Soil Erosion Features by Land Use and Land Cover in Hilly Agricultural Watersheds in Central Sichuan Province, China

Zhongdong Yin, Changqing Zuo, Liang Ma

Soil Erosion Features by Land Use and Land Cover in Hilly Agricultural Watersheds in Central Sichuan Province, China

Zhongdong Yin[1], Changqing Zuo[2], Liang Ma[3]

[1] Key Laboratory of Soil & Water Conservation and Desertification Combating, Ministry of Education, Beijing Forest University, 100083 Beijing, China;

[2] Research Center on Soil and Water Conservation of the Ministry of Water Resources, Beijing 100044, China;

[3] Key Laboratory of Water Resources and Environment of Shandong Province, Water Resources Research Institute of Shandong Province, Jinan 250013, China

Yaayp@sina.com

Abstract: The study assessed soil erosion features in hilly agricultural watersheds in central Sichuan Province, China. Relationships among area percentages of land covers, soil erosion modulus, soil loss rate, and area percentage of erosion in the watersheds were examined by multivariate regression analysis. The first two regression models were constructed with area percentages of land covers as independent variables and soil erosion modulus or soil loss rate as dependent variables. The third one was built with soil erosion modulus as dependent variable and area percentage of the four erosion intensity classes as independent variables. Results showed that for flat and slope fields, forests, shrubs, abandoned fields, and other land covers, percentage of soil loss were -6%, 89%, -4%, 11%, 12%, and -3%, and area percentage of erosion were 1%, 72%, 0%, 18%, 9%, and 0%. The slope fields were the main source of soil loss. In contrast, flat crop fields, forests and other land covers could conserve soil from eroding. Changing land covers and reducing area of slope fields to 7% and of abandoned fields to 0%, were proposed as a management strategy for soil conservation in the watersheds. As completion of the land cover conversion, percentages of the land covers should be 35%, 7%, 5%, 45%, 0%, and 8% for flat and slope fields, forests, shrubs, abandoned fields, and other land covers. The study suggested that statistical models could be successfully used for processing inventory data for make decisions in soil conservation.

Keywords: land use, soil erosion, Watersheds

1. Introduction

Hilly land in central Sichuan Province, China is the major agricultural production area in Sichuan and in the Yangtze River upstream, supporting approximate 75% of population in the province. Around 1950's and1960's, forests were harvested and the forested lands were converted to crop fields under increasing population pressure (Xu, 2000). During this period of time, the rates of deforestation and expanding of agricultural fields reached the pike. Consequently, the land cover conversion contributed to exposure of purple shale, which was vulnerable to weathering, and thereby caused serious soil erosion in the region with an soil erosion modulus of 4, 000 – 7, 000 t/km^2 • a. As massive soil particles were transported into the Yangtze River, soil fertility was declined. Consequently, agricultural productivity and local economics were influenced severely.

In order to conserve soil from erosion, key soil and water conservation projects in the upper and middle reaches of the Yangtze River (KSWCPUMRYR) has been in place for 20 years. Including central Sichuan province, it has been implemented in 7 regions across 10 provinces. It is one of the largest projects in China in ecological and environmental conservation. The goal of this project is to conserve soil and prevent soil from eroding at watershed scale through changing proportion of land covers in the watersheds. Therefore, analysis of relationships of land covers and soil erosion features could supply scientific information for successful implementation of the project.

Relationships of land cover and soil erosion have been studied extensively. Most studies have demonstrated that soil erosion is correlated to land-use type (Kosmas et al., 1997；Cerdan et al., 2002; Bakker et al., 2008). For instance, soil erosion modulus in abandoned fields (De Santisteban et al., 2006；Kakembo and Rowntree, 2003) is the highest, and then followed by cultivated land (Ge et al., 2007；Martinez-Mena, et al., 2008). In contrast, soil erosion modulus in forested land is much lower than cultivated lands (Hou et al., 2007；Cox et al., 2006), even in some cases, the soil loss in forested land is less than 10% of the total loss (Fox and Papanicolaou, 2008). However, the loss in forested land varies to a great extent by types of forests (Andreu et al., 1998). The main research methods in exploring the relationships between soil erosion and land cover consist of remote sensing (Pandey et al., 2007; Huang et al., 2007), tracer element (Song et al., 2003; Fox and Papanicolaou, 2007), and field investigation (Hartanto et al., 2003). Advantage of these methods is the high accuracy of the collected data, but most results from the data are site-specific. Applying statistical methods in studying relationships between soil erosion and land cover at large sale may be an alternative approach as adequate sampling data are collected. Therefore, the goal of this study is to analyze relationships of land covers with soil erosion features in agricultural watersheds using statistical modeling approaches. The watersheds located in hilly lands, with crop coverage greater than 60%, in four cities and 13 counties in Sichuan Province, China (Fig. 1).

