

Assessment of soil erosion using RUSLE and GIS: a case study of the Maotiao River watershed, Guizhou Province, China

Xu Yue-qing · Peng Jian · Shao Xiao-mei

Received: 10 October 2007 / Accepted: 24 February 2008 / Published online: 11 March 2008
© Springer-Verlag 2008

Abstract Due to the existence of fragile karst geo-ecological environments, such as environments with extremely poor soil cover, low soil-forming velocity, and fragmented terrain and physiognomy, as well as inappropriate and intensive land use, soil erosion is a serious problem in Guizhou Province, which is located in the centre of the karst areas of southwestern China; evaluation of soil loss and spatial distribution for conservation planning is urgently needed. This study integrated the revised universal soil loss equation (RUSLE) with a GIS to assess soil loss and identify risk erosion areas in the Maotiao River watershed of Guizhou. Current land use/cover and management practices were evaluated to determine their effects on average annual soil loss and future soil conservation practices were discussed. Data used to generate the RUSLE factors included a Landsat Thematic Mapper image (land cover), digitized topographic and soil maps, and precipitation data. The results of the study compare well with the other studies and local data, and provide useful information for decision makers and planners to take appropriate land management measures in the area. It thus indicates the RUSLE–GIS model is a useful tool for evaluating and

mapping soil erosion quantitatively and spatially at a larger watershed scale in Guizhou.

Keywords Soil erosion · RUSLE · GIS · Guizhou Province · China

Introduction

Soil erosion, considered one of the most important forms of soil degradation worldwide (Oldeman 1994), is a major environmental problem in China. The total area of soil erosion in China is 3.6 million km², accounting for 37% of the total national territory; annual soil erosion amounts to 5 billion tons (Liu 2004). There is a population of 1×10^8 in the karst area of southwestern China and minority nationalities account for about 2×10^7 . There are 48 different nationalities residing in these areas, and they are the most poverty-stricken in China. Due to extremely poor soil cover, fragmented terrain and physiognomy, rapid water loss, and inappropriate and intensive land use, the geological environment is extremely fragile. Carbonate rock strata were deposited from the Proterozoic to Trias period with a thickness of more than 10,000 m and carbonate rocks cover about 42.6×10^4 km². Pure carbonate rocks are low in acid-insoluble components (about 4% on average), which means there are only small amounts of residues left after dissolution, so the rate of soil formation is extremely low (Wang et al. 2004). It takes about 8,000 years to form 1 cm of soil, on average, under the present climatic condition. Soil layers, developed on the basement carbonate rocks are generally 30–50 cm thick. At present, in the karst region of southwestern China, the total area of soil erosion has reached 17.9×10^4 km², or 40% of the region. The area of moderate to strong erosion

X. Yue-qing (✉)
Department of Land Resources and Management,
College of Resources and Environment,
China Agricultural University, 100094 Beijing, China
e-mail: xmoonq@sina.com

P. Jian
School of Management,
Central University of Nationalities, 100081 Beijing, China

S. Xiao-mei
Key Laboratory of Land Use, Ministry of Land and Resources,
China Land Surveying and Planning Institute,
100035 Beijing, China

is about $6.6 \times 10^4 \text{ km}^2$, or about 37% of the region (Wang et al. 2004). As a result, larger and larger surface areas have become nearly naked due to rapid topsoil loss, which is called “rocky desertification” (Fig. 1) (Zhang et al. 2006). Severe soil erosion has not only led to the impoverishment of cultivated land and poverty of the local people, but also to desertification that destroys the conditions crucial for human survival. Soil erosion is seriously constraining the sustainable development of southwestern China.

Guizhou, a southwestern province of China, covers an area of $17.6 \times 10^4 \text{ km}^2$ and is located in the center of southwestern China’s karst mountains, about 73% of which is covered with typical karst landscapes (Zhang et al. 2001). Pure carbonate rocks in Guizhou Province cover an area of 57,408 km^2 , which accounts for 32.6% of the province. Guizhou is a rugged region, with 97% of its area covered by mountains and hills. At present, 81% of cultivated land is on slopes of 6° or more and about 20% of the total cultivated land area is on slopes over 25° . With relatively thin soils, a rainy subtropical monsoon climate (usually more than 1,000 mm precipitation a year), and great population pressure (a population density as high as 219 people per km^2 in 2003) on the fragile karst geo-ecological environment, Guizhou is suffering serious soil erosion. According

to investigation, the area of soil erosion was $2.5 \times 10^4 \text{ km}^2$ in the 1950s, $3.5 \times 10^4 \text{ km}^2$ in the 1960s, $5 \times 10^4 \text{ km}^2$ in the 1970s, and $7.7 \times 10^4 \text{ km}^2$ by 1995. Presently, it extends $8.8 \times 10^4 \text{ km}^2$, or about 50% of the province (Wan 2003). Soil erosion as well as the resultant rocky desertification, called “the cancer of the earth” in karst areas, has been the obstacle to sustainable development in the locality. Guizhou has long been one of the poorest provinces in China due to the extremely fragile environment (Huang and Cai 2006), and has received attention from the Chinese Government and researchers (Zhu et al. 2004; Lin and Zhu 1999; Department of Earth Science, Chinese Academy of Sciences 2003; He 2000; Deng et al. 2000; Wu et al. 2005; Gao and Li 2006). Unfortunately, available or financially viable means of measuring soil erosion is lacking in Guizhou. There is an increasing demand for predicting annual soil loss from erosion and characterizing the spatial distribution of soil erosion to provide a scientific basis for soil conservation planning.

