DEVELOPING NEW SPECTRAL INDICES FOR KARST ROCKY DESERTIFICATION MONITORING IN SOUTHWEST CHINA

Yuemin Yue[*a], Kelin Wang[a], Junsheng Li[b], Bing Zhang[b], Bo Liu[c], Quanjun Jiao[b], Xiaonan Zhang[a]*

[a]Institute of Subtropical Agriculture, Chinese Academy of Sciences, Changsha 410125, China;
[b]Center for Earth Observation and Digital Earth, Chinese Academy of Sciences, Beijing 100080, China;
[c]State Key Lab of Remote Sensing Science, Institute of Remote Sensing Applications, Chinese Academy of Sciences, Beijing 100101, China

ABSTRACT

Karst rocky desertification is a special kind of land desertification developed under violent human impacts on the vulnerable eco-geo-environment of karst ecosystem. The fractional cover of photosynthetic vegetation (PV), non-photosynthetic vegetation (NPV), bare soil and exposed bedrock are key indicators of the extent and degree of land degradation in karst region. The vegetation fractional cover can be estimated approximately from remote sensing with vegetation indices. However, the vegetation indices cannot be easily applicable to all land cover types. In this study, we developed new spectral indices, karst rocky desertification synthesis indices (KRDSI), were then designed based on tied-spectrum permutation and unique spectral characteristics of main land cover types. Comparing with the use of traditional vegetation indices and LSU, the KRDSI was more consistent with the field measurement of main land cover fractions. Our study indicates that KRDSI is a useful tool for karst rocky desertification monitoring with remotely sensed data.

Index Terms— Reflectance spectra, karst rocky desertification synthesis indices (KRDSI), vegetation indices, land degradation, Southwest China

1. INTRODUCTION

Karst region is a typical ecological fragile zone constrained by geological setting, with small environmental and anti-interference capability [1], [2]. Southwest China is one of the largest karst regions in the world. It is estimated that the karst geomorphology covers about 540, 000 km^2 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 under violent human impacts on the vulnerable eco-geological setting. 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 problems in China [3].

To prevent and control karst rocky land degradation process, the point is to quickly and accurately understand the distribution, occurrence, development, and evolvement of karst rocky desertification. The fractional cover of photosynthetic vegetation (PV), non-photosynthetic vegetation (NPV), bare soil and exposed bedrock are essential in characterizing the surface symptoms of the extent and degree of karst rocky desertification [2], [4]. These degradation features can be detected directly or indirectly by using remote sensing images [5], [6]. The analyses of the fraction images yield the most information about land degradation [7]. The fractional cover of vegetation can be estimated approximately from remote sensing images through vegetation indices. Previous researches have proposed a color index, form index and intensity index for mapping land degradation [8], [9]. However, the vegetation indices cannot be easily applicable to all land cover types. The principal objective of this study is thus to develop and evaluate new spectral indices for karst rocky desertification in Southwest China. Specific objectives included: (1) comparing and evaluating the existed and widely used vegetation indices for extraction of fractional cover of PV, NPV, bare soil, and exposed bedrock; (2) analyzing the unique spectral characteristics of PV, NPV, bare soil, and exposed bedrock and developing new spectral indices for estimating the fractional cover of surface symptoms of karst rocky desertification; (3) comparing the performance and suitability of new developed spectral indices with linear spectral unmixing approach.

2. METHODS

2.1 Study area

The study area of this study is located in Huanjiang County, Guangxi Procinve, Southwest China (E108°18′, N24°43′).

All the sites are at Huanjiang Experimental Station of Karst Ecosystem, Chinese Academy of Sciences, which belongs to Chinese Ecosystem Research Network (CERN). It is a typical karst geomorphology. Mean annual precipitation is 1389 mm/yr, and mean annual temperature is 19.9℃. The vegetation cover is mainly made up of typical climbing shrub in carbonate rock region.

2.2 Data collection and processing

Data collection took place during May 1-8, 2008, which was in the peak growing season. A total of 91 samples were randomly selected with different abundance of PV, NPV, bare soil, and exposed bedrock. We measured the spectra of each sample by using an ASD FieldSpecFR spectrometer and placed a black colored circle frame to mark the area covered by the sensor, and took a photograph of it with a digital camera. To reduce the noise level, every measurement was recorded as the average of 10 consecutively acquired spectra. The conversion to spectral reflectance was done by dividing the radiance spectra of the vegetation samples by the radiance spectra of the spectralon panel.

To estimate the PV, NPV, bare soil, and exposed bedrock of each sample, we firstly clipped the sampling area surrounded by the black circle frame in a digital photo with Photoshop software. And then visually marked the borders of PV, NPV, bared soil, and exposed bedrock as regions of interest (ROIs) in ENVI (Environment foe Visualizing Images). The number of PV, NPV, bare soil, and exposed bedrock pixels was counted by a program coded in IDL (Interactive Data Language).

