Journal of Geography and Cartography (2022) Volume 5 Issue 1
doi:10.24294/jgc.v5i1.1410

ORIGINAL RESEARCH ARTICLE

Estimation of soil erosion in loess plateau based on geographic information system

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ABSTRACT

One of the core problems in soil erosion research is the estimation of soil erosion. It is a feasible method and technical approach to estimate soil erosion in Loess Plateau region by using USLE model, GIS and RS technology and using DEM data, meteorological data and land-use type data. With the support of GIS and RS technology, the USLE factors and soil erosion in Loess Plateau region were estimated, and the soil erosion intensity was classified according to the Chinese soil erosion intensity classification standard. The results can provide reference for the development of soil erosion control measures in the Loess Plateau.

Keywords: Loess Plateau; Soil Erosion; General Soil Loss Equation; Geographic Information System; Erosion Intensity; Level

ARTICLE INFO

Received: 22 September 2021
Accepted: 25 October 2021
Available online: 11 November 2021

1. Introduction

Loess Plateau's loose soil, fine soil particles with large amount of easy dissolved minerals, plus ground slopes, sparse vegetation, and heavy rain in the summer, result in accelerating soil loss in the area. At the same time, human activities have also caused environmental damage, such as soil erosion, vegetation damage, hacking, unreasonable farming system, harmful pollutant emissions. Under the double role of natural factors unique to the Loess Plateau and the social factors of human activities, the Loess Plateau has become the most serious region of soil erosion in China.

Soil erosion comprises complex humanities and natural factors, and its occurrence and development is the result of integrated factors such as terrain, vegetation coverage, regional precipitation, land management and utilization. In the traditional method of soil loss investigation, the cycle time is long, the statistical efficiency is low, and the amount of erosion of large area of soil cannot be completely determined. It will bring inconvenience to long-term planning and scheme formulation of local water and soil conservation in the future, and it is even more impossible to realize quantitative monitoring of the effectiveness of local water and soil conservation in corresponding areas. Soil erosion quantitative estimation based on GIS (geographic information system) and remote sensing technology has been widely used in recent years. The method mainly obtains the type of land utilization, combined with terrain, rainfall, and other data by interpreting remote sensing images, using (revised universal soil loss equation) RUSLE model algorithm[1], with the GIS graphics operation function, the factors in the model are spatially positioned, and soil erosion status is located and quantitatively estimated. With Loess Plateau as the research object, through GIS technology combined with universal soil loss model, the soil erosion modulus of the study is calculated, and at the same time, according to China's soil erosion intensity grading standards, the intensity of soil erosion in the Loess Plateau is classified, in order to provide corresponding scientific basis for formulating the specific circumstances of soil erosion strength and comprehensive management measures for the Loess Plateau soil erosion[2,3].

2. Research area and data source

2.1 Research area overview

The Loess Plateau is located in the north of central China. It is about 1,010 km from east to west, and 700 km from south to north, covering the east of Riyue Mountain in Qinghai province, the west of Taihang Mountain, the south of the Great Wall and most of the areas in the north of Qin Ling, totaling 400,000 km^2 in area. The Loess Plateau covers a deep loess layer. In addition to a few stone mountains, the loess coverage has a thickness between 50–80 m, and the thickness can reach 150–180 m. Due to the lack of protection of soil environment in human long-term production activities and the lack of awareness of vegetation protection, coupled with heavy rain in summer, vegetation on the ground is sparse and soil erosion is serious under the long-term erosion of running water. In a large number of soil and water conservation studies on the Loess Plateau, researchers have included about 62×10^4 km^2 of the middle reaches of the Yellow River into the Loess Plateau for the integrity of drainage basins and water and sediment sources, including parts of northern Shaanxi and Gansu, which are the places with the most serious soil and water loss in China.

The climate of the Loess Plateau region is typical of continental monsoon climate. The average annual rainfall in this region is 466 mm, and the trend of rainfall decreases gradually from southeast to northwest. According to the trend of rainfall, it can be divided into sub-humid, semi-arid and arid regions.

2.2 Source of data

2.2.1 Types of land-use data

In this study, the interpretation of Landsat7 remote sensing images obtained by the State Environmental Protection Administration in 2008 was used as land-use type data.

2.2.2 Meteorological data

Monthly precipitation data from 1980 to 2010 from 84 national meteorological stations over the Loess Plateau and its surrounding areas were obtained from China National Meteorological Information Sharing Center (www. nmic.gov.cn).