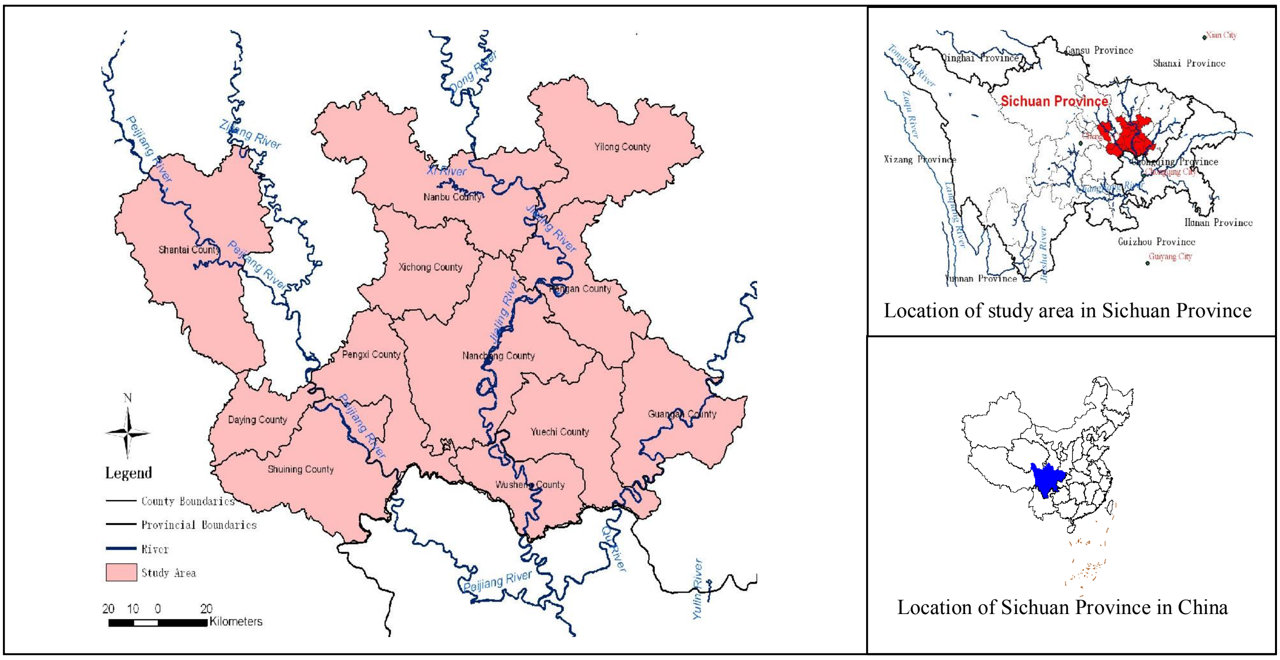

Fig. 1 Study area in central Sichuan Province, China

2. Methods

2.1 Study area

The hilly land in central Sichuan province is located in central part of Sichuan Basin, north of the Yangtze River, south of Jiange, Cangxi, and Yilong Counties, east of Longquan Mountain, and west of Hua Ying Mountain, and across 9 cities and 48 counties. The region occupies a total land area of 120 thousand km^2, with 29.5% cultivated land, 21.3% forestland, and 7.5% water bodies. The low hilly land occupies 21.4% of the purple soil region, mid-hilly 25.5%, and low mountain 25.5% (State Land Bureau of Sichuan province, 1989).

In the purple soil hilly land region, elevation with a range of 300-700m decreases gradually from north toward south. The soil is mainly from purple-red mudstone and sand-stone formed in Mesozoic period. This region has a subtropical humid climate characterized by average annual temperature about 17ºC, an annual average precipitation of 1000 mm, reaching the pikes between May and September, and about 280 - 330 non-frost days.

In Sichuan, erosion area and amount of soil loss account for 70% of the total areas and loss in the Yangtze River upstream. Hilly land in central part of the province is suffering the severest soil erosion, where erosion area and soil loss comprise 21.19% and 24% of the totals in the entire upstream of the river. Intensity of soil erosion reaches class moderate and above it, and soil erosion modulus climbs up to $3000t/km^2 \cdot a$ as remotely sensing data reveal（China PRC, 2002）.

