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Discussing the Genesis of Karst Rocky Desertification-research Based on the Correlations between Cropland and Settlement in Typical Peak-cluster Depressions

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Abstract: This paper attempts to explain the theoretical reasons why the local farmers took irrational activities such as steep slope land cultivations in order to reveal the mechanism of Karst Rocky Desertification (KRD) through those typical case studies. Firstly, this paper assumes that the low land capacity is the genesis cause of KRD in peak cluster-depression areas. Furthermore, the ecological quality of the peak cluster-depression zone is influenced by the relationship between the area of depressions and the population of residential areas. The results show that, six typical peak cluster-depression areas in Guizhou Province were selected to compare the distribution circumstances of croplands, the characteristics of settlements and the formation of KRD. Also, the results show that there is a negative correlation between the percentage of the cultivated land and the percentage of KRD (including light KRD, moderate KRD and severe KRD at peak cluster-depressions. The relationship could be concluded as three situations of the process of KRD, which are low, middle and upper carrying capacity of land. The severe KRD is only distributed in peak-cluster depression areas with less flatland, low land capacity and high population. The harmonization between population pressure and bearing capacity of land will influence the ecological qualities in the peak cluster depressions. Therefore, the hypothesis suggested by this paper is correct, and this result will contribute to understanding the natural mechanism of KRD and guide the ecological restoration of KRD land.

Key words: Peak-cluster Depression; Cropland; Settlement; Karst Rocky Desertification; Genesis

1 Introduction

Desertification is defined as ‘land degradation in arid, semi-arid and dry subhumid areas resulting from various factors, including climate variation and human activities (UNCCD, 1994), and has been recognized as an integrated environmental-development problem that combine a natural and social cause–effect cycle for several decades (Bisaro et al., 2014; Torres et al. 2015). Desertification does not involve only arid lands, is not necessarily irreversible and does not necessarily lead to desert landscape (Le Houérou HN, 2009). So even, in tropical areas, there is a risk of desertification (Izzo et al., 2013), and desertification is now considered a result of a long-term failure to balance and protect ecosystems services in drylands (Bisaro et al., 2014). Desertification as land degradation has usually occurred in the northern and western parts of China, therefore, some Chinese scholars they don't state explicitly that Chinese desertification includes the Karst Rocky Desertification in southwest China (Miao et al., 2015; Wang et al., 2015).

Karst area is a kind of vulnerable eco-environment (Praiser & Pascali, 2003; Gams 1993; Sauro, 1993; Yuan, 2008; North et al.,2009; Gabrovšek et al., 2011). The "Classic" Karst area in Europe is traditionally known as a bare, non-forested stony grassland area when the area suffered severe deforestation, erosion, and almost desertification (Gams, 1993). However, an almost treeless stony grassland landscape on the "classic" Karst was converted to a forest-dominated landscape in only 250 years(Kaligarič et al., 2014). In Karst mountainous area in Southwest China, there is long-term irrational land use, leading to intense erosion and vegetation degradation, namely Karst rocky desertification (KRD), which has become a hot topic and the Chinese government began to pay attention to it because of its importance in recent years (Jiang et al., 2014). Wang Shijie considers that KRD refers to the degradation process of desert-like landscapes with severe soil erosion, and a severe decline in land productivity under the fragile subtropical Karst environment damaged by irrational social and economic human activities (Wang, 2002), and Yuan Daoxian believes that KRD refers to changing processes: Karst soil cover is eroded of vegetation and soil (Yuan, 1997). The dynamic geological process (Zhang et al., 2001), the effect of lithology (Wang et al., 2004) and meteorological factors (Xiong et al., 2009) upon KRD are emphasized when some scholars explain the causes of KRD. Population, per capita cropland and farmers' concept about the relationship between people and land can explain 79% of the environmental pressure of KRD (Wu et al., 2011), major distance impact of rural settlement on the KRD is 4 km (Jiang et al., 2009).

The KRD phenomenon occurred in karst mountains in Southwest China is a result of integrated impacts by physical and human factors, irrational human activity is the incentive of KRD, per capita cropland and rural settlement can influence KRD. KRD is related with different types of land use and a great number of sloping cropland is still the main driving force of KRD (Li et al., 2009). In the severe KRD area, sloping land is overly reclaimed, why farmers are doing this, the reasons are attributed to the macro socio-economic circumstances of rural locality (Yan & Cai, 2015). However, the present studies do not explore the formation and development of KRD according to cropland resources, settlement population and relevant ecological impact. It also, does not reveal why the Karst mountain farmers engage in irrational activities, and explain why the KRD occurred in Karst land.

Peak-cluster depression areas is one of the most typical Karst topography and the most serious KRD (Jiang et al.,

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2007). A composite nature of degenerative condition is formed in this area where a fragile ecological environment is the basis, human disturbance is the strong driving force, the vegetation decline is a incentive and land productivity degradation is the nature (Peng et al., 2011). All these factors make KRD, the most difficult to control (Li et al., 2005). Therefore, this paper explores mutual correlations among farmland resources, settlement patterns and KRD of Karst mountains. Through typical case studies of peak-cluster depression areas, this study tries to theoretically answer why the local farmers engage in irrational activities, and reveals the mechanism of KRD occurring in nature in Karst mountains.

