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Evaluation of Karst Soil Erosion and Nutrient Loss Based on RUSLE Model in Guizhou Province

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Abstract. Based on GIS technology and RUSLE model, the spatial variation characteristics of soil erosion were analyzed in karst areas, and the relationship between soil erosion and soil nutrient loss was discussed. The results showed that the soil differences in spatial variation between nutrient losses. The results illustrate the total soil erosion in is 10316.31 × 10⁴ t·a⁻¹, accounting for 84.95% of the total land area in Guizhou Province. The spatial distribution of soil erosion showing the characteristics of the southeast to the northwest strip. The annual average soil erosion modulus is 691.94 t·km⁻²·a⁻¹, of which karst is 720.28 t·km⁻²·a⁻¹ and non-karst is 689.53 t·km⁻²·a⁻¹. The total nutrient losses such as soil organic carbon (SOC), total nitrogen (TN), total phosphorus (TP) and total potassium (TK) were 596.72 × 10⁴ t·a⁻¹ due to soil erosion, and SOC, TN and TP and TK were 38.13, 1.61, 0.41 and 14.70 t·km⁻²·a⁻¹, respectively. The average amount of loss and total loss are the largest in non-karst, and four kinds of nutrient is the smallest in karst gorge. The spatial variation of soil erosion in the study area is the process of increasing the erosion area with the increase of the erosion rate, and the difference of the spatial distribution of soil erosion determines the spatial distribution of soil nutrient loss.

1. Introduction

Soil erosion is a worldwide environmental issue, which on the one hand directly leads to the loss of nutrient-rich surface soil, lest the land degradation, production level decreased [1] [2]. On the other hand, due to runoff and its carrying sediment is the carrier of soil nutrient loss, runoff, sediment loss and sedimentation, soil nutrients also migrate, resulting in siltation of rivers and reservoirs, receiving water eutrophication [3] [4], the global soil ecological security pattern poses a huge threat.

Many factors affect the evolution of soil erosion and nutrient loss in karst areas because of the complicated natural conditions. Therefore, it explores the spatial characteristics of soil erosion and the
law of nutrient loss in karst area, which is of great significance to the study of ecology and soil erosion in karst area. Many scholars have done a lot of research on soil erosion and nutrient loss, there are a lot of achievements in the aspects of the trigger of loss, the process of loss, the way and way of loss and the impact on the environment, including the different slope [5], different underlying surface [6], different land use [7], different water conservation measures [8] and different Vegetation types [9] and other aspects have been discussed. However, the current research area on soil erosion and nutrient loss is mainly concentrated in non-karst areas or watersheds, while the karst area is extremely fragile in the ecological and environmental environment. Therefore, the analysis of soil erosion and its nutrient loss in the karst area are overwhelmingly lacking, and the lack of such research leads to the misjudgment of the environmental in the area. Soil erosion and its occurrence of rocky desertification have affected the survival and development of 220 million people. How to take effective methods and means to study the spatial distribution of karst soil erosion and its nutrient loss law and contribution rate, which is still an urgent issue to be solved.

In view of this, this paper is based on RUSLE model and GIS technology, which mainly solves the following problems in the typical karst area research area in southern China: (1) to determine the area of soil erosion in Guizhou Province; (2) The spatial distribution data of various soil nutrients were calculated in ArcGIS software, and the contribution rate of each nutrient factor with soil erosion was obtained through statistical data; (3) and classify them according to the different landform types of karst, reveal the spatial distribution characteristics and regularity of soil erosion and nutrient loss in Guizhou Province.

2. Materials and Methods

2.1. Study Area

Guizhou landform belongs to the western China plateau mountain, in the Chinese terrain on the second ladder. The territory of the West high east low, the average elevation of about 1100 m. The geomorphology of the province can be divided into six types (karst gorges, karst troughs, karst plateau, peak-cluster depression, rift basins and non-karst topography). The annual rainfall of 1100 ~ 1300mm, the total rainfall distribution from south to north, from east to west decreasing trend.

Figure 1. Location of the study area.
2.2. Data Sources
The related data collected based on the RUSLE model mainly include the following: (1) daily rainfall data in the study area for 2015 from the China Meteorological Network (http://www.cma.gov.cn/). (2) The soil type is derived from the Resources and Environment Science Center of the Chinese Academy of Sciences (http://www.resdc.cn), particle size, and the content of organic substances in various soil types that are mainly based on Chinese soil records. (3) A digital elevation model (DEM) and NDVI data was obtained from the Chinese geospatial data cloud platform (http://www.gscloud.cn), with a spatial resolution of 30 m. (4) Land use from the Chinese Academy of Sciences Resources and Environment Science Data Center (http://www.resdc.cn), the spatial resolution of 100m; (5) Data on soil physical and chemical properties obtained from field investigation.