The Revised Universal Soil Loss Equation (RUSLE) (Renard et al. 1997) is an empirical soil erosion model designed by the Universal Soil Loss Equation (Wischmeier and Smith 1978). It not only predicts erosion rates of ungauged watersheds using knowledge of the watershed characteristics and local hydroclimatic conditions (Angima et al. 2003), but also presents the spatial heterogeneity of soil erosion. Because of its convenience in application and compatibility with a GIS, the RUSLE has been the most frequently used empirical soil erosion model worldwide.

Taking the Maotiao River watershed in central Guizhou as a case study, the RUSLE and GIS is applied to estimate the soil loss and soil erosion potential, describe the spatial heterogeneity, calculates the capability of soil conservation for different land use types and discusses measures for soil conservation planning in the area. It is hoped that the results of the study provide useful information for decision makers and planners to take appropriate land-management measures in the area.

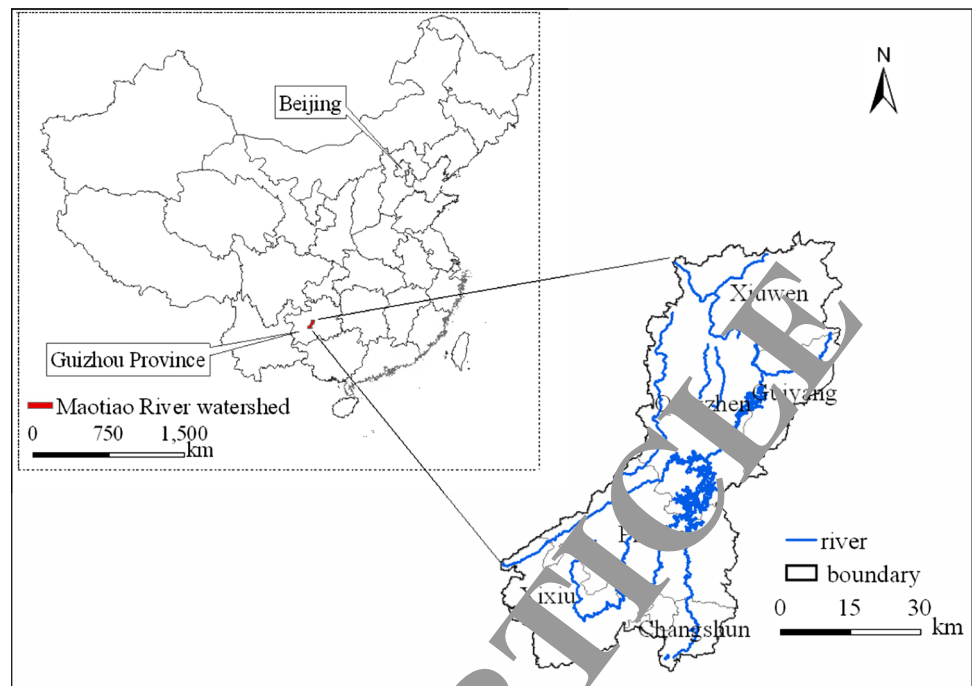
Study area

The study area, the Maotiao River watershed ($106^\circ00' - 106^\circ53'E$, $26^\circ00' - 26^\circ52'N$), covers an area of 3,109 km^2 and is located in central Guizhou, southwestern China (Fig. 2). The region has a subtropical and monsoonal climate with an annual average temperature of 14.2°C and an average annual precipitation of 1,300 mm, most of which occurs between May and September. Elevation in the study area varies from 775 to 1,762 m above sea level and generally decreases from southwest to northeast. About 82.2% of the watershed is located between 1,200 and 1,400 m above sea level. Generally speaking, the Maotiao River watershed is composed of two geomorphological



Fig. 1 a Landscape of karst rocky desertification resulting from soil erosion in southwestern China, with extensive exposure of the basement rocks b Cultivated fields dotted among exposed rocks and in fissures. Note the growth of maize

Fig. 2 Location of the study area within Guizhou Province, southwestern China



units, namely, a plateau area and canyon area. The plateau area is mainly located in the upper watershed of the Maotiao River, and is relatively smooth and often occupied by cone-shaped karst hills and karst basins (Fig. 3). The canyon area is mainly distributed in the lower watershed of the Maotiao River, and is usually dissected by steep and narrow gorges (Fig. 4). The area with an average gradient less than 5° accounts for 26.3% of the study area, gradients of 5–15° account for 36.6%, gradients of 15°–25° account for 23.1%, and gradients above 25° account for 14.0%.

Influenced by humid subtropical monsoonal climate and extensively exposed carbonate rocks, the most widely distributed soil types in the Maotiao River watershed are

yellow soil and calcareous soil. Yellow soil, formed in humid subtropical mountainous areas or in plateau areas with evergreen broad-leaf forest, is zonal soil and mainly distributed in basins or on the plateau surface in the watershed. Calcareous soil, formed largely by the weathering of calcareous rocks at a slow rate, is a kind of non-zonal soil, distributed in rugged grikes of the valley. Land uses in this area derived from Landsat Thematic Mapper image taken on 30 August 2002, include dry farmland, paddy farmland, forestland, sparse forestland, orchards, water bodies, and residential and built-up land (Table 1). Agriculture is the main land use in the watershed which has a long history of cultivation. The major agricultural crops



Fig. 3 Landscape of the plateau area with cone-shaped karst hills and karst basins in the upper watershed of the Maotiao River



Fig. 4 Landscape of the canyon area dissected by steep and narrow gorges in the lower watershed of the Maotiao River

Table 1 Portion of each land cover type for the Maotiao River watershed

Class	Area (ha)	Percentage (%)
Paddy field	53322.9	17.2
Dry farmland	83390.9	26.8
Forestland	40340.1	13
Sparse forestland	21024.5	6.7
Other forestland (orchard, etc.)	997.1	0.3
Grassland	71508.4	23
Water body	9094.8	2.9
Residential and built-up land	13914.8	4.5
Barren rock	17315.6	5.6

are rape, rice, bean and maize. The Maotiao River watershed is representative of Guizhou. Natural resources, land use patterns, and population densities in the watershed are typical of the surrounding region.