2.2 Data Collection

The data for this study were collected by following standard methods in “Annual Inspection and Evaluation Regulations of KSWCPUMRYR” and “Detailed Inspection and Evaluation Regulations Enforced as Completion of KSWCPUMRYR.” First of all, the land covers were classified into five categories of crop, forest, pasture, abandoned land, and others, and then area percentage of each land cover was calculated. After than, the land cover was further classified into 13 classes including paddy fields , terrace, slope fields with slope less than 25º and greater than 25º, forests, shrubs, sapling/seedling forests, orchards, abandoned land, pasture, water, wastelands, and others. In reality, the first land classification scheme was too broad and not practicable. As the area fractions of the 13 classes were used to develop a model for simulation of the relations between land cover and soil erosion, the model did not fit the data well. Therefore, we combined the original 13 land cover classes into six: flat crop fields (including paddy fields and terraces), slope fields（include slope fields with slope less than 25º and greater than 25º), forests, shrubs (consist of shrubs, sapling/seedling forests, and orchards), abandoned land (comprise abandoned land and pasture), and others (include water, wastelands, and others).

3. Model Development

Relationships between soil erosion and land cover were analyzed by constructing regression models with variables of absolute area or area fraction of land covers in watersheds and total soil loss from the watersheds. A preliminary study showed that a satisfied result could be achieved as absolute area of each land cover was used. But this approach did not consider effects of watershed size on amount of soil loss. If area percentages of land covers were employed, then the effects of watershed areas on total soil loss could be minimized. However, adding or removing independent variables in regression analysis could impact the modeled relations to a great extent.

The first two multivariate regression models were constructed with area percentages of land covers as independent variables and soil erosion modulus or soil loss rate as dependent variables. The third model was constructed with soil erosion modulus as dependent variable and area percentage of the four erosion intensity classes as independent variables. All statistics analysis were conducted by running software SPSS.

In the regression equation $Y = b_1X_2 + b_2X_2 + \ldots + b_iX_i + \ldots + b_nX_n$, Y was soil erosion modulus (t/ $km^2 \cdot a$), and X stood for percentage area of land covers with subscript *i* representing types of land cover. Percentage of soil loss for a land cover (P) in a watershed was computed by the equation 1:

$$P_i = \frac{b_i X_i}{\sum_{i=1}^{6} b_i X_i} \qquad (1)$$

The percentage of soil loss for a land cover in all 40 watersheds was computed by the equation 2:

$$\overline{P}_i = \frac{\sum_{j=1}^{40} b_i X_{ij}}{\sum_{i=1}^{6} \sum_{j=1}^{40} b_i X_{ij}} \qquad (2)$$

where j was index of the watersheds, from 1 to 40.

The acceptable maximum area percentage of slope fields for soil conservation was computed by equation 3:

$$P = 500/b \qquad (3)$$

where b was the regression coefficient of slope fields.

4. Results

4.1 Soil erosion in the watersheds

Average area of the 40 watersheds was 31.03 km^2 with 35% flat crop field, 36% slope fields, 5% forests, 11% shrubs, 5% abandoned fields, and 8% other land covers. The average annual soil loss in the watersheds was 79187t, with average soil erosion modulus of 2562 $t/km^2 \cdot a$. Soil erosion modulus in 16 watersheds was between 500 and $2500t/km^2 \cdot a$, in 23 watersheds between 2500 and $5000t/km^2 \cdot a$, and only in one watershed between 5000 and $8000t/km^2 \cdot a$. In the study area, 51.2% land area did not show apparent soil erosion. In contrast, on 48.8% eluding land, the percentage area of light, moderate, intense and above erosion accounted for 9.3%, 19.1%, and 20.4% (Table 1).

Table 1 Soil erosion characteristics by erosion intensities

	Land area percentage	Average soil erosion modulus	Average percentage of soil loss	Reduction of soil loss[b]
	(%)	($t/km^2 \cdot a$)	(%)	(%)
insignificant[a]	51.2%	-397.78	-7%	
Light	9.3%	1639.95	6%	4%
Moderate	19.1%	5000.00	34%	31%
intense and above	20.4%	9119.12	67%	64%

[a]Insignificant erosion denoted the erosion class for which soil erosion modulus was less than $500t/km^2 \cdot a$

[b] Reduction of soil loss was the percentage of soil loss after to before the conservation. After the conservation, the soil erosion modulus was decreased to $500t/km^2 \cdot a$.

4.2 Soil erosion by erosion intensities

A regression equation between soil erosion modulus and area percentage of the four class of erosion intensity was constructed and expressed below:

$$Y = -397.78X_1 + 1639.95X_2 + 5000X_3 + 9119.12X_4 \quad R^2 = 0.761 \tag{4}$$

Y was soil erosion modulus in $t/km^2 \cdot a$, X_1-X_4 were percentage areas of the four erosion intensity classes: insignificant erosion, light, moderate, intense and above.

