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Remote sensing of fractional cover of vegetation and exposed bedrock for karst rocky desertification assessment

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Abstract

The fractional cover of vegetation (PV) and exposed bedrock are key ecological indicators of the extent and degree of land degradation in karst regions. In this study, we suggested and compared new methodology for direct and objective estimation of key indicators of karst rocky desertification with hyperspectral and multispectral imagery. The results showed that the Hyperion estimated fractional covers of PV had good correlation with the field surveyed fractional covers and the R^2 (coefficient of determination) and *RMSE* (root mean square error) for PV was 0.91 and 0.05, respectively; while for exposed bedrock was not so good, 0.53 and 0.11, respectively. It demonstrated that hyperspectral imagery was able to directly estimate the key ecological indicators of karst rocky desertification, which was in a heterogeneous landscape. As for the ASTER imagery, the results were not so accurate. It showed that multispectral imagery could not be used to effectively estimate the fractional cover of PV and exposed bedrock. Our study indicates that it could use hyperspectral imagery to directly and effectively estimate the fractional cover of PV and exposed bedrock for karst rocky desertification assessment in a heterogeneous landscape of karst ecosystem.

Keywords: fractional cover; KRDSI; karst rocky desertification; Hyperion; ASTER

1. Introduction

Karst regions are typically ecological fragile zones constrained by geological setting, with small environmental and anti-interference capability [1-2]. Southwest China is one of the largest karst regions in

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the world. It is estimated that the karst geomorphology covers about 540, 000 km2 in this region. Karst rocky desertification there has expanded at an overwhelming rate during the past few decades. Karst rocky desertification is a special kind of land degradation process that soil was eroded seriously or thoroughly, bedrock was exposed widespread, carrying capability of land declined seriously, and ultimately, landscape view of karst land degradation appeared similar to desert [3]. Karst rocky desertification, which followed sandy desertification in Northwest China and soil and water loss in loess plateau, becomes one of the most seriously ecological and environmental problems in China [4].

The analyses of the fraction images yield the most information about land degradation [5]. As key ecological indicators, fractional cover of green vegetation (PV) and exposed bedrock are utilized to characterize the surface symptoms of the extent and degree of karst rocky desertification [1]. In karst regions, land covers are often mixtures of several types, thus even relatively fine-resolution remote sensing data do not measure pure spectra, but instead mixed reflectance of vegetation and non-vegetation, rendering it was difficult to estimate the fractional cover of PV and exposed bedrock.

To estimate proportions of land cover at the sub-pixel scale, the most commonly used approach is spectral mixture analysis [6]. However, the utilization of this approach is limited by the variability of endmembers, especially for highly heterogeneous landscape in karst regions. Another widely used method is based on vegetation indices. However, the vegetation indices cannot be easily applicable to all land cover types. Many researches have been expended to improve vegetation indices and render them insensitive to variations in illumination conditions, observing geometry, and background. The performance and the suitability of a particular index are generally determined by the sensitivity of the index to characteristics of interest [7]. Previous researches have proposed a color index, form index, enhanced index and intensity index for mapping land degradation [8], but these indices do not fit to extract the cover information of exposed bedrock, which was essential information for karst geomorphology researches. Our former research had proposed a new spectral index, karst rocky desertification synthesis index (KRDSI) that could be used to extract the fractional cover of non-vegetation [9]. But it was just exploited with field spectral data, needing further research with remote sensing imagery. Therefore, the principal objective of this research is to explore methodology for direct and objective estimation of key indicators of karst rocky desertification with hyperspectral and multispectral imagery.

