

# Application of Remote Sensing for Karst Rocky Desertification in Southwest China

Jiangpan Bian

School of Computer Science, Wuhan University, Hubei, 430000, China

2020302111037@whu.edu.cn

**Abstract.** Karst rocky desertification (KRD) is a special kind of desertification occurring in karst areas, which has caused a great impact on the natural environment, economy, and society in southwest China and has received wide attention from the government and researchers. Remote Sensing can monitor large area, and has fast and accurate data acquisition capability, which provides the scientific basis for evolution analysis and subsequent management of KRD and lays the foundation for conducting related research. This paper analyzes the application of Remote Sensing in the study of KRD in southwest China. Firstly, it introduces how Remote Sensing was used in the assessment of the severity of stone desertification, as well as the commonly used models and research ideas, summarizes the advantages and disadvantages of each model, and explains the advantages of using Remote Sensing. Then, the paper introduces how Remote Sensing was applied in the study of the correlation between geological factors, vegetation factors, and human factors and rocky desertification. Finally, the paper summarizes the possible prospect using Remote Sensing to assist KRD study. This paper expects to inspire researchers by summarizing and analyzing the common ways of Remote Sensing in the study of KRD in southwest China and hopes to enrich the Remote Sensing's usage to assist in the study of KRD in southwest China.

**Keywords:** Karst rocky desertification, remote sensing, degree evaluation, influence factors analysis.

## 1. Introduction

Karst rocky desertification (KRD) is a special kind of desertification that occurs in karst areas. Dr. Yuan et al. first proposed the concept of KRD in 1991, and he believed that KRD is the process of vegetation and soil exposure in karst areas transforming into rocky karst landscapes, and under the tropical and subtropical humid monsoon climate, the ecosystem of southwest karst areas is particularly fragile. Under such special natural conditions, rocky desertification is easily formed in those areas. Together with the problem of human-land conflict and unreasonable anthropogenic activities and other anthropogenic factors, the severity of KRD and the difficulty of its management are aggravated [1]. In southwest China, the KRD area is the source of the Pearl River and an crucial recharge area for the Yangtze River and some international rivers in Southeast Asia, as well as an important ecological barrier. Rocky desertification has caused a great impact on the natural environment, economy, and society, and has received wide attention from the government.

Remote Sensing can monitor large area, and has fast and accurate data acquisition capability. Using Remote Sensing, we can quickly, accurately, and economically obtain data of KRD distribution, providing researchers with the scientific foundation for monitoring, evaluation, evolution analysis, and subsequent management of desertification [2].

There are many precedents for using remote sensing data to assist KRD research in southwest China. Various models for assessing the degree of KRD based on remote sensing data have been proposed and applied, and remote sensing data has already been used to help researchers to obtain information on the surface cover and topography of the study area and correlate them with the degree of KRD.

This paper analyzes the way of Remote Sensing being used in the study of KRD in southwest China. Firstly, the article introduces how Remote Sensing was used to assess the degree of KRD, as well as the models and research ideas commonly used in the calculation using remote sensing data. Then, summarizes the advantages and disadvantages of each model, and explains the advantages of using Remote Sensing. Then, the paper introduces the role of Remote Sensing in the study of the

correlation between geological factors, vegetation factors, and human factors and rocky desertification. Finally, the paper summarizes the possible prospect of using Remote Sensing to assist the study of KRD.

