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Analysis of Rocky Desertification Monitoring Using MODIS Data in Western Guangxi, China

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1. Introduction

Rocky desertification (RD) is the process of land degradation characterized by soil erosion and bedrock exposure. It is one of the most serious land degradation problems in Karst areas especially in western Guangxi of southwest China, which is usually regarded as an obstacle to the local sustainable development. Recent investigations suggest that the RD is mainly caused by direct human activities, but some researchers also take account the climate change into a key factor of RD (e.g., Yao et al., 2001; Jing et al., 2003; Liao et al., 2004; Hu et al., 2004; Wang et al., 2004; Xiong et al., 2008).

Most areas in the western part of Guangxi Province belong to the Karst region. Similar to the other Karst areas in the southwest China, the geological environment is fragile and sensitive, with a high density of population but a low degree economic development. These aspects make the environment degraded quickly. RD is one of the most serious weaknesses of sustainable development in western Guangxi of southwest China. The investigation of the RD and its change monitoring are very significant and also necessarily meaningful.

In Guangxi, the area of Karst regions is about 89,500 km^2, which takes up 37.8% of the total area of Guangxi Province. Among them, the exposed surface of the Karst area is about 78,800 km^2, at 88% of the total Karst area in Guangxi. In the past few decades, due to deforestation, over cutting and grazing, the forest in the mountains was severely damaged, which led to serious soil erosion. According to the recent survey, the RD land is more than 233×104 hm^2, about 10% of the total area of Guangxi; the potential RD land area is more than 186×10^4 hm^2, about 8% of the total area. The RD land is mainly distributed in the middle of Guangxi: Red River Basin, Liujiang Basin; and western Guangxi: Left, Right River Basin; northeast of Guangxi: the two sides of middle and lower reaches of Li River. There are 32 counties (cities, districts), and Karst areas take up more than 60% of the administrative areas. The typical characteristics of RD areas are lack of soil, water, food and fuel with a lower economic level. 28 counties are designated to be poor ones, and 23 of them located in the Karst Rock Hill areas take up more than 30% of the administrative areas. RD in Guangxi has become a main cause of disaster and poverty, which constrains the regional economic and social development.

In China, studies on RD have been paid a lot of attention by many researchers since 1980s. Remote sensing and GIS technique always plays an important role in this research field. Landsat TM image, topographic map, geological map and GPS in-situ data were applied to produce a RD classification distribution map in Du'an Yao Autonomous County of Guangxi (Jiang et al., 2004) and to monitor the RD area in Wenshan County of Yunnan Province (Wu, 2009). ASTER image was used to study the situation of RD and its change trend from 2000 to 2005 in the Karst area of Guizhou Province (Chen et al., 2007). In addition, NOAA/AVHRR and MODIS data were used to monitor land desertification (Liu et al., 2007), in which humidity index was used to define the desertification area and two suitable classification methods were established to monitor the desertification dynamics from 1995 to 2001.

MODIS data was first applied in the western Guangxi of southwest China to monitor the rocky desertification with the change of land cover types from 2000 to 2010. The study area covers 30 counties in the western Guangxi. The study tends to give some suggestions to the local governments on the reconstruction of the rocky desertification and defense on new desertification in order to sustain the balance of the whole eco-geo-environment in western Guangxi of southwest China in the near future.

2. Study area

The study area is located in the western Guangxi province of southwest China (see Fig. 1), which is adjacent to Vietnam. The study area contains 30 counties with the total area of about $7.4\times10^4 km^2$, 31% of the whole province's area of Guangxi (23.76×10^4 km^2). Its geographic location is north latitude 21°36′N to 25°40′N, and east longitude 104°20′E to 108°31′E. The area is mountainous region and belongs to subtropical zone with enough rainfall and rich natural resources.

The conflict between human and land in Guangxi is very sharp, but in the western Guangxi, it is even more severe. The land resources in this area have the following characteristics:

a. the area of land is large but the farmland is very limited due to mountainous and rocky landform;
b. a high density of population in Guangxi results in the small farmland per capita, which is less than 0.1 hm^2. In the study area it is much smaller;
c. the land cannot be utilized adequately as the whole agricultural productivity with a very low land quality. Most of the farmland belongs the second or third class. Moreover, the land is difficult to be utilized in the Karst area;
d. soil fertility was lost due to a serious soil erosion.

The study area is mainly composed of carbonate rocks, granite, purple sandstone and shale with weak anti-erosion properties. Climate in the study area is complex and changeable, and sunlight and rain is abundant all over a year, which may accelerate soil erosion. Additionally, with the increasing population and development of economy, human activities impact the probability of soil erosion. All of the characteristics of the study area made the Karst rocky desertification more seriously.