2 Material and methods

2.1 The study area

In the typical Karst area of Guizhou Province, we select Huajiang gorge in Zhenfeng County, Pingle town in Anlong County, Wangjiazhai small watershed in Qingzhen City, Houzhaihe in Puding County and Dongtang town in Libo County as the study area (Figure 1). These areas we selected are different topography and combined pattern of land resource, including: 1) Peak cluster depressions-canyon type; 2) Continuous closed peak cluster-depression group; 3) Peak cluster-depression-valley combination; 4) Opening peak cluster-depressions; 5) Peak-cluster depressions surrounded by flat land and shallow peak cluster-depression (Figure 1). The socio-economic factors of this 6 study areas include different types of economic development and quite different road accessibilities. The Wangjiazhai is adjacent to city, and its development is driven by the city, the Houzhaihe area is influenced by the county and towns economic radiation, Huajiang area's development is driven by the poverty alleviating and KRD control policy, Dongtang is influenced by the national nature reserve, and Pingle town is at the Karst mountain hinterland which is away from town traffic trunk roads with slow development. Therefore, these areas under study are typical Karst mountains, basically covering the natural and socio-economic backgrounds in southwest Karst region of China.

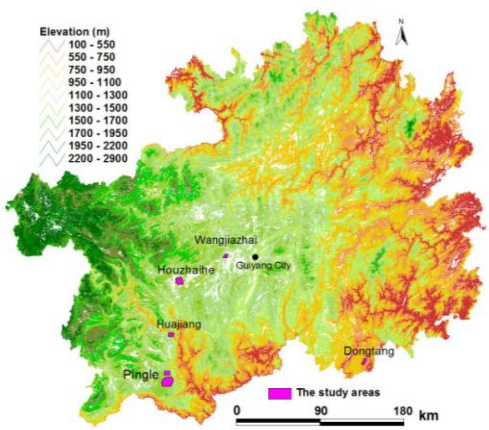

Figure 1 Distribution of the study areas

2.2 Data sources and methods

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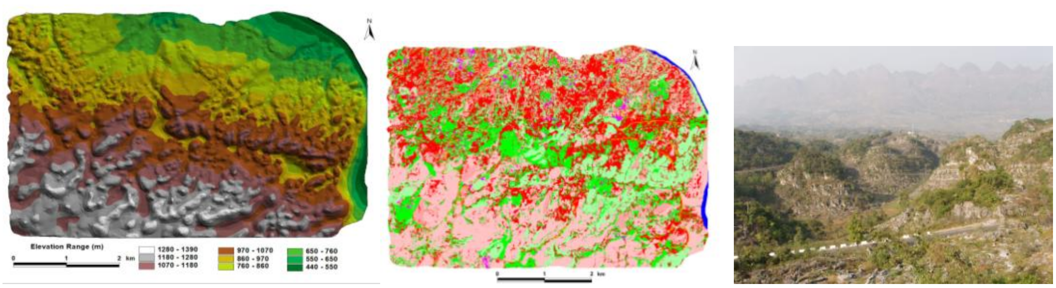
The land use data used in the study, including settlement and cropland, come from the interpretation of Advanced Land Observation Satellite (ALOS) images (with a resolution of 10m×10m) in 2010, combined with local statistics, field surveys and 2.5m supplementary images (with a resolution of 2.5m×2.5m) . The land use/cover types were divided into seven subclasses such as cropland, settlement, road, water, slope cropland, wood land and shrub grassland. Judgment on the KRD land is basically the same nowadays, so this paper take KRD land classification criteria as follows(Table 1), based on other researcher's work (Zhou et al., 2007; Xiong et al., 2002; Li et al., 2007; Wang et al., 2007). The NKRD refers to the concentrated and contiguous woodland and the flatland with no land degradation, the PKRD refers to the karst slope land where the land ecosystem has been degraded slightly, but the percentage of bare rock is less than 30%, and the slope cropland, shrub grass land may be in land degradation state of LKRD, MKRD and SKRD. The distribution maps of land use and KRD land in 6 study areas had been made using a the human–computer interactive interpreting method, and the vector data layers are amended according to the result of the field sampling inspection and investigation in 2010, the interpretation accuracy of sampling patches is more than 90%. The topography, land use and KRD of these study areas are provided by Figure 2. The slope gradient is generated by Digital Elevation Model (DEM) digitized according to the topographic map at a 1:10000 scale.

Table 1 The classification criterion and characteristic code of Karst rocky desertification (KRD) types

	No Karst rocky desertification (NKRD)	Potential Karst rocky desertification (PKRD)	Light Karst rocky desertification(LKRD)	Moderate Karst rocky desertification (MKRD)	Severe Karst rocky desertification(SKRD)
Exposure of basement rocks (%)	<10	<30	30—50	50—70	70—90
Characteristics of ALOS image	deep red patch	light red	shallow spot red, interspersed grey	shallow contiguous grey	contiguous grey and white