2.3 Selected vegetation indices

To compare and evaluate the possibility to extract fractional cover of different land cover types with traditional vegetation indices, we estimated the coverage of different land cover types with existed and widely used vegetation spectral indices. The vegetation spectral indices were selected as follows: (1) indices based on absorption features of photosynthetic pigments: area of red edge (ARE), area of chlorophyll absorption (ACA); (2) indices based on the normalized difference: simple ratio vegetation index (RVI), normalized difference vegetation index (NDVI); (3) indices based on soil-line: soil-adjusted vegetation index (SAVI), modified soil-adjusted vegetation index (MSAVI); indices based on three discrete bands: triangular vegetation index (TVI), modified chlorophyll absorption ratio index (MCARI). Each vegetation index was formulated as [10]:

$$\mathrm{ARE} = \sum_{\lambda=680}^{780} \rho'_\lambda$$

$$\mathrm{ACA} = \mathrm{S}_0 - \mathrm{S}$$

$$\mathrm{RVI} = \rho_{860} / \rho_{660}$$

$$\mathrm{NDVI} = (\rho_{860} - \rho_{660}) / (\rho_{860} + \rho_{660})$$

$$SAVI = (1+L)(\rho_{860} - \rho_{660}) / (\rho_{860} + \rho_{660} + L)$$

$$MSAVI = (2\rho_{860} + 1) - \sqrt{(2\rho_{860}+1)^2 - 8(\rho_{860} - \rho_{660})} \Big/ 2$$

$$TVI = 0.5[120(\rho_{750} - \rho_{550}) - 200(\rho_{660} - \rho_{550})]$$

$$MCARI = [(\rho_{700} - \rho_{660}) - 0.2(\rho_{700} - \rho_{550})](\rho_{700} / \rho_{660})$$

Where ρ is the spectral reflectance; S_0 is the integral area formed by point (550 nm, ρ_{550}) and (730 nm, ρ_{730}) connected beeline; S is the integral area formed by 550-730 nm spectral curve. The value of factor L=0.5.

2.4 Developing new spectral indices

Many researches have been expended to improve vegetation indices and render them insensitive to variations in illumination conditions, observing geometry, and background. Thus, the performance and the suitability of a particular index are generally determined by the sensitivity of the index to characteristics of interest [10]. As the mixture pixel spectra is more close to the highest abundance of its components, we built several spectral variables based on unique absorption features of different land cover types. But, there are differences among spectrum of inter-type, and then we used tied-spectra, a spectral characteristic normalized method of subtracting the spectral reflectance values within a given wavelength range by the reflectance value at the first wavelength, to reduce the differences of inter-type. The new spectral indices, karst rocky desertification synthesis indices (KRDSI), were built as follows:

$$KRDSI_1 = (\rho_a + \rho_b) / 2\rho_c$$

$$KRDSI_2 = \rho_a + \rho_b - 2\rho_c$$

$$KRDSI_3 = \rho_0 - \rho_c$$

$$KRDSI_4 = S_0 - S$$

Where ρ is the spectral reflectance with tied-spectra permutation; S_0 is the integral area formed by point (a, ρ_a) and (b, ρ_b) connected beeline; S is the integral area formed by a to b spectral curve. For NPV, a=2100 nm, b=2200 nm, c=2300 nm; for bare soil, a=2100 nm, b=2230nm, c=2330 nm; for exposed bedrock, a=2200 nm, b=2380 nm, c=2350nm.

3. RESULTS AND DISCUSSION

3.1 Estimation of fractional cover with vegetation indices

We used linear regression method to compare and evaluate the appropriate of estimation of fractional cover of different land-cover types with existed and widely used vegetation spectral indices. The results show that the fractional cover of vegetation can be estimated approximately from remote sensing images through vegetation indices (Table 1). While the fractional cover of NPV, bare soil, and exposed bedrock cannot be easily and directly estimated by using of traditional vegetation spectral vegetation. This can be illuminated from Fig.1. Other vegetation spectral indices did not demonstrated here. It may be due to the fact that most vegetation spectral indices were built based on red and infrared spectral regions, which were the spectral features of vegetation spectral curve.