Materials and methods

This paper uses the RUSLE empirical model to predict annual loss. The RUSLE can be expressed as (Renard et al. 1997)

$$A = R \times K \times LS \times C \times P \tag{1}$$

where A is the average soil loss caused by erosion ($t\ ha^{-1}\ year^{-1}$), R is the rainfall erosivity factor ($MJ\ mm\ ha^{-1}\ h^{-1}\ year^{-1}$), K is the soil erodibility factor ($t\ ha\ h\ MJ^{-1}\ ha\ year^{-1}$), L is the slope length factor, S is the slope steepness

factor, C is the cover and management practice factor, and P is the conservation support practice factor. The L , S , C , and P factors are dimensionless.

The RUSLE model was run by means of a GIS platform (ESRI ArcGIS 8.3). The following sections describe the computation of the R -, K -, LS -, C -, and P -factors from precipitation data, soil surveys, a digital elevation model (DEM) and land use maps. The spatial resolution of the data was set at 25 m, which is consistent with the Landsat Thematic image. Figure 5 illustrates the procedure of the actual and potential soil loss calculation.

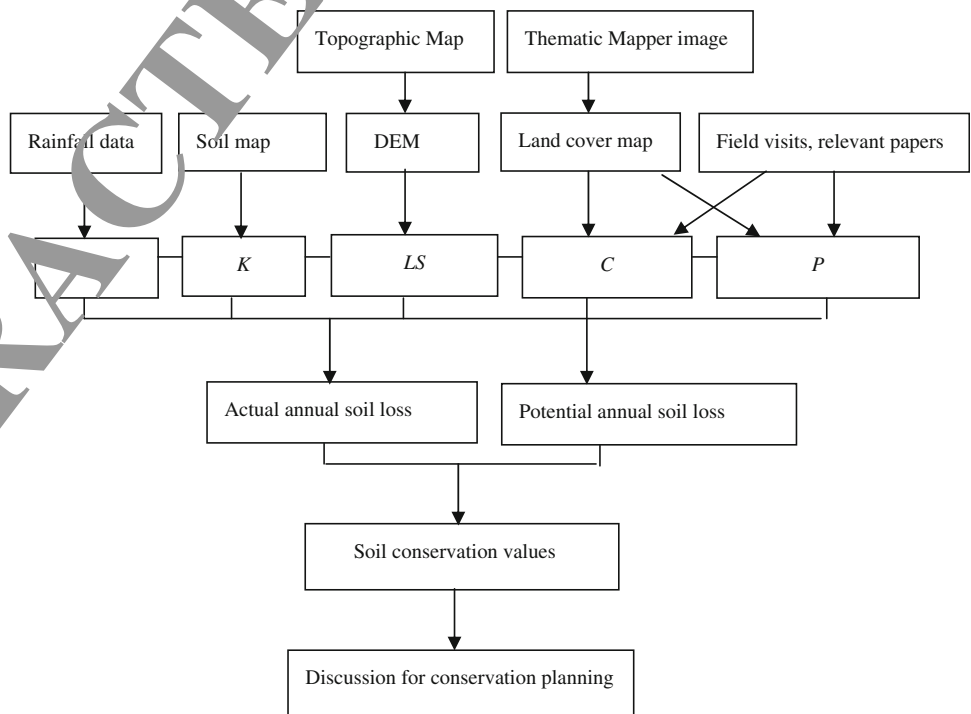
Rainfall erosivity factor (R)

The R -factor quantifies the effect of rainfall impact and also reflects the amount and rate of runoff likely to be associated with precipitation events. Within the RUSLE, rainfall erosivity is estimated using rain gauge measurement (Renard et al. 1997). There are five meteorological stations in or near the Maotiao River watershed. Because none of the five stations recorded rainfall intensity, the following model (Yu et al. 1998) was adopted to calculate the monthly rainfall erosivity based on the daily rainfall data of the five meteorological stations and then the 12 months of each year were summed:

$$E_j = \alpha [1 + \eta \cos(2\pi f j + \omega)] \sum_{d=1}^N R_d^\beta \quad R_d > R_0 \tag{2}$$

where E_j is the monthly rainfall erosivity ($MJ\ mm\ ha^{-1}\ h^{-1}\ year^{-1}$), R_d is the daily rainfall, R_0 is the daily rainfall threshold causing erosion (in general, R_0 is 12.7 mm), and

Fig. 5 Flow chart of soil erosion assessment in the Maotiao River watershed



N is the number of days on which the precipitation corresponds to a monthly rainfall ≥ 12.7 mm. $f = 1/12$ is the frequency and ω is equal to $5\pi/6$. α , β , and η are the model parameters, and the relationship between α and β is expressed as formula (3), where the annual rainfall is above 1,050 mm. The relationship between η and the annual rainfall P is shown in formula (4). The β value ranges from 1.2 to 1.8 and β is taken as 1.5 in this study.

$$\log \alpha = 2.11 - 1.57\beta \tag{3}$$

$$\eta = 0.58 + 0.25P/1,000 \tag{4}$$

Using the above formulas and the daily rainfall data of the five meteorological stations during the period of 1980–2002, the monthly rainfall erosivity of each station was calculated, and the 12 monthly values were summed for each year. The average R -factor values for meteorological stations of the study watershed were obtained by averaging the yearly values from 1980 to 2002 and the R -factor map layer was made by Kriging interpolation in the GIS (Fig. 6).

