RETRACTED ARTICLE: Assessment on erosion risk based on GIS in typical Karst region of Southwest China

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ABSTRACT

This study evaluates the potential danger of soil erosion with regard to the current poor situation in the typical karst area of Anshun City in Guizhou Province (China) and provides a reference for the prevention and control of soil erosion in karst areas. The criteria of the Standards for classification and gradation of soil erosion and Techniques standard for comprehensive control of soil erosion and water loss in karst area in non-karst and karst areas, respectively, GIS, and high-resolution remote sensing image interpretation results of land use are used to explain the intensity of soil erosion and soil loss tolerance. Results show that soil erosion rate calculated by different standards in the karst area is consistent with the monitoring value. The average erosion modulus of Guizhou Anshun is 446.83 t/(km\textsuperscript{2}·a), the soil erosion area is 2,861.01 km\textsuperscript{2} with a ratio of 30.9\%, the soil erosion potential danger index (SEPDI) value is relatively small and mainly includes free- and light-danger types, and the average SEPDI value is 1.7. The soil erosion control project of Anshun City can range according to the SEPDI level of villages, which can be comprehensively managed from high to low. Soil erosion prevention and control in karst areas should use SEPDI as the core indicator rather than soil erosion intensity grade.

Introduction

Soil erosion is one of the most serious environmental problems that cause soil nutrient loss and land degradation (Arnhold et al., 2014; Park et al., 2011) and threaten regional even global ecological security patterns and human development (Borrelli et al., 2016; Martínez-Casasnovas et al., 2016). In karst areas, soil formation is slow, and soil conservation is difficult. Hence, the soil becomes the key factor in the environment and ecological systems in these areas. Soil erosion is the core problem of rocky desertification. Thus, soil erosion must be controlled in karst areas. Limestone cover about 1.3 × 10\textsuperscript{5} km\textsuperscript{2} of China and are particularly dominant in the south and southwest. The stratigraphical sequence from the Cambrian to Triassic is largely formed of limestone, the end of the Mesozoic was marked by general uplift and widespread deposition of Cretaceous and Tertiary red beds (sandstone and clay) took place over the limestone. Subsequent erosion and removal of the clay and sandstones exposed the underlying limestone, and this erosion has given rise to the most highly developed karst landscapes in the world, there is a greater range of karst landforms than in any area of comparable size in the world. With serious soil erosion and rocky desertification, the environment becomes sensitive and fragile. Karst areas have become one of the most typical fragile ecological areas in China (Xiong et al., 2012).

Since 2000, karst rocky desertification has received extensive attention, and its control has been put on the national level. In 2008, China launched a special project for comprehensive treatment of rocky desertification of eight provinces and autonomous areas in Southwest China. In 2013, the Ministry of Water Resources and Ministry of Finance had launched the comprehensive agricultural soil erosion control project in karst area in the three provinces of Yunnan–Guizhou–Guangxi. The studies on soil erosion in Chinese karst areas have developed rapidly, and the main research achievements are found in the following reports: Theoretical research of soil erosion (H.S. Wang et al., 2015), Soil loss equation (Chen et al., 2017); Evaluation standard of soil erosion in karst area (Cao, Jiang, et al., 2008); Quantitative research of underground erosion proportion (Wei et al., 2010; Zhang & Wang, 2016); Contribution rate of human and natural factors to soil erosion; New technology \textsuperscript{137}Cs tracer, Application of 3S technology on soil erosion survey (H. Li et al., 2009; Yang et al., 2007); Soil erosion characteristics (Xiong et al., 2012); Measures to control the Karst environment (Cao, Yuan, et al., 2008); and Location monitoring and evaluation (Zhou et al., 2000). H. Li et al. (2009) monitored soil erosion in...
karst areas and studied the distribution characteristics of soil $^{137}$Cs in the karst slope of Northwest Guangxi. He argued that the current $^{137}$Cs tracer method is not suitable to measure soil loss in karst slope land. Zhou et al. (2000) applied the soil erosion model, analyzed the spatial and temporal data of various factors by GIS based on RUSLE, and monitored soil erosion in the karst area of Guizhou Province. Chen et al. (2017) analyzed the characteristics of soil and water loss in Guizhou Province based on CSLE. Y. Li et al. (2017) evaluated the spatial heterogeneity of soil loss tolerance and its effects on erosion risk. These studies provide valuable data for the control of water and soil loss in karst areas.

