Scenario Analysis of Soil and Water Conservation in Xiejia Watershed Based on Improved CSLE Model

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Abstract. According to the existing research results and related data, use the scenario analysis method, to evaluate the effects of different soil and water conservation measures on soil erosion in a small watershed. Based on the analysis of soil erosion scenarios and model simulation budgets in the study area, it is found that all scenarios simulated soil erosion rates are lower than the present situation of soil erosion in 2013. Soil and water conservation measures are more effective in reducing soil erosion than soil and water conservation biological measures and soil and water conservation tillage measures.

1. Introduction
Soil erosion has both natural and man-made causes, and the increase of soil erosion can cause the ecological environment to deteriorate, which is the common concerned of the ecological and environmental problems. Soil erosion is mainly affected by such factors as topographic factors, soil types, precipitation characteristics, and land cover. Topography, soil type and precipitation characteristics will not change very much in the short run for the impact of human activities, while surface coverings change easily [1]. Through the implementation of comprehensive control of soil erosion, and artificially change land cover it can reduce soil erosion and control its development, so as to achieve the goal of ensuring the safety of the ecological environment. This paper takes Xiejia watershed as the study area, on the basis of existing studies, and analyses the soil erosion in different scenarios. Then compare with the soil erosion status in the basin, evaluate and analyse the change of soil erosion intensity under different scenarios, to provide scientific basis for effective control of soil erosion and assessment of watershed ecological security.

2. Overview of Research Area, Research Data and Research Methods
2.1. Overview of Research Area
Xiejia watershed is located in the northwest of Fangtian township, longitude 116 °33 ’E and latitude 26 °12’N (Figure 1). Watershed lie in the east of Wuyi Mountain, which relative height is generally
between 100m. Xiejia watershed belong to subtropical monsoon climate zone, which has abundant rainfall, mild climate and obvious monsoon. The forest resources in the study area are unevenly distributed that most of the tree species are coniferous forests with single stand structure, and the proportion of sparse forest is large and site conditions are poor. In addition, human activities reduced the area of native forest vegetation, resulting in bare land surface and weakened forest capacity for regulating surface water storage and runoff that aggravated soil erosion.

![Figure 1. Geographic locations of the study area and meteorological stations.](image)

2.2. Research Data

Data Source:

(1) DEM data with a resolution of 30m of Xiejia watershed is available for free download via ASTER GDEM.

(2) Remote sensing image data: Landset-8OLI image data with imaging time on August 11, 2013.

(3) Meteorological data: daily rainfall data provided by China Meteorological Science Data Sharing Service Network.

(4) Soil data: 1: 250000 soil type database obtained by Ninghua County Land Bureau.

(5) Other data: Ninghua County Statistical Yearbook from the Ninghua County Bureau of Statistics; The present situation of soil and water loss in Ninghua County was obtained from the Fujian Provincial Water Resources Bulletin in 2013; The required data are pretreated according to model requirements and research purposes.

2.3. Research Methods

2.3.1. Scenario Analysis. Scenario analysis, also known as prospects description methods, is a method of predicting the consequences of a prediction phenomenon or a situation that may occur if a trend or a phenomenon is assumed to be sustained to the future, which is considered to be an extension of the Multi - objective Planning and Screening Method for System Engineering [2]. By setting different scenarios, quantitatively calculate the soil erosion levels under the different soil erosion scenarios.
Then compare the advantages and disadvantages of each scenario, in order to provide suggestions and reference for the calculation of soil erosion modulus and soil erosion control [3-4].

2.3.2. Scenarios Design of Xiejia Watershed. At present, the main ways of comprehensive management of soil erosion are to adjust the land use, rational allocation and implementation of soil and water conservation measures. The natural factors such as soil, rainfall and slope will not change greatly with human activities in a short period of time [5-6]. Therefore, the most important consideration in scenario setting is the factor of soil and water conservation under human action. The study based on the present situation of soil erosion in Xiejia watershed and the key control decisions of soil erosion, worked out the scenario programs of soil erosion in Xiejia watershed (Table 1).