## 2. Application of Remote Sensing to KRD degree evaluation

### 2.1. Evaluation Model Based on a Single Indicator

#### 2.1.1 Evaluation model based on Vegetation Index (VI)

One of the typical features of KRD is vegetation degradation. Because of the thinning soil layer and exposed rocks caused by rocky desertification, the space available for vegetation growth is reduced, therefore, the overall vegetation cover condition of rock desertification areas is worse than that of the neighboring areas without KRD. VI can reflect the status of land cover vegetation and can be calculated through different bands of remote sensing data using different formulae. The most common used VI in research on KRD is the normalized difference vegetation index (NDVI), which can be calculated using equation (1).

$$NDVI = \frac{NIR-RED}{NIR+RED} \quad (1)$$

Where, NIR is the near-infrared band, and Red is the red band [3]. Values of NIR and Red can be obtained from products of the satellites carrying the corresponding sensors, like Landsat and Sentinel. The value of NDVI ranges from -1 to 1. The better the vegetation covering status of an area, the higher the NDVI value, and the sparser the vegetation, the lower the NDVI value.

To evaluate the vegetation cover status of an area more intuitively, Vegetation coverage (FVC) was introduced based on NDVI. FVC reflects the percentage of vegetation cover in the study area [4]. Assuming a confidence interval of 0 to 1, FVC can be obtained using the equation (2). Since noise is usually inevitable,  $NDVI_{max}$  and  $NDVI_{min}$  are generally taken as the maximum and minimum values within a certain confidence level. In the FVC calculation of Dafang County, Guizhou Province by Jiaju Cao et al. an interval from 5% to 95% of the cumulative frequency was used. When  $NDVI_{max} \leq NDVI$ , the value of FVC is taken as 1. When  $NDVI \leq NDVI_{min}$ , the value of FVC is taken as 0. When  $NDVI_{min} < NDVI < NDVI_{max}$ , FVC is calculated using equation (2).

$$FVC = \frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}} \quad (2)$$

In addition to NDVI and FVC, several other vegetation indexes can also be used to evaluate the vegetation cover (Table 1).

**Table 1.** Common Vegetation indexes

Vegetation Index	Formula
simple ratio vegetation index (RVI)	$NIR/RED$
soil-adjusted vegetation index (SAVI)	$\frac{(NIR - RED)(1 + L)}{NIR + RED + L}$
modified soil-adjusted vegetation index (MSAVI)	$(2NIR + 1) - \frac{\sqrt{(2NIR+1)^2 - 8(NIR-RED)}}{2}$
enhanced vegetation Index (EVI)	$G \times \frac{NIR - RED}{NIR + c_1 \times RED - c_2 \times BLUE + L}$
transformed vegetation index (TVI)	$\sqrt{\frac{NIR - RED}{NIR + RED}} + 0.5$

BLUE, RED, and NIR are blue, red, and near-red bands. The value of L in the SAVI index is 0.5; The value of Gain factor G, soil adjustment factor L, and the two correction factors  $c_1$  and  $c_2$  in EVI are 2.5, 0.10, 6.0, and 7.

