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Land use change and soil erosion in the Maotiao River watershed of Guizhou Province

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Abstract: Due to the extremely poor soil cover, a low soil-forming rate, and inappropriate intensive land use, soil erosion is a serious problem in Guizhou Province, which is located in the centre of the karst areas of Southwest China. In order to bring soil erosion under control and restore environment, the Chinese Government has initiated a serious of ecological rehabilitation projects such as the Grain-for-Green Programme and Natural Forest Protection Program and brought about tremendous influences on land-use change and soil erosion in Guizhou Province. This paper explored the relationship between land use and soil erosion in the Maotiao River watershed, a typical agricultural area with severe soil erosion in central Guizhou Province. In this study, we analyzed the spatio-temporal dynamic change of land-use type in Maotiao River watershed from 1973 to 2007 using Landsat MSS image in 1973, Landsat TM data in 1990 and 2007. Soil erosion change characteristics from 1973 to 2007, and soil loss among different land-use types were examined by integrating the Revised Universal Soil Loss Equation (RUSLE) with a GIS environment. The results indicate that changes in land use within the watershed have significantly affected soil erosion. From 1973 to 1990, dry farmland and rocky desertified land significantly increased. In contrast, shrubby land, other forestland and grassland significantly decreased, which caused accelerated soil erosion in the study area. This trend was reversed from 1990 to 2007 with an increased area of land-use types for ecological use owing to the implementation of environmental protection programs. Soil erosion also significantly varied among land-use types. Erosion was most serious in dry farmland and the lightest in paddy field. Dry farmland with a gradient of 6°–25° was the major contributor to soil erosion, and conservation practices should be taken in these areas. The results of this study provide useful information for decision makers and planners to take sustainable land use management and soil conservation measures in the area.

Keywords: land-use change; land-use type; soil erosion; Revised Universal Soil Loss Equation; Guizhou Province of China

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1 Introduction

The karst mountain region of Southwest China is one of the largest karst areas in the world, where karst landforms cover about 620,000 km^2, and the ecological environment is extremely fragile (Huang and Cai, 2009). In the past few years, owing to the irrational, intensive land use on this fragile karst geo-ecological environment, serious soil erosion has expanded at an overwhelming rate. The total area of soil erosion has reached 17.96×10^4 km^2, affecting 40% of the total land area. The area of moderate to strong erosion is about 6.61×10^4 km^2, accounting for about 37% of the total area (Wang *et al.*, 2004). The soil in karst areas forms very slowly and regolith with 1 cm thickness will take about 2000–8000 years. As a result, larger and larger surface areas have become nearly naked due to rapid topsoil loss, which is called “rocky desertification” (Zhang *et al.*, 2006) and becomes one of the most seriously ecological problems in China. 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. Many case studies and investigations related to soil erosion and rock desertification have been done in the karst mountains of Southwest China (Wang and Li, 2007; Liu *et al.*, 2008; Xiong *et al.*, 2009; Zhang *et al.*, 2011).

Soil erosion is also a relatively great concern in Guizhou Province, located in the center of Southwest China’s karst mountains, and about 73% of which is covered with typical karst landscapes (Zhang *et al.*, 2006). Guizhou Province is one of the least developed areas with the largest number of counties in poverty and the widest coverage of karst landscape in China. Pure carbonate rocks in Guizhou Province cover an area of 57,408 km^2, which account for 32.6% of the province. Owing to the great population pressure (a population density as high as 225.6 people per km^2 in 2007), and rugged topographic conditions (97% of its area covered by mountains and hills), unsustainable land-use practices such as deforestation and land reclamation, farming of steep slopes and overgrazing are common in Guizhou Province. At present, 81% of cultivated land in Guizhou Province is on a slope 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 1000 mm precipitation a year), and unsustainable land-use practices, Guizhou Province has one of the most severe soil erosion problems in China, with its total affected area reaching 44%. Soil erosion as well as the resultant rocky desertification, called “the cancer of the earth” in Guizhou Province, has caused so many disasters that it has been identified as the most severe environmental problem in this area. It is not only a major obstacle to the productive agriculture and livelihood in this area, but also has greatly aggravated the floods in the Yangtze River Valley. In recent years, many researchers have paid high attention to the study of the soil erosion and rocky desertification in Guizhou Province (Huang and Cai, 2006; Xu *et al.*, 2009; Peng *et al.*, 2011).

To address devastating environmental crisis and to improve human well-being, China has been implementing a serious of ecological rehabilitation projects, for example, the Natural Forest Protection Program (NFPP) in 1998 and the Grain-for-Green Programme (GFG) in 1999. The Grain-for-Green Programme is also called the Conversion of Cropland to Forests and Grassland Programme (Wang *et al.*, 2007). The main feature of this programme is the provision of free grain and cash payments for participating farmers if they convert cultivated and grazing land to forests and grassland (Long *et al*., 2006). Being the important ecological barrier of the the Yangtze and Pearl rivers upper reaches, Guizhou Province is unquestionably a significant area for the implementation of NFPP and GFG. Therefore, Guizhou Province has long been experiencing dramatic land-use change during the past three decades due to the initiation of the ecological protection projects and socio-economic development and has received more attention from the Chinese government and researchers (Department of Earth Science, Chinese Academy of Sciences, 2003; Wu *et al*., 2005; Zhou *et al*., 2007; Chen and Wang, 2008., Chen *et al*., 2010).