The average annual R factor value varies from 3,509 to 6,847 $\text{MJ mm ha}^{-1} \text{h}^{-1} \text{year}^{-1}$ and the mean value is 4,978 $\text{MJ mm ha}^{-1} \text{h}^{-1} \text{year}^{-1}$. The SD is 739. There is more rainfall erosivity in the south and southwest of the watershed than that in the north and northwest and this has a close relation with the decreasing trend of rainfall from the south to the north and non-uniformity of spatial distribution of rainfall in the Guizhou Plateau (Xu et al. 2005).

Soil erodibility factor (K)

The soil erodibility factor K value is the rate of soil loss per rainfall erosion index unit as measured on a standard plot and often determined using inherent soil properties (Parsons et al. 2003). The K -factor is related to soil texture, organic matter content permeability, and other factors and

is basically derived from the soil type (Wischmeier 1971). The K -factor value was calculated using (Renard et al.1997; Liu et al. 2001):

$$K = 7.594 \left\{ 0.0034 + 0.0405 \exp \left[-1/2 \left((\log D_g + 1.659) 0.7101 \right)^2 \right] \right\} \tag{5}$$

$$D_g = \exp \left(0.01 \sum f_i \ln m_i \right) \tag{6}$$

where D_g is the geometric mean diameter of soil particle, m_i is the arithmetic mean of the particle size limits of class i and f_i is the particle size fraction in percent of class i .

The data on soil texture were collected from Guizhou Soil produced by the Agricultural Bureau of Guizhou Province (1980) and soil information data were put into the attribute database of the soil map, which was digitized from a 1:50,000 soil map; classes were generated with definite boundaries. The erodibility K factor was then calculated for each soil mapping unit using formulas (5) and (6) in the GIS and the average K value in the study area is 0.04 $\text{t ha h MJ}^{-1} \text{ha}^{-1} \text{mm}^{-1}$. The K factor value is higher in the northern than in the southwest, except for some particular locations (Fig. 7).

Topographic factor (LS)

Within the RUSLE, the LS factor reflects the effect of topography on erosion, the slope length factor (L) represents the effect of slope length on erosion, and the slope steepness factor (S) reflects the influence of slope gradient on erosion (Lu et al. 2004). The raster grid cumulation and maximum downhill slope methods developed by Hickey and Van Remortel (Hickey 2000; Van Remortel et al. 2001) were adopted and the Arc Macro Language (AML1) program downloaded from Van Remortel's

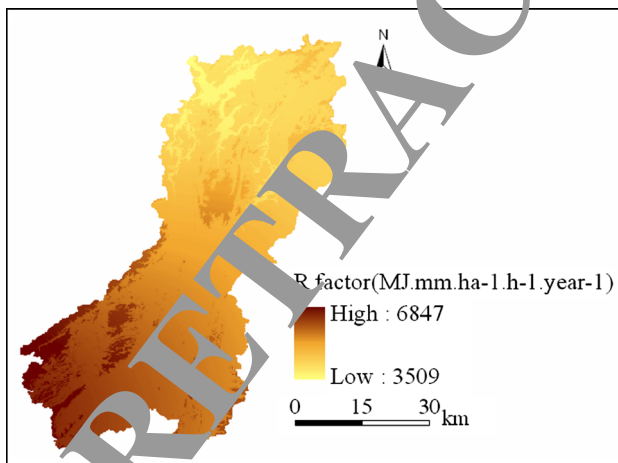


Fig. 6 Grid surface of the Maotiao River watershed showing the distribution of R

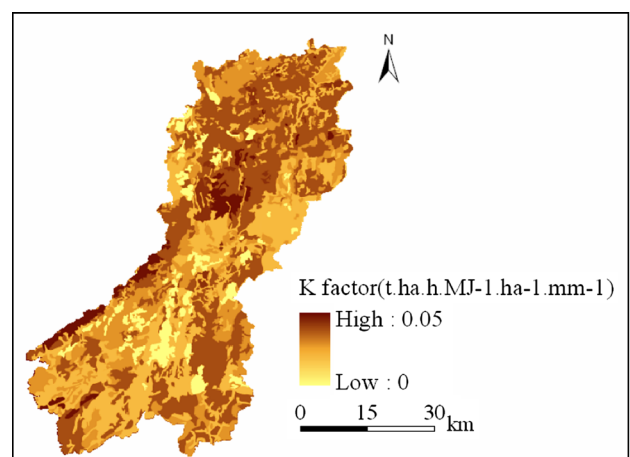


Fig. 7 Grid surface of the Maotiao River watershed showing the distribution of K

website (<http://www.cwu.edu/~rhickey/slope/slope.html>) was applied to generate an *LS*-factor grid map by inputting the 25 m DEM dataset of the Maotiao River watershed, which was integer formatted. The generation of the DEM for the Maotiao River watershed involved digitizing 20 m contour lines from a 1:50,000 topographic map, and the vector elevation map was converted to 25 m raster.

