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Soil erosion dynamic changes and its impact factors in Zhifanggou watershed of the Loess Plateau, China

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Abstract

In order to explore the soil erosion rules in loess hilly-gully area of the Loess Plateau, Zhifanggou Watershed was selected to evaluate the soil erosion dynamic changes and its impact factors from 1938 to 2010. Based on GIS technique, the revised universal soil loss equation (RUSLE) was used to evaluate spatial and temporal change of soil erosion and the effect of terrain and land use on soil erosion in the past 70 years. The results showed that 1) soil erosion modulus increased significantly from 7584.39 $t \cdot km^{-2} \cdot a^{-1}$ in 1938 to 46,392.56 $t \cdot km^{-2} \cdot a^{-1}$ in 1958, and it decreased to 5150.80 $t \cdot km^{-2} \cdot a^{-1}$ in 2010; 2) the area of moderate erosion and below accounted for 52.99% of the whole area in 1938; during the period from 1958 to 1978, severe erosion become the dominant pattern which was up to 67.05% of area in whole watershed, and the most severe erosion accounting for 78.61% happened in 1958; soil erosion declined slightly during the period from 1979 to 1998, and this decreasing trend continued until 1999 in which severe erosion area only occupied 8.96%. 3) Soil erosion intensity and quantity increased significantly with the slope increasing, area of the slope steeper than 15° took up 81.95%, but disproportionally contributed 96.76% of the total soil erosion amount, while slope steeper than 25° contributed nearly 80%. Soil erosion intensity at sunny and half sunny slope was higher than that at shady and half shady slope, sunny and half sunny slope covered 48.25% of the total area, but contributed 52.42% of the soil erosion amount. 4) Soil erosion intensity of forestland was slightest while strongest in unutilized land. Farmland was the major source of soil erosion during 1958-1998, and grassland was the major source of soil erosion in the following period. With persistent ecological management and protection over past 30 years, the eco-environment in Zhifanggou watershed was improved remarkable, but soil erosion needs to be paid more attention in the future conservation, especially in the steep slope and gullies areas.

Key words: Soil erosion, GIS, RUSLE, dynamic change, Loess Plateau.

Introduction

Soil erosion is one of the most serious eco-environmental problems throughout the world, which has greatly threatened the sustainable development of human being. Many scientists and researchers have focused on this hot topic all over the world [1, 2]. China is one of the countries most seriously suffering soil erosion in the world, the soil and water loss area is 3.67 million km^2 and accounted for 38.2% of the national land area. Due to the physical and anthropogenic factors, soil erosion has become a serious problem in the Loess Plateau where great studies have been conducted in order to learn soil and water conservation. Soil erosion is temporally and spatially affected by many factors such as climate, geology, geomorphology, soil, vegetation and human activities, therefore, it is of great significance to investigate soil erosion spatio-temporal patterns and its impact factors. As the basic unit of soil erosion development, small watershed serves as the fundamental object for the exploration of soil erosion mechanism and evaluation of watershed management. However, how to understand the intensity, scale and spatial distribution of soil erosion efficiently remains an urgent problem to be solved. Small watershed soil erosion model based on GIS provides an efficiency approach for these purposes. Combined the factors mentioned above, RUSLE has been commonly applied to assess soil erosion[3-6]. Zhifanggou watershed located in the Loess Plateau, is typically featured by its hilly gully geomorphology, and has been preserved and recovered by practice of afforestation since 1974. The eco-environment has been improved significantly since 1986, especially Grain for Green Project implemented in this area. Even though soil and water conservation measures have been taken and some firsthand data was collected and analyzed [7-11], the scientific significance of results cannot be completely understood and accepted. In addition, most reports focused on data gained before 2000[12,13], but investigations in terms of soil erosion estimation during the policy period are seldom released. Moreover, the occurrence and development of soil erosion are affected and controlled by underlying surface condition. Land use change affects the dynamic of soil erosion and anti-erosion resistance systems by changing the origin types and coverage of vegetation and microtopography, it is an important dynamic parameter affecting soil erosion. Topography and morphology are the most direct factors to cause soil erosion. The study of the relationship

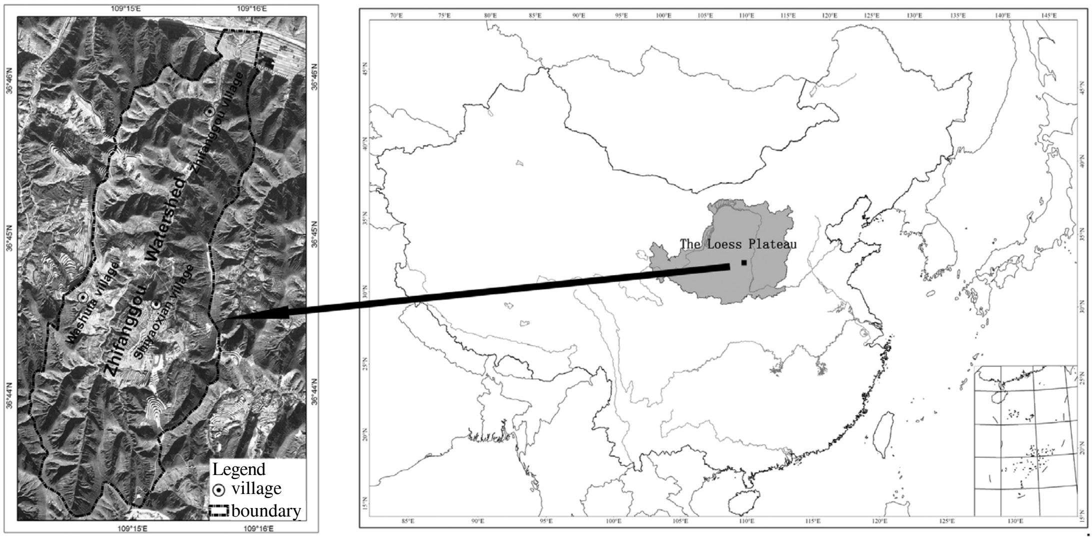

Figure 1. Location of the study area.

between soil erosion and its impact factors has important practical significance for formulating soil and water conservation measures as well as consummating soil erosion model. Therefore, based on RUSLE and GIS, quantitive analyses were used to study soil erosion characteristics from 1938 to 2010 in this area in order to clarify the erosion process and its impact factors comprehensively and systematically, in small catchment scale of the Loess Plateau.