Peak cluster-canyon

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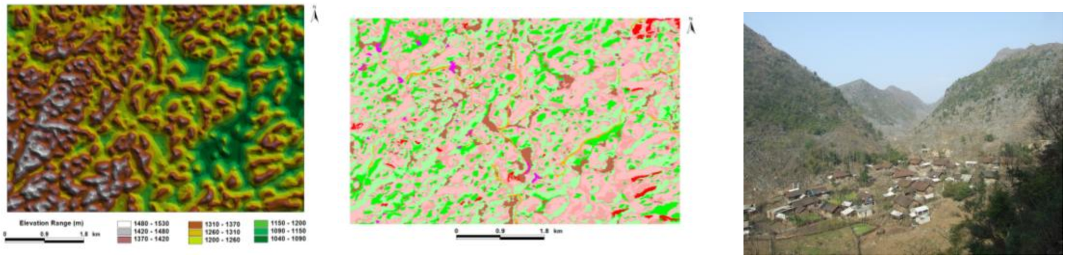
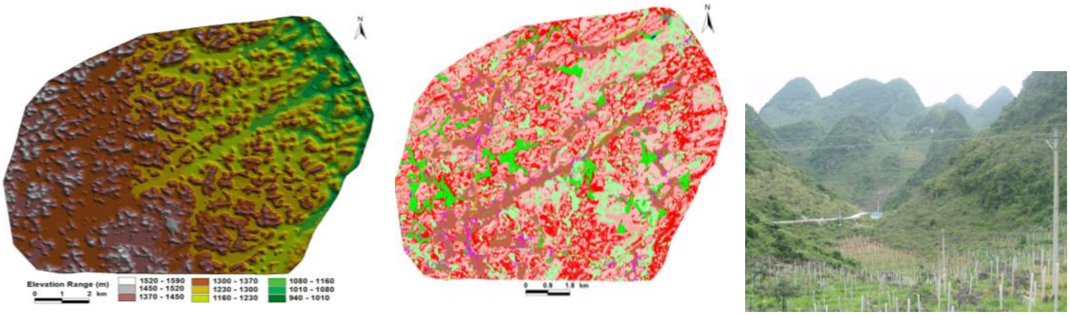
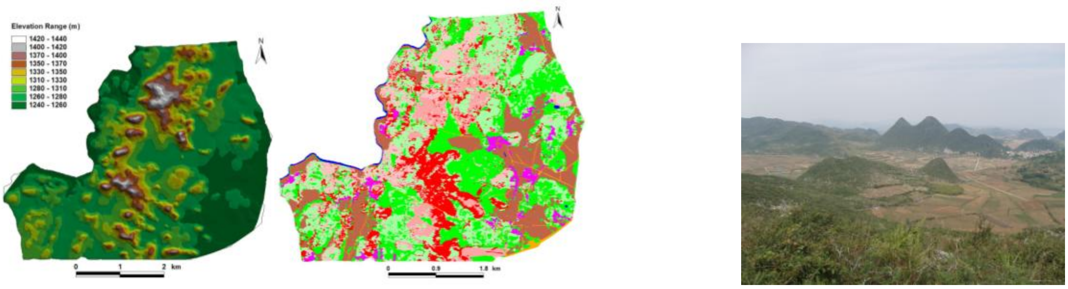


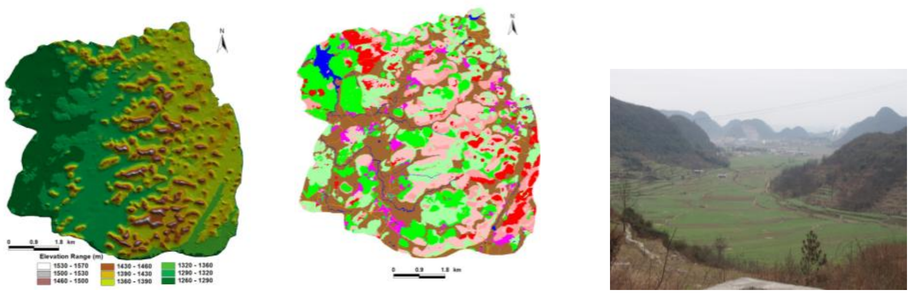
Continuous deep depression



Peak cluster depression-valley combination



Open peak cluster-depression



Peak cluster-depression surrounded by shallow hill

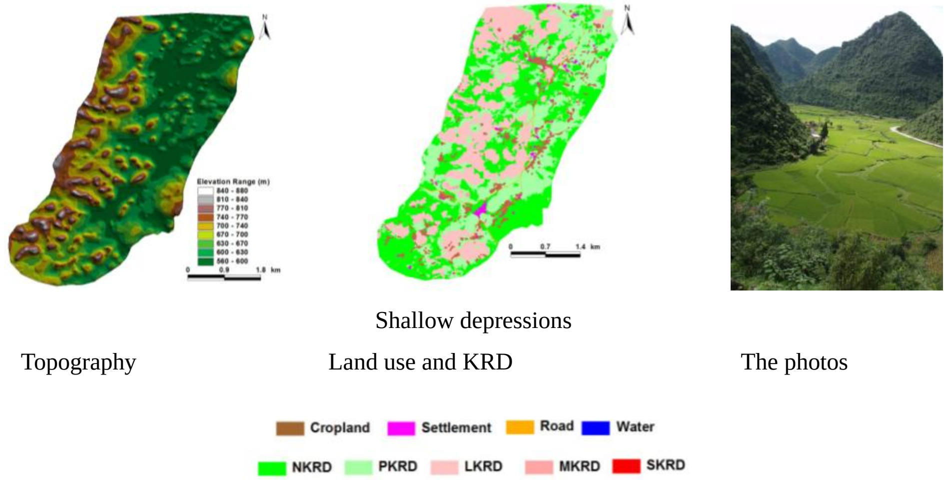


Figure 2 The digital topography, land use and KRD of the study areas

Because the sloping cropland is still the main driving force of KRD (Li et al., 2015), so, the farmland referred in this paper only is only those with slope<6°, the area of flat cropland with slope <6° is used to represents land carrying capacity. The ratio of settlements area accounted to the cropland area is used to represent population pressure, which both data acquired from ALOS image interpretation.

If the percentage of arable land resources to total area is less than 10%, we define the study area is lack of arable land resource, if not, the study area is rich in land resource. In order to further illustrate the spatial distribution of agglomeration and the fragmentation characteristics of cropland patches at six study sites, we divide the area of cropland patches into eight levels: 1. ≤0.1/hm^2;2. 0.1-1/hm^2; 3. 1-5/hm^2; 4. 5-10/hm^2; 5. 10-20/hm^2 ; 6. 20-50/hm^2; 7. 50-100/hm^2; 8. >100/hm^2, and count the total number and total area of cropland patches of different sizes levels. Aggregation refers to the tendency of patch types to be spatially aggregated, so, aggregation index was computed using FRAGSTATS4.2, For the definitions and full descriptions of these metrics, please see FRAGSTATS 4.2 user's guide.