The *LS*-factor value in the study area varies from 0 to 143, the mean value is 5.5, and the majority of the study area has *LS* values of less than 10. Some specific areas with steep slopes, such as along the river in the northwest of the watershed, have *LS* values of greater than 20.

Cover and management practices factor (*C*)

The *C*-factor is used to reflect the effect of cropping and management practices on soil erosion rates in agricultural lands and the effects of vegetation canopy and ground covers on reducing soil erosion in forested regions (Renard et al. 1997), which varies with season and crop production system. The relative impacts of management options can easily be compared by making changes in the *C*-factor which varies from near zero for well-protected land cover to 1 for barren areas (Lee and Lee 2006). The *C* factor on a large scale can be extrapolated from the plot scale if there are basic data for plots or if evaluation is done qualitatively in the case of no basic data (Fu et al. 2005). A land use map of the study area derived from the Landsat Thematic Mapper image taken on 30 August 2002 was used as a basis for determining the *C* factor values. Information on the cropping history (1990–2002) was collected to determine crop rotations. Knowledge of the crop type and growth and harvest stages were obtained through field visits to the Maotiao River watershed in summer and autumn 2004. Experimental results for the *C*-factor for cultivated land, forest land, sparse forestland and orchard in southwestern China and qualitative data were adopted from the literature (Yang 1999, 2002; Wang 2001; Cai et al. 2000). The *C*-factor of different land use types was obtained by synthesizing this information. The average *C*-factor values were assigned as attributes in the land use map. The *C*-factor value varies from 0 to 0.22 and the mean value is 0.1. A higher *C* factor value occurs for hillside because of its larger area of dry farmland.

Support practice factor (*P*)

The *P*-factor is a ratio of soil loss with a specific support practice to the corresponding loss with upslope and downslope tillage (Renard et al. 1997). The lower the *P* value, the more effective the conservation practice is deemed to be at reducing soil erosion. According to field surveys and relevant information, the soil conservation

techniques used in the Maotiao River watershed are terracing, contour tillage, and most of the dry farmland is upslope-downslope tillage without conservation support practices. Experimental results for the *P*-factor were adopted for cultivated land in southwestern China and qualitative data from the literature (Yang 1999, 2002; Wang 2001). The average value of *P* for individual map units was then determined combining the conservation practices obtained from the field survey. Forestland, sparse forestland and grassland were assigned a value of 1, representing they were without conservation support practices.

The *P* factor value varies from 0 to 1 and the mean value is 0.54. A higher *P* factor value occurs north of the watershed, because of its larger area of forestland.

Results and discussion

Actual annual soil loss

The five-parameter layers were all converted into a grid with 25 × 25 m cells in a uniform coordinate system. The GIS input layers were then multiplied, as described by the RUSLE, to estimate annual soil loss on a pixel-by-pixel basis, and the spatial distribution of the soil erosion in the study area was obtained. As seen in Fig. 8, average annual soil loss in most of the area is between 5 and 80 t ha⁻¹ year⁻¹. The mean value of the actual soil loss is 28.2 t ha⁻¹ year⁻¹ and the gross amount of actual soil loss amounts to 875.6 × 10⁴ t year⁻¹ (Table 2). With regard to the spatial variation, the northwest part of the watershed, with some specific areas in excess of 200 t ha⁻¹ year⁻¹, has more erosion than the southeast part. Soil loss has a close relationship with land use and topography. The calculation

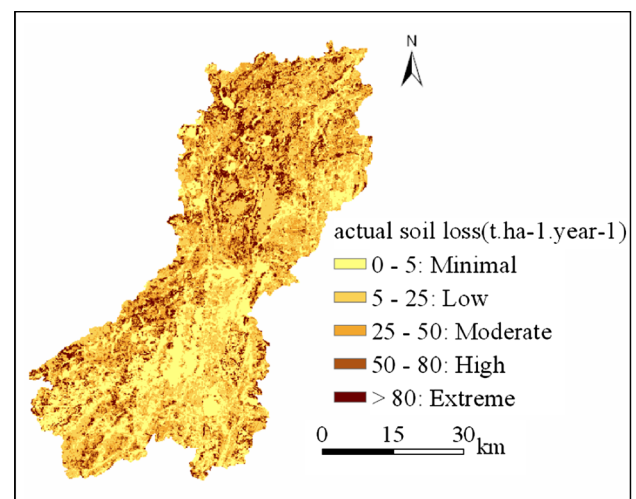


Fig. 8 Grid surface of the Maotiao River watershed showing the distribution of actual soil loss

Table 2 Ordinal categories of soil erosion and the area and the amount of soil loss of each category

Erosion categories	Numeric range (t ha ⁻¹ year ⁻¹)	Area (×10 ⁴ ha)	Area percent (%)	Soil loss (×10 ⁴ t year ⁻¹)	Soil loss percent (%)
Minimal	<5	13.3	42.8	8.5	1
Low	5–25	7.9	25.6	108.4	12.4
Moderate	25–50	4.1	13.1	149.9	17.1
High	50–80	2.6	8.3	164.1	18.7
Extreme	>80	3.2	10.2	444.7	50.8
Total		31.1	100	875.6	100

results compare well with the other studies and local data, for example, an average of 25–30 t ha⁻¹ year⁻¹ in the Maotiao River watershed from the Agricultural Synthetic Regionalization Staff of Guizhou Province (1988), which demonstrates it is a feasible approach to apply the GIS technology and RUSLE model to estimate soil erosion loss in Guizhou.

