Sensitivity Analysis of Vegetation Coverage to Soil Loss Rate in Red Soil Region of South China

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Abstract: Vegetation is an important basic component of terrestrial ecosystem and one of the most sensitive factors affecting soil erosion. How to analyse the quantitative relationship between fractional vegetation cover (FVC) and soil erosion and determine the sensitive coverage of erosion is of great significance for guiding government departments to implement soil and water conservation policies. In this paper, through the variable-controlling method, the forest land, grassland and bare land in Changting County, a typical red soil region in southern China, were used as experimental areas to study the sensitivity of FVC change to soil erosion. The soil erosion amount was calculated by RUSLE model, and soil loss rate (rₙ) were used to characterize soil erosion. The results show that when FVC changes from 0 to 0.8, the fitting curves rₙ are in accordance with the logistic model distributions, with a high coefficient of determination R², and the sensitivity of rₙ is less sensitive in the range of 0~0.05, it is most sensitive when FVC reaches a certain level, and there is basically no sensitivity when it reaches 0.7 or above; the fitting curves of rₙ at different slope levels are similar to their overall distribution, which are consistent with the logistic models, and R² is above 0.99, the curves of rₙ at each slope level are different in the same FVC interval, for areas with poor vegetation coverage (0~0.2) and high slope (>25°), the curve is less sensitive to terrain; rₙ generally has higher sensitivity in the range of 0.2~0.6 coverage; in areas above 0.6, the sensitivity decreases to zero.

Keywords: Southern red soil; Changting County; soil erosion; FVC; sensitivity

1. Introduction

In the quantitative study of soil erosion based on the Universal Soil Loss Equation (USLE) and its revised version (RUSLE), the cover and management factor (C-factor) is the most sensitive factor to erosion among all factors [1][2]. As a comprehensive quantitative index to intuitively describe the growth of terrestrial vegetation, FVC directly affects the value of C-factor, and usually shows an exponential or linear negative correlation with soil loss rate [3]. China is a country with frequent soil erosion, and the key erosion areas are mainly the loess plateau and the red soil areas in the south, among which the vegetation in the red soil areas in the south is mainly evergreen woody plants. FVC is less affected by seasonal changes, but still has strong forest rain splash erosion. In addition to the influence of complex topography, soil and other factors, soil erosion in this region mostly changes due to the change of FVC [4]. Therefore, the quantitative relationship between FVC and soil erosion is analysed by remote sensing technology to determine the sensitive coverage of soil erosion in the red soil region of southern China, which is of great significance for guiding local government departments to implement targeted soil and water conservation policies.

2. Materials and methods

2.1 Study area

Changting County is affiliated to Fujian Province on the southeast coast of China, located in the
The southwestern part of the province (25°18'04" -26°02'05" N and 116°00'45" -116°39'20" E). The research area is located in the area where subtropical monsoon climate prevails, with two distinct dry and wet seasons (rainy season: 3 ~ 9 months; Dry season: 10 ~ 2 months), annual average temperature is about 18.3°C, annual average rainfall is about 1737mm. The soil in this area is dominated by loose granite red soil, which is highly erosive [5]. On the basis of considering the erosion characteristics of water body, impervious surface and arable land, this paper uses Changting County forest land, grassland and bare land as the experimental area to carry out research.

Figure 1. (a) Geographical location and elevation distribution of Changting County; (b) Distribution of research area and non-study area under the results of land use/land cover classification in Changting County; (c) Area ratio of each slope level in the study area.

2.2 Data collection

In order to explore the quantitative relationship between FVC and soil erosion, data on soil erosion impact factors such as rainfall, topography, land use and soil type were collected, including the following categories: ① the 2017 rainfall data was collected from the Changting Weather Station, with the hourly data of 16 monitoring stations were accumulated and used to calculate the annual average rainfall by Kriging interpolation, it is similar to the annual average rainfall for many years and is representative; ② land use/land cover data is extracted from thematic information of remote sensing data (GF-1/WFV: 16m in 2017) to calculate conservation support practice factor; ③ the terrain data is the DEM of 30m spatial resolution downloaded by ASTER, used to calculate the slope length and steepness factor. In order to ensure the accuracy of the results, all data must be kept at the same resolution (16m) and projected to the same coordinate system (WGS_1984) in the final calculation.

2.3 Methods

The Revised Universal Soil Loss Equation (RUSLE) is used to estimate the soil erosion modulus of Changting County. The specific formula is as follows:

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

where \( A \) is the mean annual soil loss (\( \frac{t}{hm^2 \cdot a} \)), \( R \) is the rainfall-runoff erosivity factor (\( \frac{MJ \cdot mm}{hm^2 \cdot h \cdot a} \)), \( K \) is the soil erodibility factor (\( \frac{t \cdot h}{MJ \cdot mm} \)), \( LS \) is the topographic factor integrating slope length and steepness (dimensionless), \( C \) is the cover-management factor (dimensionless), \( P \) is the conservation support practice factor (dimensionless).