The equation showed that soil erosion modulus differed by erosion intensity. The soil erosion modulus rose with increasing erosion intensity. For the intense and above erosion as well as moderate intensity, percentages of soil loss were 67% and 34%. On the contrary, for the light intensity, the erosion area and rate were low (6%).（Table 1）

Among all 40 watersheds, soil loss in 32 watersheds was mainly due to intense erosion, and only in eight watersheds, the loss was primarily from the moderate erosion intensity. The percentage of soil loss for erosion intensity of light, moderate, intense and above varied by watersheds and presented wide ranges of 0% - 21%, 8% - 100%, and 11% - 98% for the three intensities. In contrast, the retained soil on insignificant erosion land was 3% - 23%.

4.3 Area percentage of soil erosion by land covers

The regression model with soil loss rate as dependent variable and area percentage of flat crop field (X_1), slope fields (X_2), forests (X_3), shrubs (X_4), abandoned fields (X_5), and other land covers (x_6) as independent variables was constructed and expressed below:

$$Y = 0.01X_1 + 0.99X_2 + 0.78X_4 + X_5 \quad \text{Where } R^2 = 0.936. \tag{5}$$

The model was constructed by setting ranges of regression coefficients between 0 and 1. Forests and other land covers were excluded from the model owing to the preset regression conditions. Based on regression coefficients, the area percentage of soil loss for slope fields was the highest (72%), and then followed by forests (17%), abandoned fields (10%), and flat crop fields (1%), indicating that area of soil loss on slope fields was the highest, and prevention erosion on slope fields should the priority of soil conservation. In addition, the soil erosion rate showed that 100% of abandoned fields experienced soil erosion, then followed by slope fields (99%), shrubs (78%), flat crop fields (1%), forests (0%), and other land covers (0%)。(Table 2)

Table 2 Soil erosion by land covers

Land cover	Land area percentage (%)	Soil erosion modulus ($t/km^2 \cdot a$)	soil loss rate %	area Percentage of erosion %	Percentage of erosion %	Reduction of soil loss[a] %	structure design %
Flat crop fields	35%	-458.27	1%	1%	-6%		35%
Slope fields	36%	6410.80	99%	72%	89%	82%	7%
Forests	5%	-2083.89	0%	0%	-4%		5%
Shrubs	11%	2668.43	78%	18%	11%	9%	45%
Abandoned fields	5%	6639.33	100%	9%	12%	21%	0%
Others	8%	-759.60	0%	0%	-3%		8%

[a] Reduction of soil loss was the percentage of soil loss after to before the conservation. After the conservation, the soil erosion modulus was decreased to or less than $500t/km^2 \cdot a$.

In the 40 watersheds, area percentage of soil loss in slope fields was the highest. Range of the area percentages for slope fields, shrubs, abandoned fields, and flat crop fields were 52% - 96%, 4% - 39%, 5% - 26%, and 0.3% - 2%.

4.4 Soil erosion modulus by land covers

The regression equation between soil erosion modulus and percentage area of the different land covers was built and expressed below:

$$Y = -458.273X_1+6410.798X_2-2083.886X_3+2668.428X_4+6639.325X_5-759.599X_6 \quad (6)$$

$$R^2 = 0.574$$

Where, X_1 through X_6 represented area percentage of flat crop field, slope fields, forests, shrubs, abandoned fields, and other land covers in the watersheds. The equation revealed that soil loss was mostly from slope fields where percentage of soil loss reached 89%, then followed by abandoned fields (12%) and forests (11%). The remaining land covers contributed about 13% of soil loss. Among all the land covers, percentage of soil loss in slope fields was the highest (Table 2). The percentage ranged by land covers with 67% - 121% for slope fields, 2% - 37% for shrubs, and 0% - 29% for abandoned fields. Even though the soil erosion modulus in abandoned fields was the highest, but the soil loss from the land was low because of small area fraction in the watersheds.