Table 1 Linear regression of fractional cover of vegetation with vegetation indices

Vegetation spectral indices	Linear regression	R^2
ARE	y=300.17x-11.02	0.80
ACA	y=4.88x-2.66	0.81
RVI	y=12.52x-14.88	0.79
NDVI	y=128.35x-31.70	0.78
SAVI	y=1.84x-0.18	0.82
MSAVI	y=1.79x-0.13	0.82
TVI	y=0.04x-0.04	0.81
MCARI	y=7.32x-0.00	0.81

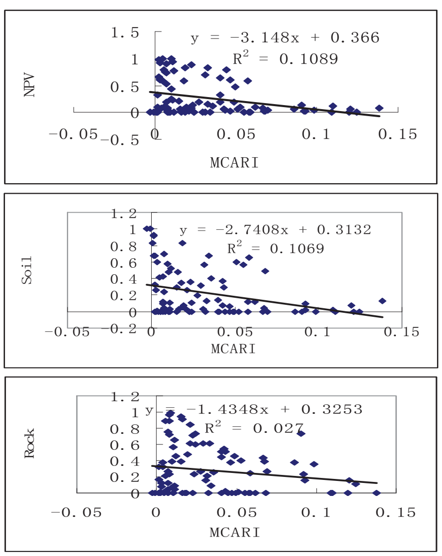

Fig. 1 Linear regression of fractional cover of NPV, bare soil, and exposed bedrock with MCARI.

3.2 Spectral features of main land cover types

We analyzed the spectral features of PV, NPV, bare soil, and exposed bedrock and were shown in Fig.2. PV shows characteristic absorption features in the VNIR mainly, from chlorophyll (near 400-600 nm) and water absorption bands (910, 1100, 1400, 1900 nm). PV can be recognized with the appearance of the red edge at 680-760nm nm and continuous drop in reflectance afterward, with a very low reflectance in shortwave infrared region. NPV shows a soil-like slow continuous rise in reflectance in the VNIR. This is the reason why NPV cannot be differentiated from the soil, since it uses only the red edge as green indicator. NPV spectra shows characteristic absorption features mainly in the shortwave spectral region at near 2100 and 2300 nm, which was dominated by cellulose and lignin spectral features.

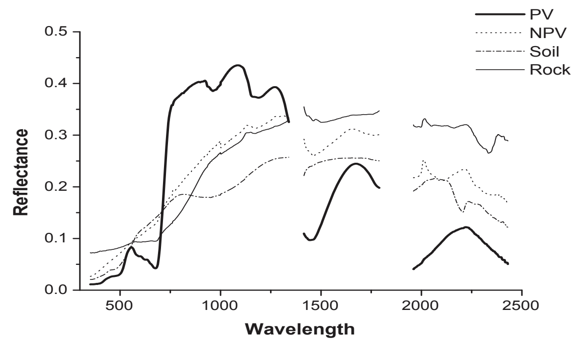

Fig. 2 Spectral features of PV, NPV, bare soil, and exposed bedrock.

As for bare soil and exposed bedrock, the short wavelength infrared (SWIR, 2100-2350 nm) spectral range allows to differentiate between bare soil and exposed bedrock. The bare soil shows clay characteristic feature near 2200 nm and the carbonate spectral typical feature near 2330 nm. In the exposed bedrock, double absorption feature near 2200 nm is often identified for bedrock in karst regions is mostly carbonate rock and is clay-rich rocks. While in the bare soils where smectite is more often the type of clay detected and have single absorption near 2200 nm [11]. Therefore, the short wavelength infrared (SWIR, 2100-2350 nm) was the best option for characterization of PV, NPV, bare soil and exposed bedrock.

3.3 Performance of new developed spectral indices.

We used the spectral features above-mentioned to built new spectral indices, karst rocky desertification synthesis indices (KRDSI). As there are differences among spectrum of inter-type, and thus we used tied-spectra to reduce the differences before calculating KRDSI. The performance of KRDSI was showed in Table 2 and Fig.3. The KRDSI, which built based on NPV and bare soil absorption features, were relatively well estimated the fractional cover of NPV and bare soil. However, the estimated results of exposed bedrock were relative not so well but had largely improved compared with traditional vegetation indices. It was due to the weathering processes of carbonate rocks in karst regions and resulted in the variability of absorption features of bedrock [12]. We also compared KRDSI with linear spectral unmixing (LSU) to estimate fractional cover of exposed bedrock. The performance of KRDSI was better (Fig. 3).

Table 2 Linear regression of fractional cover of NPV, bare soil, and exposed bedrock with KRDSI.