Erosion is one of the most significant forms of land degradation (soil truncation, loss of fertility, slope instability), greatly influenced by land use and management (Bini *et al*., 2006). A wide variety of research has reported that soil erosion is significantly related to land use (Del *et al*., 1998; Meng *et al*., 2001; Hessel *et al*., 2003; Fu *et al*., 2004; Bakker *et al*., 2005; Mutua *et al*., 2006; Sharma *et al*., 2011). Many researchers have used models and laboratory experiments to identify the relationship between land use and soil erosion. For example, Solaimani *et al.* (2009) explored the relationships between land use pattern, soil erosion and the sediment yield in Neka River Basin, using geographic information systems and EPM model. Meanwhile, there is also relevant research concerning soil erosion and land-use policy, management and planning (Hanson *et al*., 2004; Long *et al*., 2006; Xu *et al*., 2008). However, knowledge of the specific relationship between land use and soil erosion is limited in Guizhou Province. There is an increasing demand for examining the temporal and spatial dynamics of land-use change and soil erosion, and investigating the effects of land use on soil erosion in this typical area to provide a scientific basis for sustainable land-use management and soil conservation planning. Therefore, the Maotiao River watershed, as a typical agricultural area with severe soil erosion in central Guizhou Province, was chosen as a case study. The objectives of this study were: (1) to examine the dynamics of land-use change and soil erosion in the study area; (2) to identify the relationship between land use and soil erosion and (3) to provide useful information for decision makers to take appropriate land-use management and soil conservation measures in the study area.

2 Data and methods

2.1 Study area

The Maotiao River watershed (106°00′–106°53′E, 26°00′–26°52′N) is located in the central part of Guizhou Province, Southwest China and covers an area of 3109 km^2 (Figure 1). It is situated in a subtropical zone with a monsoonal climate. The annual average temperature is 14.2℃ and average annual precipitation is 1300 mm, most of which occurs between May and September. Elevation in the study area decreases from southwest to northeast with a variation from 775 to 1762 m above sea level. Limestone deposited in the Permian and Trias covers more than 80% of the watershed and karst landforms in the watershed develop well. Owing to the influence of humid subtropical monsoonal climate and extensively-exposed carbonate rocks, two main soil groups occur in the study watershed, namely, yellow soil and calcareous soil. Yellow soil, formed in humid subtropical mountainous areas or in plateau areas with evergreen broad-leaved 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. The watershed is a typical karst watershed with extremely fragile ecosystems. Agriculture is the main industry of the study area and the major agricultural crops are rape, rice, bean and maize. Land covers in the watershed have experienced remarkable changes due to the rapid development of socioeconomy over the recent years. 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.

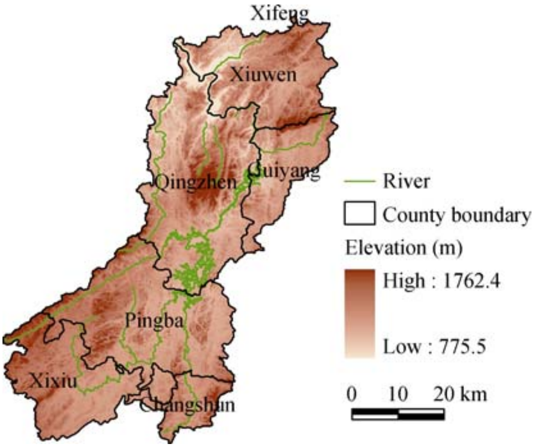

Figure 1 A map of the Maotiao River watershed in Guizhou Province, Southwest China

2.2 Data sources and processing methods

The materials used for the study included Landsat-MSS image (with a resolution of 57 m×57 m) in 1973 for the generation of 1973 land-use map, Landsat TM images (with a resolution of 30 m ×30 m) for the generation of 1990 and 2007 land-use maps, Digital Elevation Model (DEM) at a 1:50,000 scale for the generation of slope gradient and slope length, maps of soil at a 1:50,000 scale and soil data for the generation of soil erodibility factor K, the daily rainfall data of the meteorological stations in the study area during 1980–2007 for the generation of rainfall erosivity factor (R). The key GIS operations conducted included digitization, rasterization, interpretation, overlaying and map calculations of various map features.