3 Results and analysis

3.1 Distribution of cropland resources

In the Karst peak cluster-depression area, different combinations of small terrain result in differences of negative terrain (referring to depressions in this paper) and form different area proportions of cropland resources. For the 6 study areas, the flat cropland area is the lowest at the peak cluster-canyon, in which distribute small and scattered cropland patches. The area percent of the combination of peak cluster depression-canyon increases to 10.74%, and the number of open peak cluster-depression is the highest(Table 2). In terms of the percentage of cropland resources to total area, we divide 6 study points into two kinds with plenty or shortage of cropland resources, where continuous

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deep depressions, shallow depressions and peak cluster-canyon are scanty with cropland resources, open peak cluster-depression and peak cluster depression-valley combination are rich in cropland resources comparatively and peak cluster depression-valley is the transitional one.

Table 2 The characteristics of cropland in the study areas

Land form	The percentage of flat land/%	Largest patch area/hm^2	Least patch area /hm^2	Mean patch size /hm^2	Aggregation index of cropland
Peak cluster-canyon	0.12	0.56	0.01	0.037	60.90
Continuous deep depression	5.41	10.44	0.01	0.74	83.40
Shallow depression	5.94	9.84	0.02	0.55	82.06
Peak cluster depression-valley combination	10.74	241.68	0.06	3.36	92.67
Open peak cluster depression	15.51	44.55	0.01	2.63	91.92
Peak cluster depression surrounded by shallow hill	26.36	107.09	0.01	2.55	93.24

The flat cropland patches, range in sizes from ≤ 0.10 hm^2 to 0.1-1 hm^2, are the most. But there are only 17 cropland patches each area over 20 hm^2 and the total area of these 17 patches account for 67% of the total cropland area in the peak-cluster depression-valley combination (Figure 3). This indicates that the cropland is relatively concentrated and contiguous in this kind of landform with characteristics of big patches located in valley and larger depression while small patches are located in small depression centers.

The number of croplands in size from 0.1-1 hm^2 to 1-5 hm^2 are 162 and 39, accounting for 28.24% and 36.12% of the total cropland area respectively. However, there are only 2 patches with size between 10-20 hm^2 and accounting for 10.10% of the total cropland area in the continuous deep depressions. The cropland patches with sizes of 0.1-1 hm^2 is the most, there are 162 patches and their total area is up to 55.51 hm^2, the number of cropland patches with sizes of 1-5 hm^2 is 38 and their total area is 65.11 hm^2 at the shallow depressions areas in Dongtang. There are 37 patches of flat cropland, with a total area of 3.7 hm^2 and the largest area of these patches is up to 0.56 hm^2 in peak cluster-canyon combination. In the peak cluster-depressions surrounded by shallow hill, there are hundreds of pieces of small farmland less than 0.1 hm^2, for a total of only 1.8 hm^2. Patches over 1hm^2 account for a large area, especially the cropland patches between 20-50 hm^2 account for 35.11% of the total cropland area. The cropland patches over 1 hm^2 account for 96.62% of the total cropland area, and those sizes between 20-50 hm^2 account for 39.68 % of the total cropland area in the open peak cluster-depressions.

According to characteristics of cropland in different sizes and their aggregation, we categorize the cropland spatial

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distribution of the six study points into two types as follows: (1) fragmented cropland, including the continuous deep depressions, shallow pond depressions, peak cluster-canyon, in which there are a great number of cropland patch with the size of 0.1-1 hm^2 mainly, small and scattered cropland accounts for a high proportion of the total cropland area; (2) centralized cropland, including peak cluster depression-valley combination, peak cluster-depression surrounded by shallow hill and open peak cluster-depression, the cropland distribution of this type is relatively concentrated, and cropland patches with large size account for a high proportion of the total area.