2. Methods

2.1. Data collection and processing

For exploring new methodology for direct and objective estimation of key indicators of karst rocky desertification with hyperspectral and multispectral imagery, EO-1 Hyperion and EOS Terra ASTER imagery was used to further validated the extraction of the fractional cover of PV and exposed bedrock. The EO-1 Hyperion imagery was acquired at March 3, 2008, and covered a typical karst rocky desertification area near Qibainong, Dahua County, Guangxi Province. Hyperion image was atmospherically corrected with Atmospheric Correction Now (ACRON) and geometrically corrected based on 1:50, 000 DEM. In addition, for the comparison of ability of Hyperspectral and Multispectral imagery used to extract indicators of karst rocky desertification, we convolved the Hyperion spectral reflectance to multispectral ASTER according to ASTER spectral response functions:

$$\rho_s(\lambda) = \frac{\sum_{i=1}^{n} E(\lambda_i)\rho_s(\lambda_i)\psi(\lambda_i)\Delta\lambda}{\sum_{i=1}^{n} E(\lambda_i)\psi(\lambda\ )\Delta\lambda} \qquad (1)$$

where $\rho_s(\lambda)$ is the simulated reflectance of broad-band satellite, n is the number of points of spectral response function in broad-band range, $\rho_s(\lambda_i)$ is the reflectance of object at i th responding band by spectrometer, $E(\lambda_i)$ is the radiance of whiteboard at i th responding band by spectrometer （$W/m^2/sr/nm$）, namely incident solar radiance, $\psi(\lambda_i)$ is the values of spectral response function of different satellite sensors at i th band, $\Delta\lambda$ is the interval of spectral response band.

2.2. Image segmented

For reducing the effects of heterogeneous landscape on the estimation of vegetation fractional cover, we suggested a method for considering the concept of spatial autocorrelation of ground objects. That is, the ground object was similar with its adjacent object, although it is high heterogeneity on large scale landscape, it may be relatively low heterogeneity on small scale landscape. Therefore, if segment the images into relatively homogeneous subsets, it will reduce the effects of high heterogeneous landscape on information extraction. In this study, we segment the satellite images with fraction of relatively homogeneous subsets based on spectral similarity for Hyperion and slipped windows for ASTER, and then estimate the vegetation fractional cover with dimidiate pixel model based on EO-1 Hyperion and ASTER. The slipped windows for ASTER were 35×35 pixels. Spectral similarity was calculated by the spectral angle of pixel wise:

$$\theta = \arccos\frac{T \bullet R}{|T||R|} \tag{2}$$

$$\theta = \arccos\frac{\sum_{i=1}^{n} t_i r_i}{\sqrt{\sum_{i=1}^{n} t_i^2}\sqrt{\sum_{i=1}^{n} r_i^2}} \qquad \theta \in [0, \frac{\pi}{2}] \tag{3}$$

where θ is the spectral angle of pixels, T, R is spectral vector. The similarity of T and R was larger with the decrease of θ.

2.3. Strategies for extraction of fractional cover of vegetation and exposed bedrock with hyperspectral and multispectral imagery

For extraction of key indicators of karst rocky desertification with hyperspectral imagery, a series of spectral variables in SWIR is employed to describe or capture the spectral absorption features of exposed bedrock. These spectral parameters were called KRDSI (karst rocky desertification synthesis index), and our former study had shown that the KRDSI3, which was used to describe the absorption depth, could directly be used to extract exposed bedrock fractional coverage [9]:

$$KRDSI_3 = \rho_0 - \rho_c \tag{4}$$

where ρ_c is the sample spectral reflectance at wavelength c of the SWIR; a, b and c are the wavelengths of the two shoulders and the peak absorption, respectively; and ρ_0 is the estimated reflectance at wavelength c, assuming there were no absorption features present and therefore interpolating linearly between the reflectance at wavelengths a and b. The fractional cover of vegetation was extracted with dimidiate pixel model that pre-segmented Hyperion with spectral similarity.

Daughty [10] had shown that lignin cellulose absorption index (LCA) was linearly related to the fractional cover of soil and non-photosynthesis vegetation (NPV):

$$LCA = 100 \times [(ASTER6 - ASTER5) + (ASTER6 - ASTER8)] \quad (5)$$

where ASTER5，6，and 8 was the spectral reflectance of ASTER band 5 (2.145-2.185μm), 6 (2.185-2.225μm), and 8 (2.295-2.365μm) in SWIR, respectively. For extraction of key indicators of karst rocky desertification with multispectral imagery, lignin cellulose absorption index (LCA) could be employed to extract the fractional cover of non-photosynthetic vegetation and soil, whereas PV could be estimated with dimidiate pixel model that pre-segmented ASTER with slipped windows of 35×35 pixels. Therefore, the fractional cover of exposed bedrock could be estimated: 100%-PV%-soil%-NPV%.