2.2.1 Land use classification and data processing

The human-machine interaction interpretation of the satellite image was carried out under ARC/INFO GIS environment. For the geometric rectification and matching, DEM was introduced to correct the relief induced distortions with the geometric precision no less than 0.5 pixel. DEM was generated from the contour lines of the 1:50,000 topographical map in the study area. In view of the rugged and fragmental topography in the study area, four times field investigations were performed and 168 GPS points were acquired in the study area to guarantee the consistency and accuracy of interpretation. In the field investigation, verification of land-use type identified in the polygons was done by testing all the sampling sites representative of the various land covers, and the image characteristics and biophysical features at each sampling site were compared. In view of the discrepancy in resolution of images in the three years, Landsat-MSS images in 1973 were resampled with the same pixel size of 30 m×30 m as Landsat-TM images in 1990 and 2007. In addition, the topographical map at 1:50,000 based on the aerial photo recorded in 1973, which contained much valuable information on land covers of the study area, was employed in the interpretation of Landsat-MSS image in 1973.

Eleven land-use types, namely paddy field, dry farmland, forestland, shrubby land, other forestland (tea garden land etc.), grassland, water body, urban settlements, rural settlements, construction land mainly for transportation, mining and water conservancy facilities land, and rocky desertified land were identified and delineated in each map. The classification was then evaluated using Kappa index. The Kappa indices were 0.81, 0.86 and 0.86 respectively for the year of 1973, 1990 and 2007. In order to reveal the spatio-temporal characteristics of land use change, the land-use maps were overlaid with each other in the GIS environment by converting the three land-use vector format maps into raster format with a spatial resolution of 30 m×30 m using ESRI's ArcGIS spatial analyst module. Two land cover change maps between the three study periods were generated and the general characteristics of land cover changes were statistically analyzed and presented in a tabular form.

2.2.2 Evaluation of soil erosion

Owing to the lack of extensive data in the study area, a requirement for the available physically distributed model, the Revised Universal Soil Loss Equation (RUSLE) was chosen in this study. The RUSLE model is an empirical soil erosion model designed on the Universal Soil Loss Equation (Renard *et al.*, 1997), which has been extensively used to estimate soil erosion loss. The RUSLE can be expressed as:

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

where A is the average annual soil loss (t $\text{ha}^{-1}\,\text{y}^{-1}$), R is the rainfall-runoff erosivity factor (MJ mm $\text{ha}^{-1}\,\text{h}^{-1}\,\text{y}^{-1}$), K is the soil erodibility factor (t ha h $\text{MJ}^{-1}\,\text{ha}^{-1}\,\text{mm}^{-1}$), L is the slope length factor, S is the slope steepness factor, C is the cover-management practice factor, and P is the conservation supporting practice factor. 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. In this study, the rainfall-runoff erosivity was determined by calculating the monthly rainfall erosivity using the method described by Yu and Rosewell (1998). Rainfall data were collected from five meteorological stations within the watershed from 1980 to 2007. The average R values for meteorological stations were obtained by averaging the yearly values from 1980 to 2007 and the R-factor map was produced by Kriging interpolation in GIS. The monthly rainfall erosivity formula is expressed as:

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

where E_j is the monthly rainfall erosivity (MJ mm $\text{ha}^{-1}\,\text{h}^{-1}\,\text{y}^{-1}$), R_d is the daily rainfall, R_0 is the daily rainfall threshold causing erosion (in general, R_0 is 12.7 mm), and N is the number of days on which the precipitation corresponds to a monthly rainfall $\geqslant$12.7 mm. f = 1/12 is the frequency and ω is equal to 5π/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 1050 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.

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

$$\eta = 0.58 + 0.25P/1000 \tag{4}$$

The soil erodibility factor K represents the average long-term soil and soil-profile response to the erosive power associated with rainfall and runoff (Renard *et al.*, 1997), which is related to soil texture, organic matter content permeability, and other factors and is basically derived from soil types (Wischmeier, 1971). In this study, the value of the K-factor was calculated using the following formula (Renard *et al.*, 1997; Liu *et al.*, 2001):

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

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

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. Basic data for estimating soil erodibility were collected from soil samples in the study area and Guizhou soil produced by Agricultural Bureau of Guizhou Province (1980). The erodibility K factor was calculated for each soil mapping unit using formulas (5) and (6) in GIS.

The LS factor reflects the effect of topography on erosion in RUSLE (Lu *et al.*, 2004). In this study, the calculation of LS was calculated by the following formula (Wischmeier and Smith 1978):

$$LS = (\lambda/72.6)^n(65.41\sin^2\beta + 4.56\sin\beta + 0.065) \tag{7}$$

where λ is the slope length, β is the angle of slope in degrees, and n is a constant dependent on the value of the slope gradient: 0.5 if the slope angle is greater than 2.86°, 0.4 on slopes of 1.72° to 2.86°, 0.3 on slopes of 0.57° to 1.72°, and 0.2 on slopes less than 0.57°. 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 website (www.cwu.edu/_rhickey/slope/slope.html) was applied to generate an LS-factor grid map by inputting DEM dataset of the Maotiao River watershed, which was integer formatted.

The C-factor reflects the effects of cropping and management practices on soil erosion rates (Renard *et al.*, 1997), which varies with season and crop production system. 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). The land-use maps of the study area derived from the Landsat image in 1973, 1990 and 2007 as the basis for determining the C-factor values. Information on the cropping history (1990–2007) was collected to determine crop rotations. Knowledge of the crop types, and growth and harvest stages were obtained through field visits to the Maotiao River watershed. In addition, previous experimental results for the C-factor for cultivated land, forestland, shrubby land and grassland in southwest China were adopted (Yang, 1999, 2002; Wang, 2001; Cai *et al.*, 2000). Average C-factor values were assigned as attributes in the land use maps.