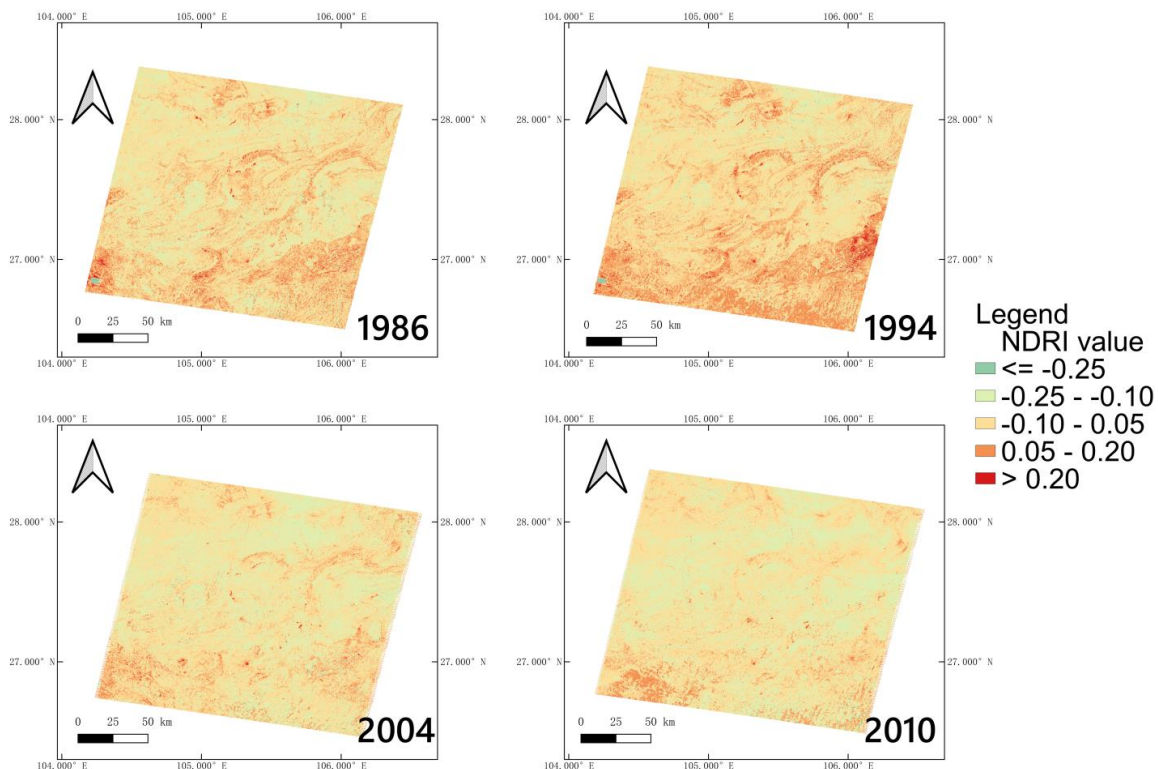
VI is easy to acquire through remote sensing data. However, VI evaluates vegetation cover rather than bare bedrock cover. In addition, VI is generally not directly used to give evaluations on the degree of KRD because vegetation cover is usually complex and topography can also influence the accuracy of NDVI value [5].

### 2.1.2 Evaluation model based on rock index (RI)

In studying the evolution of KRD, rock exposure is a direct factor to evaluate the severity of rocky desertification. Rock indexes like normalized difference rock index (NDRI) can be used to evaluate the rock exposure status of an area (equation (3)).

$$NDRI = \frac{SWIR - NIR}{SWIR + NIR} \quad (3)$$

NIR is the near-infrared band, and SWIR is the short-wave infrared band. A 180km\*180km area centered on Bijie City, Guizhou Province was selected for NDRI calculation (Fig. 1). Landsat5 remote sensing data from 1986, 1994, 2004, and 2010 were used. The overall value of NDRI increased from 1986 to 1994 and decreased from 1994 to 2010.



**Figure 1.** NDRI distribution map of the selected area (Picture credit: Original)

Based on NDRI, the rock exposure rate (FR) can be calculated. FR is used to show the percentage of exposed rock [6]. Assuming a confidence interval of 0 to 1, FR was obtained using the equation (4).

$$FR = \frac{NDRI - NDRI_{min}}{NDRI_{max} - NDRI_{min}} \quad (4)$$

Similar to the calculation of FVC,  $NDRI_{max}$  and  $NDRI_{min}$  are also generally taken as the maximum and minimum values within a certain confidence level. When  $NDRI_{max} \leq NDRI$ , the value of FR is taken as 1. When  $NDRI \leq NDRI_{min}$ , the value of FVC is taken as 0. When  $NDRI_{min} < NDRI < NDRI_{max}$ , the FVC is calculated using Equation 4.