In order to study the changes of soil erosion sensitivity of different FVC, this paper uses the variable-controlling method to change the FVC value and analyze the change of soil erosion caused by Fvc change while keeping other factors unchanged. The specific variation is to change Fvc from 0 to 0.80 with an interval of 0.05. The soil loss rate (\( r_{sl} \)) are used in this paper. \( r_{sl} \) refers to the ratio of the...
area higher than the allowable loss of soil to the total area of the study area, reflecting the condition of the erosion area. The soil tolerable loss in the southern red soil area is 500t (km²·a) [6][7].

3. Results and analysis

3.1 Analysis of sensitivity of different FVC to soil erosion

On the basis of controlling the invariance of other factors except vegetation factors in the experimental area of Changting County, the FVC was subjected to isometric increasing changes (i.e., 0, 0.05, 0.10...). The \( r_{sl} \) corresponding to the FVC gradient value in the experimental area were calculated. Their changes and fitting equations were shown in figure 2. It can be seen that the characterization parameters of soil and water loss results decrease with the increase of FVC, and eventually tend to be flat.

The fitting curve of \( r_{sl} \) with FVC change results as Logistic model distribution, and its determination coefficient \( R^2 \) also reached 0.996. The fit curve of \( r_{sl} \) approaches the anti-"S" type distribution. Therefore, with the increase of FVC, the sensitivity of vegetation to the soil erosion characterized by \( r_{sl} \) firstly increases from small to large, and then when the vegetation coverage increases to a certain extent, the vegetation coverage is the strongest sensitivity to \( r_{sl} \). After that, it gradually weakens from the strongest range and eventually approaches zero. The specific performance is that when the FVC is between 0.2 and 0.6, the impact on \( r_{sl} \) is greater and the sensitivity is higher. When the FVC is less than 0.2 or greater than 0.6, the influence on the \( r_{sl} \) is weakened and the sensitivity is low; especially in the interval of 0~0.05, because in the calculation of \( r_{sl} \), after the slight loss of large area is excluded, the change of vegetation cover from 0 cannot cause the sharp change of \( r_{sl} \), showing lower sensitivity.

3.2 Analysis of the sensitivity of FVC to soil erosion under different slope levels

According to the results of the change of \( r_{sl} \) with FVC under different slope levels, curve fitting is used to obtain the relationship curve and equation, as shown in Tables 1, and all the fitting equations are very high determination coefficient \( R^2 \), both greater than 0.99.

| Slope level | Fitting equation | \( R^2 \) |
|-------------|------------------|----------|
|<5°|\( r=0.716 / (1+0.04 e^{-0.05}) \)|0.996|

Figure 2. Simulated soil erosion evaluation parameters with vegetation cover curve

Figure 3. Curves of characterization parameters of soil erosion with FVC under different slope levels
It can be seen from Figure 3 that the typical exponential distribution of $r_{sl}$ with FVC changes at different slope levels, and the slope of the curve exhibits an urgent and then gentle change. The change of $r_{sl}$ with FVC is similar to the whole at different slope levels. The fitting equations of the changes are also consistent with the Logistic model, but the fitting curves of each slope level are different in the same FVC interval. For areas with poor vegetation coverage of 0~0.2, the sensitivity decreases with increasing slope, and when the slope is less than 15°, it shows high sensitivity, while the slope is more sensitive when the slope is greater than 15°, especially in the area above 35°, it is basically insensitive, because in the area with high slope, it is affected by the terrain, and the sparse vegetation cannot achieve good control effect, only when the vegetation reaches a certain degree of coverage can it inhibit erosion better. In the variation range covered by 0.2~0.6, with the increase of FVC, the slope curves generally have higher sensitivity, and the sensitivity will increase relatively as the slope becomes steeper. In the area above 0.6, for the area with slope less than 15°, higher vegetation coverage has achieved better control effect, basically no loss, showing insensitivity, while the vegetation coverage required for the slope above 15° is higher, so it still shows certain sensitivity, and tends to zero when FVC increases to above 0.7.

4. Conclusions

Based on the 2017 soil erosion data of Changting County in the southern red soil region, this paper studies the sensitivity changes of FVC changes to $r_{sl}$. The fitting curves of $r_{sl}$ at the whole or different slope levels are consistent with the Logistic distribution and have a high coefficient of determination $R^2$. Under the overall situation, as the regional FVC changes from 0 to 0.8, which is more sensitive to slope, with the increase of FVC, the sensitivity of vegetation change to soil erosion is increasing, and when the vegetation reaches a certain range, the sensitivity is the strongest; the curves of $r_{sl}$ at each slope level are different in the same FVC interval, for the region with FVC<0.2, the sensitivity decreases with the increase of slope, when FVC changes between 0.2 and 0.6, the sensitivity is positively correlated with the slope; as FVC continues to increase, $r_{sl}$ tends to be insensitive.

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