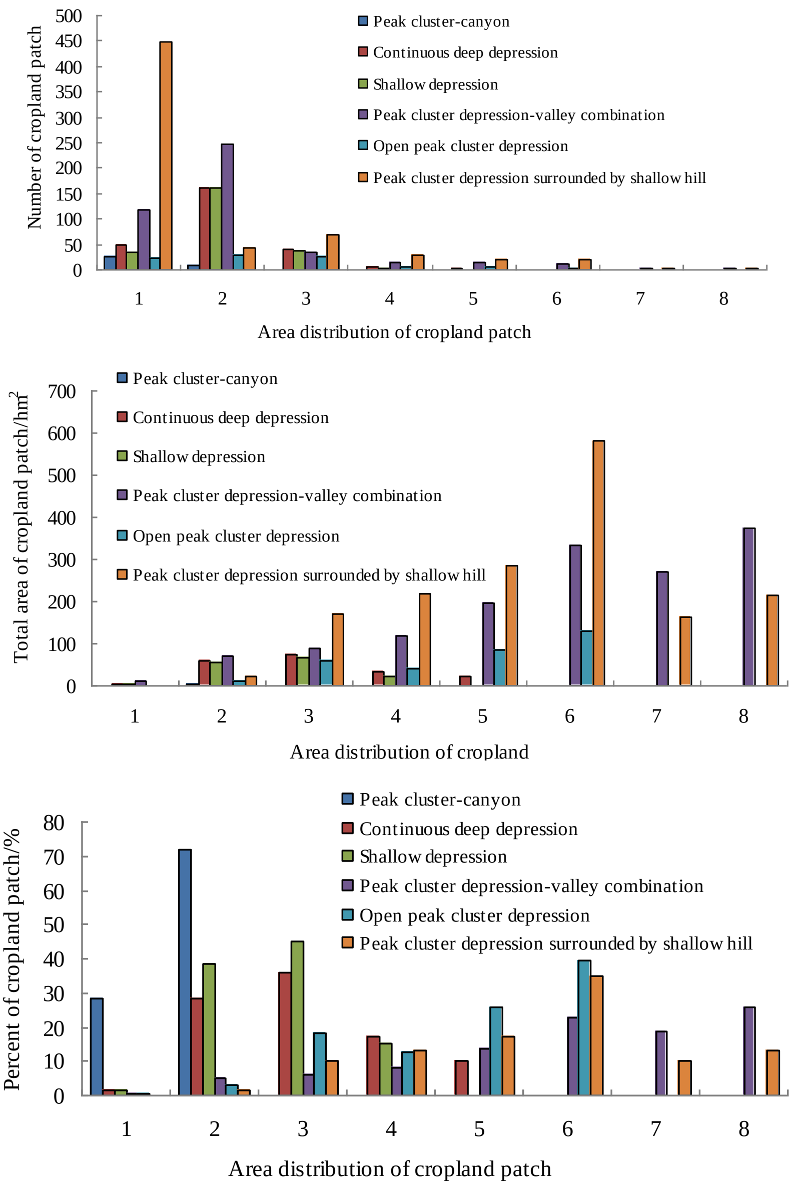

Figure 3 The distribution characteristics of cropland patches

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(1. ≤0.1/hm^2;2. 0.1-1/hm^2; 3. 1-5/hm^2; 4. 5-10/hm^2; 5. 10-20/hm^2 ; 6. 20-50/hm^2; 7. 50-100/hm^2; 8. >100/hm^2)

3.2 The number of settlements and spatial distribution in the study area

In Wangjiazhai, the open peak cluster-depressions, there are 3 peak cluster-depressions with cropland and without settlement distribution, these depressions area are so small where settlement is located in the open of large depressions with convenience farming and good accessibility. Settlement located in peak cluster depression accounts for 26.58% of the total settlement area (Table 3).

In Houzhaihe, there are 20 peak cluster-depressions surrounded by shallow hills, its settlements are both located in depressions with cropland. Another seven peak cluster depressions with crpland, because of their small size, or remote location, shows no settlement distribution and the settlement distributed in peak cluster depression accounts for 10.03% of the total settlement area.

In the peak cluster depression-valley, the cropland and settlement mainly distributed in larger valley. Settlement distributed in three valleys accounting for 29.49% of the total settlement area, and 21 settlements distributed among 29 peak cluster-depressions with cropland, 4 settlements distributed in non-arable peak cluster depressions. The peak cluster-depressions with cultivated land and without settlements have small areas or its surrounding areas have big settlement patches. Each slope of peak cluster-depression has KRD land distribution.

In the continuous peak cluster-depressions, the average area of settlement patch is 0.367 hm^2 which are widely distributed in depressions with cropland. Each slope of peak cluster-depression has light and moderate KRD land distribution.

In shallow depressions of Dongtang, the average area of settlement patch is 0.371 hm^2 and distributed in arable peak cluster-depressions, forming the pattern of one peak cluster-depression with cropland, one settlement basically, and only 4 of 15 peak cluster depressions exist in LKRD lands.

In peak cluster-canyon, the average area of settlement patches is 0.0587 hm^2, because of less flat land, 8 settlements distributed in peak cluster depressions without cropland, and except for 5 NKRD peak cluster-depressions, the other's landscape are constituted by LKRD and SKRD land mainly.

Table 3 The distribution of cropland, settlement and KRD in peak-cluster depressions of study areas

Land form	Total number of peak cluster-depression	Peak cluster-depression with only cropland	Peak cluster-depression with settlement and cropland	Peak cluster with KRD	Peak cluster-depression with only settlement
Peak cluster-canyon	21	2	6	16	8
Continuous deep depression	27	7	14	27	1
Shallow depression	15	3	13	4	0
Peak cluster depression-valley	35	8	21	35	4

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combination					
Open peak cluster-depression	8	3	4	4	0
Peak cluster-depression surrounded by shallow hill	20	7	7	7	0

In the peak cluster-depressions with cropland and settlements of the 6 study points, the area ratio of settlement to cropland varies greatly. The ratios of settlement to cropland of open peak cluster-depression, peak cluster-depression surrounded by shallow hill, peak cluster-canyon, shallow depression, continuous depressions and peak cluster depression-valley are respectively 15.15%, 24.36%, 18.62%, 20.79%, 37.95% and 36.98%, there are 1, 2 and 3 peak cluster-depressions respectively in the last three places, the settlement area of these peak cluster depressions account for more than 50% of the cropland (Figure 4).