5. Discussion

5.1 Methods of studying relations between soil erosion and land use

Many studies have demonstrated that soil erosion modulus varies by land covers of crop, forests, uncultivated lands (Vacca et al., 2000；López-Vicente et al., 2008; Capolongo et al., 2008; Zhang et al., 2003; McDonald et al., 2002). The applied research methods mainly include remote sensing, field observation, and isotope tracer. These methods have their own advantages or disadvantages. For instance, remote sensing techniques are appropriate for assessing large area soil erosion. The land covers derived from remote sensing is very close to the field investigation. However, models such as USLE, SWAT, and WEPP are also required for studying soil erosion (Pandey, et al., 2007; Baban and Yusof, 2001； Demissie et al., 2004; Catani et al., 2002; Cochrane and Flanagan, 1999). These methods did not directly target on soil erosion as field investigations and are complicated for applications.
The field investigations can accurately measure the amount of soil loss. However, the field investigations usually do not cover the all land as the soil conservation regulations require. Therefore, the research activities cannot supply practical information for land management and soil conservation (Okoba and Sterk, 2006). In addition, sampling sites are often too few to represent characteristics of soil erosion for large area.
However, government inventory data covering the entire watersheds collect data from enormous field sites. Therefore, accuracy of the data is not high enough as the data collected from fixed plots. Therefore, errors in the inventory data have to be minimized by using appropriate research methods, such as fixed plots. It necessities to explore which method is the best.

5.2 Soil erosion by erosion intensities

This study showed that soil erosion modulus varied by erosion intensity, implying that the various strategies for soil conservation could be taken for the specific soil erosion condition. In addition, the rates of soil loss for moderate and intense erosion intensity were much higher than the lowest limits in the Standards for Classification and Gradation of Soil Erosion proposed by the Ministry of Resources of the People's Republic of China. Therefore, the conservation measures should be enhanced based on the results from this study.
This study indicated that percentages of soil loss varied greatly by erosion intensities. The percentage for intense and above erosion intensity reached 67%, which was very close to the loess soil erosion (Pan and Dong, 2006). If soil erosion on the land with intense and above erosion intensity were controlled to insignificant erosion intensity (<500t/km^2·a), then soil loss could reduce 64%, and the average soil erosion modulus might be decreased to 932t/km^2·a. Therefore, controlling intense and above soil erosion could apparently reduce soil loss in the watersheds. Strategy of controlling intense and above soil erosion should be addressed as the priority in KSWCPUMRYR. Percentage of soil loss on moderate erosion land (34%) was lower than it on the intense and above erosion land. If the moderate erosion were controlled to the insignificant erosion intensity, then soil erosion modulus could be reduced to 1776t/km^2·a.
Even though the reduction of soil loss from controlling moderate erosion was much lower than it from the intense and above erosion, the moderate erosion had to be prevented for meeting the criterion of controlling erosion to insignificant erosion intensity in the watersheds. For light erosion, both the

erosion area and the soil erosion modulus were lower than those of the moderate and sever erosions, and the soil loss was only 6% of the total loss in the watersheds. After completion of conserving soil from intense and moderate erosions, even the light erosion was not be conserved, the soil erosion modulus in the watersheds could be reduced to $149/km^2$•a. Therefore, the study suggested that it was not necessary to protect light erosion land. However, due to the possible conversion of the light to moderate erosion and the difficulties in controlling soil loss from moderate erosion, therefore, simple measures, such as enclosing, were recommended for the conservation. For insignificant erosion, it was not necessitated to apply any conservatory measures.

5.3 Area percentage of soil erosion by land covers

Soil loss rate in abandoned land in the watersheds reached to 100%, implying soil erosion on the land should be conserved firstly. The land was vulnerable to soil erosion owing to low vegetation coverage, high slope degree, and low fertility. In terms of amount of soil loss and erosion area, which land, shrubs or abandoned fields, should be conserved firstly have to be determined according to specific situations on the watersheds.

In terms of erosion areas, the sequential priority on soil conservation should be slope fields first, then followed by shrubs, and abandoned fields. However, in some watersheds, the erosion area of abandoned land was greater than that of shrubs. Therefore, conservation of abandoned land should be set earlier than forests.

5.4 Soil erosion rate by land covers

The typical feature of land cover in the study area is the low rate of forest coverage (5%) caused by population pressure and deforestation in 1950's and 1960's (Xu, 2000). The dominant agricultural land cover was formed at this period of time. As the region was encompassed in the KSWCPUMRYR, the soil has been conserved through changing the land use and land covers by following polices proposed by KSWCPUMRYR.

The study revealed that in the purple soil region in central Sichuan province, the soil erosion modulus varied greatly with land covers. In slope fields, the average soil erosion modulus was $6410t/km^2 \cdot a$, which is similar with the values by previous studies (Shi, 1999； Cui et al., 2008). In the slope fields, the percentage of soil loss was 89%, and area percentage of soil loss was 72%, which were greater than the values by Cui et al.(2008) and Hua et al.(2007). The possible reason is that the studied watersheds are agricultural land dominant, and amount and area of soil loss are great too.