The NDRI and FR provide a more direct rock exposure in the study area than the vegetation index, but bare bedrock and built-up areas can hardly be discerned simply by NDRI value [5]. The rock index can be easily acquired, which makes it convenient for researchers to have an overview on the severity and changes of KRD in a certain area. Nevertheless, both rock index and vegetation index

are affected by the light conditions and cloud coverage of the environment, and the evaluation index is relatively single and influenced by noise. In actual studies, they are often combined with other indicators to obtain a more accurate assessment of the extent of rock desertification. In addition, the band ranges of NIR and SWIR of different satellites may be different, for example, the NIR wavelength range (micrometers) of Landsat5 is 0.76~0.90. The SWIR wavelength range is 1.55~1.75 and the NIR wavelength range of Landsat8 is 0.85~0.88 and the SWIR wavelength range is 1.57~1.65. Because of the difference in band ranges, if both Landsat5 and Landsat8 data are used in the same study, the resulting VI or RI values cannot be directly compared and need to be further processed.

### 2.1.3 KRDSI-based evaluation model

Remote Sensing monitors different wavelengths of electromagnetic waves reflected from the ground, and the degree of KRD can be assessed according to the difference in the reflectance of light from different ground covers.

According to the research of Yue et al., SWIR (2100-2350nm) is the best choice for characterizing exposed bedrock, bare soils, photosynthetic vegetation (NPV) and photosynthetic vegetation (PV) [7]. Accordingly, Yuemin Yue et al. proposed a new spectral KRD composite index KRDSI (equation (5)-(8)) [7].

$$KRDSI_1 = \frac{(\rho_a + \rho_b)}{2\rho_c} \quad (5)$$

$$KRDSI_2 = \rho_a + \rho_b - 2\rho_c \quad (6)$$

$$KRDSI_3 = \rho_0 - \rho_c \quad (7)$$

$$KRDSI_4 = S_0 - S \quad (8)$$

where,  $S_0$  is an integral area formed by (a,  $\rho_a$ ) and (b,  $\rho_b$ ) connected beeline;  $S$  is an integral area formed by a to b spectral curve;  $\rho$  is the spectral reflectance.

For NPV, a, b, c are taken as 2100 nm, 2200 nm, 2300 nm, respectively. For bare soil, a, b, c are taken as 2100 nm, 2230 nm, 2330 nm, respectively. For exposed bedrock, a, b, c are taken as 2100 nm, 2380 nm, 2350 nm [7].

Yue et al. compared KRDSI with LSU. By constructing linear regression models, the superiority of KRDSI in monitoring the extent of exposed bedrock cover can be seen by constructing linear regression models for the cover fraction of exposed bedrock, exposed soil, and NPV with KRDSI [8]. KRDSI has been applied in rocky desertification studies. Xia Zhang et al. used the KRDSI index to correct the MCARI2 (Modified Chlorophyll Absorption Ratio Index) in a study of linear spectral decomposition method to estimate ecological indicators of desertification in karst rocks, and the results were validated [9].

The superiority of KRDSI in exposing the extent of bedrock cover monitoring, however, there are limitations in the study because KRDSI is based on hyperspectral images only, which are limited by the spectral resolution [5].

## 2.2. Evaluation Model Based on Multivariate Indicators

### 2.2.1 Evaluation model combining the ratio of vegetation cover and rock exposure

In some studies, the combination of the ratio of vegetation cover and rock exposure was also used to make the assessment on how severe KRD is in a certain area. According to the grading standards of the degree of KRD, the degree of KRD per unit area can be rated based on the values of FVC and FR. Cao et al. used the method of combining FVC and FR to jointly assess the degree of KRD in the selected area in their study on KRD in Dafang County, Guizhou Province [3]. The degree of KRD was divided into six grades: (i) Nothing (FR from 0 to 40; FVC from 70 to 100): areas covered by water, constructions and forest. (ii) Potential (FR from 40 to 60; FVC from 50 to 70): areas covered by shrubs and grass. (iii) Light (FR from 60 to 70, FVC from 35 to 70): areas covered by sparse shrubs and grass, sloping farmland and unused land. (iv) Moderate (FR from 70 to 80, FVC from 20

to 35): areas covered by sparse shrubs and grass, sloping farmland and unused land. (v) Severe (FR from 80 to 90, FVC from 10 to 20): areas covered by sparse grass, stone-sloping farmland and unused land. (vi) Extremely severe (FR from 90 to 100, FVC from 0 to 10): areas covered by sparse grass, stone-sloping farmland and unused land. Yang et al. used a similar approach in their evaluation of the extent of KRD in Zhudong area. The KRD severity level was graded according to the ratio of exposed rock and 0.2 km<sup>2</sup> unit of vegetation and soil cover, and the results were used for supervised learning classification.