The karst and non-karst strata are interlaced, exposed, and have various forming speeds, soil thickness backgrounds, and years of soil erosion resistance. The acid-insoluble matter in carbonate rock is low, the soil-forming ability is poor, the soil layer is thin, and the soil loss tolerance is lower than that of the non-karst area. So the universal soil loss equation (USLE) and the modified soil loss equation (RUSLE) are not applicable for the karst and non-karst staggered distribution areas. Most previous studies used the same method to classify soil erosion, ignoring the fact that the amount of soil and water loss in karst area and non-karst area are totally different. The soil erosion intensity level can only reflect the intensity of soil erosion, and different rocks have various soil formation rates. The soil-forming rate and soil erosion speed should be considered, and soil erosion control should further consider the danger of soil erosion. However, few studies were conducted on soil erosion risk classification evaluation in karst areas. This work uses different standards for soil erosion investigation. These standards are based on soil thickness and different rock soil formation rates and combined with soil erosion rate to further evaluate soil erosion risk and predict the possibilities of erosion in a non-obvious soil erosion area. Furthermore, assessment and prediction of the possibility of erosion in non-obvious soil erosion areas and the possibility of erosion intensification in soil erosion areas is more meaningful than simple soil erosion ratio investigation, and can better guide the management of karst soil erosion and rocky desertification work.

Study area

The Karst area in southern China, centered on the Guizhou Plateau, is the world’s largest and most contiguous karst ecological fragile area. It is also the most typical, most complex, and most landscape-rich area for karst development (Sweeting, 1993). Anshun City is located in the Midwestern Guizhou Province of China (Figure 1), with east longitude of 105°13′–106°34′ and north latitude of 25°21′–26°38′, including Xixiu, Zhenning, Ziyun, and other six counties, which cover a total area of 9,253.06 km². The strata of Anshun are fully exposed, except for Silurian; all other strata are exposed, and the main strata are Triassic and Permian. The lithology is dominated by carbonate rocks, which account for approximately 77.5% of the land area of the entire city, a typical karst landform concentrated area. Karst distribution, landform types in Anshun City can be highly representative in the karst area of southern China. The average altitude of Anshun is between 1,102 and 1,694 m. Anshun has a typical plateau humid subtropical monsoon climate that experiences abundant rainfall with an annual average of 1,360 mm, average annual temperature of 14.1°C, and average annual relative humidity of 80%. This city is located in the watershed belt between the Wujiang Basin of Yangtze River and the North Panjiang Basin of the Pearl River. The large river brings rich hydropower resources. Coniferous forests, broad-leaved forest, shrub and grass are non-existent in this area, and vegetation area, altitudinal belts, and mosaicism are widely distributed.

Materials and methods

Materials

Data and data sources include (1) 2.1 m resources, ZY-3 high-resolution satellite remote sensing images of China center for resources satellite data and application in 2015, (2) 10 m resolution DEM data, (3) lithologic map of the study area (1:50,000), (4) rocky desertification distribution map of the study area (1:10,000), (5) soil type map, soil thickness database of Guizhou Province (1:50,000), (6) 29 meteorological sites within the 30 km range of Anshun and its surrounding areas; each site contains annual and monthly rainfall data from 1952 to 2013, and (7) 1 km grid World Soil Database soil bulk density data jointly launched by the United Nations Food and Agriculture Organization, International Institute for Applied Systems Analysis, Holland ISRIC-World Soil Information, Nanjing Institute of soil science, Chinese Academy of Sciences, and Joint Research Council of the European Commission in March 2009.