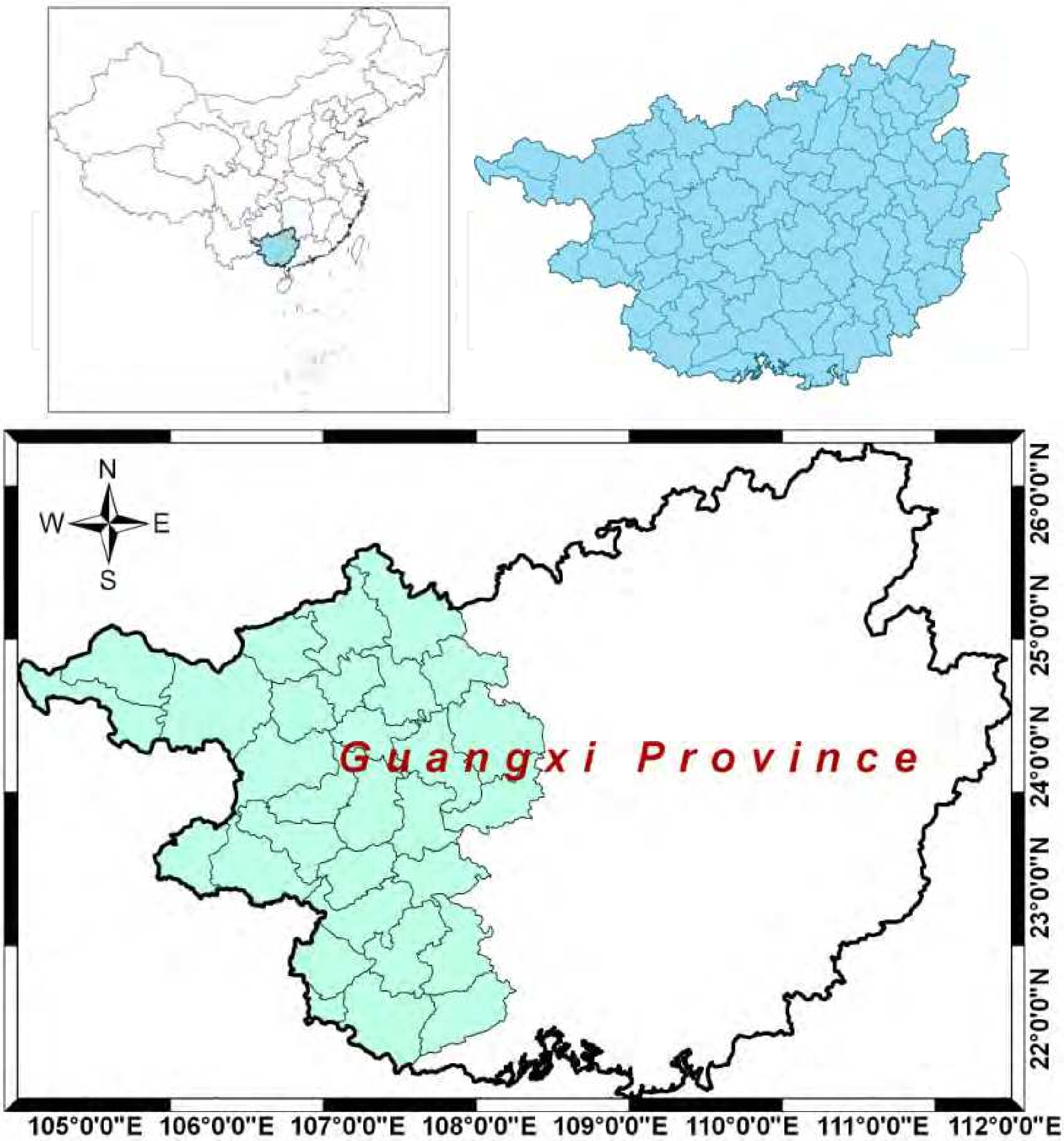

Fig. 1. Location map of the study area in western Guangxi, China.

3. Data and methods

3.1 Data

In this study, MODIS L1B data were used because of its large covered area with a coarse resolution. Other data sources included vector data, administrative maps, some information from previous research and the yearbook of Guangxi.

3.1.1 MODIS data

The MODIS instrument is operating on both the Terra and Aqua spacecraft. It has a viewing swath width of 2,330 km and views the entire surface of the Earth every one to two days, its detectors measure 36 spectral bands, 0.405μm~14.385μm, covering the range of the electromagnetic spectrum. Among these bands, the 1-19 and 26 bands are for the visible and near-infrared channels, and the remaining 16 bands are thermal infrared channels. In addition, MODIS data have three spatial resolutions: 250 m (2 bands), 500 m (5 bands) and 1 km (29 bands). Compared with NOAA/AVHRR and MODIS data are of high spatial, temporal and spectral resolution. Therefore, MODIS data have been widely used in a lot of studies on land use land cover (LULC) mapping and LULC change detection at both global and local scales (Perera and Tsuchiya, 2009; Friedl et al., 2002).

MODIS Level 1B data with 250 m resolution were used in this study. Although the number of bands is limited, the two bands are in the red and near-infrared wavelengths, which are among the most important spectral regions for remote sensing of vegetation. MODIS L1B 250 m radiance data have been utilized for detection of vegetative cover conversion caused by recent significant natural events (burning and flooding) and human activities (deforestation) (Zhan et al., 2002). MODIS L1B data with 250 m resolution in November of 2000, 2003, 2006, 2008 and 2010 were downloaded to detect changes, because the weather in this month does not change too much and it is easier to get clear and cloudless images.

3.1.2 Other supporting data

The boundary vector data of the study area is from the National Fundamental Geographic Information System with a scale of 1:4,000,000. It contains the information of borders (national, province, city, county), rivers (the first, second, third class), main roads, main railways, and residences (e.g., city and county). In this study, the border and residence data are mainly used. In addition, local administrative maps, information from previous research and the yearbooks of Guangxi are used as supporting data in the study.