The advantage of this method is that it is simple, clear, and fast. And using two indicators to measure the degree of KRD is to some extent more accurate than a single indicator. However, this method requires the setting of threshold values for each class according to the characteristics of different areas. The size range of vegetation cover and rock exposure rate of each class needs to be obtained with the help of previous experience or based on a large amount of data of the selected area, so a lack of corresponding experience and data may hinder the research.

### 2.2.2 Multi-feature evaluation model combined with machine learning

Cao et al. used a multiple linear regression model [3]. Six training areas of heavy KRD, moderate KRD, potential KRD, light KRD, water bodies, vegetation, and built-up sanding were selected to extract waveform information, calculate NDVI and NDRI, and test the relationship between NDVI, NDRI, topography, and the degree of KRD. The four features with the highest correlation coefficients with KRD classification, including NDVI, NDRI, slope and DEM, are selected for multiple linear regression.

This method does not require the researcher to set accurate classification criteria and requires less experience from the researcher. In addition, it takes into account other factors associated with the degree of KRD in addition to the ratio of vegetation cover and rock exposure. At the same time, this approach eliminates the influence of different satellite band ranges, because different models can be trained separately for different satellite data. However, the disadvantages of this method are also obvious. Because of the need to do feature extraction and model training, it is more time-consuming and complicated than other methods. In addition, the obtained formulae are difficult to be used directly in other studies, because the selected features and the weights of each feature may be different for different regions and at different times, so it is necessary to retrain the model in other studies to get the formulae that fit the new study area or new period.

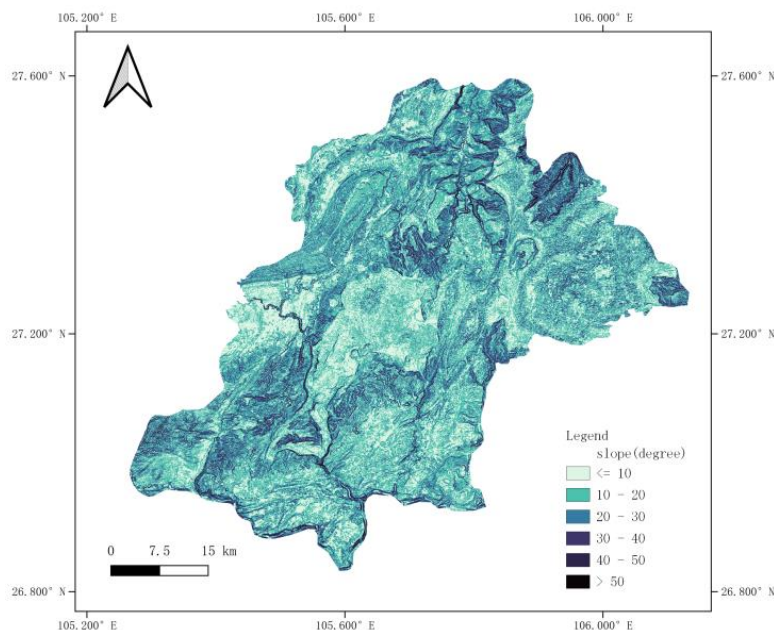
## 3. Application of Remote Sensing to the Analysis on KRD Influence Factors

### 3.1. Analysis of Geological Factors

#### 3.1.1 Slope

The degree of KRD has close correlation with the slope of the ground. Generally, KRD easily occurs on slopes, rarely occurs on flatlands, and generally does not occur in lowlands, but in the slope areas of river valleys, especially the convex slope parts, stone desertification occurs more strongly, and mostly forms intense and very intense rock desertification [10].