Materials and Methods

Study area: Zhifanggou watershed was selected in Ansai county, Shaanxi Province (36°5'30" N, 109°19'30" E), located in the hill-gully area of the Loess Plateau (Fig. 1). The area of whole catchment is 8.27 km^2 and the altitude ranges from 1040 to 1425 m. In this watershed, gully density is up to 8.06 km/km^2 which means the terrain quiet rugged and ups and downs of whole area. The region has semi-humid and semi-arid climate with an average annual rainfall of 482.7 mm. The precipitation distribution with great inter-annual variability and rainfall from June to September accounts for 73.6% of the annual precipitation. In terms of soil, developed on wind accumulated loess parent material, is loess soil and with long-term erosion great volumes of soil has lost through runoff and sediment. The soil type of the study area is loess with silt content ranging from 53.9% to 74.8% and clay from 16% to 26%. Soil organic matter content is very low and it is weakly resistant to erosion [14]. Because of its location where it is in the northern edge of the forest steppe zone, natural vegetation is dominated by semi-xerophytic grasses and shrubs which are scattered and limited. To ensure human survival and development, disturbance activities have destroyed the original ecology environment of Zhifanggou watershed. These explorations have triggered sever soil erosion with 14,000 $t/km^2 \cdot a^{-1}$. Fortunately, due to nation policies and local protection, these serious problems have been improved especially in vegetation richness and abundance.

Data description: A total of 18 landuse maps were collected which covered the study period from 1938 to 2010. Landuse map of 1938 was derived through household surveys, fieldwork investigation and literatures comparing and summarizing. Maps of 1958, 1975, 1978, 1987, 1990 and 2003 were obtained from remote sensing images of 1:10,000 by visual interpretation, and the rest were drawn by field measuring. The daily precipitation data from 1956-1984 were collected from Zhifanggou Gauging Station and the other three station, named nearby. DEM of 5 m resolution and a soil type map of 1:10,000 were also employed in this paper.

Methods: This paper uses the RUSLE empirical model to predict annual loss. The RUSLE [1] can be expressed as :

$$A = R \cdot K \cdot LS \cdot C \cdot P \quad (1)$$

where A is the average soil loss caused by erosion ($t \cdot hm^{-2} \cdot year^{-1}$), R is the rainfall erosivity factor ($MJ \cdot mm \cdot hm^{-2} \cdot h^{-1} \cdot a^{-1}$), K is the soil erodibility factor ($t \cdot hm^2 \cdot h \cdot hm^{-2} \cdot MJ^{-1} \cdot mm^{-1}$), L is the slope length factor, S is the slope steepness factor, C is the vegetation cover and management factor, and P is soil and water conservation factor.

Erosion factor calculation method

Rainfall erosivity factor (R): Rainfall erosivity factor reflects the power of rainfall which can cause separation and transport of soil particles even potential ability to lead to soil erosion. It is supposed to be calculated each erosivity of all single rainfall events accurately in the given time period [1, 15]. However, it is difficult and impractical to gain long-term single rainfall data. Therefore, annual rainfall erosivity was determined with daily precipitation data and the equations were used as following [16, 17]:

$$R_i = \alpha \sum_{j=1}^{k} (P_j)^{\beta} \quad (2)$$

$$\alpha = 21.586\beta^{-7.1891} \quad (3)$$

$$\beta = 0.8363 + 18.144P_{d12}^{-1} + 24.455P_{y12}^{-1} \quad (4)$$

where R_i is the annual rainfall erosivity of year i, in $MJ \cdot mm \cdot hm^{-2} \cdot h^{-1} \cdot a^{-1}$; k is the number of rain days in one year; P_j is the quantity of erosive rain in a certain day j (referring to the rainfall erosivity criteria for the Loess Plateau [18]: if $P \leq 12$ mm, then

$P_j = 0$ mm); α, β are precipitation parameters for the study area; P_{d12} and P_{y12} are daily precipitation and annual precipitation respectively.

Considering the watershed area and precipitation distributioned homogeneous, rainfall erosivity was calculated uniformly with rainfall data gathered at the outlet of the watershed.

Soil erodibility factor (K): Soil erodibility factor (K) represents the average long-term soil and soil-profile response to erosive agents associated with rainfall and runoff. It is defined as the soil loss caused by rainfall erosivity within a standard unit. K can be calculated by EPIC model [19]:

$$K = \{0.2 + 0.3\exp[0.0256SAN(1 - SIL/100)]\}\left[\frac{SIL}{CLA + SIL}\right]^{0.3} \left[1.0 - \frac{0.25O}{O + \exp(3.72 - 2.95O)}\right]\left[1.0 - \frac{0.7SN1}{SN1 + \exp(-5.51 + 22.9SN1)}\right] \quad (5)$$

where *SAN*, *SIL*, *CLA* represent the content of sand, silt, and clay, respectively; *O* is the content of organic carbon. The results obtained from the equation are in American unit (t·acre·hr·/ 100·acre·feet·tonf·inch), and they can be translated into international unit (t·hm^2·h/hm^2·MJ·mm) by multiplying 0.1317.

Length and steepness of slope factor (LS): The effect of topography on soil erosion is determined by slope steepness (S) and slope length (L). Slope length factor in the paper was evaluated with the equations Wischmeier and Smith proposed [15]. Under steep slope conditions, slope steepness factor can be computed with the model proposed by McCool [20] and the model by Liu [21]:

$$L = (\lambda / 22.13)^{\alpha} \quad (6)$$

$$\alpha = \beta / (\beta + 1) \quad (7)$$

$$\beta = (\sin\theta / 0.0896) / [3.0 (\sin\theta)^{0.8} + 0.56] \quad (8)$$

$$S = \begin{cases} 10.8\sin\theta + 0.03, \theta < 9\% \\ 16.8\sin\theta - 0.50, 9\% \le \theta < 14\% \\ 21.9\sin\theta - 0.96, \theta \ge 14\% \end{cases} \quad (9)$$

where *L*, *S* stand for slope length factor and slope steepness factor respectively; α is the slope length index; and λ, θ are slope length and slope steepness generated from DEM respectively, using generating tools [22].