3.2 Methods

The processing steps of the study are shown in Fig. 2. Firstly, the MODIS L1B data were pre-processed and the study area of western Guangxi was retrieved using the border vector data. Secondly, the images and other data were projected to the same coordinate system and spatial resolution after geo-reference calibration. MODIS data with 250 m spatial resolution in 2000, 2003, 2006, 2008, and 2010 were obtained with two bands of red and infrared bands, respectively. Thereafter, two methods were used to monitor the RD: a) NDVI calculation to identify the extent of RD; and b) analysis on land cover change after classification on the two images. Finally, the changed information was extracted and compared. Through a statistical analysis, the RD results were quantitatively analyzed.

3.2.1 RD identified by NDVI calculation

NDVI (Normalized Difference Vegetation Index) is a simple numerical indicator that can be used to analyze remote sensing measurements. NDVI provides a crude estimate of vegetation health and a means of monitoring changes in vegetation over time. Vegetation index is extracted from the multi-spectral remote sensing data, it can quantized reflect the plants situation and helps strengthen our interpretation of remote sensing images. As a means of remote sensing, it is widely used in monitoring land-use cover, vegetation cover, density assessment, crop identification and crop forecasting. It has enhanced the ability of the classification in the topic mapping (Du, 2008).

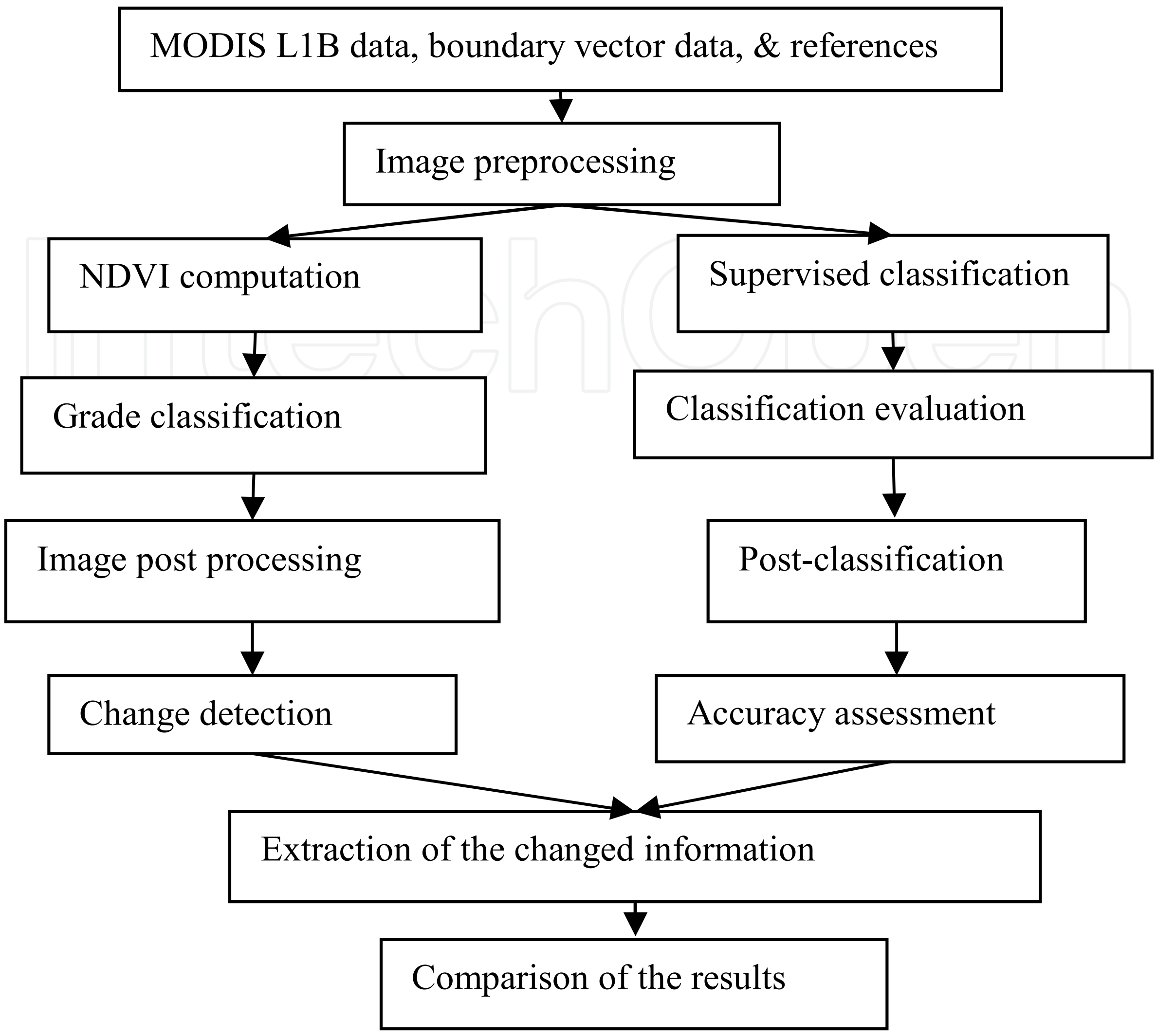

Fig. 2. The flowchart of data processing

The vegetation index is linear correlation to vegetation distribution density, the bigger of NDVI, the better of vegetation cover. The formula for NDVI calculation can be expressed as follows:

$$NDVI = (R_{nir} - R_{red}) / (R_{nir} + R_{red}) \quad (1)$$

Where, R_{nir} in the formula is the reflectance of near infrared band and R_{red} the reflectance of the red band, corresponding to the second band and the first band of MODIS L1B data with 250 m spatial resolution, respectively.