P-factor is the ratio of soil loss with a specific support practice to the corresponding loss with upslope and downslope tillage (Renard *et al*., 1997). According to field surveys and relevant literatures, 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. The previous experimental results for the P-factor for cultivated land in southwest China were adopted (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.

3 Results and analysis

3.1 Land-use change in the study area

According to the analysis of the three land-use maps in 1973, 1990 and 2007 (Figure 2), the area of the main land-use type for the three-time period was assessed (Tables 1 and 2). Land

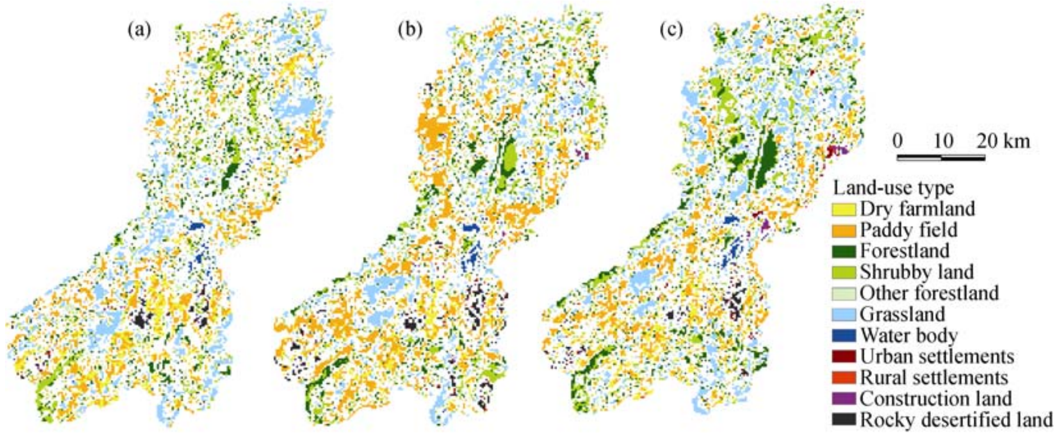

Figure 2 Gridded land-use types in the Maotiao River watershed in 1973 (a), 1990 (b) and 2007(c)

Table 1 Matrix of land-use change in the Maotiao River watershed during 1973–1990 (ha)

1973	1990												Change rate (%)
	PF	DF	FL	SL	OF	GL	WB	US	RS	CL	RL	Total	
PF*	30034	16752	858	1247	93	6547	291	53	741	286	859	57761	–18.95
DF	9128	34928	1804	2530	254	17596	326	185	1046	642	1366	69804	38.49
FL	711	2863	8704	4803	82	5424	103	0	46	16	144	22895	14.38
SL	1000	7838	9435	13629	70	18606	334	3	117	156	1965	53151	–41.35
OF	357	3166	360	1030	777	1559	119	1	45	5	41	7459	–80.01
GL	4629	29621	5000	7392	194	29904	549	15	518	629	5437	83886	–2.19
WB	305	445	22	116	12	484	4959	0	1	2	13	6359	5.2
US	47	4	0	0	0	3	0	226	0	18	0	298	62.7
RS	204	254	2	41	6	203	4	3	544	46	21	1329	135.25
CL	28	24	0	2	3	76	0	0	18	406	11	567	292.86
RL	372	778	2	382	0	1647	6	0	51	24	4657	7920	83.25
Total	46815	96673	26188	31172	1491	82048	6690	486	3126	2229	14513	311431	

*PF-Paddy field; DF-Dry farmland; FL-Forestland; SL-Shrubby land; OF-Other forestland; GL-Grassland; WB-Water body; US-Urban settlement; RS-Rural settlement; CL-construction land mainly for transportation and mining land; RL-Rocky desertified land

Table 2 Matrix of land-use change in the Maotiao River watershed during1990–2007 (ha)

1990	2007												Change rate (%)
	PF	DF	FL	SL	OF	GL	WB	US	RS	CL	RL	Total	
PF*	35946	3489	218	885	64	3469	250	693	1122	572	89	46796	5.57
DF	10240	51655	802	4013	320	26183	466	299	1439	719	601	96736	–31.21
FL	79	118	23728	1453	31	720	22	1	23	37	1	26213	43.32
SL	222	401	9733	15587	125	4709	54	0	182	74	109	31195	13.01
OF	105	327	7	5	866	114	5	0	40	18	2	1490	23.17
GL	2578	9697	3013	12355	355	51342	496	60	565	646	1004	82110	11.47
WB	54	211	50	48	28	120	6137	0	18	5	10	6681	11.50
US	2	1	0	0	0	2	0	470	0	6	0	481	229.35
RS	60	59	3	8	4	36	0	29	2918	4	5	3127	102.30
CL	6	47	3	10	1	103	0	31	0	2029	5	2236	84.56
RL	110	540	10	888	41	4733	19	0	19	17	8134	14510	–31.37
Total	49401	66544	37568	35253	1835	91531	7449	1583	6326	4127	9959	311574	