According to the soil erosion rate standard, Technological Standard of Soil and Water Conservation SD238-87, issued by the Ministry of Water Resources of China, the quantitative output of predicted soil loss was divided into five ordinal classes as shown in Table 2. Most areas of the watershed fall within the minimal (42.8%) and low erosion categories (25.6%), which are mostly seen in the southeast of the watershed. About 20% of the watershed is in the high to extreme erosion category, which is mostly found in the northwest of the watershed. With regard to the gross amount of soil loss, 13.4% of the total soil loss occurred in the areas of minimal to low soil erosion categories and 69.5% occurred in areas of high to extreme soil erosion categories. It is obvious that management practices should be adopted to reduce soil erosion in areas of high to extreme erosion.

Potential annual soil loss

Within the RUSLE, the rain erosivity, soil erodibility and topographic factor can be considered as naturally occurring

factors determining the erosion processes. Together, they can be considered as the erosion susceptibility or potential soil erosion loss for the area. The potential soil erosion loss can be estimated when *C* and *P* are set to 1.0, assuming no canopy-cover and no support practices existed within the study area. The RUSLE can be simplified as

$$Ap = R \times K \times LS \tag{7}$$

The potential soil loss is then obtained by overlaying the three grid surfaces over the Maotiao River watershed.

It is important to evaluate the potential soil erosion loss for identifying high erosion areas and assessing erosion impacts of various cropping systems and conservation support practices. The potential average annual soil loss in most of the area is between 100 and 2,000 t ha⁻¹ year⁻¹, and 50% of the watershed has erosion exceeding 500 t ha⁻¹ year⁻¹. The mean value of the potential soil loss is 49.3 t ha⁻¹ year⁻¹ and the gross amount of potential soil loss amounts to 25971.3 × 10⁴ t year⁻¹ (Table 3). Because of land surface fragmentation and steeper slope, there is more potential soil loss north of the watershed than to its south.

Capability of preventing soil erosion

The value for soil conservation due to vegetation coverage and support practice management was obtained by overlaying the two layers of the watershed in the GIS;

Table 3 Quantities of soil erosion and soil conservation capability of land use types

Land use	Total soil loss (×10 ⁴ t year ⁻¹)		Soil erosion per unit area (t ha ⁻¹ year ⁻¹)		Soil conservation		Soil conservation capability
	Potential	Actual	Potential	Actual	Total soil loss (×10 ⁴ t year ⁻¹)	Soil conservation per unit area (t ha ⁻¹ a ⁻¹)	
Paddy field	2875.9	2.6	539.3	0.5	2873.3	538.8	1111.3
Dry farmland	6441.9	511.3	772.5	66.5	5930.6	705.9	12.6
Forestland	5925.8	32.7	1468.9	9.1	5893.1	1459.9	181.3
Sparse forestland	3137.7	30.1	1492.4	15.5	3107.5	1476.9	104.0
Other farmland (orchard, etc.)	72.6	2.0	728.0	21.2	70.6	706.8	36.9
Grassland	7517.4	296.9	1051.3	45.1	7220.6	1006.1	25.3
The study area	25971.3	875.6	949.3	28.2	25095.7	920.6	33.7

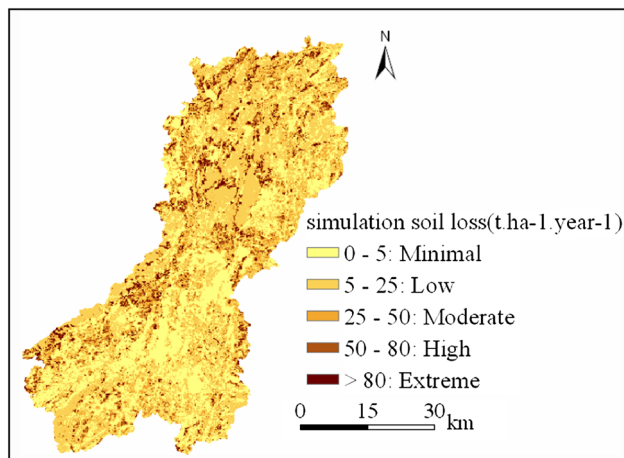


Fig. 9 Grid surface of the Maotiao River watershed showing the distribution of soil erosion simulation

specifically, the actual annual soil loss was subtracted from the potential annual soil loss in GIS. The average annual soil conservation for most of the watershed is less than $2,000 \text{ t ha}^{-1} \text{ year}^{-1}$ and the mean value is $920.6 \text{ t ha}^{-1} \text{ year}^{-1}$. There is more soil conservation in the north of the watershed than in the south due to the larger area of forestland located in that area. The annual gross amount of soil conservation of the watershed amounts to $25095.7 \times 10^4 \text{ t year}^{-1}$. The soil conservation values of the forestland, sparse forestland and grassland are the highest in the watershed with all exceeding $1,000 \text{ t ha}^{-1} \text{ year}^{-1}$ (Table 3). The ratio of the potential annual soil loss to the actual annual soil loss of different land use types was considered to be the capability of preventing soil erosion by land use type. It can be seen from Table 5 that the capability of soil conservation in the paddy field is the

strongest, with a value of 1111.3, and that of the forestland is the second, with a value of 181.3. The dry farmland, most of which is situated on the hillside and is without conservation support practices, has the smallest soil conservation capability, with a value of 12.6. The mean value of soil conservation capability in the Maotiao River watershed is 33.7.