Methods

Anshun City belongs to the Southwest Rocky Mountain Area of water erosion types in China, of which karst area accounts for more than 70%. The use of loss intensity standard is not suitable in non-karst areas. Years of soil erosion and soil conservation work showed evident differences in soil erosion intensity, soil erosion risk, and soil erosion resistance age in karst and non-karst areas. Therefore, when the soil erosion grade is used, the pure carbonate rock area
and carbonate rocks intercalated with noncarbonate rocks are defined as karst area according to the Techniques standard for comprehensive control of soil erosion and water loss in karst area of Standard Water Resources of the People’s Republic of China (SL461-2009). Noncarbonated rock-exposed area is defined as the non-karst area based on the standards for classification and gradation of Standards for classification and gradation of soil erosion of the Standard Water Resources of the People’s Republic of China (SL190-2007). With reference to the above soil erosion grading standards for karst and non-karst areas, soil erosion intensity is judged by an indirect index, extract 5 thematic layers of lithology, bare rock ratio, vegetation coverage, slope and land use, using the spatial analysis function of GIS, according to the thematic layers in the standard, corresponding search for which level of soil erosion should be classified in the standard. Soil loss tolerance is calculated according to 1:50,000 lithologic map, whereas soil erosion resistance age is calculated according to the soil thickness and bulk density. The potential danger of soil erosion has been classified by utilizing the characteristics of soil erosion based on the water conservancy
The bare rock rate of bedrock is calculated by remote sensing inversion. Based on multispectral remote sensing images, the method of calculating bare rock rate takes single pixel as the basic unit of calculation and analysis, and the range of naked rock rate of each pixel is 0–100% in the Karst area. The land cover structure of areas except for construction land and water area can be divided into three, namely, vegetation, soil, and rock. Therefore, the calculation method of bare rock rate based on multispectral remote sensing images is that in the unit area, if the vegetation coverage reaches X%, then soil exposure rate accounts for Y%, and the bare rock rate is \( (1 - X\%) - Y\% \). The mathematical equation can be expressed as follows:

\[
BR_p = (1 - BSp - Fc)100\% \tag{2}
\]

where \( BR_p \) represents a bare rock rate, \( BSp \) indicates the soil exposure rate, \( Fc \) means the vegetation coverage using the two-pixel model to calculate vegetation coverage. Calculating soil exposure rate is mainly by the bare soil index and using NDVI to estimate the vegetation coverage. Under the premise of extracting the bedrock exposure rate, the bare rock rate in Anshun rocky desertification map is revised to improve the accuracy of bedrock exposure rate.

**Determination of soil erosion grade**

All the vegetation coverage, land use type, slope, lithology, and rock exposure rate thematic layers are converted into 10 m of grid data after unified projection in ArcGIS software using GIS overlay analysis function (Figure 2); the five factors are overlaid; and soil erosion intensity, surface erosion classification index in the Standards for classification and gradation of soil erosion in non-karst areas, as well as Techniques standard for comprehensive control of soil erosion and water loss in karst area according to lithological differences to calculate soil erosion, are adopted.

**Estimation of soil erosion resistance age**

The soil erosion resistance age is the ratio of the effective soil thickness and the average annual erosion depth of eroded soil after deducting the critical soil layer (Wang et al., 2016):

\[
YC = 10^4 \times (H - 10) \times D/A \tag{3}
\]

where \( YC \) is the soil erosion resistance age, \( H \) is the soil thickness (cm), \( D \) is the soil bulk density (g/cm³), \( A \) indicates the annual erosion modulus [t/(km²·a)], 10 is the unit conversion factor, and 10 is the critical soil thickness (cm).

The potential danger of soil erosion can be divided into five grades according to the standards formulated by the Ministry of Water Resources, namely, free dangerous, light dangerous, dangerous, extremely dangerous, and destructive.