NDVI value	<0.2	0.2-0.4	0.4-0.6	>0.6
The extent of RD	Intensity	Moderate	Mild	Good protected

Table 1. The relationship of NDVI and the extent of RD (adopted from Hu et al., 2004)

There is a relationship between NDVI and the extent of RD (Hu et al., 2004) as shown in Table 1. From the table, one can see that if NDVI value is below 0.2, it means there is little vegetation cover on this area, and much rocky land exposed to the air, so the RD here is intense; if the NDVI value is between 0.2 and 0.4, the extent of RD is moderate; if NDVI is between 0.4 and 0.6, the extent of RD is mild; when the NDVI is above 0.6, it means these areas are good protected.

3.2.2 Land cover classification

After the detection of NDVI change, it is still needed to know the specific changes of land cover types in the study area. Generally, there are two methods to distinguish and interpret the remote sensing image: supervised classification and unsupervised classification. Supervised - image analyst "supervises" the selection of spectral classes that represent patterns or land cover features that the analyst can recognize. Unsupervised - statistical "clustering" algorithms used to select spectral classes inherent to the data, more computer-automated.

Supervised classification was used in this study. It is much more accurate for mapping classes, but depends heavily on the cognition and skills of the image specialist. The strategy is simple: the specialist must recognize conventional classes (real and familiar) or meaningful (but somewhat artificial) classes in a scene from prior knowledge, such as personal experience with what is present in the scene, or more generally, the region it is located in, by experience with thematic maps, or by on-site visits. This familiarity allows the individual(s) making the classification to choose and set up discrete classes (thus supervising the selection) and then, assign them category names.

Training ground and training sample selection is very important in supervised classification, the classification result will have a big different in supervised classification if the training sample is different. So it should be careful to select the training ground and choose the represented training sample correctly. These are the key points to produce a good classification result. In this study, supporting data and local land cover maps were used to help distinguish the land cover types. Due to the coarse resolution of MODIS data, it is not credible to classify many detailed land cover types. Thus based on information from supporting data and local land cover maps, six types of land cover were to be classified: water, wood, grassland, residence, farmland and unused land. After the classification, post-processing of image classification should be performed to get more reliable land cover maps, whilst accuracy assessment would be done.

4. Results

4.1 NDVI distribution and change of RD from 2000 to 2010

NDVI values were calculated by equation (1) and their distribution maps of 2000 and 2010 were obtained using ENVI software. Difference can be seen in the NDVI maps of the two years. In north part of the study area, NDVI values decreased in November 2008 compared with that in November 2000. However, NDVI maps can not show these changes distinctly. To distinguish the extent of the RD from 2000 to 2010, a decision tree upon Table 1 was produced as shown in Fig. 3. The Decision Tree classifier performs multistage classifications by using a series of binary decisions to place pixels into classes. Each decision divides the pixels in a set of images into two classes based on an expression. Based on these rules, the extent distribution of RD from 2000 to 2010 can be mapped clearly (see Fig. 4).

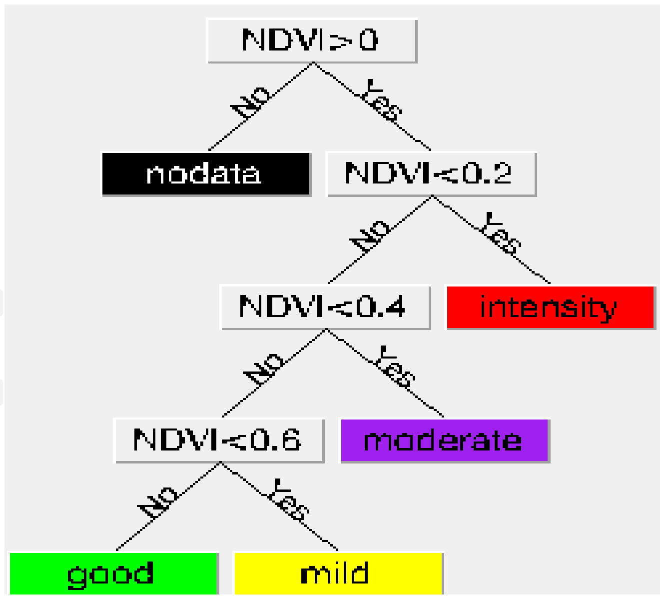

Fig. 3. Level slicing for the extent of RD (This is a segmentation method called level slicing).