The areas of moderate to extreme categories were estimated to be at risk of erosion. Presently, about $9.9 \times 10^4 \text{ ha}$ or 31.6% of the study area is considered to be at risk of erosion (Table 2). The impact of management practices on soil erosion can easily be evaluated by making changes to the *C*-factor and *P*-factor with the RUSLE. Considering that the slope farmlands with a gradient $>25^\circ$ have all been reverted into forestland, the sparse forestland and grassland have become mature forestland, and the barren area has undergone re-vegetation, the *C* factor and *P* factor values were reassessed and the average annual soil loss in the study area was simulated by overlaying the five factor maps using RUSLE. As seen in Fig. 9, the average annual soil loss in most of the study area is less than $50 \text{ t ha}^{-1} \text{ year}^{-1}$ and the mean value is $18.5 \text{ t ha}^{-1} \text{ year}^{-1}$. The total annual soil loss is reduced to 65.7% ($575.7 \times 10^4 \text{ t year}^{-1}$) of the actual annual soil loss ($875.6 \times 10^4 \text{ t year}^{-1}$) but 17.2% of the study area is still at risk of erosion (Table 4). It can be seen from Table 5 that 82.2% of the total soil loss occurs on dry farmland with a gradient $>25^\circ$; in particular, 36.5% of the total soil loss occurs on dry farmland with a gradient 6° – 15° , and 29.5% on dry farmland with a gradient 15° – 25° . It is obvious that dry farmland with a gradient 6° – 25° is the major contributor to soil erosion, where soil loss is 66% of the total soil loss.

Table 4 Simulation of soil erosion in each erosion category

Erosion category	Numeric range ($\text{t ha}^{-1} \text{ year}^{-1}$)	Area ($\times 10^4 \text{ ha}$)	Area percent (%)	Soil loss ($\times 10^4 \text{ t year}^{-1}$)	Soil loss percent (%)
Minimal	0–5	15.9	51.1	11.9	2.1
Low	5–25	9.8	31.7	109.4	19.0
Moderate	25–50	2.0	6.4	69.5	12.1
High	50–80	1.3	4.2	82.5	14.3
Extreme	>80	2.1	6.6	302.4	52.5
Total		31.1	100	575.7	100

Table 5 Simulation of soil erosion in different land use types

Land use type	Erosion area proportion (%)	Soil loss proportion (%)
Paddy field	4.1	0.2
Dry farmland $<6^\circ$	13.4	16.2
Dry farmland 6 – 15°	14.6	36.5
Dry farmland 15 – 25°	7.4	29.5
Forestland	60.5	17.6

Conservation practices for soil erosion

As can be seen from the above analysis, the capability of soil conservation in paddy field and forestland is higher, and that in dry farmland is lower. However, the larger area of the dry farmland in the study area is situated on hillside, some of which is on slopes with gradients $>25^\circ$ and which undergoes conventional tillage rather than conservation oriented practices. Therefore, reconvertng forest to its natural condition, eliminating human disturbance in barren areas, and reverting farmland with a gradient $>25^\circ$ to forestland are feasible conservation practices for minimizing erosion.

The simulated results indicate that even if all sloping cultivated land with a gradient $>25^\circ$ is reverted to forestland, if sparse forestland and grassland become mature forestland, and all barren areas undergo forestation, then the serious soil erosion problems in the study area can still not be completely solved. Therefore, implementing conservation practices on dry farmland with a gradient of $6\text{--}25^\circ$ such as terracing and contour tilling is urgently needed.

Conclusions

Due to the typical karst mountain landscape having extremely poor soil cover, a low soil-forming rate, and fragmented terrain and physiognomy, etc., soil loss and the resulting rock desertification is a serious problem in the Chinese province of Guizhou. It is necessary to evaluate the soil loss and its spatial distribution for sustainable land use and comprehensive soil conservation management. Adopting a RUSLE model and GIS and using local data, the actual and potential soil losses in the Moutiao River watershed, located in central Guizhou were evaluated, the soil conservation capability of land use types was obtained, and soil conservation practices in the watershed were discussed. The results of the application of the RUSLE model are consistent with those obtained with local data. The results show that implementing conservation practices on dry farmland with a gradient $6\text{--}25^\circ$ is urgently needed. The methods and results described in this article are valuable for understanding the relationship between soil erosion risk and land use types and are useful for managing and planning land use that will avoid soil erosion. This study indicates that it is feasible to apply GIS technology and the RUSLE model to quantitatively and spatially estimate soil erosion loss at a larger watershed scale in Guizhou, even though there are some limitations in determining the RUSLE factors in this study due to the spatial heterogeneity in the watershed. In further studies, more attention should be paid to the regional karst landscape characteristics and the preprocessing of data sources, such as data interpolation, to improve the model result and efficiency.

Acknowledgments This research was supported by the Project of National Natural Science Foundation of China (40701091) and National Science and Technology Support Program of China (2006BAD20B07). The authors are grateful to the anonymous reviewers and the editors of the journal for their valuable comments and suggestions.