This study demonstrated that abandoned fields experienced intense soil erosion, which is in agreement with previous studies (De Santisteban et al., 2006; Lesschen et al., 2007). In terms of soil erosion modulus, abandoned fields should be conserved firstly. The results in this study also implied that flat crop field, forest, and other land covers had the ability reducing soil erosion. The other land covers consisting of water bodies and urban area could decrease soil erosion as Wu et al. (2007) demonstrated. However, other lands are not for crop productivity, area of these land covers cannot be expanded on the bases of the land resist to soil erosion. In addition, Hou et al.(2007) reported that cultivated land located at the foot of hills and paddy fields were areas for sediment deposition. In terms of percentage of soil loss, soil conservation should start on slope fields first, and then on shrubs, and abandoned fields.

5.5 Strategies of changing land covers for soil conservation

Based on soil erosion modulus on various land covers, the upper limits of land area for different covers could be calculated by regression equation 2 as the soil erosion modulus was set as 500 t/ km^2·a. Owning to small area of abandoned fields and low soil erosion modulus of forested lands in the region, the calculated values was actually for slope fields. The computed upper limit of 7% for hilly crop land indicated that 29% slope fields should be converted to other uses according to the average percentage of slope fields in all the watersheds. In addition, on 5% abandoned fields and 11% other land covers, the soil loss rates were greater 500 t/ km^2·a too. The shrub lands are not needed to be converted but conservation measures are required to protect soil from eroding. The economic and ecological benefits of abandoned fields are not high, therefore, the cover should be converted. Overall, for most watersheds, about 34% of land cover should be converted, most of which are occupied by slope fields and abandoned fields.

When the slope fields and abandoned fields are planning to be converted to other uses, the conversion strategies should consider soil erosion. The slope fields should be converted to flat crop fields, shrubs, or other land uses. Flat crop fields along with the remained 7% slope fields already accounted for 42% of the total watershed area, implying this type of land cover does not need any changes. The percentage of forests could be increased to 45% through afforestation and planting fruit trees (Table 2). After land cover changes, the soil erosion modulus could be changed to 1324 t/ km^2·a. However, the soil erosion modulus on 7% the slope fields and 45% shrubs were still greater than 500t/km^2·a. The soil erosion on the left 7% slope fields could be reduced by planting vegetation fence, applying tillage practices, or, construction of some engineering structures (e.g. small ditches). In addition, the soil erosion modulus could be gradually declined as forests grow to mature.

6. Summary and Conclusion

Quantitative analysis of effects of land covers and erosion loss on soil erosion modulus, percentage of soil loss, and area percentage of soil loss at watershed scale can supply information to policy-makers for soil conservation. Analysis of inventory data with statistical methods for soil erosion is a good approach to study erosion in multiple watersheds, and the results could be a good representation of the erosion for large area. This research studied features of soil erosion in response to various land use and land cover, as well as divergent erosion intensity by constructing regression models among soil erosion modulus, area percentage of the land covers in 40 watersheds. Results showed that for the four classes of erosion intensity of insignificant erosion, light, moderate, and intense and above erosions, the soil erosion modulus were -397.78t/km^2·a, 1639.95t/km^2·a, 5000.00t/km^2·a, and 9119.12t/km^2·a, percentage of soil loss were -7%, 6%, 34%, and 67%, and the percentages in all watersheds varied at a range of -3% - -23%, 0% - 21%, 8% - 100%, and 11% - 98%. In 80% watersheds, soil loss is mainly from intense erosion, and for the remains, it is from moderate erosion. For flat and slope fields, forests, shrubs, abandoned fields, and other land covers, the soil erosion modulus were 458.27t/km^2·a, 6410.8t/km^2·a, -2083.89t/km^2·a, 2668.43t/km^2·a, 6639.33 t/km^2·a, and -759.6 t/km^2·a, percentage of soil loss were -6%, 89%, -4%, 11%, 12%, and -3%, and area percentage of erosion were 1%, 72%, 0%, 18%, 9%, and 0%. The slope fields were the main source of soil loss, and then followed by abandoned fields, and shrubs. In contrast, other land covers could conserve soil from eroding. Changing land covers, reducing area of slope fields to 7% and of abandoned fields to 0%, were proposed as a management strategy for soil conservation in the watersheds. As completion of the conversation, percentages of the land covers should be 35%, 7%, 5%, 45%, 0%, and 8% for flat and slope fields, forests, shrubs, abandoned, and other land covers. As forests growing to mature, the tillage practices, reforestation, and constructing soil conservation measures could reduce soil erosion.