**Calculation of SEPSDI**

SEPSDI shows the SEPSDI value of an area or land, which is evaluated according to the weight of the SEPSDI of different grades in an area or land, and the calculation method is as follows:

\[
SEPSDI = \left( \frac{M_1 + 2M_2 + 3M_3 + 6M_4 + 9M_5}{M_1 + M_2 + M_3 + M_4 + M_5} \right) \tag{4}
\]

where \( M_1 \) is the free danger area (I), \( M_2 \) means the light danger area (II), \( M_3 \) is the dangerous area (III), \( M_4 \) is the extreme dangerous area (IV), and \( M_5 \) indicates the destructive area (V). The SEPSDI ranges 1–9, and the greater its value, the greater the potential danger of soil erosion in an area or land.

**Soil erosion thematic factor extraction**

Land use can affect soil erosion, and irrational land use is one of the major reasons for soil erosion. ERDAS software is used to extract the remote sensing image of ZY-3, and the vector data of land use types in the study area are obtained. Land use types are divided into paddy fields, dry land, woodlands, shrubs, waterbodies, settlements, grassland, and bare land.

In this study, 1:5 000 topographic map is used as the base map, and the DEM data are vectorized. The slope of the study area with 10 m is calculated. The ground slope is divided into six grades according to the surface erosion grading index in the grading standards.

A model that uses vegetation index to estimate vegetation coverage is built based on the relationship between vegetation index and vegetation coverage. The normalized difference vegetation index (NDVI) can be used according to the two-pixel model. A pixel value of NDVI can contain NDVI veg, which partially determines the green vegetation and non-vegetation coverage. The vegetation coverage can be obtained by integrating the normalized difference vegetation index into the following equation:

\[
F_c = \frac{(NDVI - NDVI_{soil})}{(NDVI_{veg} - NDVI_{soil})} \tag{1}
\]

The lithologic data of the study area directly refer to the 1:5 vector geological map of Anshun and are converted into karst and non-karst areas according to stratum information. The bare rate of bedrock is calculated by remote sensing inversion. Based on multispectral remote sensing images, the method of calculating bare rock rate takes single pixel as the basic unit of calculation and analysis, and the range of naked rock rate of each pixel is 0–100% in the Karst area. The land cover structure of areas except for construction land and water area can be divided into three, namely, vegetation, soil, and rock. Therefore, the calculation method of bare rock rate based on multispectral remote sensing images is that in the unit area, if the vegetation coverage reaches X%, then soil exposure rate accounts for Y%, and the bare rock rate is \( (1 - X\%) - Y\% \). The mathematical equation can be expressed as follows:
Results and discussion

Soil erosion calculation results

Under the support of ArcGIS10.3 software, the above factor layers are converted into raster layers in 10 m × 10 m of the same coordinate (Figure 2). We use Standards for classification and gradation of soil erosion (SL190-2007) criteria in karst area and Techniques standard for comprehensive control of soil erosion and water loss in karst area (SL190-2009) criteria in non-karst area. Figure 3 maps the spatial distribution of soil erosion grade in the study area.

For Anshun, the total erosion amount is $4.13 \times 10^6$ t, average erosion modulus is 446.83 t/km²·a, and soil erosion area is 2,861.01 km² with a rate of 30.9%, in which Anshun’s micro-degree erosion is the largest with an area of 6,392.05 km² accounting for 69.1% of the total area (Table 1). It is followed by the mild erosion which accounts for 16.5%. The maximum amount of erosion is moderate erosion of $1.24 \times 10^5$ t,
followed by strong erosion of $1.08 \times 10^5$ t. Overall, the erosion degree in the study area are mainly slight and mild erosions. Moderate and strong erosions contribute most to the total soil loss according to the analysis of various erosion ratings of the total soil loss. Moderate and strong erosions should strengthen the erosion management efforts to reduce soil erosion. From the spatial distribution analysis, serious areas of soil erosion in Anshun City are mainly distributed in the southern part of the Zhenning and Ziyun, northwestern Puding and western Guanling, whereas Pingba Xixiu and Zhenning in the middle have lower levels of soil erosion (Figure 3).

