Monitoring and assessment on the land degradation in hilly karst Guangxi of China

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ABSTRACT

With a subtropical climate, Guangxi has a typical karst landscape. Land degradation has become a serious environmental issue due to its high vulnerability caused by the joint effect of natural settings in geology, topography, rainfall, and vegetative cover, as well as human activities such as deforestation. Its eco-environment has deteriorated over recent years while cultivated land is disappearing quickly. This, in turn, has exacerbated the poverty level in rural areas. In this study we monitored the spatial distribution of land degradation and its temporal evolution using Landsat TM/ETM images of the late 1980s, mid-1990s and late 2000 (for simplicity, we identified them as 1985, 1995 and 2000). We also explored the causes of its initiation and expansion. Through constructing regression models using all the relevant variables and considering the lagged effects as well as fixed effects, we quantified the exact role of different factors in causing land degradation in the study area with new findings. Based on these results we further analyzed the hazard of land degradation and proposed a few practical rehabilitation measures, including forestation, infrastructure projects, and ecological projects. The findings in this study are invaluable in preserving, restoring, and reconstructing the degraded environment in Guangxi and other karst areas in Southwest China while alleviating poverty in rural areas.

Keywords: Land degradation, spatial distribution, rehabilitation, Landsat TM, Guangxi, China

1. INTRODUCTION

Land degradation is a human induced or natural process which negatively affects the land to function effectively within an ecosystem, by accepting, storing and recycling water, energy, and nutrients. Severe land degradation affects a

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significant portion of the earth's arable lands, decreasing the wealth and economic development of nations. The link between a degraded environment and poverty is direct and intimate. As the land resource base becomes less productive, food security is compromised and competition for dwindling resources increases, the seeds of potential conflict are sown. Land degradation in Guangxi mainly refers to the phenomenon of severe land degradation in carbonated degraded areas as a consequence of accelerated soil erosion and loss of water and soil due to removal of forest and other vegetative covers under the action of natural and human-made factors [1-7]. It is an important indicator of ecological vulnerability of land in karst areas [8].

Guangxi exemplifies the karst landform in China and even around the world [1, 5, 9-11]. It is full of world-renowned and representative tropical karst landforms such as the marvelous sceneries of forest-like hilly peaks in Guilin, and groups of eroded depressions covered with clustered hilly peaks in Du'an and Dahua. As a matter of fact, karst landforms make up 37.8% of the total territory of this region, mounting to 89,500 km^2 in size. Of this land, mountains of denuded rocks are extensively distributed over 78,800 km^2, accounting for 33.3% of the total area. Among the 95 counties (cities) in this region, those with a predominantly (>30%) karst landform are numbered 36 (37.9%). Most of them are heavily concentrated in a few catchment areas in the western and northwestern parts of the whole region where the ecosystem is highly vulnerable. Human disturbance over an extended period has led to severe destruction to forest and other vegetative covers, soil erosion and denudation of buried bedrock. In fact, land degradation has become the most threatening environmental issue in Guangxi [5, 6, 9, 11]. It is so severe that the land is incapable of supporting the local population any more, imposing a threat to the survival of local farmers.

In this paper we monitored the spatial distribution of land degradation and examined its pattern of evolution in Guangxi from the 1980s to the end of 1990s using Landsat TM/ETM satellite data. After that, we further assessed hazard of land degradation and discussed rehabilitation of degraded land. A number of practical and easily implementable measures were put forward to tackle the issue. Results obtained in this study provide valuable references for the restoration and reconstruction of the degraded ecosystem in karst areas in Guangxi and Southwest China.

2. METHODOLOGY

2.1 Data

The main data used in this study are Landsat TM/ETM images recorded in the mid-1980s, mid-1990s and late 2000 (for simplicity, they are referred to as 1985, 1995 and 2000). The color composites of bands 2, 3, and 4 formed the primary data source. These images were recorded in a season when cloud cover was minimal (e.g., <10%). Besides, only those images recorded on a date as closely as possible were collected to minimize the impact of seasonal variation in land cover. Also collected were the most recent topographic maps at a scale of 1:100,000 and 1:50,000, and 1:200,000 hydrological maps. Other materials in the forms of documents and statistical data that may facilitate the study of land degradation from satellite images were also collected. They included existing studies on land degradation, thematic maps, boundary maps of watersheds, hydrological and climate data.