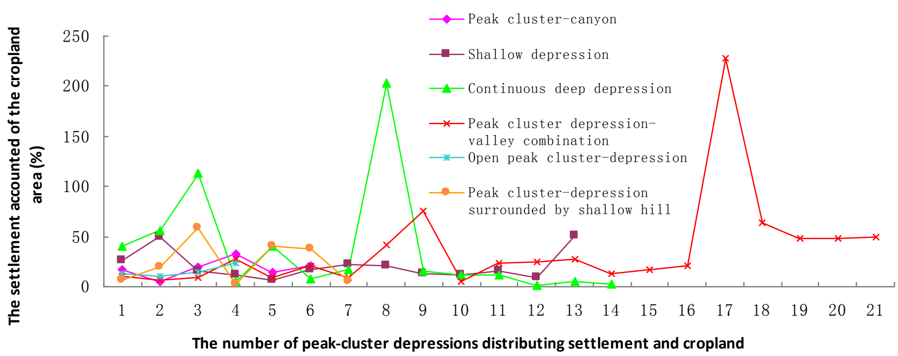

Figure 4 The ratio of settlements area to the cropland area in each study plot

3.3 The relationships between cropland settlements and KRD in study area

A significant negative correlation exists between the percent of cropland area and the percentage of KRD area (Table 4). For continuous depressions, shallow depressions and peak cluster-canyon, the cropland accounts for less than 6% and KRD area account for over 50%. Cropland area in peak cluster depression-valleys accounts for 10.74%, but its settlement area exceeds 20.32%, so the areas over LKRD account for 60%. Cropland is relatively rich in peak cluster-depressions surrounded by shallow hills and open peak cluster-depressions. Area over LKRD accounts for 30% or so, but the percentage of KRD area of open peak cluster depressions is larger because of its higher ratio of settlement to cropland. Obviously, KRD is more serious for peak cluster-depressions with higher ratios of settlement area to cropland.

Table 4 The Percentage of cropland, settlements and KRD land (including light, moderate, severe KRD)

Land form	Farmland/%	KRD	Settlement/%	settlement/farmland/%	Arable slope land/%
Shallow depression	5.94	26.09	0.88	14.88	20.9

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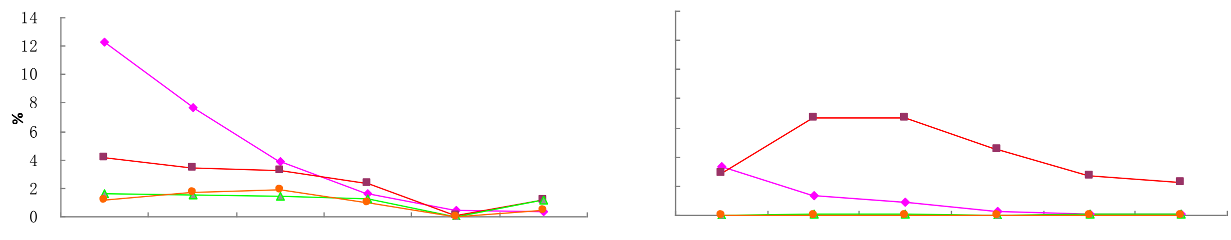
Peak cluster-depression surrounded by shallow hill	26.36	30.74	3.44	13.05	27.26
Open peak cluster-depression	15.51	31.25	3.37	21.74	10.84
Continuous deep depression	5.41	54.19	0.51	9.44	20.672
Cluster-canyon	0.12	62.5	1.18	9801.04	12.06
Peak cluster depression-valley combination	10.74	63.74	2.18	20.32	18.62

Furthermore, the settlements of the 6 study points are taken as centers to build buffer belts with distance of 0-200 m, 200-400 m, 400-600 m , 600-800 m , 800-1000 m, > 1000 m, then, the changes of cropland and KRD land percentage in buffer zones of the 6 study points are compared. The results show that the cropland decreases as the buffer distance increases, in areas within 400m buffer distance, the cropland proportion in peak cluster-depressions surrounded by shallow hills is highest, the lowest is the peak cluster-canyon and its cropland only distributes at this buffer range (Figure 5). Comparatively, the proportion of LKRD is highest within 200-400m buffer distance, and from peak cluster-canyon, continuous deep-depressions, shallow-depressions, peak cluster depression-valleys, this proportion reduces in turn. The proportion of MKRD is highest within 200-400m and 0-200m buffer distance, and the proportions peak cluster depression-valleys and continuous deep depressions are higher than other 4 study points, this proportion of MKRD of shallow depression area is less than 0.1%. The highest proportion of SKRD is within 0-200m, and then 200-400m buffer distance at the peak cluster-canyon area. The relatively high proportion of SKRD of peak cluster depression-valleys is within 0-800m. But at the open peak cluster-depressions area, this SKRD proportion is high relatively in 800-1000m buffer distance, where the slope land had been cultivated, now abandoned. The SKRD proportion within 200-400m buffer distance at the continuous deep depressions is 0.44% and there is no SKRD in shallow depressions. What are reasons of this phenomenon? We find that, in the Karst mountains, the radius of cultivation is no more than 1000m, if the ratio of cropland surrounding settlements is lower, then, the slope reclamation, deforestation and other irrational disturbance is more severe, which lead to the more frequent occurrence of KRD also.



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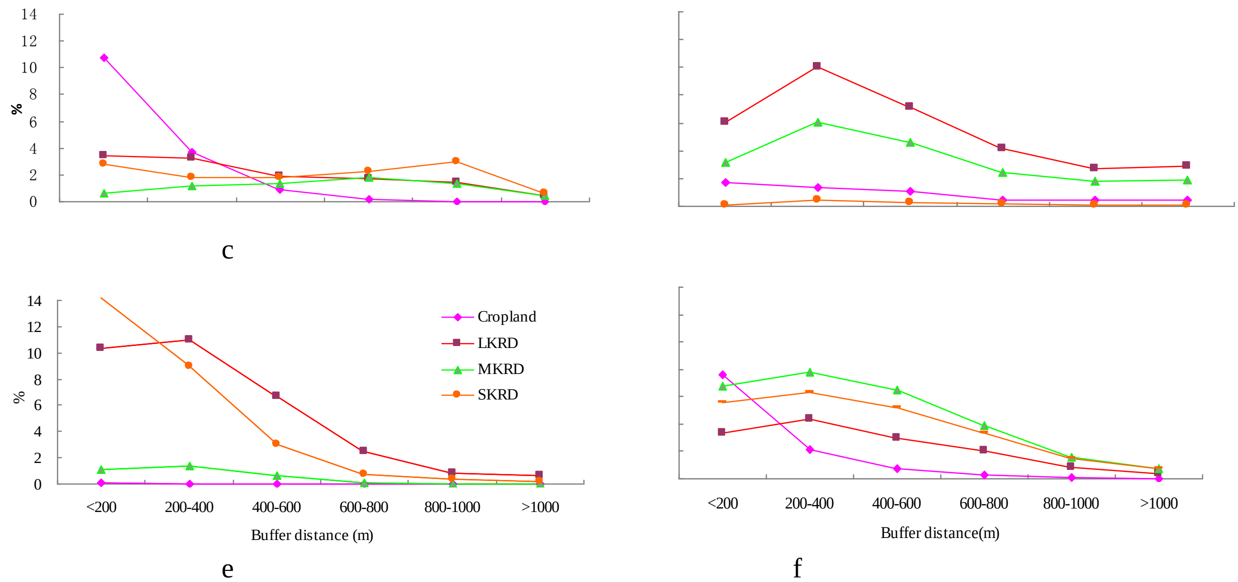