2.3. RUSLE Model Calculation
In this study, RUSLE [10] and GIS techniques were used to study the spatial distribution characteristics of soil erosion in Guizhou Province:

\[ A = R \cdot K \cdot L \cdot S \cdot C \cdot P \]

where A refers to the amount of soil loss \((t \cdot km^{-2} \cdot a^{-1})\). R is the rainfall erosivity factor \((MJ \cdot mm \cdot h^{-1} \cdot a^{-1})\), and the CREAMS model [11] is used to calculate the R in the karst area erosive rainfall standard with daily precipitation \(\geq 30mm\). K refers to the soil erodibility factor \((t \cdot hm^{-2} \cdot h)/(hm^{-2} \cdot MJ \cdot mm))\), we use Williams [12] in the EPIC model estimation method. L and S refer to the slope aspect factor, according to the results of Liu Baoyuan [13], the slope length of Guizhou Province is calculated. C refers to the coverage factor for vegetation, according to Cai Chongfa [14] and others method, and refer to Tan Bingxiang [15] and other algorithms to calculate vegetation coverage. P refers to the conservation measure factor. The above factor layers are converted into raster layers in 100×100m equal coordinates with ArcGIS software. All of the layers are multiplied to obtain the spatial distribution of the soil erosion modulus in the study area. Reference SL190-2007 criteria are used for the classification and grading of soil erosion intensity relative to water erosion grading standards for Guizhou (Fig. 2).

2.4. Estimation of Soil Nutrient Loss
In this study, soil organic carbon (SOC), total nitrogen (TN), total phosphorus (TP) and total potassium (TK) data were collected, and linked to soil type map with ArcGIS support to generate nutrient spatial maps and turn to raster maps. Considering the scope of the study area, the computational complexity, the lattice space resolution is 100m. In the ArcGIS, the spatial distribution of soil nutrient loss was obtained by multiplying the soil nutrient and the soil erosion modulus, and then multiplied by the total amount of soil nutrient loss in the grid area.

3. Results Analysis

3.1. Spatial Distribution of Soil Erosion
The results show that the total soil erosion is \(10316.31 \times 10^4 \ t \cdot a^{-1}\) in 2015, and the area affected by erosion accounts for 84.95% of the province's land area. The spatial distribution of soil erosion is characterized by northeast and northwest fringe distribution.

The area of micro-erosion accounts for 14.68% of the total erosion area in the three study periods; The proportion of the area with mild erosion is showing a decreasing trend. Among them, the mild erosion area accounts for about 22.04% of the total erosion area, the largest area in all erosion. Moderate erosion area accounted for 18.25%, second only to the mild erosion area, mild erosion and moderate erosion area of the total reached 40.29%. The intensity erosion area is 16.00%, the ultimate erosion area is 17.67%, the eroded area is 11.36%. It can be seen that the overall increase in the degree of erosion from the erosion area is gradually decreasing in Guizhou Province.
From the amount of soil erosion, all erosion amount in the study area increased with the increase of erosion grade. The contribution of erosion is mainly strong and severe erosion in Guizhou Province, and the proportion of erosion amount is 70.59% of the total erosion amount, while the proportion of micro-erosion erosion amount is minimal, only 0.31%. The area of severe erosion accounted for 11.36% of the total erosion area, while the erosion amount reached 42.89%.

**Table 1.** Soil erosion statistics in Guizhou Province.

| Erosion rating | Erosion area (km²) | Area ratio (%) | Average modulus (t/km²·a) | Total soil loss (×10⁴ t/a) | Erosion ratio (%) |
|----------------|--------------------|----------------|--------------------------|----------------------------|------------------|
| Micro-degree   | 21887.89           | 14.68          | 14.83                    | 32.47                      | 0.31             |
| Mild           | 32854.77           | 22.04          | 141.73                   | 465.66                     | 4.51             |
| Moderate       | 27203.67           | 18.25          | 371.42                   | 1010.4                     | 9.79             |
| Strength       | 23857.01           | 16.00          | 639.37                   | 1525.35                    | 14.79            |
| Extreme        | 26345.80           | 17.67          | 1084.85                  | 2858.11                    | 27.70            |
| Violent        | 16942.81           | 11.36          | 2611.32                  | 4424.32                    | 42.89            |

In summary, the contribution of erosion amount is mainly focused on mild erosion, extreme erosion and severe erosion in Guizhou Province. A wide range of land has undergone mild erosion and moderate erosion in 2015, with erosion area have reached more than 40.29%, while the corresponding soil erosion accounted for only 4.51% of the total erosion, 9.79%. The area of strength and violent erosion is only 29.03% of the total erosion area, but the erosion amount is concentrated on the extreme erosion and violent erosion, which accounts for 70.59% of the total amount.