2.2.3 Other related data

Digital elevation model data (DEM) of soil type[4] and the Loess Plateau border. Among them, DEM datum all adopt SRTM data jointly measured by NASA and NIMA, with a spatial resolution of 89 m; 1:1,000,000 soil type data from Institute of Soil Science, Chinese Academy of Sciences is adopted; the boundary set by the comprehensive scientific investigation team of the Loess Plateau region of the Chinese Academy of Sciences in 1991 is adopted as the boundary of the Loess Plateau.

3. Research method

The study mainly adopted the universal soil loss equation (USLE) modified by the United States Department of Agriculture to calculate the amount of soil erosion by using the one-year observation data of 8,000 runoff plots in 36 regions. The equation expression of this model is[5,6]:

$$A = fRKLSCP \tag{1}$$

In equation (1): A is the soil loss of the unit area, $t/(km^2 \cdot a)$; R is a rainfall erosion factor; C is the operation management and vegetation coverage factor; K is the soil modification factor; L is a slope length, and S is the slope; P is the water and soil retention measures. Converting A's unit to $t/(km^2 \cdot a)$ constant f, its value is 224.2.

3.1 Calculation of the factors of soil loss equations

3.1.1 Slope (*S*) and slope length (*L*)

The acceleration factors of soil erosion are slope and slope length, mainly in terms of terrain and geomorphic characteristics on soil erosion. Slope directly affects soil erosion. Under the same condition, the greater the slope and the stronger the scouring capacity is, the more serious soil erosion will be. Soil erosion increases as the slope length (*L*) and the slope (*S*) increase. Therefore, the composite factor *LS* is often used to reflect the relationship between the two and the amount of erosion. The calculation formula of the composite factor *LS* is[7]:

$$LS = 1.07\left(\frac{\lambda}{20}\right)^{0.28}\left(\frac{\alpha}{10^{\circ}}\right)^{1.45} \tag{2}$$

In equation (2): λ is the slope length; α is a slope; DEM data of the study area in this region were calculated by using the spatial analyst tool and hydrology module in ArcGIS to generate slope (**Figure 1**(**a**)) and slope length (**Figure 1**(**b**)), respectively.

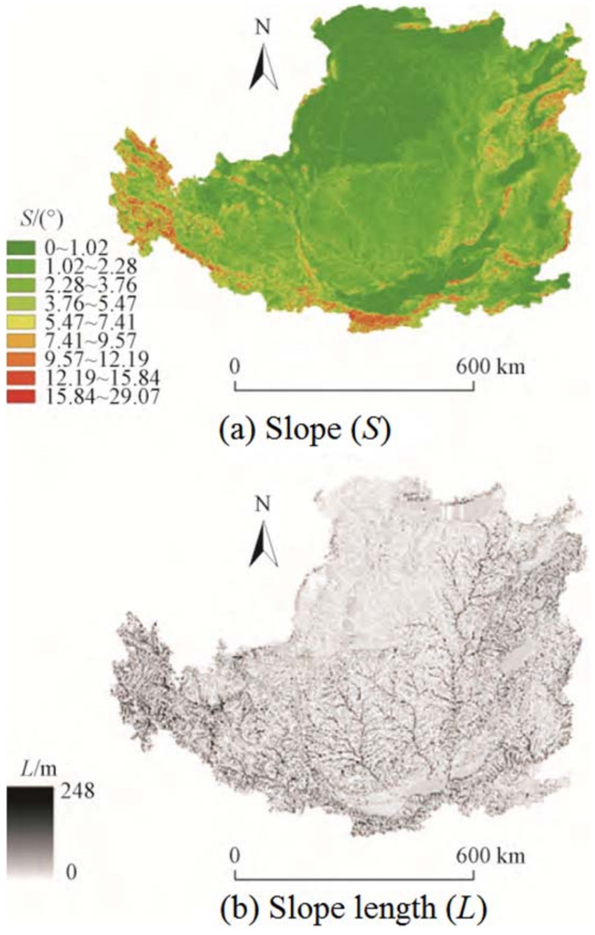

Figure 1. Gradient and slope length grid layer.

3.1.2 Rainfall erosion factor (*R*)

Rainfall erosion is the primary base factor in the soil loss equation. According to Wischmeier, the empirical formula of *R* can be deduced by using the average monthly rainfall over many years[8]:

$$R = \sum_{i=1}^{12} 1.735 \times 10^{1.5lg\frac{P_i^2}{P} - 0.8188} \tag{3}$$

In equation (3): P_i is the average rainfall of each month, *P* is perennial mean rainfall, and *R* is rainfall erosion. The monthly and annual average rainfall data of 85 national meteorological stations in and around the Loess Plateau from 1980 to 2010 were adopted, and *R* of each meteorological station was obtained according to equation (3). Finally, Kriging interpolation method was used in ArcGIS to obtain rainfall erosivity *R* (**Figure 2**).