Vegetation cover and management factor (C): Vegetation cover and management factor (C) reflects the effect of cropping and management practices on the soil erosion rate. Based on the basic theory of USLE /RUSLE, C factor for the case in the Loess Plateau was estimated [23, 24], and figured out that C factor of corn, potato, millet and soybean for the area were 0.28, 0.47, 0.53, 0.51, respectively. The average of the above values was taken as the overall C factor, because of the lack of data of other crops. According to the previous studies [7-9, 24], C values of woodland, seedling forests, sparse woodland, shrub land, artificial grassland and natural grassland are 0.004, 0.225, 0.144, 0.06, 0.26 and 0.24, respectively. According to the survey, different crops were inter-growing within an orchard in study area, so the C value of orchard was generated by averaging the values of sparse woodland and farmland as 0.297, C values of residential area and water body are assigned as 1 and 0.

Soil and water conservation factor (P): Soil and water conservation factor is defined as the ratio of soil loss with a specific support practice to the corresponding soil loss with downslope cultivation. It is general that with lower P-value, soil erosion can be reduced and conservation practices are more effectively. Soil erosion is generally alleviated by altering the topography and runoff converges, thus reducing the energy and velocity of runoff is vital to soil protection and conservation. According to the field survey, soil and water conservation measures within the catchment are level terrace, level trench, fish-scale pits, grass-crop strips rotation, warping dam, etc. Studies show that the conservation efficiency for level terrace and level trench were 91.6%, 56.1-87.17%, and the values for scale pit and grass-crop rotation were 75.0 -81.3%, 40.0 - 50.0% [11, 25-28]. So the values of 0.084, 0.329, 0.219, and 0.55 were attributed to P factors for the above four practices, respectively. In addition, P value is assigned 0 for check dams without erosion, and 1 for any land use types without conservation practice. Farmland in the study area was mainly associated with contour farming, and specific P factors for farmland are given in the Table 1 based on previous researches [29]. P factor layer was generated by attributing different P values to corresponding land use types in the GIS interface.

Table 1. The value of tillage measures in Zhifanggou watershed.

Slope range(θ)	0°	0<θ≤5°	5<θ≤10°	10<θ≤15°	15<θ≤20°	20<θ≤25°	>25°
The Value of tillage measures	1	0.100	0.221	0.305	0.575	0.735	0.800

Results

Evolvement character of the erosion factors

Rainfall erosivity factor (R): In the watershed, the rainfall erosivity over the past 54 years was estimated with the rainfall erosivity model (formula 2, 3, 4) based on daily data (Fig. 2). The figure shows that the maximal rainfall erosivity was 3278.87 MJ·mm·hm^{-2}·h^{-1}·a^{-1} in 1964, the minimal value was 437.31 MJ·mm·hm^{-2}·h^{-1}·a^{-1} in 1997, and the average over the study period was 1427.96 MJ·mm·hm^{-2}h^{-1}·a^{-1}, which was used as the rainfall erosivity of 1938 to estimate soil erosion.

Soil erodibility factor (K): The study area is featured mainly by loess soil, and K factor for the area was determined by formula 5 and then added as a field to soil type map. K factor maps were generated by converting vector map into the raster map with a resolution of 5 m ones (Fig. 4). The results showed that K value in the study area ranged from 0.0327 to 0.0522t·hm^2·h (hm^2·MJ·mm)$^{-1}$, with an average of 0.04315 t·hm^2·h (hm^2·MJ·mm)$^{-1}$.

Length and steepness of slope factor (LS): Based on a 5 m resolution DEM of the study area (Fig. 3), LS factor (Fig. 5) was generated using LS generating tools [22]. The LS factor value varied from 0 to 58.5 with average value of 10.46.

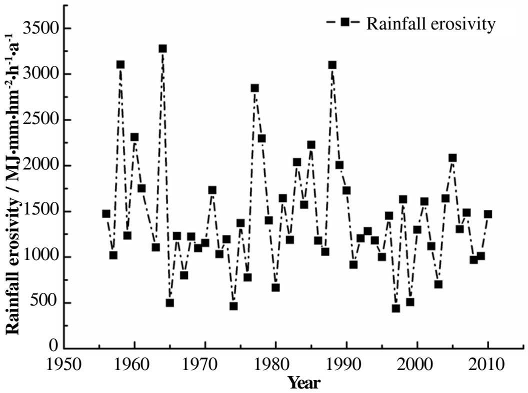

Figure 2. The rainfall erosion force during 1956 to 2010 in Zhifanggou watershed.

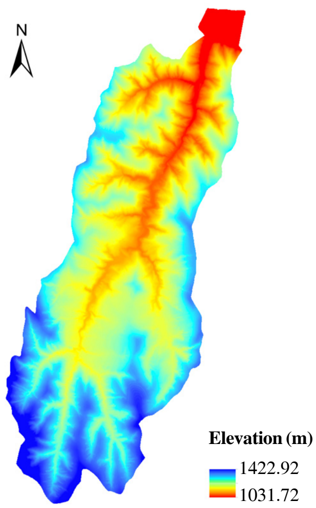

Figure 3. DEM of the study area.

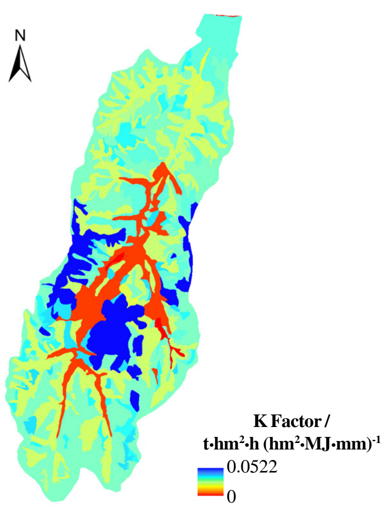

Figure 4. K map of the study area.

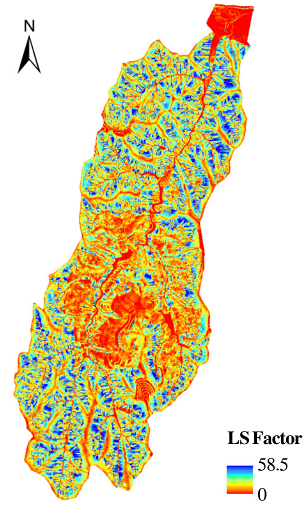

Figure 5. LS map of the study area.