Acknowledgements

This study was sponsored by the Open Projects Foundation of Key Laboratory of Soil and Water Conservation & Desertification Combat（Beijing Forest University）,Ministry of Education, “Modeling for soil erosion control process on “Changzhi” Project” (201006)；the National Basic Research Program of China (No. 2007CB407207-1)； the Fundamental Research Funds for the Central Universities(BLYX200927)； Key Projects in the National Science and Technology Pillar Program in the 11th Five Year Plan Period(2009BADC6B06), the Governmental Public Industry research Special Funds for Projects（200901049）.

References

1. Andreu, V., Rubio J. L., Gimeno-García, E., Llinares, J. V., 1998. Testing three Mediterranean shrub species in runoff reduction and sediment transport. Soil Till. Res. 45, 441-454.
2. Baban, S.M.J., Yusof, K.W, 2001. Modelling soil erosion in tropical environments using remote sensing and geographical information systems. Hydrolog Sci. J. 46,191-198.
3. Bakker, M.M., Govers G., van Doorn, A. , Quetier, F., Chouvardas D., Rounsevell, M. , 2008. The response of soil erosion and sediment export to land-use change in four areas of Europe: The importance of landscape pattern. Geomorphology. 98,213-226.
4. Capolongo, D.,Pennetta, L.,Piccarreta, M., Fallacara, G., Boenzi F., 2008. Spatial and temporal variations in soil erosion and deposition due to land-levelling in a semi-arid area of Basilicata (Southern Italy). Earth Surf. Proc. Land. 33, 364-379.
5. Catani, F., Righini, G., Moretti, S., Dessena, M.A., 2002. Remote sensing and GIS as tools for the hydro-geomorphological modeling of soil erosion in semi-arid Mediterranean regions. MIS 2002 Third International Conference on Management Information Systems Incorporating GIS and Remote Sensing. WIT Press, Southampton, 43-52.
6. Cerdan,O., Le Bissonnais, Y., Couturier, A., Saby, N., 2002. Rill erosion on cultivated hillslopes during two extreme rainfall events in Normandy, France. Soil Till. Res. 67, 99-108.
7. China PRC, 2002. The proclamation of the national soil and water loss by Ministry of Water Resources 2001. http://www.swcc.org.cn/
8. Cochrane, T. A., Flanagan, D. C., 1999. Assessing water erosion in small watersheds using WEPP with GIS and digital elevation models. J. Soil Water Conserv. 54, 678-685
9. Cox, C.A., Sarangi, A., Madramootoo, C.A, 2006. Effect of land management on runoff and soil losses from two small watersheds in St Lucia. Land Degrad. Dev. 17, 55-72.
10. Cui, P., Wang, D.J., Fan, J.R., Wang, Y.K., He X.B., Zhu, B., Wei, F.Q., Wang, G.X., 2008. Current status and comprehensive control strategies of soil erosion for the upper Yangtze and other rivers in the Southwestern China. Science of Soil and Water Conservation, 6, 43-50.
11. De Santisteban, L.M., Casali, J., Lopez, J.J., 2006. Assessing soil erosion rates in cultivated areas of Navarre (Spain). Earth Surf. Proc. Land. 31,487-506.
12. Demissie, T., Storm, D.E., White, M., 2004. A GIS-based watershed modeling and water resources use

optimization under dynamic changing land use/land cover conditions. ASAE Annual International Meeting 2004. American Society of Agricultural and Biological Engineers, 1473-1475.