Remote Sensing can help researchers to obtain topographic data. And the topographic data can be processed with the help of GIS tools such as QGIS, ArcMap and ENIV to generate the slope map. Fig. 2 shows the slope map of Dafang County, Guizhou Province, made by using QGIS, and the data source is SRTM.



**Figure 2.** Slope map of Dafang County, Guizhou Province, China. (Picture credit: Original)

In a study analyzing the correlation between KRD and topographic slope in karst areas, Zhou Zhongfa used ArcGIS as the analysis platform to analyze the spatial correlation between topographic slope and KRD in Qingzhen, Guizhou Province, and the results showed that KRD was most serious in areas with a slope above  $60^\circ$  in Qingzhen; the potential KRD was most serious in areas with a slope between  $35^\circ$  to  $45^\circ$  are the most serious potential KRD [11].

### 3.1.2 Lithology

Lithology is also one of the factors affecting KRD. According to the spectral characteristics of rocks, Remote Sensing can obtain the lithological information of the study area.

Commonly, researchers acquire lithological information through Multispectral and Hyperspectral Remote Sensing. Multispectral Remote Sensing lithology identification is mainly based on the spatial grayscale characteristics of the image, using transformation methods to enhance the differences in hue, color, and texture of the image, as well as to extract texture information, or using the method of multi-source data fusion to achieve the purpose of lithology identification [12]. Multispectral remote sensing data covers a large spectral interval with low spectral resolution, which cannot fully represent the spectral characteristics of the features and are suitable for large-scale lithology information acquisition. In contrast, the recognition of lithology by hyperspectral Remote Sensing relies on the spectral characteristics of rocks and can identify rock types and extract quantitative information based on measured spectra, spectral library spectra, or image pure image element spectra. Hyperspectral data have high spectral resolution and contain rich texture information, which is beneficial to lithology identification [12].

In the analysis of the relationship between lithology and stratigraphic lithology in the selected area of Qingzhen City, Zhou Zhongfa et al. used the GIS applications to superimpose the lithology map on the outcropping rock distribution map, forming a map to analyze the relationship between local lithology and lithology [13].

Compared with fieldwork, remote sensing can reduce the labor cost of research and can quickly obtain the lithological characteristics of a large area.

### 3.2. Analysis of Land Use Type Factors

The influence of land use type on KRD is significant. Land type information can also be obtained by processing remote sensing images. The remote sensing image of the study area is first acquired, and a suitable combination of wavebands is selected to generate a false color image so that the land types to be distinguished can be highlighted on the image. Li Wenhui et al. used TM remote sensing

data in a study of remote sensing survey techniques for KRD in karst rocky mountain areas. The three bands TM1, TM4, and TM7 with the best dispersion of reflectance for plants, clay, and carbonate bare rocks were selected to produce pseudo-color composite images. The obtained images can better distinguish the three types of features, such as vegetation, clay, and carbonate bare rock [14]. First, a training sample including all the types of features to be distinguished was selected from the area under study, and then the brightness values of each type of feature on the images of different bands were determined from them to determine the characteristic parameters and establish the discriminant function.

However, because this method has a problem that it relies too much on manual sampling if there is no suitable combination of wavebands for the land use types to be classified can make each type have a large difference in color on the false-color image, or the reflectance of different land use classes to light is relatively close, it is difficult for the human eye to effectively distinguish, resulting in a large noise in the sampling, thus affecting the accuracy of the classification. For areas with more complex land types, this method has some limitations.