Figure 5 The proportions of cropland and KRD of different buffer accounted for the total area of the study area （a. Peak cluster-depression surrounded by shallow hill. b. Shallow depression. c. Open peak cluster-depression. d. Continuous deep depression. e. Peak cluster-canyon. f. Peak cluster depression-valley combination.）

4 Discussions

4.1 The process of KRD in peak cluster depressions

The analysis above shows that the KRD area and distribution is related to the quantity and distribution of cropland and settlement in the six study points. Actually this relationship reflects human (settlement)-environment (cropland) interaction. Under the special human-environment relationship in Karst peak- cluster depressions, those relationships reflect 3 scenarios of KRD forming processes:

(1) The scenario of KRD with low land carrying capacity: small cropland, small population, but population and arable land resources are at a low level of coordination causing insignificant land degradation (KRD). The shallow depressions are an example of the first scenario. Cropland is small and population pressure exceeds land carrying capacity which leads to mild or moderate degradation (mainly LKRD or MKRD). Continuous peak cluster depression is typical in this scenario. Little cropland, but population pressure exceeds land carrying capacity, causing land degradation (mainly SKRD and MKRD), taking Huajiang peak cluster-valley as an example.

(2) The scenario of KRD with moderate land carrying capacity. There are a large amount of depressions and valleys but population concentrated over land carrying capacity. Reclaim slope land will cause more intense land degradation, peak cluster depression-valley combination is an example.

(3) The process of KRD with high land carrying capacity. The Houzhaihe and Wangjiazhai areas are two examples. There is larger cropland because of continuous flat land or bigger depressions which can basically carry more

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population, so there are only a few slopes being reclaimed at surrounding peak-clusters. Therefore, most of the land is degraded slightly, only a few of them are degraded severely.

4.2 A theoretical model of KRD formation

The cropland resource pattern in peak cluster-depression area is characterized by: fertile land concentrated in the depressions, and poor land or wasteland distributed on the peak cluster slopes around the depressions. Although there exist some aggregation effect of cropland, the degree is not high and the scale is small, therefore, the farming radius is still large in this area (Wu et al., 2007). Generally, the gentle farmland forms light KRD landscape; the steep land forms moderate KRD landscape due to slope soil erosion which makes KRD landscape evolve to a higher level (Dan et al., 2009).

Based on the above analysis, the present study put forward a theoretical hypothesis: in the peak cluster -depression areas, the proportion of negative terrain (referring to depressions, often cultivated land resources) may determine population distribution, and the realistic population pressure (population density) determine whether the peak cluster-depression areas will be degraded. If we define the ratio of cultivated land to the total area representing land bearing capacity and the ratio of settlement area to cultivated land area represents population pressure, the formation KRD in the peak cluster-depression areas can use the variations of these two ratios to clarify (Figure 6). As the percent of cropland decreases and the percent of settlement dedicated to the croplands increases, the severity of KRD increases. That is to say, the more serious rocky desertification KRD only occurs under the regions of low land carrying capacity and high population pressure where farmers have to take extreme steep reclamation activities. Thus, in the peak cluster-depression areas, low land carrying capacity is the fundamental cause of KRD. In general, the harmony between depression area (negative terrain) and population determines ecological quality of peak cluster-depression areas.

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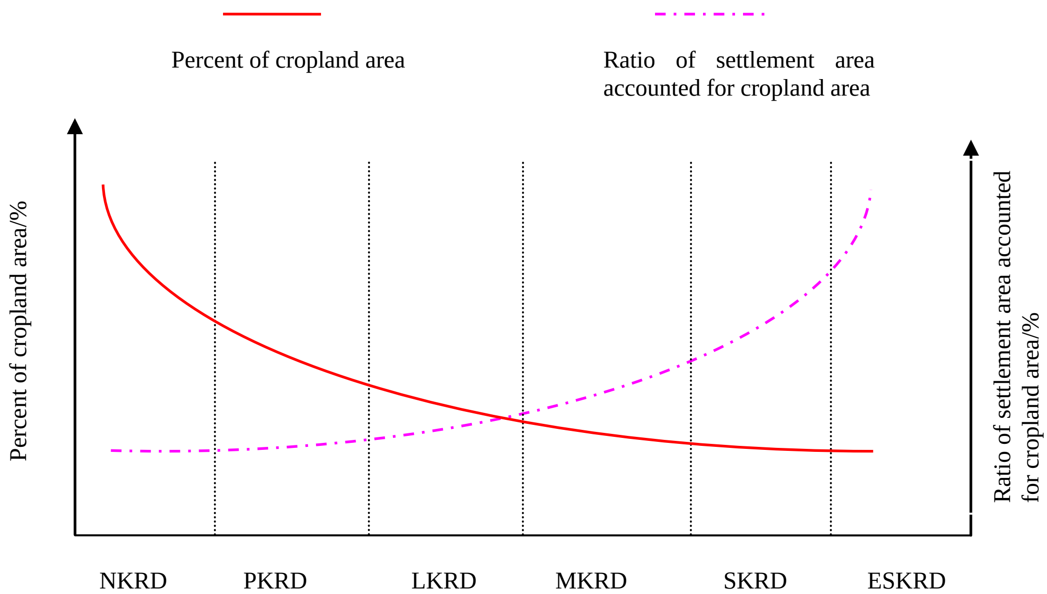