**Calculation results of potential danger of soil erosion**

The distribution of Anshun City’s erosion resistance age is estimated based on the soil erosion calculation results, combined with soil effective thickness and soil bulk density data in soil type chart property table, and soil erosion resistance age estimation method. The
potential danger of soil erosion is divided into five grades according to classification standards of the Ministry of Water Resources, and the grading map of SEPDI value is generated (Figure 4). In Figure 4, the soil erosion danger of the entire area is relatively small, where the free-dangerous type accounts for 61.6%, light-dangerous type for 22.4%, dangerous area for 12.6%, extremely dangerous for 1.7%, and destructive area for 1.9% (Table 2). Areas with the potential danger of soil erosion above the light-dangerous type should be the focus of key prevention and control areas of Anshun City in the future. The spatial distribution characteristics of the potential danger of soil erosion in Anshun are evident. The danger degree is higher in the south and northwest, whereas lower in the middle east. According to Section 3.2.4, the calculated Anshun City soil erosion danger index is 1.7, which shows that the total danger is not serious.

First, classify the slope of the study area slope map and obtain the slope classification map, and then overlay it with SEPDI overlay figure, analyze the overlay layer, and draw all the soil erosion danger degree distributions of each slope level (Figure 5). From Figure 5, SEPDI increases with the increase of slope. In the range of 0–15°, SEPDI is less than the average level (1.7). When the slope is greater than 35°, SEPDI reaches 2.19 higher than the average SEPDI of the entire study area. SEPDI is closely related to the slope band with a correlation coefficient of 0.96; hence, future soil erosion control should focus on comprehensive governance of slopes greater than 25° to reduce the potential danger of soil erosion.

Figure 6 shows the degree of distribution of potential danger of soil erosion in different land use types by conducting an overlay analysis of Anshun City land use type.
utilization map and SEPDI classification results, from which we can identify the SEPDI values of various land use types in Anshun City: dry land > wasteland > average value (1.7) > wood land > other forest lands, in which the dry land danger index is as high as 2.74, and the potential danger of paddy field, water, forest land, and shrub land are relatively small. The SPEDI value of the paddy field is only 1.1. However, the correlation coefficients of SEPDI and land use are not high, and their correlation coefficient is 0.01. Overall, areas in the water zone, residential land, and forest land have smaller potential danger, which distribute few dangerous and extremely dangerous types. Residential lands are mainly free- and light-danger areas, and their SEDPI values are less than 1.5. Dry and unused lands have the maximum potential danger of soil erosion. The SEDPI value of wasteland is 2.07 and that of the dry land is 2.74. Their comparison revealed that terracing measure is particularly helpful to reduce the potential danger of soil erosion. The woodland (including arbor, shrub, and woodland) also has a small SPEDI value, which indirectly shows that the implementation of the policy of returning farmland to forest in this region has achieved good results.

Analysis of potential danger index of soil erosion in sub-villages

The previous soil erosion controls in China are based on the general administrative unit or small watershed management unit. This study takes administrative villages in Anshun to better indicate the urgent areas to be controlled in Anshun City and analyzes the SEPDI values of the villages (Figure 7). Results show that the SEPDI of 1,830 of 2,244 statistical villages is found between 2 and 3 (Table 3), which account for 77.9% of the total, which have light danger. The governance is not urgent. In addition, SEPDI of 33 villages is
within 3–4, which covers an area of 1,763.94 km² and accounts for 19.1% of the total area of Anshun. From the spatial distribution analysis, the SEPDI of Anshun City administrative villages has a certain link with soil erosion intensity distribution. The villages with high SEPDI are mainly distributed in the west of Anshun, south of Zhenning and Ziyun, and northwest of Puding. In the SEPDI chart of villages in Anshun, the urgent areas of Anshun City are proposed to be governed according to the SEPDI of each village and controlled from high to low.

Discussion

Using different standards to calculate the soil erosion of the karst areas and non-karst areas in Anshun is more in line with the actual situation of soil erosion area. Calculating the soil erosion danger degree revealed that the potential danger of soil erosion degree is not high, by estimating SEPDI of 1,830 villages of Anshun City and pointing out the governance direction of soil erosion in karst area.