Table 1. Setting of scenarios for soil erosion control in Xiejia watershed.

| Situational condition | Scenario setting |
|-----------------------|------------------|
| soil and water conservation biological measures | (a1) maintaining the status in 2013 |
|                      | (a2) the naked land was changed into irrigated grassland |
| soil and water conservation tillage measures | (b1) maintaining the status in 2013 |
|                      | (b2) change the cultivated land with a slope of 15 degrees or more to grassland |
|                      | (b3) change the cultivated land that slope is above 25 degrees into forest land |
| soil and water conservation engineering measures | (c1) maintaining the status in 2013 |
|                      | (c2) measures for soil and water conservation projects will be implemented in the whole watershed according to local conditions |

The above scenarios are combined to obtain 10 kinds of soil erosion scenarios in Xiejia watershed. On the basis of existing studies, changing the factor values of the B, E, T and estimate soil erosion value in study area under different soil and water conservation measures. The current situation of soil erosion in 2013 is set as a1b1c1, which is the background value of soil erosion. Then compare and analyze the degree of soil erosion under the combination of scenarios, so as to evaluate the influence of soil and water conservation measures on soil erosion, and to provide scientific basis for soil erosion control in the future.

3. Scenario Analysis of Soil Erosion in Xiejia Watershed

In this paper, the CSLE model is used to calculate the soil erosion modulus [7-8], and the model of soil erosion in China is expressed as:

\[ A = R \times K \times L \times S \times B \times E \times T \]

where \( A \) is the amount of soil loss (t/ km²•a); \( R \) is rainfall erosive factor (t/ km²•a); \( K \) is soil erodibility factor ((t•km²•h) / (km²•M J. mm)); \( L \) is slope length factor; \( S \) is slope factor; \( B \) is biological measures factor; \( E \) is engineering measure factor; \( T \) is tillage measures factor. According to the design of soil erosion scenarios in Xiejia watershed in 1.2.2 section, applied formulas (1) to estimate soil erosion modulus under different soil erosion scenarios. Then compare the degree of soil erosion under different situations, and evaluate the impact of soil and water conservation measures on soil erosion [9-15].

3.1. Effects of Soil and Water Conservation Biological Measures on Soil Erosion.

Keeping the E and T factor unchanged, and changing the B factor, obtain different biological conservation measures scenario. CSLE equation is used to estimate the total amount of soil erosion
under each scenario. According to the "Soil Erosion Classification Criteria" (SLJ90-2007) in the southern soil erosion grading standards, grade the soil erosion amount and calculate the area of soil erosion type under different scenarios by using GIS software.

It can be seen from Table 2 that when the soil and water conservation biological measures are simulated in bare land, the soil erosion rate of Xiejia watershed has declined. In 2013, 24.13% decreased to 23.71% and 23.54%, the decrease rate is not obvious, because the total land area of the bare in Xiejia watershed is small, only 0.15 km² and the contrast is not significant. As can be seen from Table 1, scenario scenarios a₁b₁c₁ and a₂b₁c₁ have improved in all types of erosion compared to the 2013 situation, and the area of mild erosion type accounted for a larger proportion. Contrasting scenario scenarios a₂b₁c₁ and a₁b₁c₁, a₂b₁c₁ are lower than the a₂b₁c₁ in the other types of erosion types, except the intensity erosion type area. It shows that compared with planting grassland in bare land, afforestation in soil erosion area is more effective for soil erosion improvement.

Table 2. The statics of soil erosion in different soil erosion conservation biological measures (m²).

| Project | Scenarios | Erosion rate (%) | Slight | Moderate | Strength | Extreme | Violent |
|---------|-----------|------------------|--------|----------|----------|---------|---------|
| 2013    | a₁b₁c₁    | 24.13            | 5783400| 867600   | 277200   | 164700  | 41400   |
| S1      | a₂b₁c₁    | 23.71            | 5767200| 843300   | 244800   | 122400  | 30600   |
| S2      | a₂b₁c₁    | 23.54            | 5734800| 841500   | 244800   | 110700  | 28800   |