2.4. Validation of extraction of fractional cover of vegetation and exposed bedrock with Hyperion and ASTER

The mixed pixels were severe for the high heterogeneity of karst environment. So, we used field surveyed points to validate the accuracy of extraction of evaluation indicators of karst rocky desertification with Hyperion. A total of 21 effective points were collected. The results of validation were shown with the coefficient of determination R2 and cross-validation RMSE of linear relationship between field surveyed fractional cover and extracted from Hyperion and ASTER.

3. Results and Discussion

3.1. Estimation of fractional cover of PV and exposed bedrock with EO-1 Hyperion

The results showed that the Hyperion estimated fractional covers of PV had good correlation with the field surveyed fractional covers and the R2 (coefficient of determination) and RMSE (root mean square error) for PV was 0.91 and 0.05, respectively; while for exposed bedrock was not so good, 0.53 and 0.11, respectively (Fig1, 2). It was due to that the KRDSI did not take the spectral differences of limestone and dolomite into consideration. It demonstrated that hyperspectral imagery was able to directly estimate the key ecological indicators of karst rocky desertification, which was in a heterogeneous landscape.

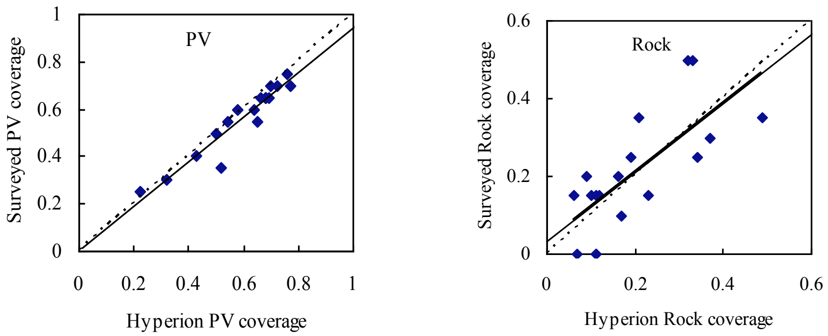

Fig. 1 Scatter diagram and 1:1 straight line (dashed line) and fitting line (solid line) of fractional cover predicted by field surveyed and Hyperion.

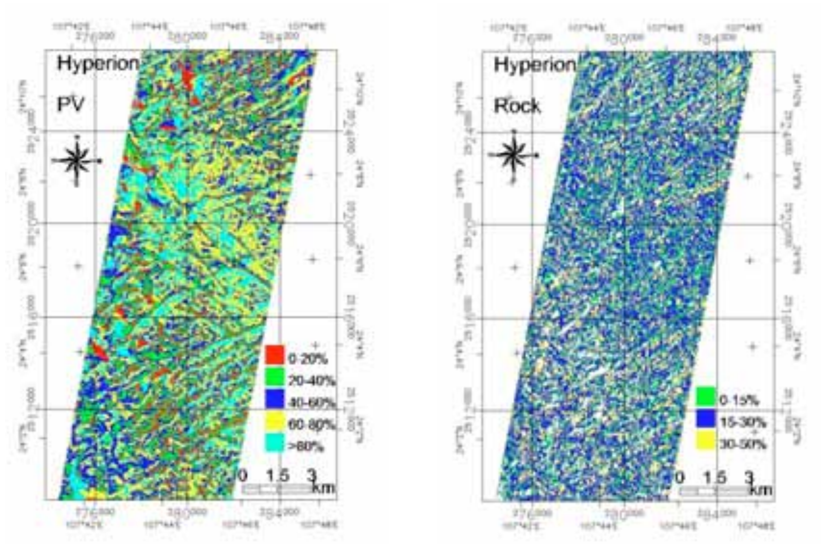

Fig2. Mapping of fractional cover of PV and exposed bedrock with EO-1 Hyperion.