### 3.3. Analysis of Human Activity Factors

Human activities are the main driving force of rocky desertification. Remote Sensing can also be of great help in obtaining information on human activities. In addition to the above-mentioned classification approach for human settlement analysis, Night-light Remote Sensing can also be used. At cloudless night, remote sensing satellites are able to monitor the visible illumination sources like city lightings and fire points.

Night-light Remote Sensing has the capability to reflect the social activities of human beings. It can be used in many fields such as GDP estimation, population estimation, electricity consumption estimation, carbon emission estimation, and urbanization monitoring. In the study of KRD, Night-light Remote Sensing can be useful for monitoring human activities in the study area. In a study on whether increased human activities would affect KRD in southwest China, Shi et al. used nocturnal remote sensing images to analyze human activities and desertification levels in Chongqing, Sichuan, Yunnan, Guizhou, Guangxi, and Guangdong provinces in China and could reveal a significant increase in nighttime lighting in the study area [15]. The highest increase in total light (TL) values at night was observed in the areas of light KRD in Yunnan, and the fastest increase in TL values in the areas of heavy KRD in Guizhou Province, where human activities are likely to have a great impact on the areas of heavy KRD in Guizhou.

The use of Night-light Remote Sensing to monitor human activities saves human resources and time. At the same time, the statistical system is weak in some areas where the statistical data errors are large or even missing, so the night light can provide a basis for estimating human activity information in these areas.

## 4. Prospect

Compared with acquiring data through fieldwork, using Remote Sensing has advantages like wide monitoring area and high timeliness, and it has provided much help to researchers in monitoring and researching KRD in southwest China.

The future development trend of Remote Sensing in the study of KRD in southwest China can be divided into the following points: (i) Exploring new RGB band combinations or degree calculation models to improve the accuracy of assessment. (ii) Combining multiple types of remote sensing data to obtain a more comprehensive assessment of the KRD situation in the study area. In most studies, only 1-2 types of remote sensing images were used. In the future, multiple types of remote sensing data can be combined, such as NDVI data, topographic data, and night-light remote sensing data. Researchers can use those data together to make an assessment on the KRD status in the study area. (iii) Combining with artificial intelligence technology to improve the accuracy of remote sensing image recognition and predict the future trend of KRD changes. At present, many researchers have

introduced machine learning models in the assessment of the degree of KRD. Cao et al. used the FLUS model to make predictions on the development of the degree of KRD in Dafang County, Guizhou Province in 2015, and the actual data were compared with the predicted data with an overall accuracy of 0.69 and good simulation results [3]. This shows the feasibility of using remote sensing data together with machine learning to predict the change in KRD. (iv) Using Remote Sensing to assess the effectiveness of management measures. KRD in southwest China has received the attention of the government, and the management of many areas has been effective, and some locally successful management models have been explored. For example, the Dingtian model, the Pingshang model, the Qinglong model, the courtyard economy model, the biogas-based rural energy construction model, the migrant development model, etc. [10]. Different management measures should be adopted for different natural and human conditions of the KRD areas. With the help of remote sensing data, researchers can evaluate the applicability of the treatment measures and adjust the measures in time according to the results, which can help in the prevention and control of KRD.

## 5. Conclusion

Remote Sensing makes the study of KRD in southwest China more informative and effective. With the help of Remote Sensing, combined with different models, researchers can better assess the extent of KRD in the study area and observe the changes; at the same time, Remote Sensing can also quickly obtain information on the topography, land type, and human activities in the study area, helping researchers to quantitatively study the correlation between the extent of rock desertification and the influencing factors. Remote Sensing has some potential to be applied in the study of KRD in southwest China. There are many models for assessing the degree of KRD, but each model has its advantages and disadvantages. In the future, we can explore more waveband combinations or calculation models for the degree of KRD, or combine different types of remote sensing data to augment the assessment accuracy. The prediction of KRD changes can also be made by combining artificial intelligence techniques. In addition, Remote Sensing has further usages on the assessment of the effectiveness of management measures.

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