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# Estimating ecological indicators of karst rocky desertification by linear spectral unmixing method

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ABSTRACT

Coverage rates of vegetation and exposed bedrock are two key indicators of karst rocky desertification. In this study, the abundances of vegetation and exposed rock were retrieved from a hyperspectral Hyperion image using linear spectral unmixing method. The results were verified using the spectral indices of karst rocky desertification (KRDSI) and an integrated LAI spectral index: modified chlorophyll absorption ratio index (MCARI2). The abundances showed significant linear correlations with KRDSI and MCARI2. The coefficients of determination ($R^2$) were 0.93, 0.66, and 0.84 for vegetation, soil, and rock, respectively, indicating that the abundances of vegetation and bedrock can characterize their coverage rates to a certain extent. Finally, the abundances of vegetation and bedrock were graded and integrated to evaluate rocky desertification in a typical karst region. This study suggests that spectral unmixing algorithm and hyperspectral remote sensing imagery can be used to monitor and evaluate karst rocky desertification.



## Introduction

Karst is widely distributed and accounts for 12% of the total global land area. It is also one of the most ecologically fragile zones. Karst environments have attracted a great deal of research attention in international geoscience in recent years, particularly in regard to the serious problem of rocky desertification (Wang and Li, 2007). Southwest China, with one of the three largest continuous distributions of karst with exposed carbonate rocks in the world, has experienced severe and rapidly accelerating rocky desertification in the past few decades (Yue et al., 2010, 2013). Owing to its solubility and low acid-insoluble matter content, carbonate forms soil slowly, resulting in a thin soil layer. In addition, disturbances by human activities aggravate soil erosion, forming a unique type of desertification termed “karst rocky desertification.”

Research on karst land degradation has mainly relied on ground surveys and statistical data, which limit multi-temporal comparison and multi-scale research. Recently, recognizing the benefits of remote sensing techniques, some researchers have started to employ this approach to monitor and assess karst rocky desertification (Huang and Cai, 2007). However, such methods mostly involve the visual interpretation and computer-assisted digital processing of aerial photographs and satellite images, with high subjectivity and low efficiency. Moreover, multispectral remote sensing images have been mainly used (Hu et al., 2008; Li et al., 2012), and the shortage of spectral information in such images limits the ability to finely discriminate and identify ground objects in karst rocky desertification areas. Because of the lack of spectral information, the vegetation coverage/fraction has been calculated using the dimidiate pixel model. Among linear unmixing models, the simple form of the dimidiate pixel model has been the most extensively used to estimate vegetation coverage and monitor dynamic changes in vegetation on a large scale (Cui, 2010; Zeng et al., 2000; Xiao and Moody, 2005). This model assumes that a pixel consists of two components, vegetation and soil, but ignores the type of vegetation (Xiao and Moody, 2005; Liang et al., 2012). It also does not account for rocks, which are distributed widely in karst rocky desertification regions.

As key ecological indicators, coverage rates of vegetation and bedrock are usually used to characterize the surface symptoms, extent, and degree of karst rocky desertification. Hyperspectral remote sensing imagery, composed of hundreds of continuous narrow bands obtained by imaging spectrometry, allows us to characterize the coverage rates of land cover in two ways. The first is to solve a spectrum mixture model and obtain the abundance of each component in each pixel with high accuracy. The abundance could represent the coverage rate. The second is to develop a spectral index sensitive to the coverage rate. However, only a few previous studies have attempted to develop spectral indices to characterize the coverage rate of vegetation, soil, and rock in karst rocky