3.2. Effects of Soil and Water Conservation Tillage Measures on Soil Erosion.

In the land use types of Xiejia watershed, the cultivated land accounts for a larger proportion of the total land area, therefore, the implementation of reasonable soil and water conservation tillage measures can effectively improve soil erosion in the study area. In combination with the actual situation, under the condition that B and E factor remain unchanged and T factor are changed, two soil and water conservation tillage measures, namely a₁b₂c₁ and a₂b₂c₁, are obtained (Table 3). According to the above mentioned method, calculate the soil erosion rate of each scenario. It can be seen from Table 3 that the soil erosion rate decreased after the two soil and water conservation tillage measures were carried out in the watershed. The decrease was small, because most of the cultivated land in the valley was located in the mountain depression which slope below 5°. However, the soil erosion is still severe in the cultivated area above 15 ° where human activities are more frequent. There is little difference in soil erosion rate and each erosion type between scheme a₁b₂c₁ and scheme a₂b₂c₁. In addition, the area of slight erosion have decreased greatly, both decreased more than 400000m². This shows that the implementation of returning farmland to cropland or returning farmland to forest in the cultivated area can achieve better effects of soil erosion control.

Table 3. The statics of soil erosion in different soil erosion conservation tillage measures (m²).

| Project | Scenarios | Erosion rate (%) | Slight | Moderate | Strength | Extreme | Violent |
|---------|-----------|------------------|--------|----------|----------|---------|---------|
| 2013    | a₁b₁c₁    | 24.13            | 5783400| 867600   | 277200   | 164700  | 41400   |
| G1      | a₁b₂c₁    | 22.66            | 5355900| 864900   | 274500   | 162900  | 41400   |
| G2      | a₂b₂c₁    | 22.60            | 5366700| 851400   | 274500   | 158400  | 37800   |

3.3. Effects of Soil and Water Conservation Engineering Measures on Soil Erosion.

The common measures such as tractor road construction, drainage and water reservoir are classified as slope change ladder and other surface treatment which use to harness the small watershed, therefore, select slope change ladder as soil and water conservation engineering measures. The forest land and
grassland which no engineering measures are implemented and the vegetation coverage is below 60%, are managed by slope and ladder. In the same situation as other soil and water conservation measures, change the soil and water conservation engineering measures, then calculate the soil erosion rate under different scenarios with the method mentioned above, and count the area of different types of soil erosion under different schemes(Table 4). Compared with the data in the comparison table, the soil and water conservation governance effect is obvious after the soil and water conservation project measures are implemented. Soil erosion rate decreased by 7.85%, among the soil erosion types, the area of slight erosion, moderate erosion and severe erosion decreased by nearly 50%. The reason is that the total area of forest land and grassland in the watershed reaches 62.84%, therefore, the implementation of a large area of water and soil conservation measures in the watershed has positive effects on soil erosion improvement in the study area.

**Table 4.** The statics of soil erosion in different soil erosion conservation engineering measures (m $^2$).

| Project | Scenarios | Erosion rate (%) | Slight | Moderate | Strength | Extreme | Violent |
|---------|-----------|------------------|--------|----------|----------|---------|---------|
| 2013    | a$_1$b$_1$c$_1$ | 24.13            | 5783400| 867600  | 277200  | 164700  | 41400   |
| C1      | a$_1$b$_1$c$_2$ | 16.28            | 3984300| 432000  | 244800  | 122400  | 28800   |