*PF-Paddy field; DF-Dry farmland; FL-Forestland; SL-Shrubby land; OF-Other forestland; GL-Grassland; WB-Water body; US-Urban settlement; RS-Rural settlement; CL-Transportation and mining land; RL-Rocky desertified land

use has changed significantly over the whole period from 1973 to 2007 in Maotiao River watershed. During the period from 1973 to 1990, the most dramatic change took place to construction land that has the highest increase of 292.86%. Dry farmland, forestland, water body, urban settlements, rural settlements, and rocky desertified land gained 26,869 ha, 3293 ha, 331 ha, 187 ha, 1797 ha, and 6594 ha, or at a rate of 38.49%, 14.38%, 5.2%, 62.7%, 135.25%, and 83.25%, respectively. In contrast, paddy field, shrubby land, other forestland, and grassland decreased by 10,946 ha, 21,979 ha, 5968 ha and 1838 ha at the same period, or at a rate of 18.95%, 41.35%, 80.01% and 2.19%, respectively. The lost of paddy field, other forestland and grassland were mainly changed into dry farmland, with 16,752 ha (29%), 3166 ha (42.44%) and 29,621 ha (35.31%), respectively. The lost shrubby land was mainly changed into grassland with 18,606 ha (35.01%). However, during the period 1990–2007, all the land-use types took an increasing trend except for dry farmland and rocky desertified land. By the end of 2007, paddy field, forestland, shrubby land, other forestland, grassland, water body, urban settlements, rural settlements, and construction land increased by 2604 ha (5.57%), 11355 ha (43.32%), 4058 ha (13.01%), 345 ha (23.17%), 9421 ha (11.47%), 768 ha (11.5%), 1102 ha (229.35%), 3199 ha (102.3%) and 1891 ha (84.56%), respectively. The changes of dry farmland and rocky desertified land were reversed, with a decrease of 31,092 ha (31.21%) and 4551 ha (31.37%), respectively. The lost dry farmland and rocky desertified land were mainly changed into grassland, with 26,183 ha (27.07%) and 4733 ha (32.62%). The results indicate that area of the land-use types for ecological use and human residence tends to increase, but the area of the land-use types for agricultural production tends to decrease. To a large extent, land-use change from 1973 to 2007 is characterized by a replacement of paddy field, dry farmland and rocky desertified land with forestland, urban and rural settlements, and construction land.

3.2 Soil erosion change in the study area

The GIS input layers were then multiplied, as described by 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. Figure 3 illustrates soil erosion distribution in the study area in 1973, 1990, and 2007. As can be seen in Figure 3, the most significant overall trend was a shift from slight erosion to more severe erosion and then a slight erosion. The average soil erosion rate increased from 30.88 t ha^{-1} y^{-1} in 1973 to 35.08 t ha^{-1} y^{-1} in 1990, and then decreased to 26.37 t ha^{-1} y^{-1} in 2007. The gross annual soil loss considerably varied from 960.38×10^{4} t y^{-1} in 1973 to 1089.5×10^{4} t y^{-1} in 1990 and 808.81×10^{4} t y^{-1} in 2007. With regard to the spatial variation, the northwestern part of the watershed, with some specific areas in excess of 200 t ha^{-1} y^{-1}, had more erosion than the southeastern part. The calculation results compare well with the other studies and local data, for example, an average of 25–30 t ha^{-1} y^{-1} in the Maotiao River watershed from the Agricultural Synthetical Regionalization Committee of Guizhou Province (1988). In addition, some research in this area has indicated that the change trend of soil erosion resulted from RUSLE is similar with that by using ^{137}Cs technology (Lu, 2005). These demonstrate it is a feasible approach to apply the GIS technology and RUSLE model to estimate soil erosion loss in Guizhou Province.

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 estimated soil loss was divided into five ordinal classes (Table 3). Most areas of the watershed (64.5% in 1973, 58.51% in 1990 and 67.17% in 2007) fell within the minimal and low erosion category during the period 1973–2007, which were