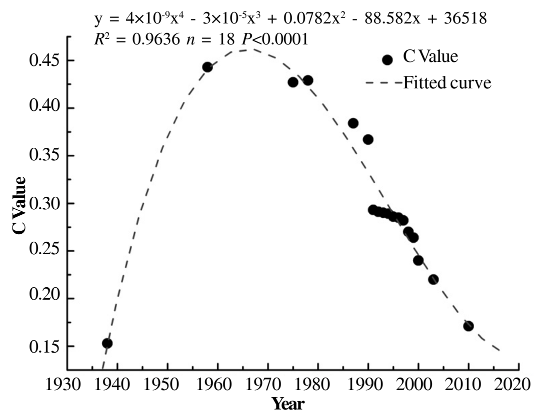

Figure 6. The change of C value in Zhifanggou watershed.

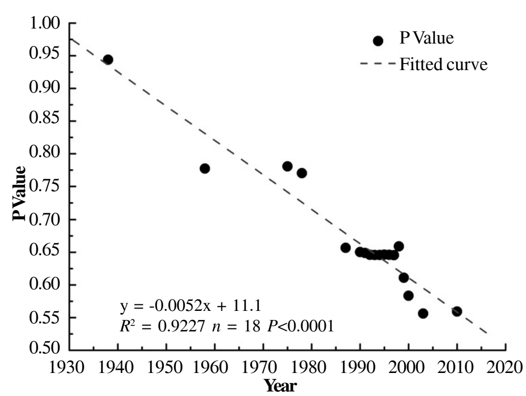

Figure 7. The change of P value in Zhifanggou watershed.

Vegetation cover and management factor (C): C values maps during the years 1938-2010 were derived from the corresponding land use maps through the attribution of C factor based on ArcGIS software (Fig. 6). The results illustrated that C factor increased from 0.153 in 1938 to 0.443 in 1958, followed by a decline trend from 0.427 in 1975 to 0.240 in 2000. What is worth mentioned is that C value in 2010 dropped to the same level in 1938. This means that after 25 years of comprehensive conservation measures and implementation of Grain for Green project, vegetation had been restored rapidly.

Soil and water conservation factor (P): Based on the land use maps of years from 1938 to 2010, P factor maps were generated through field survey and combination with the ArcGIS software (Fig. 7). The results showed that P factor in the study area presented linear relationship with decreasing trend, and that four specific periods which P factor changed were identified. P factor declined from 0.944 to 0.770 in the years from 1938 to 1978, to 0.657 in 1987, and maintained at a level between 0.650 and 0.659 in periods of 1990-1998. From year 1999 on, P value declined from 0.611 to 0.559 in 2010.

Evolvement character of the soil erosion

Soil erosion prediction result and assessment: Based on the national classification standards of soil erosion magnitude [30], the distribution maps of soil erosion intensity of 1938-2010 (Fig.8) were mapped by multiplying the five factors using the ArcGIS software based on formula 1. The results showed that the measured annual sediment load was 26,079.78 $t \cdot a^{-1}$ during 1985-2010 at the outlet of Zhifanggou Watershed, while the predictive value with RUSLE was 71,898.51 $t \cdot a^{-1}$. Two check dams with area of 0.18 and 0.72 km^2 were constructed in the watershed in 1975 for sediment control, and one of them became full in 1990 because of the limited capacity. Considering the role of check dams in trapping sediment, another check dam was built in 1987 [11]. Considering the sediment control effect of check dams, the mean annual soil erosion for the same period was estimated about 54,196.86 $t \cdot a^{-1}$, nearly two times of the designed sediment load, which is consistent with the actual situation, it is indicated that soil erosion evaluated with GIS and RULSE at a small catchment is feasible.

Annual variation of soil erosion in Zhifanggou watershed: In terms of inter-annual variations (Fig. 9), soil erosion intensity increased sharply from 7584.39 $t \cdot km^{-2} \cdot a^{-1}$ in 1938 to 46,392.56 $t \cdot km^{-2} \cdot a^{-1}$ in 1958, and followed by a decreasing trend to 5150.80 $t \cdot km^{-2} \cdot a^{-1}$ in 2010.

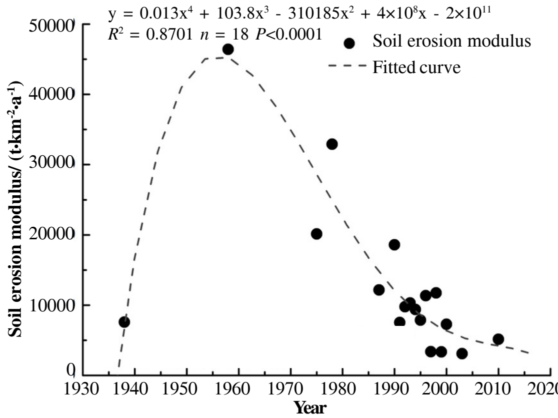

Figure 9. The change of annual average soil erosion modulus during 1938 to 2010 in Zhifanggou watershed.

Table 2 shows that various levels of erosion intensity in 1938 were distributed evenly. Slight erosion covered 25.35% of the total area, and the percentage of soil erosion intensity below 5000 $t \cdot km^{-2} \cdot a^{-1}$ was 52.99% (4.41 km^2). Severe erosion dominated with 67.05% (5.58 km^2) during 1958-1978, especially with 78.61% (6.55