References

- Agricultural Bureau of Guizhou Province (1980) Guizhou soil. Guizhou People Press, Guiyang
- Agricultural Synthetical Regionalization Staff of Guizhou Province (1988) Agricultural synthetical regionalization in Guizhou. Guizhou People Press, Guiyang
- Angima SD, Stott DE, O'Neill MK, Ong CK, Weesies GA (2003) Soil erosion prediction using USLE for central Kenyan highland conditions. *Agric Ecosyst Environ* 97:295–308
- Cai C, Ding S, Shi Z (2000) Study of applying USLE and Geographical Information System IDRISI to predict soil erosion in small watershed. *Full Soil Water Conserv* 2:19–24
- Deng P, Tu Y, Chen G (2003) Assessment of economic cost of soil erosion—a case study of Guizhou Province. *Rural Eco-environ* 2:1–5
- Department of Earth Science, Chinese Academy of Sciences (2003) Suggestions for management of rocky densification in karst areas of southwestern China. *Adv Earth Sci* 4:489–492
- Fu B, Zhao Y, Chen L (2005) Assessment of soil erosion at larger watershed scale using RUSLE and GIS: a case study in the loess plateau of China. *Land Degrad Dev* 16:73–85
- Gao H, Li R (2003) Analysis on regional soil and water loss based on ecological scale in Guizhou province. *Bull Soil Water Conserv* 3:116–118
- He T (2000) Status of soil and water loss and counter measures of ecological agriculture construction in Guizhou karst mountainous region. *J Soil Water Conserv* 5:28–34
- Hickey R (2000) Slope angle and slope length solutions for GIS. *Cartography* 29:1–8
- Huang CY (2006) Assessment of karst rocky desertification using the radial basis function network model and GIS technique: a case study of Guizhou province, China. *Environ Geol* 8:1173–1179
- Lee GS, Lee HS (2006) Scaling effect for estimating soil loss in the RUSLE model using remotely sensed geospatial data in Korea. *Hydrol Earth Syst Sci Dis* 3:135–157
- Lin C, Zhu A (1999) Study on soil erosion and prevention in karst mountainous region of Guizhou. *Res Soil Water Conserv* 2:109–113
- Liu Z (2004) Soil and conservation in China. Paper presented on the ninth international symposium on river sedimentation, Yichang, China, 18–21 October 2004
- Liu B, Xie Y, Zhang K (2001) Soil loss prediction model. China Science & Technology Press, Beijing
- Lu D, Li G, Valladares G, Batistella M (2004) Mapping soil erosion risk in Rondonia, Brazilian Amazonia: using RUSLE, remote sensing and GIS. *Land Degrad Dev* 15:499–512
- Oldeman LR (1994) The global extent of soil degradation. In: Greenland DJ, Szabolcs I (eds) Soil resilience and sustainable land use. CAB International, Wallingford
- Parysow P, Wang GX, Gertner G, Anderson AB (2003) Spatial uncertainty analysis for mapping soil erodibility based on joint sequential simulation. *Catena* 53:65–78
- Renard KG, Foster GR, Weesies GA, McCool DK, Yoder DC (1997) Predicting soil erosion by water—a guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE). Handbook no. 703. United States Department of Agriculture United States Government Printing Office, Washington, DC
- Van Remortel R, Hamilton M, Hickey R (2001) Estimating the LS factor for RUSLE through iterative slope length processing of digital elevation data within ArcInfo grid. *Cartography* 30:27–35

- Wang W (2001) Investigation of land erosion model of Houzhaihe catchment in Puding, Guizhou and its application. *Guizhou Geol* 2:99–106
- Wang J (2003) Land degradation and ecological rehabilitation in karst areas of Guizhou province, southwestern China. *Adv Earth Sci* 3:447–453
- Wang S, Liu Q, Zhang D (2004) Karst rocky desertification in southwestern China: geomorphology, landuse, impact and rehabilitation. *Land Degrad Dev* 15:115–121
- Wischmeier WH (1971) A soil erodibility nomograph for farmland and construction sites. *J Soil and Water Conserv* 26:189–193
- Wischmeier WH, Smith DD (1978) Predicting rainfall erosion losses: a guide to conservation planning. United States Department of Agriculture—handbook no. 537. United States Government Printing Office, Washington, DC
- Wu S, Zhu W, Su W, Li P, He W, Zhou Q (2005) Experiment on soil erosion and natural loss in karst area—a case in Jiuchang town, Xiuwen, Guiyang. *Carsol Sin* 3:202–205
- Xu Y, Zhou Q, Li S (2005) An analysis on spatial–temporal distribution of rainfall erosivity in Guizhou province. *Bull Soil Water Conserv* 4:11–14
- Yang Z (1999) Study on soil loss equation of cultivated slope land in Northeast mountain region of Yunnan province. *Bull Soil Water Conserv* 1:1–9
- Yang Z (2002) Study on soil loss equation in Jinsha River basin of Yunnan province. *J Mount Sci* 20(Suppl):1–9
- Yu B, Rosewell CJ (1998) Rainfall erosivity and its estimation for Australia's tropics. *Aust J Soil Res* 36:143–165
- Zhang D, Wang S, Zhou D (2001) Intrinsic driving mechanism of land rocky desertification in karst regions of Guizhou province. *Bull Soil Water Conserv* 4:1–5
- Zhang B, Xiao F, Wu H, Mo S (2006) Combating the fragile karst environment in Guizhou, China. *Ambio* 2:94–96
- Zhu A, Lin C, Yang H (1994) A study on synthetical evaluation influencing factor of soil and water loss in Guizhou mountainous areas. *J Soil Water Conserv* 4:17–24

RETRACTED ARTICLE