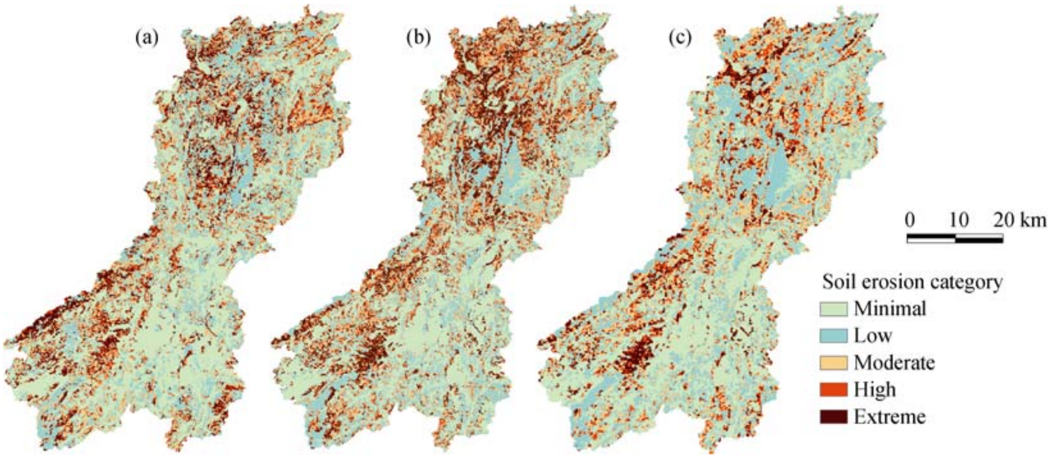

Figure 3 Spatial distribution of soil erosion in the Maotiao River watershed in 1973 (a), 1990 (b) and 2007 (c)

Table 3 Ordinal categories of soil erosion in the Maotiao River watershed in 1973, 1990 and 2007

Erosion categories	Numeric range (t ha^{-1} y^{-1})	1973		1990		2007		1973–1990		1990–2007	
		Area (ha)	%	Area (ha)	%	Area（ha）	%	Change area (ha)	Change percent (%)	Change area (ha)	Change percent (%)
Minimal	<5	101772.14	34.56	85229.19	30.05	110262.44	39.16	–16542.95	–4.51	25033.25	9.11
Low	5–25	88161.75	29.94	80705.00	28.46	78870.94	28.01	–7456.75	–1.48	–1834.06	–0.45
Moderate	25–50	43626.75	14.81	45336.69	15.99	40607.38	14.42	1709.94	1.18	–4729.31	–1.57
High	50–80	26311.69	8.93	30617.13	10.80	23787.56	8.45	4305.44	1.87	–6829.57	–2.35
Extreme	>80	34630.01	11.76	41729.38	14.71	28054.94	9.96	7099.37	2.95	–13674.44	–4.75

mostly seen in the southeast of the watershed. About 18.41%–25.51% of the watershed (20.69% in 1973, 25.51% in 1990 and 18.41% in 2007) was in the high to extreme erosion category, which was mostly found in the northwest of the watershed. From 1973 to 1990, the areas of minimal and low erosion category decreased by 4.51% (16,542.95 ha) and 1.48% (7456.75 ha), while the areas of moderate to high, and to extreme erosion category increased significantly at the same time, with an increase of 1.18% (1709.94 ha), 1.87% (4305.44 ha) and 2.95% (7099.37 ha), respectively. However, the change trend of soil erosion was reversed over the period 1990–2007. The area of minimal category significantly increased by 9.11 % (25,033.25 ha). In contrast, the areas of moderate, high and extreme erosion categories decreased by 1.57% (4729.31 ha), 2.35 % (6829.57 ha) and 4.75% (13,674.44 ha) at the same time, respectively.

3.3 Relationship between land use and soil erosion

3.3.1 Soil erosion of land-use type

The three maps of land use, soil erosion and slope conditions were overplayed in GIS to analyze the relationship between land use and soil erosion. Table 4 shows the soil erosion intensity of each land-use type of the watershed during the period 1973–2007. As can be seen, soil erosion also remarkably varied among land-use types. Erosion was most serious in the dry farmland and the lightest in paddy field. Significant differences existed in soil erosion rate reported with dry farmland being the largest, grassland ranked the second, and paddy field reported the smallest. With regard to the total soil loss amount, 51.38% of total soil loss occurred on dry farmland in 1973, 60.11% in 1990 and 45.47% in 2007, respectively. Grassland ranked the second, with 37.85% of the total soil loss in 1973, 33.81% in 1990 and 45.24% in 2007, respectively. It is obvious that soil loss mainly originates from dry farmland.

Table 4 Soil erosion rate and soil loss amount of different land-use types in the Maotiao River watershed

Land-use type*	Soil erosion rate (t ha^{-1} y^{-1})			Soil loss amount ($\times10^4$ t y^{-1})			Soil loss percent (%)		
	1973	1990	2007	1973	1990	2007	1973	1990	2007
Paddy field	0.17	0.18	0.16	1.00	0.83	0.80	0.10	0.08	0.10
Dry farmland	70.83	67.91	55.42	493.42	654.91	367.81	51.38	60.11	45.47
Forestland	7.49	8.41	8.21	17.13	21.90	30.68	1.78	2.01	3.79
Shrubby land	13.61	13.37	11.57	72.20	41.46	40.66	7.52	3.81	5.03
Other forestland	17.7	13.77	16.26	13.17	2.05	2.98	1.37	0.19	0.37
Grassland	43.4	45.01	40.04	363.46	368.35	365.88	37.85	33.81	45.24
Total	–	–	–	960.38	1089.5	808.81	100	100	100

* Soil erosion calculation of land-use types in this study did not include urban settlements, rural settlements, transportation, mining and water conservancy facilities land and water body, owing to their differences of underlying surface with arable land and ecological land. Rocky desertified land in this study means the areas with extensive exposure of the basement rocks, little vegetation cover and little soil to lose. Combined with the land-use characteristics of the study area and the objectives of the study, soil erosion of the six land-use types in Table 4 was calculated.