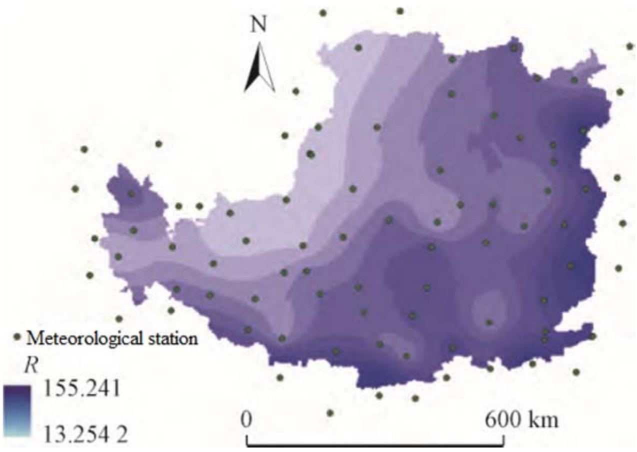

Figure 2. Rain fall erosion factor (*R*) grid layer.

3.1.3 Soil erosion factor (*K*)

An index to evaluate the degree of separation, erosion and transport of soil rainfall erosivity is regarded as soil erosibility factor *K*, which reflects the sensitivity of soil to erosion, the magnitude of runoff rate and the runoff generated by precipitation. Referring to previous research results, *K* is determined by equation (4):

$$100K = 2.1M^{1.14} \times 10^{-4}(12 - a) + 3.25(b - 2) + 2.5(c - a) \tag{4}$$

In equation (4): *a* is the percentage content of organic matter; *b* is structural encoding in the soil classification; *c* is the soil profile infiltration level; *M* is the percentage of clay and fine powder (0.05 ~ 0.50 mm). Substitute each parameter value in the formula into equation (4) to calculate *K*.

3.1.4 Factor of soil and water conservation measures (*P*)

The ratio of soil loss after taking soil and water conservation measures to the corresponding soil loss when planting along slope without taking any soil and water conservation measures is regarded as the factor of soil and water conservation measures (*P*). As far as the farming ladder is different, its *P* is different, so it is different for soil erosion. *P* of farming terraces under different farming methods is shown in **Table 1**. The determination of *P* is the same as the determination of *C*, and the value of soil and water conservation factor *P* is finally determined according to the status quo of land-use types and some investigations in the Loess Plateau and the value of *P* in different land-use types (**Table 2**). *P* of each grid layer can be obtained by modeling tools in ArcGIS (**Figure 3**).

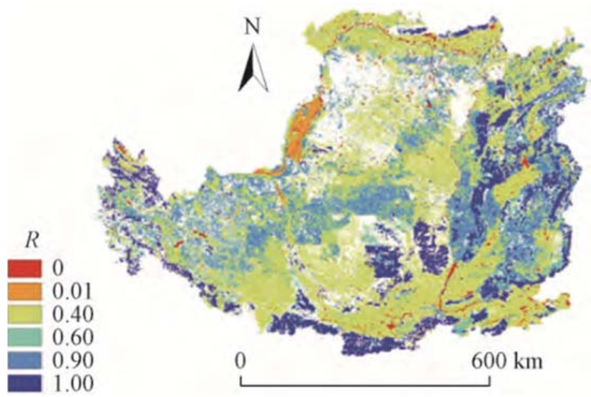

Figure 3. Soil and water conservation measures factor (*P*) grid layer.

Table 1. *P* of different land-use types

Slope/(°)	Contour strip cultivation	Strip cultivation of grass fields	Level terrace	Level trench	Contour cultivation
<5	0.3	0.1	–	0.01	0.1
5 ~ 10	0.5	0.1	0.3	0.05	0.1
>10	0.6	0.2	–	0.1	0.3

Table 2. *P* of soil and water conservation measures

Paddy field	Dry land	Woodland	Garden plot	Shrub land
0.01	0.4	1	0.4	1
Grassland	**Construction land**	**Water area**	**Bare land**	
0.9	0	0	0.4	

3.1.5 Different land-use factors (*C*)

According to the land-use status in the Loess Plateau region and the collection of some survey data, the values of *C* of different land uses are proposed, and finally *C* of different land-use types is determined (**Table 3**). Similarly, the method of calculating *P* is used to obtain the *C* grid layer (**Figure 4**).