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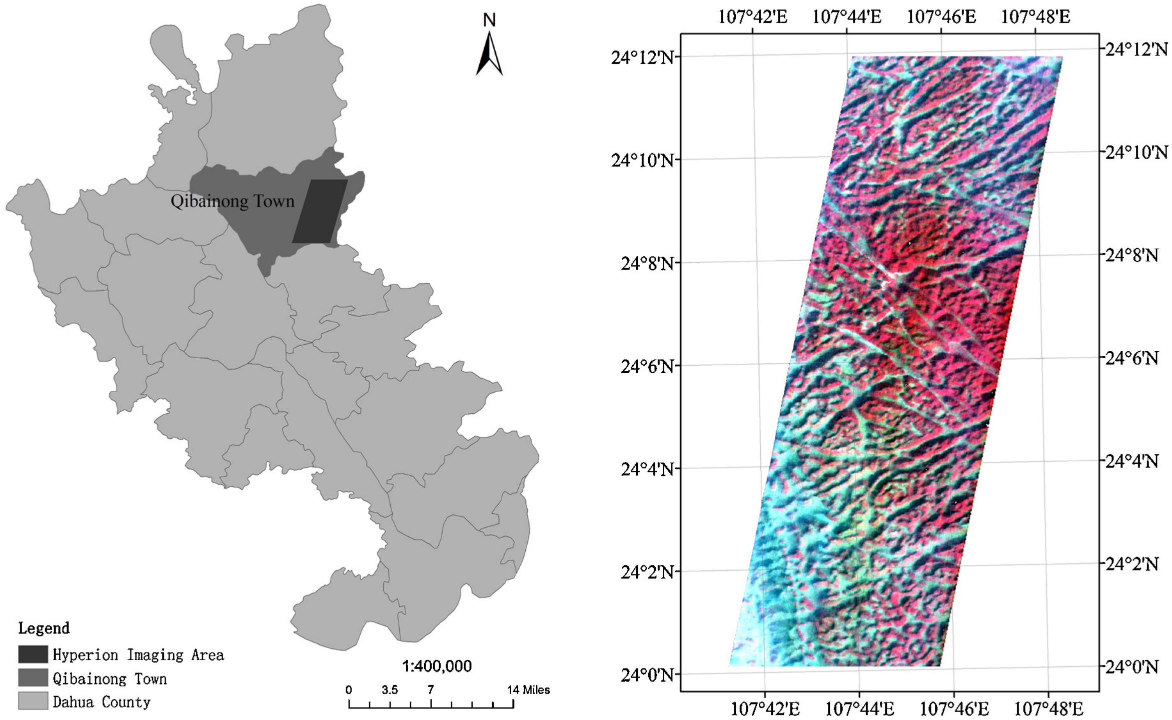


**Fig. 1.** Sketch map of locations of study site and Hyperion imaging area. The dark parallelogram in the left map indicates the location of the Hyperion imging area on the right.

desertification environments (Yue et al., 2010, 2013; Ding et al., 2011), and most were based on hyperspectral data obtained in the field.

This study explored the application of linear spectral unmixing method using hyperspectral remote sensing data for the purpose of retrieving the coverage rates of rock and vegetation in typical karst rocky desertification areas. First, newly developed spectral indices were verified using field data for their ability to characterize the coverage rates of the typical land covers. Then the best indices were applied to hyperspectral remotely sensed images, and the correlations were analyzed between the abundance retrieved by spectral unmixing and by the image-based spectral indices. Finally, the coverage rates for rock and vegetation, represented by abundances, were classified and integrated to obtain a rocky desertification evaluation map. We present the results and discuss their implication in the conclusions.

## Study site and data sets

### *Study site*

The study site was Qibainong Town, a typical limestone karst rocky desertification area (see Fig. 1). Qibainong Town is located in Dahua County, Guangxi Province, China, and has the most completely preserved karst landforms in the world. The town covers an area of 203 $km^2$ and includes more than 5000 hills rising 800–1000 m above the sea level and more than 1300 depressions. The most obvious land surface symptoms are the widespread exposure of carbonate rocks and low vegetation cover. Soil erosion is serious as a result of human disturbance and natural factors. Conifer forest, broadleaf forest, mixed forest and shrubs mainly grow on the hills with thicker soil layer. The soil in valley alluvial zone is fertile and suitable for farming, but the area is extremely limited. Moreover, the variety of complex terrain increases spatially landscape heterogeneity, which appears as discontinuously distributed soil rock, and fragmented ecological spaces for vegetation. Land covers here are often mixtures of several types.

### *Hyperspectral remote sensing imagery*

This study used an EO-1 Hyperion hyperspectral image acquired on 3 March 2008 in clear atmospheric conditions. The image, obtained from the US Geological Survey (USGS), has 242 bands in the 400–2500 nm spectral range at a spectral resolution of 10 nm and spatial resolution of 30 m. The data product is level 1R with radiometric calibration but without geometric correction. As the swath width of the Hyperion image was only 7.5 km, it covered only about 25% of the total area of Qibainong Town. The imaging area was in the west of the town (see Fig. 1).

Data preprocessing was performed on the Hyperion data, including band selection, atmospheric correction, smile effect correction, and geometric correction. Regarding band selection, 44 bands without radiometric calibration (i.e., bands 1–7, 58–76, 225–242) were removed. In addition, bands 77–78 (which repeated bands 56–57) were removed, as were 20 bands severely contaminated by water vapor. The remaining 176 bands were used for further processing and analysis. Atmospheric correction was performed using ACORN software and a reflectance image was obtained. The smile effect was corrected by using a column mean adjusted method in minimum noise fraction (MNF) space (Goodenough et al., 2003). With reference to Landsat Thematic Mapper (TM) imagery, a geometric correction was applied to the Hyperion image to obtain accuracy within 0.5-pixel root mean-square error (RMSE).

### *Field experiment data*

A field experiment was carried out at the study site in November 2010 to obtain reflectance spectra and coverage rate data for complex ground objects that corresponded to the degree of karst rocky desertification. In total, 132 samples (ground objects) were selected