2.2 Data handling

After extensive field survey to typical degraded land in the region, it was decided that severity of land degradation in the study area should be mapped into three classes of slight, moderate and severe based on the evaluation factors and their criteria listed in Table 1. In the field each visited site was photographed. The photographs were used to facilitate indoor interpretation of the satellite images later.

Table 1. Grading factors and criteria of land degradation in Guangxi

Severity	Exposed bedrock (%)	Bare land (%)	Slope (%)	Land and vegetative cover (%)	Mean soil thickness (cm)
Slight	>60	<30	>18	35-50	<15
Moderate	>70	<20	>22	20-35	<10
Serious	>80	<10	>25	10-20	<5

Field survey confirmed that seriously degraded land is characterized by a whitish or gray-whitish color patch amid predominantly red ones on the images. The white color represents exposed stony mountains of carbonated rock. Within such land soil erosion is so severe that vegetative cover mounts to only 10%-20%. Slopes have a gradient of >25°. With exposed bedrock above 80% and mean soil thickness of less than 5 cm, seriously degraded land cannot be used productively [12-14].

Moderately degraded land appears as pale green-red patches. Found within this category are short shrubs at a coverage of <45%. This land has exhibited obvious signs of soil erosion with a vegetative cover between 20% and 35%. Slope gradient is over 22° and exposed bedrock exceeds 70%. At a soil depth of less than 10 cm, the majority of this land cannot be used productively. This land is distributed mainly in hilly and mountainous areas where human activities are the most intensive.

Slightly degraded land has a pink color of starry shape [12-14]. Soil in these areas has shown noticeable signs of erosion with a mean depth of below 15 cm and a gradient above 18°. Here vegetation cover can reach as high as 35%-50%. In spite of an earth cover of less than 35% and exposed bedrock above 60%, this category of land still has the potential for farming. It is distributed mainly in predominantly limestone hills of a large to low relief.

The above categories of land degradation were interpreted directly from the TM images. Prior to interpretation all images were geometrically rectified to the Albert projection and resampled to 30 m. They were linearly enhanced to increase the visibility of the targets and to minimize interpretation mistakes. In this way the interpretation accuracy should be high enough to meet the standards of large-scale maps [15-18]. The interpretation was carried out in a digital environment that involved close machine-interpreter interactions. The interpreter decided the severity of degradation based on land use, slope gradient, vegetation coverage, and the composition of the surface material, after consultation with the topographic maps, thematic maps, and statistic data. Additionally, knowledge on the pattern of land degradation gained from the field visits was also incorporated into the interpretation. The interpreted results were delineated on the computer screen directly over an image that was zoomed in as much as possible. A final map produced at 1:100,000 showed the characteristics and spatial distribution of land degradation. The same interpretation process was repeated three times, each time for one year. The interpreted results were intersected with county boundaries to identify the quantity of degraded land in each enumeration unit.

3. ASSESSMENT OF LAND DEGRADATION

3.1 Expansion of degraded land

Comparison of the three maps of land degradation distribution reveals that it has experienced a growing trend during the 15-year study period. Its area increased from 29,000 km^2 in 1985 to 32,000 km^2 in 1995, and to 30,000 km^2 in 2000. In spite of this general trend of expansion, its total area dropped by 2,000 km^2 during the second half of the 1990s. This is explained by two factors. First, government efforts in restoring a sound ecology to the region have brought about some tangible results. Secondly, several natural processes such as enhanced climate warming and drying over recent years have suppressed the rate of land degradation over the short term.

Although the total area of degraded land remained unchanged during 1985-2000, the proportion of severely degraded land expanded considerably, causing an overall degrading trend. Of the three severity levels, slightly degraded land stood at 10,700 km^2 in 1985, accounting for 36.86%. This figure rose to 11,700 km^2 in 1995, but decreased to 10,000 km^2 in 2000. In addition, there were 11,100 km^2 of moderately degraded land in 1985. This figure rose to 12,300 km^2 ten years later. Seriously degraded land was limited at 7,200 km^2 in 1985, growing to 8,000 km^2 in 1995, but decreased to 7,500 km^2 in 2000 when moderately and seriously degraded land made up 8.55% of the total degraded land in this region. Overall, land degradation experienced a rapid expansion first, but was gradually brought under control later.