### 3.2. Spatial Distribution of Soil Erosion

Figure 2 showed the spatial distribution of soil nutrient loss caused by soil erosion in Guizhou Province in 2015. Table 2 showed the statistics of soil nutrient loss in different landforms of Guizhou Province. The spatial distribution pattern of soil nutrient loss and soil erosion intensity in Guizhou Province is opposite to that in the southwest and northeast stripes. The high value area appears on the southwest and northeast sides, and the low value area emerge in the middle.
Figure 3. Spatial distribution of soil nutrient loss in Guizhou Province.

The average loss per unit area of SOC in the study area is 38.13 t/km$^2$·a, and the wastage area accounts for 69.79% of the total area of Guizhou. The average loss of TN is 1.61 t/km$^2$·a, and the wastage area accounts for 73.21% of the total area, the main distribution area is similar to SOC distribution. The average loss of TP is 0.41 t/km$^2$·a, and the wastage area accounts for 38.94% of the total area of the province. The average loss of TK is 14.70 t/km$^2$·a, and the wastage area accounts for 41.15% of the total area of the province, the spatial distribution pattern is similar to the pattern of SOC loss.

In 2015 the study area due to soil erosion led to a large loss of soil nutrients, SOC loss of 467.07 ×10$^4$ t, TN loss of 20.70 ×10$^4$ t, TP loss of 2.83 ×10$^4$ t, TK loss of 106.12 ×10$^4$ t, the total nutrient loss total 596.72 ×10$^4$ t, SOC loss of the most serious.

Table 2. Soil nutrient loss statistics.

| Nutrient elements | Loss area(km$^2$) | Average modulus(t/km$^2$·a) | Total loss(×10$^4$t/a) |
|-------------------|------------------|-----------------------------|------------------------|
| SOC               | 122479.16        | 38.13                       | 467.07                 |
| TN                | 128478.48        | 1.61                        | 20.70                  |
| TP                | 68334.57         | 0.41                        | 2.83                   |
| TK                | 72211.79         | 14.70                       | 106.12                 |
3.3. Soil nutrient loss in different landforms

The spatial distribution of soil erosion is characterized by northeast and northwest fringe distribution. The difference of soil nutrient loss in different landforms is different, and the average loss of soil nutrients in karst area is less than that in non-karst area. In terms of karst landforms, the average nutrient loss per unit area of karst gorges is the smallest, and the average amount of soil nutrient loss in peak cluster depression is the largest. The total amount of soil nutrient loss in the non-karst area is the largest, and the total amount of the four nutrient wastes accounts for more than 16.60% of the total nutrient loss in the province; the total nutrient loss of TN is less than 0.50% of the total nutrient loss, which is mainly due to the proportion of elemental content in the soil. The study area of SOC and TN on the whole southeast-northwest line low, southwest-northeast line high, TP and TK show both sides high, middle low spatial distribution pattern on of the southwest to northeast stripes, high value appear on both sides of the southwest and northeast, and the low valleys appear in the middle.

Table 3. Statistics of soil nutrient loss in different landforms

| Landform                  | Average modulus (t/km²·a) | Total soil loss (×10^4 t/a) |
|---------------------------|---------------------------|----------------------------|
|                           | SOC | TN | TP | TK | SOC | TN | TP | TK |
| Karst Canyon              | 38.12 | 1.61 | 0.41 | 13.89 | 466.83 | 20.66 | 2.81 | 99.92 |
| Rift basin                | 38.04 | 1.60 | 0.41 | 10.95 | 465.90 | 20.57 | 2.77 | 76.80 |
| Karst valley              | 38.09 | 1.61 | 0.41 | 13.27 | 464.67 | 20.65 | 2.81 | 95.17 |
| Karst plateau             | 38.11 | 1.61 | 0.41 | 12.60 | 466.76 | 20.66 | 2.80 | 89.87 |
| Peak cluster depression   | 38.13 | 1.18 | 0.16 | 6.00  | 467.01 | 20.69 | 2.82 | 105.21|
| Non-karst                 | 38.05 | 1.60 | 0.41 | 13.29 | 466.03 | 20.60 | 2.79 | 95.32 |

4. Discussion

4.1. Spatial Characteristics of Soil Erosion

The soil erosion present that the area and erosion amount showed the characteristics of intensity, extreme intensity and severe erosion to the moderate erosion grade, which was due to the difference of rainfall space in the study area and the difference of landform leads to the spatial variation of soil erosion in Guizhou Province.