Figure 6 The theoretical formation models of KRD in the peak cluster depression areas

4.3 The significance of the theoretical model suggested in this paper to understand KRD

In Europe, climate, vegetation, soils, groundwater and socio-economic quality are environmentally sensitive area index of the sensitivity to land degradation and desertification (Symeonakis, E., et al.,2014), so, the mixture of endogenous (manual agriculture, fuel wood and fodder extraction, land tenure and steep slopes) and exogenous drivers (high rainfall variability, climate change, prolonged drought or heavy rainfall) must be taken into account in the process of combating desertification(De Pina Tavares, J. et al., 2014). Moreover, the key role of changing governance and transition towards new political and economic structures in the context of climatic variability, in shaping today's land degradation has been understood also(Stringer & Harris, 2014).The eco-environment of Karst mountain is fragile and the land degradation is mainly KRD. Now we find lithology and soil type and road influence are identified as the leading factors influencing KRD(Xu & Zhang, 2014), and the succession of RD had different impacts on soil fertility indicators(Xie et al., 2015), or attribute the genesis of KRD to irrational activities of local household (Wu et al., 2011;), but do not clarify why the local farmers take irrational activities(Yan & Cai, 2015). The cropland distribution, settlements and KRD development of the six different peak cluster-depression combinations are compared, according to the relationships among settlements, cropland and KRD at peak cluster-depressions, serious rocky desertification is found only happens at areas with less cultivated land with slope<6 °, low land carrying capacity, big population pressure, this phenomenon confirms that the theoretical assumptions we proposed is correct in this paper. Therefore, we can assume that essential reason of KRD is population exceeding land carrying capacity in Karst mountains of southwest China, that is to say, low land carrying capacity making more slope land is still the main drive factor of KRD (Xiong et al., 2012), KRD is a kind of land degradation occurred in vulnerable Karst dryland socio-ecological systems (Bisaro et al., 2014). The nature of KRD in Karst mountains is low land carrying capacity and high population pressure.

The correlations between cropland richness, land carrying capacity and KRD can reasonably explain the occurrence of KRD at different scales. This paper can help re-discover scientifically the cause of KRD formation. On the other hand, this paper also pointed out the KRD controlling including increasing land carrying capacity or decreasing population. Only revegetation is difficult to increase land carrying capacity, but decreasing population in a short term is difficult, so increasing land carrying capacity is the primary mean to control KRD.

4.4 Some insufficiencies

(1) Inadequacy analysis of ratio of settlement to cropland. Although studies show that the spatial distribution of settlement can replace population distribution (Niu et al. 2006), but the shortcomings of this paper is only using the settlement area due to some hallow settlement in recent years. The changes of settlement and population may not be exactly the same. Therefore, further research should combine the evolution of the population and the livelihoods of farmers to calculate the land carrying capacity. Meanwhile, whether adjacent depression of settlements is cultivated by farmer were not fully taken into account in some locations, and this need further strengthen field investigation.

(2) The genesis of KRD according to land use in Karst mountains are: the forest land degrade in to shrub grassland due to deforestation, then, finally slope weed by repeating disturbs; forest turns into slope cropland through deforestation, and then, turns into KRD through water and soil loss; slope cropland turns into KRD through water and soil loss; the mining land degraded to KRD by mining activities. This paper analyzes the nature of KRD from the perspective of land carrying capacity, but does not discuss other factors such as the mining rocky formation.

(3) This paper reveals the mechanism of KRD of peak cluster-depression by using the number of cropland as land carrying capacity and settlement as population pressure. The subsequent studies would consider the index of smallest per capita cropland and cropland pressure (Cai et al., 2002), so as to further explore the mechanism and process of human-environment relationship of peak-cluster depression.

5 Conclusions

The current studies do not discuss the KRD’s occurrence and development from the perspective of cropland, settlement population and its corresponding ecological impact. This paper works from the assumptions about KRD in peak cluster-depression based on previous studies, and selects six typical peak cluster depression areas in Guizhou Province to conduct case studies for this theoretical assumption. In continuous depressions, shallow depressions and peak cluster-canyon, the cropland accounts for less than 6%, and the KRD(over LKRD) areas account for more than 50%. The cropland accounts for 10.74%, and its ratio of settlement to cropland is over 20.32%, indicating heavy population pressure in peak cluster depression-valleys. So, the percent of KRD (over LKRD) areas over 60%. In peak cluster depressions surrounded by shallow hills and open peak cluster depressions, the cropland is relatively rich. KRD land (including LKRD, MKRD and SKRD) areas accounts for 30% of the total land, but the latter settlement farmland proportion is larger than that of the former, meaning that the latter SKRD proportion is higher than former. Research shows that ecological quality in peak cluster-depression areas determines whether depression areas (negative terrains) and populations are productive. SKRD only happened in areas with low land carrying capacity and big population pressure. The characteristics of KRD are: (1) population pressure exceeds land carrying capacity; (2) lack of arable depression resources makes slope land arable; (3) low land carrying capacity is the root cause of Karst rocky desertification.

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