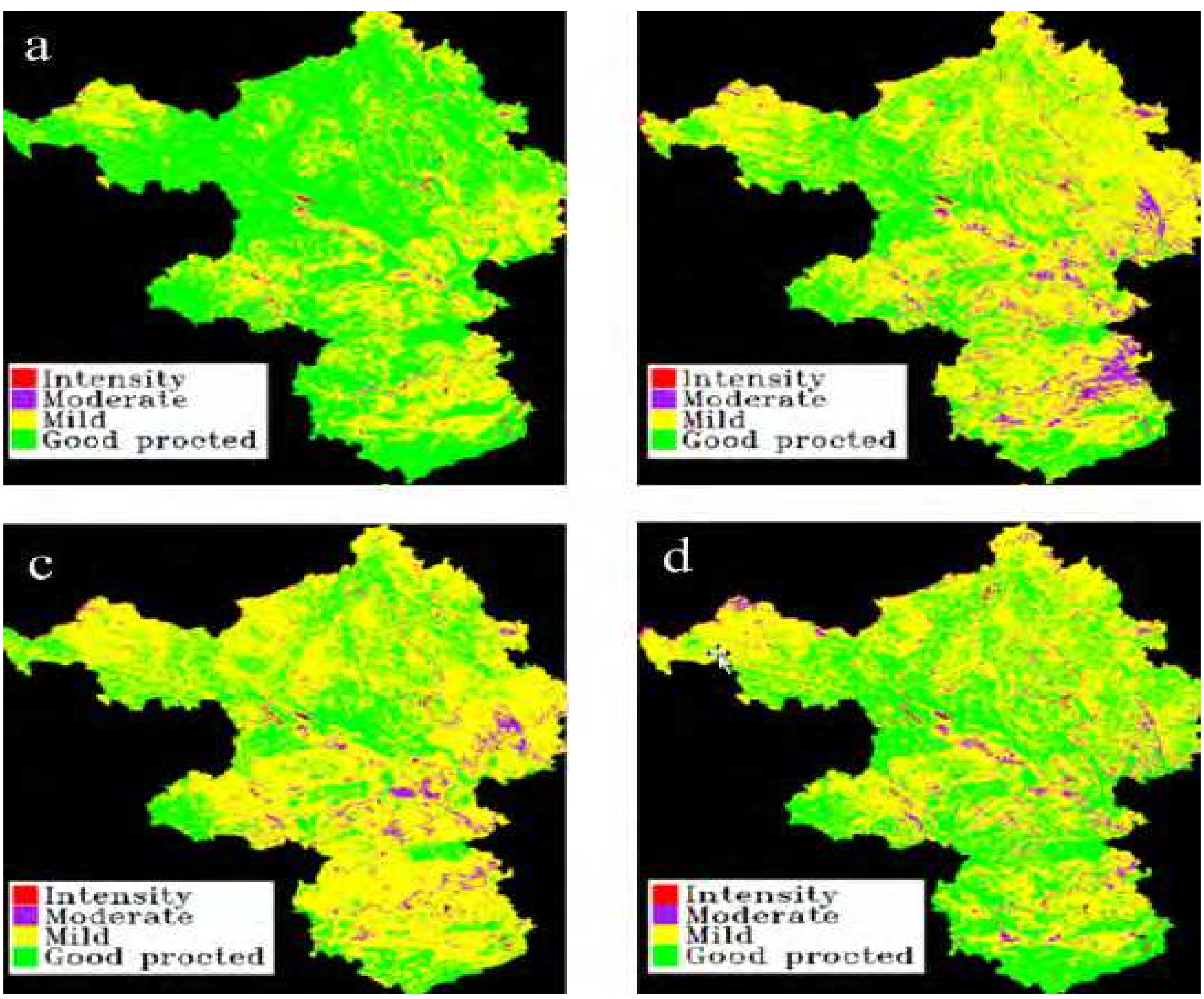

Fig. 4. (continued)

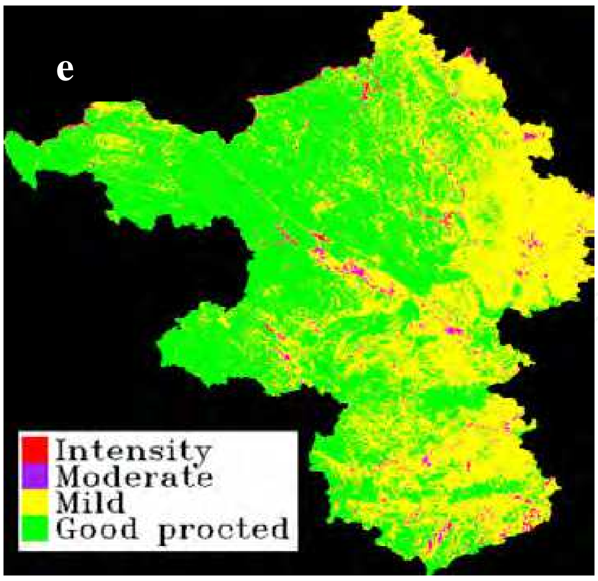

Fig. 4. The RD extent mapping in 2000 (a) 2003 (b), 2006 (c), 2008 (d) and 2010(e)

Compared the results from 2000, 2003, 2006, 2008, and 2010, it is clearly found that the good protected area has decreased from 2000 to 2006, and increased again from 2006 to 2010 in west part of the study area; the mild and moderate RD area is increasing dramatically in middle and north part of the study area. Nevertheless, intense RD area is seldom noted in all years, which may indicate that the environment of the study area does not deteriorate very badly. A change table of class statistics was made as shown in Table 2, which gives the percentages of each class in the whole area. It is clear that good protected area decreased from 2000 to 2006 and increased again from 2006 to 2010, while intense and moderate areas are relatively stable, and mild area decreased remarkably from 2006 to 2010. This indicates that many mild areas have been converted to good protected lands since 2006 due to governmental land protection policies.