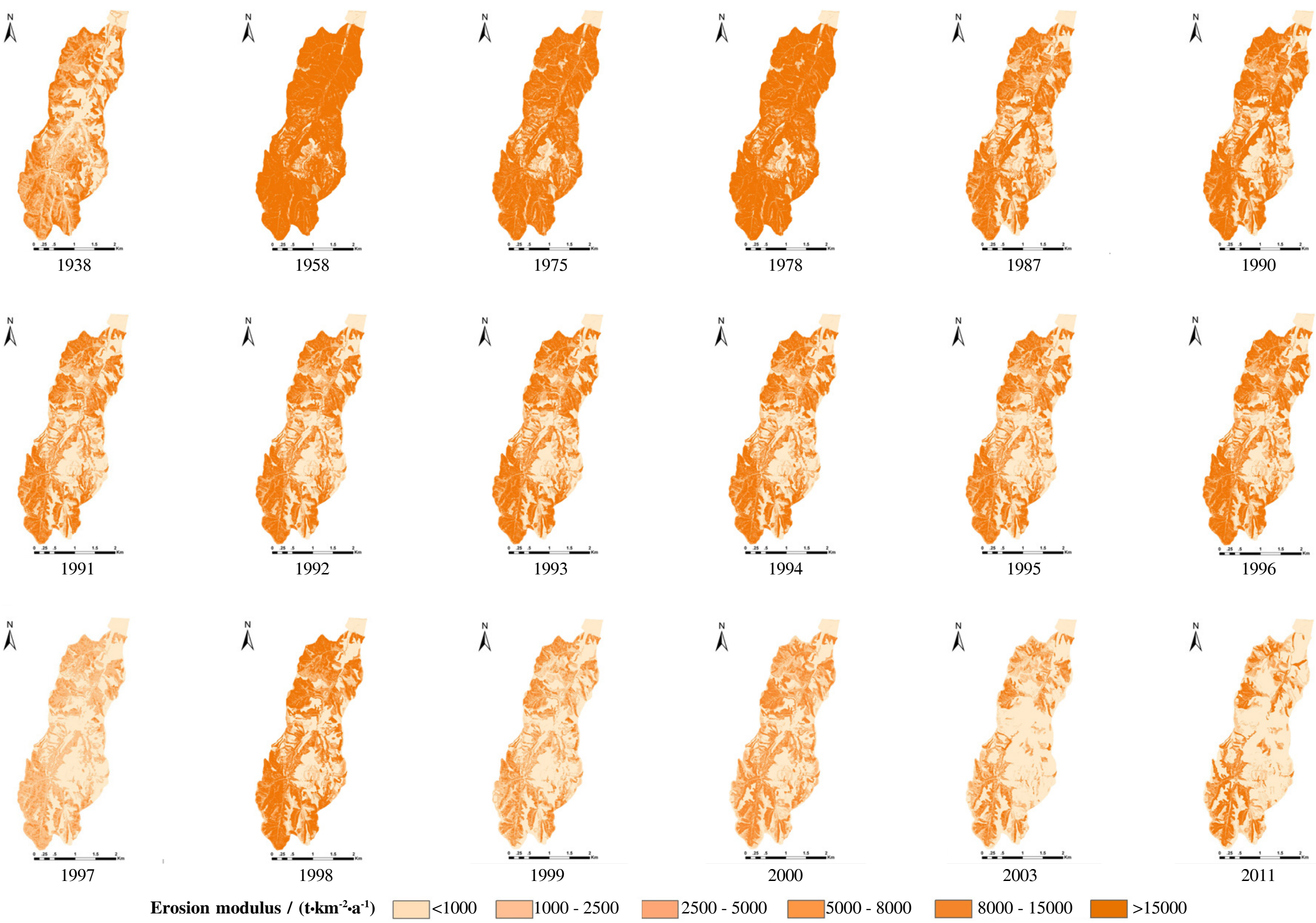

Figure 8. The map of soil erosion modulus during 1938 to 2010 in Zhifanggou watershed.

Table 2. The area and percentages change of different erosion intensity ($t\cdot km^{-2}\cdot a^{-1}$) from 1938 to 2010 in Zhifanggou watershed.

Year	Slight erosion (<1000) Area (km^2)	%	Light erosion (1000-2500) Area (km^2)	%	Moderate erosion (2500-5000) Area (km^2)	%	Intensive erosion (5000-8000) Area (km^2)	%	Extreme intense erosion (8000-15000) Area (km^2)	%	Severe erosion (≥15000) Area (km^2)	%
1938	2.11	25.35	0.86	10.36	1.44	17.29	1.16	13.89	1.41	16.95	1.35	16.17
1958	0.39	4.66	0.20	2.37	0.35	4.24	0.22	2.69	0.62	7.43	6.55	78.61
1975	0.64	7.67	0.53	6.31	0.50	5.99	0.58	6.97	1.66	19.97	4.42	53.08
1978	0.54	6.45	0.38	4.58	0.36	4.29	0.41	4.96	0.85	10.26	5.78	69.46
1987	1.96	23.59	0.81	9.68	0.81	9.69	0.74	8.94	1.41	16.93	2.60	31.18
1990	1.79	21.55	0.77	9.26	0.67	8.01	0.56	6.67	1.03	12.39	3.51	42.13
1991	2.60	31.18	0.88	10.54	0.94	11.29	0.88	10.57	1.55	18.56	1.49	17.85
1992	2.36	28.38	0.92	11.08	0.78	9.31	0.71	8.49	1.44	17.31	2.12	25.43
1993	2.28	27.42	0.96	11.57	0.77	9.26	0.67	8.00	1.33	15.97	2.31	27.77
1994	2.47	29.61	0.94	11.33	0.77	9.23	0.72	8.70	1.38	16.61	2.04	24.51
1995	2.74	32.86	0.90	10.85	0.80	9.61	0.83	9.96	1.44	17.29	1.62	19.44
1996	2.36	28.36	0.94	11.25	0.72	8.68	0.65	7.75	1.19	14.27	2.47	29.70
1997	3.66	44.00	1.08	12.98	1.36	16.29	1.11	13.29	0.95	11.40	0.17	2.05
1998	2.15	25.79	0.92	11.07	0.75	8.99	0.65	7.85	1.26	15.13	2.60	31.17
1999	3.57	42.82	1.29	15.46	1.35	16.23	1.00	12.04	0.95	11.44	0.17	2.02
2000	2.70	32.44	1.24	14.85	1.04	12.45	0.74	8.89	1.18	14.16	1.43	17.20
2003	4.56	54.75	1.17	14.07	0.81	9.74	0.67	8.01	0.77	9.27	0.35	4.17
2010	4.57	54.85	1.05	12.67	0.61	7.36	0.42	5.07	0.63	7.60	1.04	12.46
Average	2.18	28.98	0.88	10.57	0.82	9.89	0.71	8.49	1.17	14.05	2.33	28.02

km^2) in 1958. In the period of 1979-1998, slight erosion occupied 29.27% of the whole study area, and severe erosion declined to 25.12% (2.09 km^2). Since 1999, the area of severe erosion dropped to 8.96% (0.75 km^2). In general, the area associated with slight erosion and severe erosion were 28.98% and 28.02% during the whole period of 1938-2010, respectively.