On the one hand, the rainfall in the study area is decreasing from the southeast to the northwest, and the highest rainfall in the southwest is 5797.28 MJ·mm·h⁻¹·a⁻¹, the lowest value of 437.59 MJ·mm·h⁻¹·a⁻¹, resulting in the rain on the soil erosion in the corresponding reduction in space. On the other hand, due to the terrain and altitude, the elevation of Qiannan area is high, which leads to runoff and its carrying of sediment with surface runoff loss and sedimentation, soil nutrients also migrate, so that the soil erosion pattern in the study area is showing a tendency to weaken from high altitude to low altitude and soil nutrient change. The effect of topographic factors on soil nutrient loss is significant in a wide range.

4.2. Spatial Variability of Soil Nutrient Loss

Compared with non-karst areas, the average loss of soil nutrients in karst area (12.83 t/km²·a) is lower than that in non-karst area (13.34 t/km²·a). This is directly related to the thickness of the soil in the karst area, soil erosion and surface runoff are the main ways to cause N, P loss in soil [16]. The content of insoluble matter in carbonate rock in the karst area is 1–9% and is generally less than 5%. The soil-forming efficiency is low. After erosion and weathering, 630–7880 ka of carbonate is required to form a 1m thick soil layer. The soil-forming rate is 10–40 times slower than in the general non-karst area [17]. Moreover, the soil-forming rate and soil thickness are higher in noncarbonate areas than in carbonate areas. The formation time of runoff is short after rainfall, and the surface water storage capacity is low in the karst area. Rainfall forms underground runoff; hence, underground soil loss is high, and the vegetation coverage is lower than in the non-karst area.
Compared with the different karst landforms, the average loss of karst landforms has the following relationship: Peak cluster depression (11.37 t/km$^2$·a) < rift basin (12.75 t/km$^2$·a) < karst plateau (13.18 t/km$^2$·a) < karst trough (13.35 t/km$^2$·a) < karst gorge (13.51 t/km$^2$·a). The effects of different landforms on soil nutrient loss were different, and the effects of surface vegetation, slope, slope length, soil water content and soil particle on soil nutrient loss were significant. There is a phenomenon of sediment accumulation in peak-cluster depression and rift basins. Some of the areas of peak-cluster depression are located in Qiannan area, and the vegetation coverage is good. Therefore, the soil erosion is mild, and the soil nutrient loss is also lighter. The faulted basins are located in the areas with high altitude in western Guizhou, and the soil is not very large. The karst gorge valley developed in Guizhou, the lower terrain and abundant precipitation have brought a lot of kinetic energy to the soil loss, and the nutrient loss of the soil nuts has led to the loss of soil nutrient in the karst gorge than that of other karst landforms. According to the study of Dan et al. [18], It is shown that there is soil leakage in the karst trough area, and the loss is from the soil interface. Therefore, it can be seen that the soil and water loss in the karst area is mainly from the surface.

4.3. Effects of Human Activities on Soil Nutrient flow
The disturbance of artificial activities to the underlying surface condition is also an important factor leading to the loss of soil nutrient. The more artificial disturbance is, the greater the nutrient loss is. Zhang Yan, et al. [19] in the southern region of different land use types of soil erosion research process found that the loss of soil nutrient in the fields of paddy field, dry land and tea garden is the highest, and the soil nutrient loss is the highest in the paddy field, and the soil nutrient loss is less than that of the bamboo forest, the mixed forest and the chestnut forest. Guizhou Province is a large agricultural province, a large number of soil nutrients will be caused by agricultural production of greater economic losses. As a result of unreasonable use of land, leading to soil erosion, soil thinning, so that the local ecological environment becomes very fragile, seriously restricting the local production, life and economic development. Soil erosion and the resulting loss of soil nutrients, not only the development of agricultural production caused greater economic losses, and will cause a series of ecological and environmental problems, we must strengthen the soil erosion prevention and control work.

5. Conclusion
(1) The spatial variation of soil erosion in the study area is the process of increasing the erosion amount and decreasing the erosion area. Showed mild erosion over an area gradually reduced, the amount of erosion increases with increasing grade.
(2) The total amount of soil nutrient loss and loss in non-karst area is larger than that in karst area. In the karst area, the carbonate rocks are widely distributed, the soil formation rate is low, the soil is shallow, and the carbonate soil and the soil thickness are generally higher than the carbonate distribution area, and the rainfall is abundant in the study area, a large amount of soil loss, resulting in nutrient loss with soil erosion higher than the karst area.
(3) Karst area peak cluster depression, rift basin and other landforms exist soil migration and deposition phenomenon. Different karst landforms have different effects on soil nutrient loss. Some of the areas of peak-cluster depression are located in Qiannan area, and the vegetation cover is good, so the soil nutrient loss is also lighter.

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