Dry farmland in the study area, most of which is situated on the hillside and some of which is on slopes with gradient of >25° undergoing conventional tillage rather than conservation oriented practices, has experienced most serious soil erosion. The soil erosion on dry farmland under different slope conditions was obtained by overlaying the two maps of land use and soil erosion. It can be seen that soil erosion was more often occurring on dry farmland with slope of 6°–15° over the period from 1973 to 2007, where the percentage of soil loss were 40.24% in 1973, 39.90% in 1990 and 37.05% in 2007, respectively (Table 5). Soil loss on dry farmland with slope of 15°–25° ranked second, with total soil loss being 28.29% in 1973, 27.16 % in 1990, and 30.39% in 2007, respectively. It is obvious that farmland with slope of 6°–25° is the major contributor to soil erosion and soil conservation measures should be taken in this area.

Table 5 Soil loss amount on dry farmland with different slope grades in the Maotiao River watershed

Slope grade (°)	1973		1990		2007	
	Soil loss amount ($\times10^4$ t y^{-1})	Soil loss (%)	Soil loss amount ($\times10^4$ t y^{-1})	Soil loss (%)	Soil loss amount ($\times10^4$ t y^{-1})	Soil loss (%)
⩽6°	78.61	15.93	126.30	19.29	61.87	16.82
6–15	182.83	37.05	289.57	44.22	147.99	40.24
15–25	149.95	30.39	165.12	25.21	104.04	28.29
25–35	62.26	12.62	58.16	8.88	40.52	11.02
35–45	15.92	3.23	13.99	2.14	11.67	3.17
> 45	3.85	0.78	1.77	0.27	1.72	0.47
Total	493.42	100.00	654.91	100.00	367.81	100.00

Table 6 shows the land-use type with different gradients of soil erosion from 1973 to 2007. Paddy field, forestland, shrubby land and other forestland were mainly dominated by minimal and low erosion category, which accounted for about 100%, 96%–98%, 85%–90% and 78%–86% of each land-use type total area over the period 1973–2007, respectively. In contrast, high and extreme erosion category mainly occurred in dry farmland, which accounted for about 37%–47% of its total area over the period 1973–2007, respectively. Conclusion can be drawn that dry farmland is the dominant land-use type causing soil erosion in the study area.

3.3.2 Effects of land-use change on soil erosion

RUSLE has been widely used around the world as a practical tool to predict rate of soil erosion. Among the five factors of RUSLE, K-factor and LS-factor, generally speaking, are relatively stable and changed a little during the period 1973–2007 within Maotiao River watershed. In view of the rainfall erosivity factor in the study area, it was reported that rainfall decreased from the 1970s to the 1980s and increased from the 1990s to the beginning of 2000 (Peng *et al.*, 2011), which was reversed with the changing trend of soil erosion. The cover-management (C-factor) and the supporting practice (P-factor), related with land-use types and management and representing the surface conditions, were perhaps the most important factors that caused soil erosion change in the Maotiao River watershed.

Land-use change has significant impacts on soil erosion accompanied with the change of the cover-management (C-factor) and the supporting practice (P-factor) in the study area during the period 1973–2007. In the ecologically fragile areas, high population pressure and

Table 6 Soil erosion categories of different land-use types in the Maotiao River watershed in 1973, 1990 and 2007

Land-use type	Erosion categories	1973		1990		2007	
		Area (ha)	Percent (%)	Area (ha)	Percent (%)	Area (ha)	Percent (%)
Paddy field	Minimal	57718.13	99.94	46749.06	99.94	49341	99.92
	Low	32.69	0.06	27.81	0.06	35.12	0.08
	Moderate	0.00	0.00	0	0.00	1.12	0.00
	High	0.00	0.00	0	0.00	0.375	0.00
	Extreme	0.00	0.00	0	0.00	0.81	0.00
	Total	57750.82	100.00	46776.87	100.00	49378.43	100.00
Dry farmland	Minimal	5009.69	7.19	6073.5	6.30	14425.1875	21.74
	Low	18709.56	26.86	26803.88	27.80	14990.9375	22.59
	Moderate	13327.69	19.13	19235.81	19.95	12193.9375	18.37
	High	11093.44	15.92	16087.31	16.68	9392.9375	14.15
	Extreme	21523.06	30.90	28232.26	29.28	15363.8125	23.15
	Total	69663.44	100.00	96432.76	100.00	66366.81	100.00
Forestland	Minimal	10883.13	47.64	10727.13	41.16	16461.625	44.04
	Low	11376.5	49.80	14483.31	55.57	19620.875	52.49
	Moderate	570.69	2.50	833.38	3.20	1251.8125	3.35
	High	14.06	0.06	18.69	0.07	40.87	0.11
	Extreme	0.19	0.00	0.19	0.00	2.435	0.01
	Total	22844.57	100	26062.7	100	37377.6175	100
Shrubby land	Minimal	14373.5	27.09	8434.56	27.21	11851.9375	33.73
	Low	31210.38	58.81	18306.25	59.05	19611.5625	55.81
	Moderate	6565.38	12.37	3845	12.40	3358.75	9.56
	High	827.69	1.56	386.81	1.25	297.9375	0.85
	Extreme	90.75	0.17	27.94	0.09	22	0.06
	Total	53067.70	100.00	31000.56	100.00	35142.19	100.00
Other forestland	Minimal	1722.56	23.15	475.25	31.89	634.9375	34.62
	Low	4097.25	55.06	807.63	54.19	813.75	44.37
	Moderate	1180.63	15.87	154.19	10.35	268.25	14.63
	High	335.38	4.51	37.44	2.51	83.06	4.53
	Extreme	105	1.41	15.94	1.07	34.18	1.86
	Total	7440.82	100.00	1490.45	100.00	1834.18	100.00
Grassland	Minimal	12065.13	14.41	12769.69	15.60	17547.75	19.20
	Low	22735.38	27.15	20276.13	24.77	23755.4375	25.99
	Moderate	21982.38	26.25	21268.31	25.98	23510.4375	25.73
	High	14041.13	16.77	14086.88	17.21	13953.1875	15.27
	Extreme	12911.00	15.42	13453.07	16.44	12621.125	13.81
	Total	83735.02	100.00	81854.08	100.00	91387.94	100.00