3.2 Spatial variability of land degradation

The spatial distribution of degraded land is characterized by strong regional differentiation (Figure 1). It has a high concentration in the west and southwest of this region. Both areas are situated in the transitional zone from the Yuannan-Guizhou Plateau to the Guangxi Basin. Here mountains are tall, valleys deep, and terrain steep. Lack of protection by vegetation, the soil can be eroded easily. Degraded land appears as large patches over wide areas at a high density. However, it is widely dotted across the plain of central Guangxi. Patches of such land can be found only at limited localities. In addition, several places in northern Guangxi have also been affected by land degradation to some degree. Apart from these major areas of distribution, it is scantly observed in the remainder of this region at a small combined area. It is absent from southeastern Guangxi where the bedrock is mostly clast [1, 5, 6, 9, 10, 13, 14].

The observed spatial distribution is closely associated with topography. Those areas suffered from severe land degradation are located mostly in depressions and valleys covered by forest-liked hilly peaks, both being major areas of contiguous limestone karst landforms. The intensity of land degradation gradually lessens from valleys to depressions covered with clustered hilly peaks, to valleys with forest-like hilly peaks, to plains of residual hills, and to karst monticule [1, 5, 6, 9, 10, 13, 14].

Severity of land degradation and its distribution is also closely associated with poverty level. West and Southwest Guangxi are the remote and mountainous regions in this region, to which all 27 national-level poverty-stricken counties in this region are confined. Here degraded land mounted to 16,000 km^2 in 2000, accounting for 53.3% of the entire degraded land in this region. Five of these counties encompass more than 40% of degraded land, the highest proportion being 60.2% [1, 5, 6, 9, 10, 13, 14].

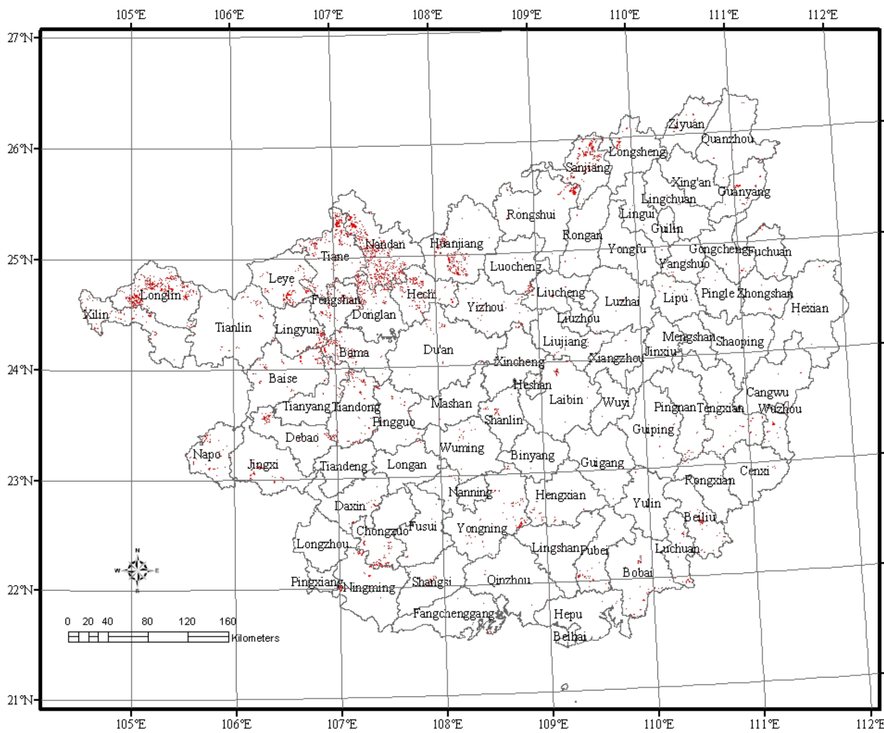

Figure 1. Spatial expansion of land degradation in Guangxi during 1985-2000.