Spatial distribution and variation of soil erosion in Zhifanggou watershed: It can be seen from Fig. 8 that in 1938, moderate erosion or below was mainly found in the center of the watershed where land was flat, while severe erosion or above was primarily associated with very steep and barren slopes and slope farmland. During 1958-1978, erosion patterns were similar and severe erosion or above play a dominant role. In 1987 and 1990, moderate erosion or below happened in forestland, terrace land and gently sloping grassland, while severe erosion or above with inter-rill sloping farmland, steep slopes in ravine, river courses and sloping bare land alongside in the middle and upper reaches of the watershed. Soil erosion was somewhat similar in spatial distribution during 1991-1998, and moderate erosion increased slightly than 1990. It mainly distributed in the central and eastern part of the watershed but intensive erosion and above occurred in inter-rill sloping farmland and steep slopes in the ravine. Due to limited precipitation, soil erosion of all levels were mitigated overall, with severe erosion and slight severe erosion accounting for 2.05% and 44% of total area in 1997, respectively. In addition, remarkable changes were identified in terms of erosion magnitude and pattern in the watershed because of the Grain for Green Project initiated in 1999. Since then severe erosion was constrained in ravines with steep and barren slopes, and moderate erosion or below distributed in the middle and lower reaches of the watershed while intensive erosion distributed in the steep slopes in the ravine. During 2003-2010, with the regrowth of vegetation, moderate erosion and above continued to reduce while moderate erosion or below expanded, with the moderate erosion and below and slight erosion accounting for 76.72% and 54.80% of the watershed, respectively.

Impact factors of soil erosion

The effects of slope on soil erosion: Table 3 shows the average erosion intensity and soil erosion amount of different slope grades during 1938 to 2010, generated by overlapping erosion intensity maps with slope rating maps. It reveals that soil erosion in the study area presented significantly positive correlation with slope steepness, and that both erosion intensity and erosion amount increased significantly as slope steepness rising. Average soil erosion on slopes below 25° was lower than the mean erosion intensity of the watershed, while average soil erosion intensity on slopes above 25° was higher than that of the watershed. This can be explained that vegetation on gentle slopes less than 25° was wide-covering enough to prevent soils from being washed away but in case of slopes more than 25°, rainfall and runoff erosivity was stronger due to less vegetation covering. In watershed scale, soil erosion from slopes above 15° contributed nearly 97% of the total erosion, and slopes more than 25° was responsible for 79.54%.

The study period of 1938-2010 was divided into four sub-periods:1938-1957, 1958-1978, 1979-1998, and 1999-2010. Soil erosion within each sub-period was quantified and compared. In general, comparing with first sub-period soil erosion amount and intensity for all slope grades increased in second sub-period, and then both of them dropped in third and fourth sub-period. No regular patterns of soil erosion change were identified for four sub-periods below 15° slopes, probably because intensive human activities disturbed dramatically in gentle sloping areas. Soil erosion decreased throughout the four sub-periods at 15-25° and 25-35°slopes, but increased over 35° slopes. It implies that soil erosion gradually changed and distributed towards to steepness slopes. This is because integrated managements, such as Grain for Green policy, have been operated below 35° slopes to combat soil erosion and degradation while steep over than 35° slopes was difficult to carry out these kinds of measurement.

The effects of aspect on soil erosion: Average erosion intensity and erosion amount with different slope aspects during 1938-

Table 3. Soil erosion of different slpoe in Zhifanggou watershed.

	Slope classification	0<θ≤5	5<θ≤8	8<θ≤15	15<θ≤25	25<θ≤35	>35
	Area (km^2)	0.42	0.23	0.85	1.97	2.16	2.70
	%	5.06	2.80	10.19	23.60	25.96	32.39
Soil erosion of average amount (t·a^{-1})	1938-1957	361.99	440.99	3138.84	14949.50	21517.35	22770.66
	1958-1978	1434.32	887.40	7263.84	49830.68	88257.92	128424.10
	1979-1998	325.21	212.21	1837.16	14130.42	26625.52	41913.69
	1999-2010	182.82	122.50	941.96	5322.32	10512.25	22169.26
	Average	480.46	317.52	2614.99	18168.61	33033.07	50880.94
Erosion amount % of total	1938-1957	0.57	0.70	4.97	23.66	34.06	36.04
	1958-1978	0.52	0.32	2.63	18.05	31.97	46.51
	1979-1998	0.38	0.25	2.16	16.62	31.31	49.28
	1999-2010	0.47	0.31	2.40	13.56	26.78	56.48
	Average	0.46	0.30	2.48	17.22	31.31	48.23
Average soil erosion intensity (t·km^{-2}·a^{-1})	1938-1957	1070.11	2266.00	4721.92	8676.48	10640.70	8719.43
	1958-1978	5329.15	8426.70	16856.77	33025.73	47022.17	51663.87
	1979-1998	1429.89	1829.62	3991.75	9212.24	14101.86	17030.02
	1999-2010	601.64	800.22	1625.64	3089.51	5158.12	8352.80
	Average	1140.15	1362.01	3080.45	9240.47	15273.79	18859.25

