPAT model is always used to analyze the influence of human factors on the environment pressure. The environment pressure can be characterized by different factors, such as carbon dioxide emission, water footprint, and amount of arable land. This is the first time the STIRPAT conceptual model was applied in the analysis of the relationship between human forces and karst rocky desertification. The results showed the potential use of model in this field, meaning the STIRPAT conceptual model has a wide application range. However, more case studies about human driving forces and the Karst rocky desertification analyzed by the STIRPAT mode are required to test the justifiability of the methodology.

4.1.2 *Application of traditional human geography research method*

This study attempts to explore the interaction between karst rocky desertification, a geographic issue, and the human driving forces. To obtain the data, the present study not only used the methods of physical geography, but also the traditional methods of human geography: the survey questionnaire. The method of questionnaire is the most common and effective way to get human geography data and material. The direct survey between researchers and study object can provide more detail and real information on the study issue, which can assist

researchers in holding the nature of phenomenon. These approaches have delivered fairly satisfactory results.

4.1.3 *Expansion of human driving forces*

Human forces study in geographical process is vital and complex. How to quantify those non-quantifiable data and material is a key and difficult point. To avoid this point, many researchers chose human force, which were quantifiable, to analyze. Thus the selection of human forces was limited.

In the indicator system of human forces built in the present study, some attention had been paid to human factors that facilitate karst rocky desertification, which not been studied deeply, for instance, farmers' field behavior and farmers' concept of human-land relationship. Through the STIRPAT model, a preliminary quantitative study was also made. Results of the present study could provide some new ideas and directions for other researches of karst rocky desertification.

4.2 Conclusions

(1) Based on remote sensing images taken in 2007 and grading system of karst rocky desertification, this study gathered comprehensive information on the areas of mild, moderate, and severe rocky desertification. The results showed the severity of rocky desertification in the study area; the moderate and severe rocky desertification areas reached 56% of the total county area.

(2) The occurrence and development of rocky desertification was mainly related to population, affluence, and farmer factor. The status of rocky desertification had a positive correlation with population size and per capita arable land area. On the other hand, the relationship between rocky desertification and farmer factor was complex. The more reasonable and scientific the farmers' concept of human-land relationship and the deeper their understanding of rocky desertification, the smaller the rocky desertification areas and the lesser the environmental pressures. The most evident factors were farmers' concept of human-land relationship and their understanding of rocky desertification. The correlation between the farmers' field behavior and the rocky desertification was not as obvious.

(3) The main driving forces varied during different periods of rocky desertification. Farmers' field behavior had a large impact on the improvement and the deterioration of rocky desertification during a mild desertification period. In the process of moving from mild-degree

to moderate-degree rocky desertification, population and per capita arable land area played an important role. The increase in per capita arable land area led to the increase in severe rocky desertification area. Thus, per capita arable land area was a key factor driving the development of rocky desertification. Models (6)–(8) showed that the more severe the rocky desertification, the more complex are the impacts of factors.

(4) This study applied the STIRPAT model of environmental study to analyze the impacts of human driving forces on rocky desertification for the first time in China. Through the case study of Guanling, the results proved that the STIRPAT model could simulate and reflect the relationship between rocky desertification and human driving forces such as population, affluence, farmer factor, and government-regulation factor effectively.

References

- Daily G C, Ehrlich P R, 1992. Population, sustainability and earth's carrying capacity. *BioScience*, 42(10): 761–771.
- Ehrlich P R, Holdren J P, 1971. The impact of population growth. *Science*, 171(3977): 1212–1217.
- Huang Q, Cai Y L, 2007. Spatial pattern of Karst rock desertification in the middle of Guizhou Province, Southwest China. *Environmental Geology*, 52(7): 1325–1330. doi: 10.1007/s00254-006-0572-y
- Huang Qiuha, Cai Yunlong, Wang Xiuchun, 2007. Progress of research on rocky desertification in karst areas of southwestern China. *Journal of Natural Disasters*, 16(2): 106–111. (in Chinese)
- Li Ruiling, Wang Shijie, Xiong Kangning et al., 2006a. Correlation between rocky desertification and slope degree in karst area of Guizhou. *Bulletin of Soil and Water Conservation*, 26(4): 83–86. (in Chinese)
- Li Yangbing, Wang Shijie, Tan Qiu et al., 2006b. Research development and problems of karst rocky desertification. *Earth and Environment*, 34(3): 9–14. (in Chinese)
- Long Aihua, Xu Zhongmin, Wang Xinhua, 2006. Impacts of population, affluence and technology on water footprint in China. *Acta Ecologica Sinica*, 26(10): 3358–3365. (in Chinese)
- Su Weici, Yang Hua, Li Qing et al., 2006. Rocky land desertification and its controlling measurements in the karst mountainous region, southwest of China. *Chinese Journal of Soil Science*, 37(3): 447–451. (in Chinese)
- Sun Ke, Xu Zhongmin, 2009. A spatial econometric analysis of the impacts of human factors on environment in China. *Acta Ecologica Sinica*, 29(3): 1563–1570. (in Chinese)
- Waggoner P E, Ausubel J H, 2002. A framework for sustainability science: A renovated IPAT identity. *The National Academy of Sciences*, 99(12): 7860–7865. doi: 10.1073/pnas.122235999
- Wang Limeng, He Kanglin, 2008. Analysis of spatial variations in environmental impact based on the STIRPAT model: A case study of energy consumption. *Acta Scientiae Circumstantiae*, 28(5): 1032–1037. (in Chinese)
- Wang Lin, Wu Ye, Yang Guishan et al., 2008. Cultivated land area change and its impact factors based on STIRPAT model. *Transactions of the CSAE*, 24(12): 196–199. (in Chinese)
- Wang Shijie, Li Yangbing, 2007. Problems and development trends about researches on karst rocky desertification. *Advance in Earth Science*, 22(6): 573–581. (in Chinese)
- Wu Lianglin, Huang Qiuyan, Zhou Yongzhang et al., 2007. Study on the spatial correlation between karst rocky desertification and human activity based on GIS/RS technology: A case study of Duan County in Guangxi Province. *Research of Soil and Water Conservation*, 14(4): 121–125. (in Chinese)
- Xiao Dan, Xiong Kangning, Lan Anjun et al., 2006. Correlation analysis between karst rocky desertification and lithology in Suiyang County, Guizhou Province. *Earth and Environment*, 34(2): 77–81. (in Chinese)
- Xu Zhongmin, Cheng Guodong, 2005. Impacts of population and affluence on environment in China. *Journal of Glaciology and Geocryology*, 27(5): 763–773. (in Chinese)
- York R, Rosa E A, Dietz T, 2003. STIRPAT, IPAT and ImPACT: Analytic tools for unpacking the driving forces of environmental impacts. *Ecological Economics*, 46(2003): 351–365. doi: 10.1016/S0921-8009(03)00188-5
- York R, Rosa E A, Dietz T, 2002. Bridging environmental science with environmental policy: Plasticity of population, affluence and technology. *Social Science Quarterly*, 83(1): 18–34. doi: 10.1111/1540-6237.00068
- Zhang Panpan, Hu Yuanman, 2008. Karst rocky desertification and its landscape ecological research prospects. *Resources and Environment in the Yangtze Basin*, 17(5): 808–811. (in Chinese)
- Zhou Zhongfa, 2006. Analysis of relation of rocky desertification to landform and gradient in karst region: A case study of Qingzhen City of Guizhou Province. *Bulletin of Soil and Water Conservation*, 26(5): 1–3. (in Chinese)