4. REHABILITATION

Generally speaking, the karst region of Guangxi and even Southwest China forms part of the world's low to medium latitude karst belt that is potentially the most vulnerable ecologically. However, it is incorrect to assume that all limestone regions are vulnerable around the world [4, 7]. The effect of the mutual interactions between human activities and the limestone ecosystem varies with geology of a limestone region. Southeast Asia, Southeast US and Central America are widely distributed with Terteriary fissure carbonated rocks. In these limestone regions vegetation plays an important role in retaining water and in improving hydro-environment. However, the eco-environment problem in the limestone region of Southwest China is serious [8, 19-26]. Initiation and development of land degradation in Guangxi may be affected by natural factors, but more so by human activities, where soil is thin and vegetation sparse. With the loss of vegetation, soil is highly vulnerable to erosion, leaving the underlying bedrock exposed. The decrease in forest cover would damage the highly vulnerable karst ecoenvironment and the increase in degraded land.

Effective rehabilitation of degraded land in karst Guangxi should aim at optimal use of water and land resources, improving living standards, and protecting the ecosystem. Alternative industries should be developed to overcome the shortage of arable land in mountainous areas.

4.1 Efficient use of water and land resources

Efficient use of water and land resources can be achieved through adoption of advanced and appropriate technologies. For instance, water can be saved through biological (e.g., cultivation of drought-resistant plants), farming technological (e.g., use of plastic sheets to cover the land, furrow tilling), engineering (e.g., construction of fish scale-shaped pits) means, in combination with frugal consumption of water. Land productivity should be improved through fertilization, stratified cultivation, as well as more rounds of cultivation a year. (1) Construction of water tanks to collect rainwater. Surplus water can be used to supplement agricultural use and for breeding stocks. A high water availability should improve agricultural output; (2) Construction of barriers to preserve soil. If soil and terrain permissible, sloping land should be converted into terraced land to grow plums and other fruit trees and other cash crops; and (3) Alternative source of fuel should be explored. Wood can be spared by the wider use of efficient stoves in rural areas. Besides, small-scale methane ponds should also be constructed to provide a renewable source of energy to rid the need of damaging natural vegetation.

4.2 Restoration of eco-economic vegetation

The key to rehabilitation of degraded land lies in restoration of vegetative cover. Percentage of vegetative cover directly shows the degree of rehabilitation. Given that the carrying capacity of the land has been considerably surpassed in degraded land in Guangxi at present, most of them can be rehabilitated through human intervention with the exception of handful areas where land condition is extremely poor. Through implementing a rewarding system based on labor contribution, rehabilitative efforts should concentrate on plantation of fruit trees and cash crops that are benign to the protection of the ecosystem. In this way the forest and vegetative cover in these areas can be greatly enlarged while land degradation can be brought under control. In this way farmers can reap financial return from the rehabilitative measures, which in turn makes the rehabilitation efforts sustainable. Nevertheless, the same rehabilitation model centered on revegetation cannot be applied indiscriminately to all degraded areas. For instance, agricultural activities should be banned in rocky mountainous areas with over 70% exposed rock to protect their thin soil, preserve scarce surface water, and to conserve the land. If the exposed rock mounts to 50-70%, those patches of land with fair vegetative cover should be rehabilitated by turning it into a forest and then sealed off to give the shrubs and mixed forest a chance to become established. The planted trees and grasses should conform to ecological principle. Namely, they must be able to thrive in the rocky mountainous environment. If the exposed degraded land mounts to only 30%-50% and the slopes are gentle, they should be used more intensively by planting fruit trees that can bring more economic return, such as grapes, plums, honey suckle, loquat, tea, as well as grasses for grazing.

4.3 Development of alternative industries

Regional economic structure and distribution should be adjusted and optimized to reap the effect of scale production. The present traditional mono-economic operation based on grain production should be diversified to include new industries suitable for the local environment, such as cultivation of special plants. (1) Rural small towns in degradation areas should be formed to transfer population relying on agriculture to non-farming. They may find employment in the service sector. In this way rural population in the affected areas can be reduced to lessen the pressure on the land. (2) Establishment of the processing industry of green products, including traditional Chinese herbs (e.g., gutta-percha, nutgall, honey suckle, Gastiodia elata, etc). Other processing items may include mutton and beef. Those animals that are suitable for the local environment, such as water buffalo, black goat should be raised more to supply raw materials for the processing industry. Agricultural activities could also be specialized by planting more fruit trees that are suited to the local settings, such as kiwi fruits, pepper and Bunge prickly ash. (3) Development of tourism. There is a rich tourism resource in degraded areas, such as caves, gorges, stone forests, as well as many other natural scenic spots, in addition to a rich diversity of minority culture. Cave exploration, gorge drifting, and cultural tourism can all be top tourist attractions [11].