		intensity	moderate	mild	good protected
2000	percent	0.12%	1.15%	37.98%	60.76%
	area(km^2)	85.71	847.40	28104.77	44962.13
2003	percent	0.21%	6.15%	66.79%	26.86%
	area(km^2)	151.98	4548.10	49422.80	19877.12
2006	percent	0.20%	3.91%	72.45%	23.44%
	area(km^2)	145.59	2892.45	53613.76	17348.20
2008	percent	0.35%	3.73%	57.49%	38.44%
	area(km^2)	257.39	2756.87	42542.88	28442.86
2010	percent	0.33%	1.68%	46.47%	51.52%
	area(km^2)	247.24	1242.65	34387.04	38123.07

Table 2. The RD extent in 2000, 2003, 2006, 2008, and 2010

4.2 Supervised classification and change analysis

MODIS L1B images in 2000 and 2010 were classified by supervised classification, in which the maximum likelihood classifying algorithm was employed as the most typical and wide method. After the ground training and selection of training samples, the image classification of the MODIS data was performed under ENVI environment. Afterwards, the post-processing classification was also made to reduce or eliminate the effect of noise caused by mixed scattered point features. Therefore, a filter kernel 3×3 matrix was used to make cluster analysis, which can smooth the classification maps and combine the similar areas to the neighbor region. The final results of the classification maps in 2000, 2003, 2006, 2008 and 2010 were shown in Fig. 5.

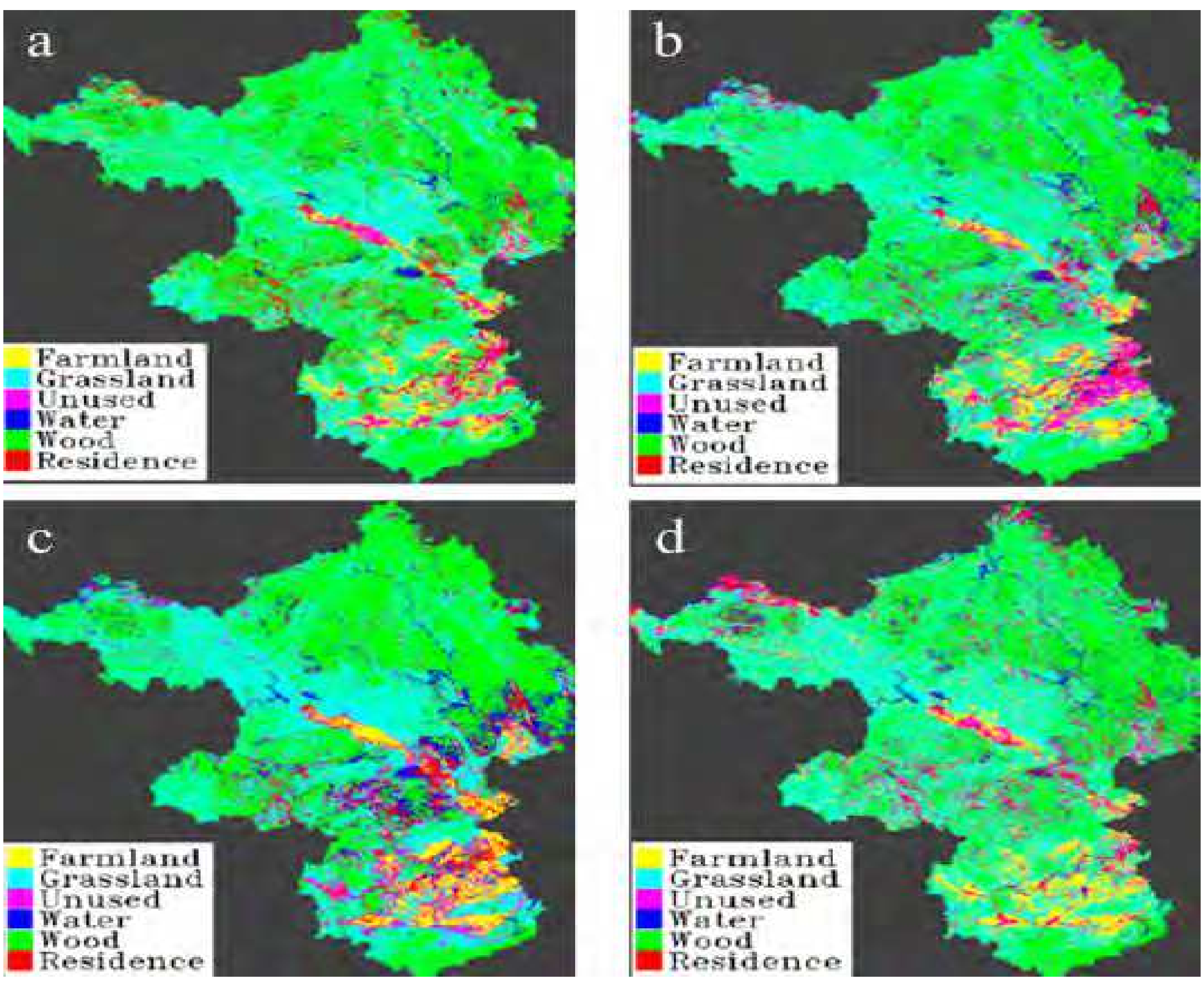

Fig. 5. (continued)