3.2. Estimation of fractional cover of PV and exposed bedrock with ASTER

The results of estimation of fractional cover of PV and exposed bedrock were not so accurate (Fig 3, 4). The R2 and RMSE for PV were 0.61 and 0.10, and for exposed bedrock were 0.48 and 0.11, respectively. It indicated that multispectral imagery could not be used to effectively estimate the fractional cover of PV and exposed bedrock. It was due to the limits of multispectral bands to identify the spectra differences of ground objects under high heterogeneity of karst ecosystem. In addition, whatever hyperspectral or multispectral imagery, it should segment the imagery into relatively homogeneous subsets firstly to reduce the effects of heterogeneity of karst ecosystem.

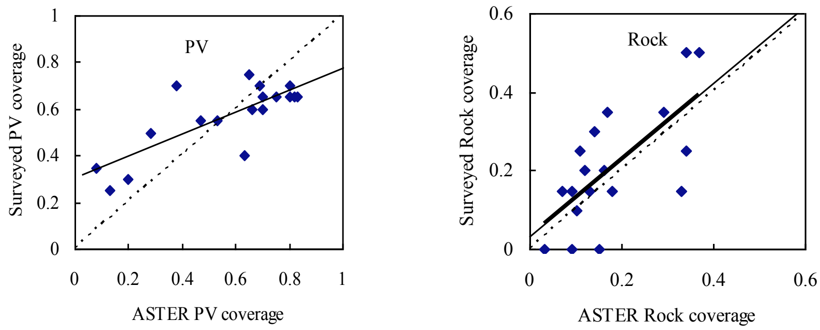

Fig. 3. Scatter diagram and 1:1 straight line (dashed line) and fitting line (solid line) of fractional cover predicted by field surveyed and ASTER.

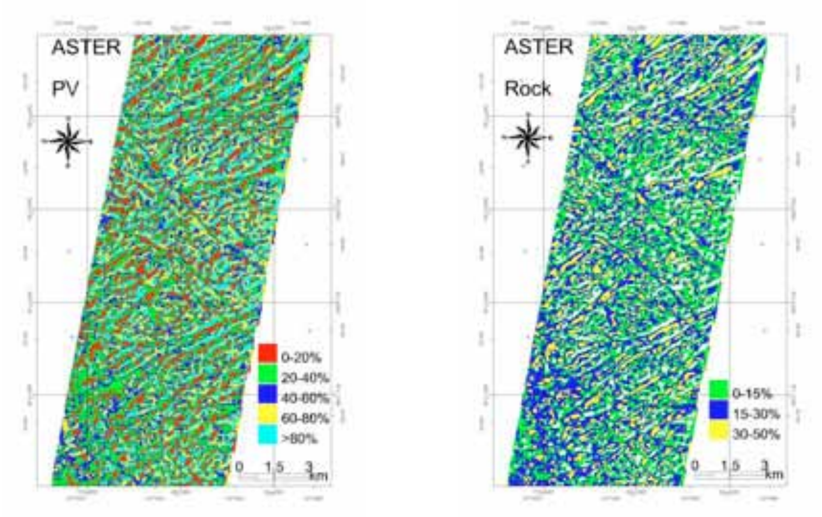

Fig4. Mapping of fractional cover of PV and exposed bedrock with ASTER.

4. Conclusions

Karst rocky desertification is a major eco-environmental problem in karst regions, Southwest China. The present study has provided the opportunity for characterizing and quantifying ecological indicators of karst rocky desertification with multispectral and hyperspectral images. Our study indicates that it could use hyperspectral imagery to directly and effectively estimate the fractional cover of PV and exposed bedrock for karst rocky desertification assessment in a heterogeneous landscape of karst ecosystem. The designed KRDSI should differentiate the spectral features of limestone and dolomite to improve the estimation of fractional cover of exposed bedrock.

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