The amount soil and water loss in karst area and non-karst area are totally different, and the karst and non-karst strata are interlaced, exposed, and have various forming speeds, soil thickness backgrounds, and years of soil erosion resistance, so the universal soil loss equation (USLE) and the modified soil loss equation (RUSLE) are not applicable for the karst and non-karst staggered distribution areas. Zhao et al. (2011) applied the estimation of RUSLE model in Guizhou Guiyang Maixi River basin soil erosion modulus estimation, and the results showed that the annual average soil erosion rate of Maixi River Basin is 1,230.81 t/(km²·a). Sun et al. (2016), under the support of GIS technology, used daily rainfall, soil type, land use, DEM, MODIS-NDVI, and
other data, combined with RUSLE model, obtained the average annual soil erosion modulus of Guizhou Province in 2010, which was 880.81 t/(km²·a), and field monitoring results. Chen (1997) measured the average annual erosion modulus of Western Xichou Fengcong area in Yunnan Wenshan, which was 387.7 t/(km²·a). Long et al. (2006) measured the lost bedload of nine check dams in Guanling County of Anshun City. The soil erosion moduli were 174.5 and 396.8 t/(km²·a) by 1999 and 2001, respectively, comparison with ground monitoring results, showing that the soil erosion evaluation system based on different bedrock types is more accurate.

The data used in this study include high-resolution remote sensing images and large-scale lithologic map and DEM data, with relatively high accuracy. GIS’s rich spatial analysis function was used to quickly and efficiently process, calculate, and analyze the data. The evaluation process is simple, and the evaluation results are scientific, which is more in line with the actual soil erosion in a karst area. However, restricted by data, soil thickness and soil bulk density scale are small, and data accuracy is not high, which will indirectly affect the accuracy of results.

By the classification study of soil erosion, the potential danger is complex, and the erosion factor weighted method is more complicated than soil erosion resistance age, which has more related factors. This study uses soil erosion resistance age method to classify and evaluate the potential danger of soil erosion. The factor is still not comprehensive, and karst region key factors should be further studied and cleared. The factors of danger evaluation method used are mainly natural factors, agricultural population density, and

| Table 3. SEPDI in each village of Anshun. |
| SEPDI | Village quantity | Area (km²) | Area ratio(%) |
|-------|----------------|-----------|---------------|
| 1–2   | 32             | 22.92     | 0.2           |
| 2–3   | 1830           | 7212.61   | 77.9          |
| 3–4   | 338            | 1763.94   | 19.1          |
| 4–5   | 41             | 294.03    | 2.6           |
| >5    | 3              | 9.56      | 0.1           |

Figure 7. SEPDI in each village of Anshun.
Conclusions

This study focuses on the potential danger of soil erosion in terms of the current poor evaluation situation of karst area soil erosion potential danger, takes Anshun City in Guizhou Province as the study area using GIS, analyzes the SEDPI of various villages in Anshun, and draws the following conclusions:

For the study area, the average annual erosion modulus is 446.83 t/km²a, which belongs to the moderate erosion. The soil erosion area is 2,861.01 km² with a rate of 30.9%. Moderate and strong erosions contribute most to the total soil loss, which accounts for 56.4% of the total. The amount of soil erosion in karst area is not large, but the soil formation rate is slow, and the soil and water conservation work is still very important.

Generally, the potential risk of soil erosion in Anshun City is small, namely, free-and light-danger areas, which cover an area of 7,769.65 km² and account for 84.0% of the total area of Anshun City. The SEPD value is 1.7. From the spatial analysis, the SEPD value has a certain relationship with slope and vegetation coverage.

By taking the administrative village of Anshun City as the statistical unit and analyzing the SEPD of various villages, the SEPD of 1,830 of 2,244 statistical villages is within 2~3, which account for 77.9% of the total with light danger. SEPD can better indicate the urgent areas to be governed. Governing soil erosion according to the SEPD of each village and controlling from high to low are necessary. The prevention and control of soil erosion in karst area should take SEPD as the core index rather than the soil erosion intensity level, which can better guide soil erosion control in karst area.

Disclosure statement

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