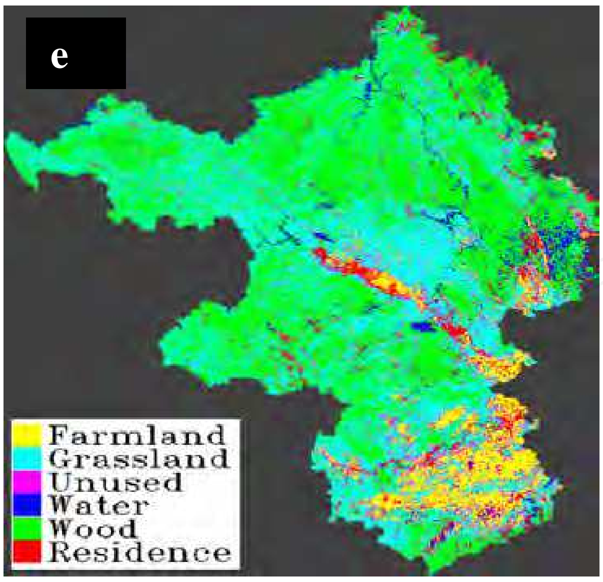

Fig. 5. Land cover classification from MODIS in 2000 (a), 2003 (b), 2006 (c), 2008 (d) and 2010(e)

A lot of change of land cover types can be found during the period from 2000 to 2010. In the classification map of 2000, woodland is the main class, which takes up to 47.68% of the study area; grassland is about 31.82% and farmland takes up to 8.32%, while other classes are relatively small. However, in 2008, the woodland only takes 38.69%, and grassland and farmland are up to 37.03% and 10.97%, respectively, which may suggest that these woodland areas were degenerating into grassland and farmland areas in a large region with the intensifying degree of RD issues. But this trend stops from 2008 to 2010. From 2008 to 2010 the woodland has increased to 44.95% and grassland and farmland decreased to 35.50% and 8.23%, respectively.

Table 3 and Fig. 6 show the total percentage and area of each land cover type from 2000 to 2010. It is clear that residential areas, farmland and grassland increased remarkably, whereas woodland decreased dramatically. In comparison, unused land areas decreased quite smaller, while water areas retains relative stable.

	water	wood	grassland	farmland	residence	unused land
2000	3.24%	47.68%	31.82%	8.32%	6.16%	2.78%
2003	4.05%	45.03%	33.52%	7.55%	3.20%	6.66%
2006	5.72%	44.09%	33.04%	6.16%	4.74%	6.24%
2008	3.30%	38.69%	37.03%	10.97%	3.74%	6.26%
2010	3.40%	44.95%	35.50%	8.23%	3.80%	4.13%

Table 3. The percentages of each land cover type in 2000, 2003, 2006, 2008 and 2010

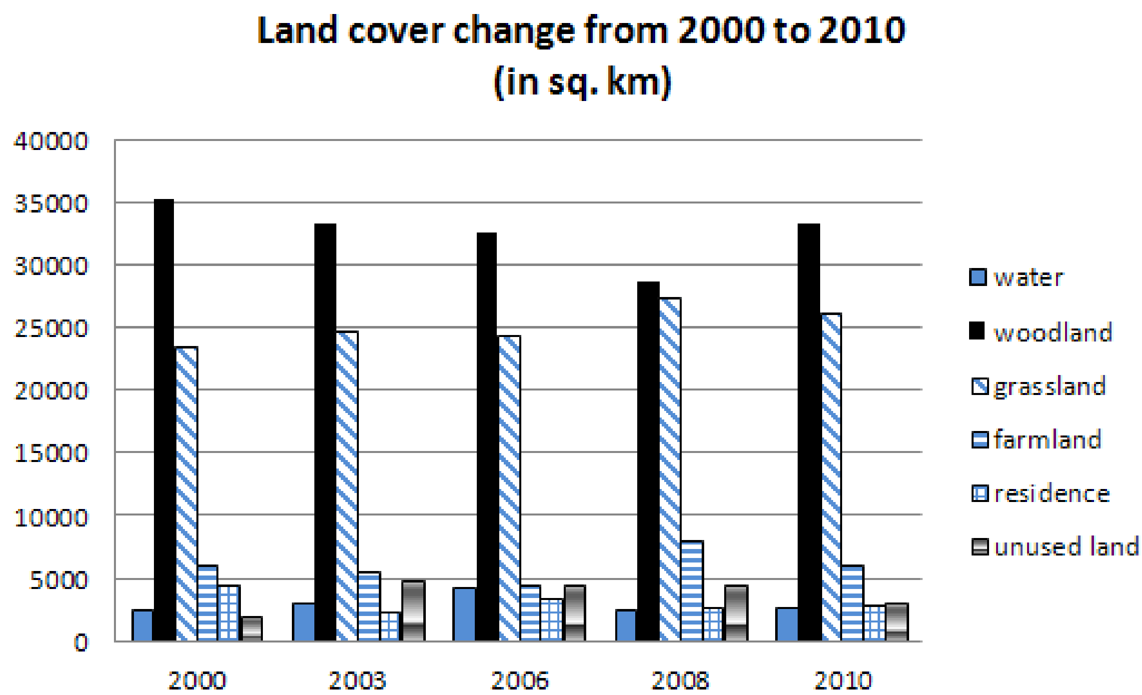

Fig. 6. The areas of each land cover type and its change from 2000 to 2010

5. Discussion and conclusion

In this study, MODIS L1B data with 250 m resolution were used to monitor the RD change in western Guangxi from 2000 to 2010. Two methods of NDVI calculation and supervised classification were performed to detect the RD extent.