2010 were generated by overlapping the erosion intensity maps with aspect maps based on the ArcGIS software, as showing in Table 4. The results showed that during study periods soil erosion intensity changed differently with slope aspect. To be more specific, during more than 70 years, the average annual erosion intensity represented this order: sunny slope was the most intensity area and half sunny slope, half shady slope, and shady slope followed. In the period of 1938-1957, the soil erosion intensity was in the descendant order of half sunny slope, sunny slope, half shady slope and shady slope, half sunny slope and sunny slope were associated with extreme intense erosion while half shady slope and shady slope with intensive erosion. In the period of 1958-1978, all of the four slope aspects were plagued with severe erosion, and the soil erosion intensity was the descendant order of half shady slope, sunny slope, half sunny slope, shady slope, which was due to 57.71%, 45.30% and 54.25% of half shady slope, sunny slope and half sunny slope were farmland, respectively, and 37.85%, 27.88% and 22.21% were deserted land, respectively. All of the four aspects were plagued extreme intense erosion in the period of 1979-1998; sunny slope suffered the strongest soil erosion, followed by half sunny slope, half shady slope and shady slope. In the period of 1999-2010, sunny slope was the most intensity area and half sunny slope, half shady slope and shady slope followed. More specifically, sunny slope and half sunny slope were plagued intensive erosion while shady slope and half shady slope were moderate erosion. Overall, soil erosion intensity in sunny slope and half sunny slope were higher than in shady slope and half shady slope. In terms of erosion amount, although sunny slope and half sunny slope covered 48.25% of the total area combined, they produced 50.50%-55.74% of the total erosion amount. Meanwhile half shady slope and half sunny slope covered 29.60% and 32.44% of the total area, respectively, and contributed 25.51-32.63% and 33.57-37.91% of the total erosion amount. So that soil erosion mainly occurred in half sunny slope and sunny areas was concluded. In semi-arid regions, water is the main limiting conditions for vegetation growth, comparing with shady slope and half shady slope area, soil is more vulnerable to erosion in sunny slope and half sunny slope areas because of where vegetation growth is limited and land is poor covered due to low soil moisture, which was caused by abundant sunlight that accelerates the evaporation of soil. Analyzed the soil erosion in different aspect suggested that sunny slope and half sunny slope were not only the unfavorable sites for vegetation restoration but also the key area of water and soil amount comprehensive harness.

The effects of land use on soil erosion: By overlapping analysis of erosion intensity maps and land use maps, erosion intensity and erosion amount for various land use types were obtained (Table 5). Farmland, forestland and grassland were the main land use types in the study area, with the area of 2.79 km^2 (33.48%), 2.36 km^2 (28.29%) and 2.86 km^2 (34.42%), respectively. During 1938 to 1957, farmland contributed around 20.85% of the total erosion amount while forestland and grassland contributed around 32.16% and 46.98%, respectively. The soil erosion intensity of farmland, forestland and grassland were 14,629.94 , 13,100.82 and 3964.43 t·km^{-2}·a^{-1} respectively.

In 1958, majority of forestland was converted to farmland, the area of farmland soared to 4.39 km^2 and the

Table 4. Soil erosion of different aspect in Zhifanggou watershed.

	Aspect	Shady slope	Half sunny slope	Sunny slope	Half shady slope
	Area (km^2)	1.85	2.70	1.32	2.47
	%	22.15	32.44	15.81	29.60
Soil erosion of average amount (t·a^{-1})	1938-1957	10753.19	23949.00	10995.88	17481.22
	1958-1978	44865.63	89280.84	45022.38	86792.47
	1979-1998	16223.26	30288.89	15087.72	23384.15
	1999-2010	7361.81	14525.58	7352.21	10011.46
	Average	18723.88	36265.71	18130.51	30652.55
Erosion amount % of total	1938-1957	17.02	37.91	17.40	27.67
	1958-1978	16.87	33.57	16.93	32.63
	1979-1998	19.09	35.64	17.75	27.52
	1999-2010	18.76	37.01	18.73	25.51
	Average	18.04	34.95	17.47	29.54
Average soil erosion intensity (t·km^{-2}·a^{-1})	1938-1957	5827.66	8863.27	8347.41	7089.61
	1958-1978	24314.78	33041.89	34178.29	35199.22
	1979-1998	8792.14	11209.60	11453.70	9483.58
	1999-2010	3989.71	5375.76	5581.36	4060.21
	Average	10147.35	13421.55	13763.59	12431.33

Table 5. Soil erosion of different LUCC in Zhifanggou watershed.

	Land use types	Farmland	Forestland	Grassland	Habitation	Water body	Unutilized land
Area (km^2)	1938-1957	0.90	5.12	2.26	0.04	0.00	0.00
	1958-1978	4.39	0.20	2.81	0.06	0.03	0.84
	1979-1998	3.02	2.17	2.89	0.06	0.03	0.15
	1999-2010	1.47	3.75	2.99	0.06	0.03	0.02
	Average	2.79	2.36	2.86	0.06	0.03	0.23
Area (%)	1938-1957	10.81	61.54	27.21	0.45	0.00	0.00
	1958-1978	52.71	2.37	33.75	0.67	0.39	10.11
	1979-1998	36.31	26.03	34.74	0.74	0.39	1.78
	1999-2010	17.65	45.08	35.93	0.77	0.39	0.18
	Average	33.48	28.29	34.42	0.72	0.37	2.72
Average soil erosion intensity ($t{\cdot}km^{-2}{\cdot}a^{-1}$)	1938-1957	14629.94	3964.43	13100.82	209.54	0.00	0.00
	1958-1978	29615.82	11579.71	30446.04	1390.03	0.00	69217.82
	1979-1998	13187.95	2891.51	11143.72	419.34	0.00	44324.84
	1999-2010	3849.92	2011.66	8510.23	356.12	0.00	37314.22
	Average	16430.72	2830.80	13773.02	547.53	0.00	59656.41
Soil erosion of average amount ($t{\cdot}a^{-1}$)	1938-1957	13159.26	20297.01	29652.71	7.79	0.00	0.00
	1958-1978	129880.43	2280.62	85495.00	77.54	0.00	58212.18
	1979-1998	39842.48	6260.92	32213.36	25.90	0.00	6579.14
	1999-2010	5652.26	7544.09	25440.47	22.90	0.00	570.67
	Average	45768.57	6662.47	39446.29	32.84	0.00	13483.92
Erosion amount % of total	1938-1957	20.85	32.16	46.98	0.01	0.00	0.00
	1958-1978	47.07	0.83	30.98	0.03	0.00	21.10
	1979-1998	46.92	7.37	37.93	0.03	0.00	7.75
	1999-2010	14.41	19.23	64.85	0.06	0.00	1.45
	Average	43.43	6.32	37.43	0.03	0.00	12.79

forestland was left only 0.20 km^2, meanwhile, 0.84 km^2 of unutilized land was formed. During the period of 1958-1978, soil erosion intensity on farmland increased to 29,615.82 $t{\cdot}km^{-2}{\cdot}a^{-1}$ and to 30,446.04 $t{\cdot}km^{-2}{\cdot}a^{-1}$ on grassland, while the figures were 69,217.82 $t{\cdot}km^{-2}{\cdot}a^{-1}$ and 11,579.71 $t{\cdot}km^{-2}{\cdot}a^{-1}$ for unutilized land and forestland, respectively. Farmland contributed around 47.07% of the total erosion amount while grassland, unutilized land and forestland contributed around 30.98%, 21.10% and 0.83%, respectively.