limitations imposed by ecological constraints may frequently result in some land-use practices that can be associated with environmental degradation (Hamandawana *et al.*, 2005). It was reported by Guizhou Statistical Bureau that the total population of the study area was less than 50×10^4 in 1973 and increased to 90×10^4 in 1990, with an increase rate of 80% over a 17-year period. According to household survey, the majority of the rural people were sticking in countryside and households of the study area made a living from farmland during the 1970s and the 1980s. In order to meet the survival need of increasing people, excessive deforestation and steep slope cultivation occurred in the study area under the condition of high population pressure, land scarcity, and poor economic performance. As can be seen from land use change analysis, dry farmland and rocky desertified land significantly expanded from 1973 to 1990, while shrubby land, other forestland and grassland significantly reduced at the same period. The lost shrubby land was mainly converted into grassland and grassland was mainly converted into dry farmland. Without the protection of vegetation cover, these lands were vulnerable to soil erosion and rocky desertification. As a result, damaging land use and reduced land cover have sharply accelerated soil erosion in the study area from 1973 to 1990, and the soil erosion rate, gross annual soil loss and areas of high to extreme categories remarkably enlarged from 1973 to 1990. Since the 1990s, a number of bio-remediation programs initiated by Chinese Government have been implemented in the study area in order to protect the ecological environment. In addition, rural non-farm employment has grown rapidly over the past two decades in the study area owing to the adoption of market principles. Households' income diversity has led to downward pressure on farmland and the farmers' awareness on environmental protection has been raised. As a result, the dry farmland and rocky desertified land in the study area significantly reduced during the period 1990–2007. In contrast, ecological land-use types such as forestland considerately increased at the same period. Therefore, the soil conservation capability has been greatly improved in the study area from 1990 to 2007. As a result, soil erosion remarkably diminished from 1990 to 2007 in the study area and soil erosion rate, gross annual soil loss and areas of high to extreme categories significantly decreased from 1990 to 2007.

4 Discussion and conclusions

(1) Land cover change directly affects ecological landscape functions and processes with far-reaching consequences for biodiversity and natural resources. The potential for surface runoff and soil erosion has been mostly affected by land use and cultivation (Van *et al.*, 2001). This study examined the temporal and spatial dynamics of land use change and its effect on soil erosion from 1973 to 2007 in Maotiao River watershed of Guizhou Province, centre of the karst areas of Southwest China. The study provides useful information for decision makers and planners to take sustainable land use management and soil conservation measures in the area.

(2) Significant change in land use occurred in Maotiao River watershed during the period from 1973 to 2007, i.e., the transformation from human-dominated exploitation, such as deforestation, steep-slope farming etc., to equally-emphasized development and ecological conservation. The severity of soil erosion obviously accelerated from 1973 to 1990 with the increase of dry farmland owing to expansion of excessive deforestation and steep slope cultivation, and then remarkably diminished with the increase of area of land-use types for ecological purpose because of the implementation of environmental protection programs from the 1990s. Significant variation in soil erosion degree also existed among land-use types reported with dry farmland being the largest and paddy field the smallest. Dry farmland with slope of 6°–25° was the major contributor to soil erosion. It is concluded that sloping farmland should be terraced on a large scale and farmland with a slope over 25°

should be converted to forest. Conservation practices on dry farmland with a gradient of 6°–25° such as terracing and contour tillage are urgently needed also.

(3) The methods and results described in this article are valuable for understanding the relationship between land use and soil erosion and are useful for managing and planning land use that will avoid soil erosion. This study indicates that it is feasible to apply the remotely sensed data, GIS and the RUSLE model to evaluate the effects of land use on soil erosion at a larger watershed scale in Guizhou Province.

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