From the above results, the distribution of RD areas extended from 2000 to 2008 and reduced from 2008 to 2010. The first method is based on the relationships between NDVI and RD. In general, if NDVI values of a region are high, it means the vegetation cover is well protected with a rare extent of RD. Otherwise the lower of the NDVI, the more serious of RD. Based on this assumption, the RD extent was determined in the study area from 2000 to 2010.

However, the RD areas were not only identified by NDVI. Some other factors may also affect the RD extent which can be extracted from MODIS data. To compare the RD extent with the change of land cover types, supervised classification was performed to determine six types of land cover in the study area (see Fig. 5). With the reference of previous studies of local land cover types (Li et al., 2006; Nong, 2007) and the yearbooks of Guangxi, the training sites and samples of six classes were selected and determined. Although there are misclassification errors involved, the results of image classification are reasonable to agree well with the previous results of land cover types and the statistic data in the yearbooks of Guangxi. Comparatively, the NDVI calculation is better and easier to be utilized to detect the RD extent than image classification in the study area.

It is reported that 37.6% RD is resulted from natural factors, while 62.4% of the RD area is caused by direct human activities (Nong, 2007). In this study, the natural factors may include:

- Climate effects: Guangxi is located in the subtropical climate with a long sunshine, much heat and rainfall. The average rainfall is usually 1400 ~ 1800mm per year, sometimes even more than 3000 mm. All these factors lead to serious soil loss, especially in the heavy rain season, in which the erodible soil is strongly rinsed off and only bare bedrocks remain;
- The impact of geological conditions: the southeast of Guangxi is granite collapse Kong area, and the northwest region is limestone area. Both of these two types of geological rocks are more prone to form RD or potential RD areas;
- Vegetation influence: Rare vegetation cover is an important factor to result in soil erosion and form RD (see Fig. 9 and Fig. 10);
- Topography effects: Soil erosion may also be accelerated by hilly and flat ground, steep slope, broken terrain and cutting deep ravines in western Guangxi (Wei, 2002).

On the other hand, direct human activities possibly cause RD or potential RD areas in the following ways:

- Excessive deforestation makes the RD area enlarge seriously;
- Human activities of production and life have an inextricably relationship with RD. The impact of anthropogenic factors is always through various forms. Along with the rapid growth of population, land and energy demand is increasing. This makes the original forest resource dissipated very quickly. Moreover, the inappropriate farming methods, such as the cultivation in high slope land, overgrazing, even excessive exploitation, as well as the quick exploration of local small mines, road building projects, and other industrial projects, make the ecological Karst areas brittle and weak, and showing a rapid trend of RD (Li et al., 2006).

The prevention and control measures of RD from the natural factors can be carried out by the following ways (Luo, 2007):

- Water storage construction. Water storage project is an effective way to control RD extending. This can reduce the seepage of rainwater, then reduce the soil erosion, and can also satisfy the industrial and agricultural water demand as much as possible;
- Forest planting. Making full use of solar thermal and water resources in the small gap of the Karst land and planting more at these areas are both effective ways to reduce the rock surface temperature and water consumption. They improve the micro-climate conditions and slow down the rock desert process;
- Development of three-dimensional ecological agriculture. In such extreme degradation ecosystems of RD areas, the natural recovery of vegetation is very difficult. So it needs biological, engineering and management measures by adjusting the irrigation system and transformation of soil quality to improve soil fertility and improve the ecological environment, in order to make the RD area back to normal.

There are also various means on prevention and control measures of RD from the human activity factors, such as development of the biogas construction, population growth controlling, industrial pollution prevention (Xu, 2006). In addition, it is effective to propagate scientific knowledge on environment protection in the Karst area (Tang et al., 2003). The obvious increase of good protected area and woodland from 2008 to 2010 indicates these propagation and prevention policies have produces positive results of reducing RD in this area. However, there is still a long rough way to go for the public and the government to bring the RD under control in western Guangxi of southwest China in the future.

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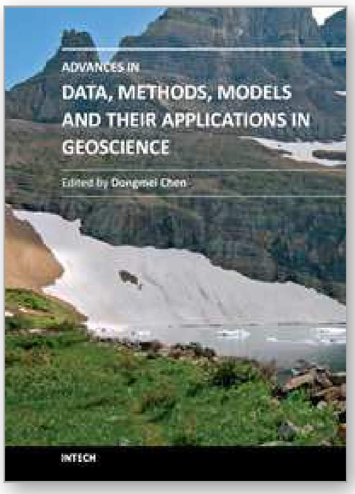

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With growing attention on global environmental and climate change, geoscience has experienced rapid change and development in the last three decades. Many new data, methods and modeling techniques have been developed and applied in various aspects of geoscience. The chapters collected in this book present an excellent profile of the current state of various data, analysis methods and modeling techniques, and demonstrate their applications from hydrology, geology and paleogeomorphology, to geophysics, environmental and climate change. The wide range methods and techniques covered in the book include information systems and technology, global position system (GPS), digital sediment core image analysis, fuzzy set theory for hydrology, spatial interpolation, spectral analysis of geophysical data, GIS-based hydrological models, high resolution geological models, 3D sedimentology, change detection from remote sensing, etc. Besides two comprehensive review articles, most chapters focus on in-depth studies of a particular method or technique.

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