13. Fox, J.F., Papanicolaou, A.N, 2007. The use of carbon and nitrogen isotopes to study watershed erosion processes. J. Am. Water. Resour. As. 43, 1047-1064.
14. Fox, J.F., Papanicolaou, A.N, 2008. An un-mixing model to study watershed erosion processes. Adv. Water Resour. 31,96-108.
15. Ge, F.L., Zhang, J.H., Su, Z.A., N, X.J., 2007. Response of changes in soil nutrients to soil erosion on a purple soil of cultivated sloping land. Acta Ecologica Sinica, 27, 459-463.
16. Hartanto, H., Prabhu, R., Widayat, A.S.E., Asdak, C., 2003. Factors affecting runoff and soil erosion: Plot-level soil loss monitoring for assessing sustainability of forest management. Forest Ecol. Manag. 180,361-374.
17. Hou, J.C., Li, Z.B., Li, M., 2007. Preliminary study on spatial distribution of soil erosion in a small watershed in purple hilly area using 137Cs tracer. Transactions of the Chinese Society of Agricultural Engineering, 23,46-50.
18. Hou, J.C., Li, Z.B., Li, M., Wang, M., 2007. Study on Effect of Landform Positions and Land Use Types on Soil Erosion and Sedimenty Yield by 137Cs Tracer in Small Catchment. Journal of Soil and Water Conservation, 21, 36-39.
19. Hua, L.Z., He X.B., Zhu, B., 2007. Soil Erosion Distribution of a Small Watershed in the Hilly Area of Central Sichuan Basin. Bulletin of Soil and Water Conservation, 27,111-116 .
20. Huang, J.X., Mao, F., Xu, W.B., Zou, J.Q., 2008. Quantitative assessment of regional soil erosion in Chengdu plain of Sichuan Province. IEEE International Geoscience and Remote Sensing Symposium, 2007. Barcelona, Spain, 3131-3134.
21. Kakembo, V., Rowntree, K.M, 2003. The relationship between land use and soil erosion in the communal lands near Peddie town, Eastern Cape, South Africa. Land Degrad. Dev. 14, 39-49.
22. Kosmas, C., Danalatos, N., Cammeraat, L.H., Chabart, M., Diamantopoulos, J., Farand, R., Gutierrez, L., Jacob, A., Marques, H., Martinez-Fernandez, J., Mizara, A., Moustakas, N., Nicolau, J.M., Oliveros, C., Pinna, G., Puddu, R., Puigdefabregas, J., Roxo, M., Simao, A., Stamou, G., Tomasi, N., Usai, D., Vacca, A., 1997. The effect of land use on runoff and soil erosion rates under Mediterranean conditions. Catena. 29,45-59.
23. Lesschen, J.P., Kok, K., Verburg, P.H., Cammeraat, L.H., 2007. Identification of vulnerable areas for gully erosion under different scenarios of land abandonment in Southeast Spain. Catena.71,110-121.
24. López-Vicente, M., Navas, A., Machín, J., 2008. Modelling soil detachment rates in rainfed agrosystems in the south-central Pyrenees. Agr. Water. Manage. 95,1079-1089.
25. Martinez-Mena, M., Lopez, J., Almagro, M., Boix-Fayos, C., Albaladejo, J., 2008. Effect of water erosion and cultivation on the soil carbon stock in a semiarid area of South-East Spain. Soil Till. Res. 99,119-129.
26. McDonald, M. A., Healey, J.R., Stevens, P.A., 2002. The effects of secondary forest clearance and subsequent land-use on erosion losses and soil properties in the Blue Mountains of Jamaica. Agr. Ecosyst. Environ. 92, 1-19.
27. Okoba, B. O., Sterk, G., 2006. Quantification of visual soil erosion indicators in Gikuuri catchment in the central highlands of Kenya. Geoderma. 134, 34-47.
28. Pan J.H., Dong X.F., 2006. GIS-and-Qu ickBird-Based quan tita tive assessmen t of soil erosion in small watershed. Journal of Ecology and Rural Environment, 22, 1-5.
29. Pandey, A., Chowdary, V.M., Mal, B.C, 2007. Identification of critical erosion prone areas in the small agricultural watershed using USLE, GIS and remote sensing. Water Resour. Manage. 21,729-746.

30. Shi, L.R., 1999. Hillside field improvement of Yangtze valley. Yangtze River, 30,25-27.
31. Song, W., Liu, P.L., Yang, M.Y., Xue Y.Z., 2003. Using REE tracers to measure sheet erosion changing to rill erosion. J. Rare Earth. 21,587-590.
32. State Land Bureau of Sichuan province, 1989. Assessment of State Land Resources of Sichuan Province. Sichuan Science Press, Chengdu.
33. Vacca, A., Loddo, S., Ollesch, G., Puddu, R., Serra, G., Tomasi, D., Aru, A., 2000. Measurement of runoff and soil erosion in three areas under different land use in Sardinia (Italy). Catena. 40, 69-92.
34. Wu, N., He, F., Yao, X.Y., Yang S.J.; Hu. X.H., 2007. Research of land use and soil erosion in upstream massif area of Huaihe river basin based on RS and GIS. Journal of Anhui Agricultural University, (4), 589-595.
35. Xu, J.X., 2000. Runoff and sediment variations in the upper reaches of Changjiang River and its tributaries due to deforestation. J. Hydraul. Eng-Asce. 1,72-80.
36. Zhang, X.B., Zhang, Y.Y., Wen, A.B., Feng, M.Y., 2003. Assessment of soil losses on cultivated land by using the 137Cs technique in the Upper Yangtze River Basin of China. Soil Till. Res. 69,99-106.