3.4. Effects of Soil and Water Conservation Measures on Soil Erosion.

Combining the soil and water conservation biological measures, the soil and water conservation tillage measures and the soil and water conservation engineering measures, five scenarios are got (Table 5). Then calculate soil erosion type area and a comparison of soil erosion rates under eleven soil erosion scenarios was obtained at last (Figure 2). As can be seen from the table, compared with the area of soil erosion type in 2013, the soil erosion types and areas calculated under the five combinations are obviously reduced in different degrees, except the scenario a$_1$b$_2$c$_2$ and a$_1$b$_2$c$_2$ which the area of severe erosion is zero, and the area of extreme strength erosion decreases greatly. From the soil erosion rates of all scenarios, scenario a$_3$b$_2$c$_2$ has the lowest soil erosion rate which assumed that the naked land in the watershed is changed to the grassland (grassland coverage >80%), and the cultivated land with the slope of 15$^\circ$ or more is transformed into the grassland, besides the engineering measures are not implemented in the watershed and Vegetation coverage below 60% of the woodland and shrubs to implement slope change ladder and other treatments to improve the effect of soil and water conservation measures in the model, so as to control the soil erosion rate and achieve the effect of soil erosion control. Although the soil erosion rate of bare land is above 90%, the proportion of bare land in Xiejia watershed is smaller, only 0.5% of the total area of soil. Compared with the single soil and water conservation measures, the combination of soil and water conservation comprehensive measures are more effective not only in the soil erosion rate but also in the soil erosion type area.

**Table 5.** The statics of soil erosion in different scenario (m $^2$).

| Project | Scenarios | Erosion rate (%) | Slight | Moderate | Strength | Extreme | Violent |
|---------|-----------|------------------|--------|----------|----------|---------|---------|
| 2013    | a$_1$b$_1$c$_1$ | 24.13            | 5783400| 867600  | 277200  | 164700  | 41400   |
| Z1      | a$_1$b$_2$c$_2$ | 7.33             | 1925100| 119700  | 51300  | 49500  | 20700   |
| Z2      | a$_1$b$_2$c$_2$ | 14.05            | 3864600| 157500  | 49100  | 55800  | 26100   |
| Z3      | a$_1$b$_2$c$_2$ | 4.69             | 1288800| 72000  | 13500  | 10800  | 0       |
| Z4      | a$_1$b$_2$c$_2$ | 11.88            | 3234600| 148500  | 48600  | 54000  | 26100   |
| Z5      | a$_1$b$_2$c$_2$ | 4.56             | 1255500| 68400  | 14400  | 9000  | 0       |
3.5. Summary

Through the study of the soil erosion situation setting and model simulation budget in the study area, it is found that the soil erosion rate simulated under all scenarios are lower than the soil erosion status in 2013, and combining scenarios of soil and water conservation measures are more effective in reducing soil erosion. As the bare area accounts for less total land area, and woodland and shrub land accounted for more than half of the total area of the watershed, therefore, compared with soil and water conservation biological measures and soil and water conservation tillage measures, the implementation of soil and water conservation engineering measures in the watershed will contribute more to the reduction of soil erosion. In addition, the soil erosion rate of bare land has reached more than 90%, which is the type of land use that must be controlled, so it is necessary to plant trees on bare land (shrub grass) when carried out the implementation of returning farmland to forests (shrubs), and the implementation of slope change ladder in forest land and grassland in Xiejia watershed, so as to achieve the effect of reducing and controlling soil erosion and ensuring the safety of the river watershed.

4. Conclusion

Based on the combination of RS/GIS and technology, this paper takes the Xiejia watershed in Ninghua County as the research area, extracts the factors affecting soil erosion and sets up the spatial data sets of environmental factors. The distribution of R factor in the rainfall erosivity of Xiejia watershed in Ninghua County is relatively uniform and the spatial difference is small. The soil erodibility factor is in the range of 0.2357 to 0.3391, and the K value of the paddy soil is the largest and its erosion resistance is the weakest. Compared with the slope length factor, the slope factor has a great influence on soil erosion. Based on the present situation of soil erosion in Xiejia watershed, formulate a scenario of soil erosion scenarios and through analysis, it is found that the soil erosion rate under different scenarios is lower than that of soil erosion in 2013. Compared with soil and water conservation measures and soil and water conservation tillage measures, water and soil conservation measures in the watershed contribute more to the reduction of soil erosion. This paper, based on the collection of large amounts of data and data, try to choose the most reasonable and scientific research method for the actual situation of the study area. However, soil erosion is uncertain, but scenario simulation is in the ideal state, and some scenarios may not be realistic enough. Therefore, how to simulate the soil erosion in the study area according to the existing research data, it will be further explored in the future research.

Figure 2. Comparison of soil erosion rate under scenario design.
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