	Spectral indices	Linear regression	R^2
NPV	KRDSI1	y=491.29x-473.96	0.602
	KRDSI2	y=2385.05x+17.37	0.643
	KRDSI3	y=2373.25x+21.17	0.708
	KRDSI4	y=20.35x+21.25	0.704
Soil	KRDSI1	y=437.07x-412.13	0.688
	KRDSI2	y=2814.96x+25.29	0.734
	KRDSI3	y=3874.08x+21.79	0.736
	KRDSI4	y=67.99x+24.40	0.646
Rock	KRDSI3	y=1823.79x+7.59	0.533
	KRDSI4	y=16.23x+14.07	0.399

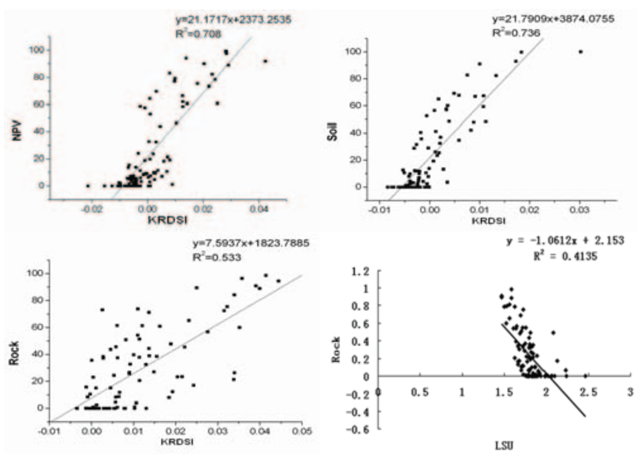

Fig.3 Compare the performance of KRDSI and LSU.

4. CONCLUSION

Karst rocky desertification is a major eco-environmental problem in karst region, Southwest China. The present study has provided the opportunity for characterizing and quantifying surface symptoms of karst rocky desertification using new spectral indices called KRDSI. KRDSI was built based on the unique spectral features of NPV, bare soil, and exposed bedrock and can be used to quickly estimate the fractional cover of NPV, bare soil, and exposed bedrock. The KRDSI is methodologically simple and is a useful tool for land degradation mapping with remote sensing images. The advent of new hyperspectral sensors will allow even more extensive applications of this spectral approach.

5. ACKNOWLEDGEMENT

This study was financed by the Major State Basic Research Development Program of China (grant No.2006CB403208) and the Chinese Academy of Sciences action-plan for West Development (grant No.KZCX2-XB2-08).

6. REFERENCES

[1] H.E. LeGrand, "Hydrological and ecological problems of karst regions", Science, vol.179, pp. 859-864, 1973.

[2] J.H. Cao, D.X. Yuan, and J.G. Pei, "Karst ecosystem of Southwest China constrained by geological setting", Geological Press, Beijing, 2005.

[3] Division of Geoscience, Chinese Academy of Sciences, "Several suggestions for the comprehensive taming to karst mountain areas in Southwest China", *Bulletin of the Chinese Academy of Sciences*, vol.3, pp. 169, 2003.

[4] R.L. Li, S.J. Wang, K.N. Xiong, and F.Q. Li, "A study on karst rocky desertification evaluation index system-a case study of Guizhou Province", *Trop. Geogra.*, vol.24, pp.145-149, 2004.

[5] L.Q. Tong, "A method for extracting remote sensing information from rocky desertification areas in Southwest China", *Remote Sens. Land. Resour.*, vol.4, pp.33-35, 2003.

[6] X.Q. Xia, Q.J. Tian, and F.L. Du, "Retrieval of rock-desertification dagree from multi-spectral remote sensing images", *J. Remote Sens.*, vol.10, pp.469-474.

[7] J. Hill, J. Megier, and W. Mehl, "Land degradation, soil erosion and desertification monitoring in Mediterranean ecosystems", *Remote Sens. Envieon.*, vol.12, pp.237-260, 1995.

[8] D. Haboudane, F. Nonn, A. Royer, S. Sommer, and W. Mehl, "Land degradation and erosion risk mapping by fusion of spectrally based information and digital geomorphometric attributes", *Int. J. Remote Sens.*, vol.18, pp.3795-3820, 2002.

[9] A.R. Huete, T. Miura, and X. Gao, "Land cover conversion and degradation analyses through coupled soil-plant biophysical parameters derived from hyperspectral EO-1 Hyperion", *IEEE Trans. Geosci. Remote Sens.*, vol.41, pp.1268-1276, 2003.

[10] D. Haboudane, J. R. Miller, E. Pattey, P.J. Zarco-Tejada, and I.B. Strachan, "Hyperspectral vegetation indices and novel algorithms for predicting green LAI of crop canopies: Modeling and validation in the context of precision agriculture", *Remote Sens. Environ.*, vol.90, pp.337-352, 2004.

[11] S. Chabrillat, H. Kaufmann, A. Palacios-Orueta, P. Escribano, and A. Mueller, "Development of land degradation spectral indices in a semiarid Mediterranean ecosystem", *Proc. SPIE*, vol.5574, pp.235-243, 2004.

[12] M.T. Younis, M.A. and Gilabert, J. Melia, "Weathering process effects on spectral reflectance of rocks in a semi-arid environment", *Int. J. Remote Sens.*, vol.18, pp.3361-3377, 1997.