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4.4 Government intervention

(1) Labor output. In order to reduce the pressure of human being in the land, the local government should team up with its counterparts in richer coastal regions in organizing targeted labor output for the surplus farmers. Through gaining working experience in a wider outside world, hopefully, the laborers will also learn something useful skills in finding more employment in non-rural sector. (2) Migration. People in the worst affected counties where the carrying capacity of the land has been stretched to the absolute limit should migrate according to a government plan, to the relatively prosperous coastal zone of this region in the south where there is a richer land resource. The government should help the migrants to settle by handing out living allowance, investing in building the local infrastructure and solving the housing problem for the settlers. Efforts should also be made to educate the new migrants by local technologists on how to settle in the new environment and how to grow crops successful according to the local environment so that they can gradually get rid of poverty. (3) Development in another region. Villagers in rocky mountainous areas should be encouraged to team up with those living with relatively more abundant and better land resource. They can complement each other's economic activities in labor and land resources. For instance, the migrants can lease the land for growing fruits and grain. In this way both parties can benefit from the arrangement. Some successful experience has accumulated in this area in one county.

5. CONCLUSIONS

Comparison of the results obtained from Landsat TM/ETM images recorded in three periods shows that land degradation in Guangxi has shown a growing trend with expanded distribution. From 1985 to 2000, areas of degradation increased by 3.45%. However, the rate of expansion is not linear within the 15-year period. During 1985-1995, the rate of increase was as high as 10.34%. During 1995-2000 the area actually decreased by 6.25% thanks to the efforts in rehabilitating the degradation land. However, this has not changed the overall severity of the problem in this region. In 2000 the proportion of severely degradation areas accounts for 25% of the total degradation area. During 1985-2000 moderately degradation area retained a steady trend of rise. As a result, land degradation has already threatened the livelihood of local farmers and affected agricultural production. In seriously degradation villages there is a shortage of water and arable land while drought and water-logging have become commonplace. Under such a harsh ecoenvironment land productivity is rather low, which is the cause of rural poverty in this region.

Land degradation is a problem restricted to karst areas. It creates a highly vulnerable ecoenvironment in karst areas. Land degradation in Guangxi is a product of joint effect from the combined effect of geology, geomorphology, vegetation, soil, rainfall and other natural variables, as well as irrational human activities. Although various variables have played a role in causing it, one of the leading factors is the long-term destruction of natural vegetation via excessive felling of trees. Land of a thin soil layer in karst Guangxi is widely scattered as small patches. Massive clearing of virgin forests accelerated soil erosion while arable farmland became more and more scarce. Local farmers earn their livelihood by tilling the remaining and precious land, continuously damaging natural vegetation and causing soil erosion through land reclamation, which in turn causes more soil erosion and exacerbating land degradation.

Successful rehabilitation of land degradation lies in the efficient and sustainable use of water and land resources in karst Guangxi. In this way the carrying capacity of land can be increased. The necessity of reclaiming new land at the expense of destroying natural vegetative cover to earn a living for generations of people in rocky areas can be eradicated. In this way the worsening spiral cycle of ever increasing soil erosion and expanding degradation can be stopped. Recovery of vegetative cover should be based on the plantation of trees that are suited to the local environment and that can also bring economic return. In this way the living conditions of the local farmers can be improved while the ecology can be improved. All of these practices are keys to stopping the trend of limestone karst degradation. Development of new industries and new means of developing the economy are the main driving forces behind poverty eradication in land degradation areas and transforming the traditional economy in the region so that social economic development is harmonious with the protection of the local ecology.

Land degradation results from the mutual interactions between karst processes and social economic processes. In order to completely stop the degradation process, attention needs to be paid to tackle the very cause of the problem, namely, how to ensure that residents in this region can earn a decent living. Rehabilitation efforts should be directed at improving agricultural production, farmers' living standard and restoration of the ecosystem. In this way the problem can be sustainably rehabilitated with maximum return.

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