During the period of 1979-1998, the area of farmland declined and forestland rose to 2.17km^2 due to the implementation of water and soil amount comprehensive harness. The soil erosion intensity was reduced to 2891.51 $t{\cdot}km^{-2}{\cdot}a^{-1}$ on forestland, which contributed around 7.37% of the total soil erosion amount, however, soil erosion intensity on the farmland was still as high as 13,187.95 $t{\cdot}km^{-2}{\cdot}a^{-1}$, responsible for nearly half of the total soil erosion amount in the watershed. Besides, the soil erosion intensity of grassland and unutilized land were 11143.72 and 44324.84 $t{\cdot}km^{-2}{\cdot}a^{-1}$, which contributed around 37.93% and 7.75% of the total soil erosion amount, respectively.

During the period of 1999-2010, the area of farmland decreased significantly to 1.47km^2 (17.65%) due to the Grain for Green Project. Meanwhile, the area of unutilized land dropped to 0.02 km^2. Conversely, the area of forestland and grassland rose to 3.75 km^2 and 2.99 km^2, respectively. The soil erosion intensity of grassland was 8510.23 $t{\cdot}km^{-2}{\cdot}a^{-1}$, however, contributing around more than 3/5 of the total soil erosion amount. Although the soil erosion intensity of unutilized land up to 37,314.22 $t{\cdot}km^{-2}{\cdot}a^{-1}$, it contributed around 1.45% of the total soil erosion amount only. The soil erosion intensity of farmland and forestland decreased to 3849.92 and 2011.66 $t{\cdot}km^{-2}{\cdot}a^{-1}$, which contributed around 14.41% and 19.23% of the total soil erosion amount.

It can be seen from the above analysis that soil erosion intensity of forestland was far lower than farmland and grassland over the whole period, the average soil erosion intensity was below 3000 $t{\cdot}km^{-2}{\cdot}a^{-1}$ during the period of 1979-1998, and became to light erosion during 1999 to 2010. It was due to vegetation cover degree of forestland was higher than others and there are herb, litter and humus on the surface, which not only reduced surface runoff through intercepting rainfall, but also weaken the impact that raindrops on the topsoil. In addition, soil and water conservation measures such as constructing fish-scale pits and level ditches also played an important part in controlling soil erosion on forestland. Generally, erosion on farmland is usually stronger than that on forestland and grassland due to poor vegetation cover and loose structure of topsoil. Erosion on slope farmland is stronger than on other types of farmland. Since 1999, most of the slope farmland has been changed into grassland or forestland. Only flat farmland and terrace exist in this area from then on. Thus, soil erosion intensity on farmland reduced significantly from the year 1999. Soil erosion on grassland became the most important part in this area because of the steep slope and the poor vegetation cover on most of the grasslands.

Discussion and Conclusions

During the study period of more than 70 years from 1938 to 2010, soil erosion experienced a deteriorating stage followed by a mitigating one. Soil erosion modulus increased significantly from 7584.39 $t{\cdot}km^{-2}{\cdot}a^{-1}$ in 1938 to 46,392.56 $t{\cdot}km^{-2}{\cdot}a^{-1}$ in 1958, while it decreased to 51,50.80 $t{\cdot}km^{-2}{\cdot}a^{-1}$ in 2010. Moderate erosion and below covered an area of 52.99% in 1938, while severe erosion covered an average area of 67.05% during 1958-1978, and up to nearly 80% in 1958 especially. Nevertheless, soil erosion declined during 1979-1998, slight erosion account for 29.27% of the total study area. Since 1999, the average area of slight erosion was up to 3.85 km^2, while severe erosion was responsible for an average of 8.96% only.

Erosion was significantly influenced by topography and increased dramatically with slope increasing. The area of slope that steeper than 15° took up 81.95%, but disproportionally contributed 96.76% of the total soil erosion amount. In comparison, slope steeper than 25° contributed nearly 80%. Noticeably, the trend that soil erosion extended to area with slope steeper than 35° was identified from 1938 to 2010. Soil erosion at sunny and half sunny slope were stronger than that at shady and half shady slope, sunny and half sunny slope covered 48.25% of the total area, but contributed more than half of the soil erosion amount.

Among various land use types, soil erosion on forestland was slightest while on unutilized land strongest. Farmland was the major source of erosion during 1958-1998, while grassland was the major source of soil erosion in the following period, and grassland became the key area for soil and water conservation.

Though the eco-environment of Zhifanggou watershed has been markedly improved through comprehensive management in the past 30 years, some steep and barren slope still suffered severe erosion, which needs to be paid more attention in the future comprehensive control.

As an empirical model, RUSLE performs well in modeling rill erosion and inter-rill erosion, however, shallow gully erosion, gully erosion and gravitational erosion are not considered. Therefore, an individual rainfall soil erosion model for simulating gully and shallow gully erosion, which based on individual rainfall and topography data of runoff plots was developed [12]. However, this model is limited for the wide application due to the data for the model is difficult to obtain. Previous study on Zhifanggou watershed showed that, the area of severe and extreme erosion were added by 8.5%, and that severe erosion area between the gullies increased by 12.83 hm^2 when considering shallow gully erosion [14]. In this paper, the assessment of erosion from slopes and gullies underestimated the actual erosion amount within the watershed, because the gentle slope-based model is not suitable for the prediction of gully erosion well. On the other hand, the erosion within the control area of check dams was overestimated for not considering the role they had played in mitigating the erosion.

In this paper, the erosion amount that calculated is greater than the observed sediment load, mainly due to the slope model is directly used for the estimation of watershed erosion. Concretely, though taking into account the sediment control effect of engineering measures, the model omitted the deposition of sediment in the delivering process. Scilicet, total soil erosion amount is simple summation of the erosion amount of each grid cell that calculated by slope model and ArcGIS, in fact, sedimentation might occur in every grid cell, it would lead to the overestimation of soil erosion, which is the common problems that many other related studies and the present one faced. Therefore, how to overcome the limitations of the model is the focus of future research.

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