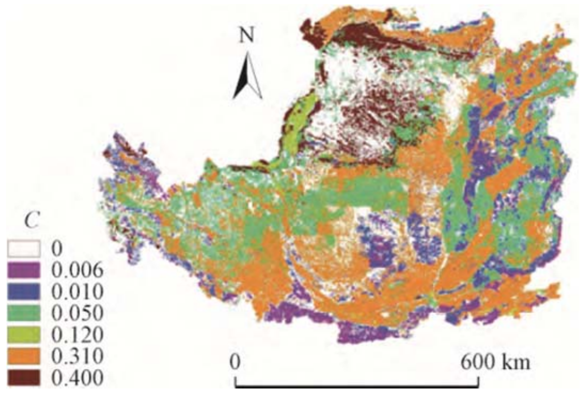

Figure 4. Different land-use type *C* grid layer.

Table 3. *C* of different land-use types

Paddy field	Dry land	Woodland	Garden plot	Shrub land
0.18	0.31	0.006	0.05	0.05
Grassland	**Construction land**	**Water area**	**Bare land**	
0.01	0	0	0.4	

3.2 Calculation of soil erosion modulus

The calculation of the soil erosion modulus is based on the value of each factor of RUSLE erosion model[9], thereby generating various factor grid layers, and the grid size weight is 1,000 m × 1,000 m, and is uniform to the same projection system; finally, the Raster Calculator tool under the Spatial Analyst module was used in ArcGIS software to obtain a spatial distribution of soil erosion space in Loess Plateau (**Figure 5)**.

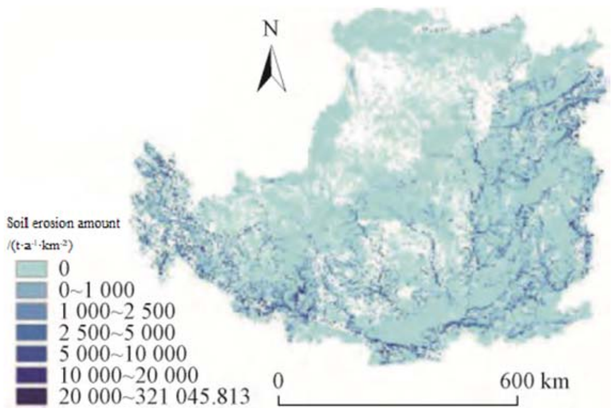

Figure 5. Spatial distribution of soil erosion modulus.

4. Results and analysis

4.1 Soil erosion modular grading

Soil erosion modulus refers to the size of erosion amount of soil and soil parent material per unit area in unit time, which is an indicator of soil erosion strength and is used to reflect the erosion intensity in a regional unit time. According to China's standard for classification of soil erosion intensity levels, soil erosion modulus can be divided into six categories according to the range of soil erosion modulus, including slight erosion, mild erosion, moderate erosion, intense erosion, extremely intense erosion and severe erosion, so as to classify the calculated distribution map of soil erosion modulus (**Figure 6**).

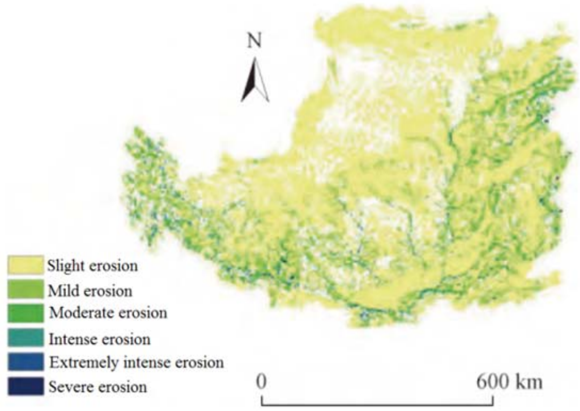

Figure 6. Soil erosion grade results.

4.2 Analysis of soil erosion simulation results

The size of soil erosion is due to the results of rainfall, terrain, vegetation, soil and other factors. According to the statistical results of soil erosion grades in the study area (**Table 4**), the total soil erosion volume in the Loess Plateau is 1.25×10^8 t/a. Among them, the amount of slight erosion and mild erosion is larger, accounting for 62.64% of total erosion, the moderate erosion is accounted for 16.54%, and the above-moderate erosion volume accounts for 20.82%. The average erosion modulus is 3,825.39 $t \cdot km^{-2} a^{-1}$, which belongs to moderate erosion[10,11].

Table 4. Soil erosion intensity classification of the research area

Erosion category	Erosion modulus/($t \cdot km^{-2} \cdot a^{-1}$)	Area/km^2	Area ratio/%	Erosion volume/(10^7 $t \cdot a^{-1}$)
Slight erosion	<1000	12,281	37.40	4.69
Mild erosion	1,000 ~ 2,500	8,288	25.24	3.17
Moderate erosion	2,500 ~ 5,000	5,431	16.54	2.08
Intense erosion	5,000 ~ 10,000	3,712	11.31	1.42
Extremely intense erosion	10,000 ~ 20,000	1,865	5.68	0.71
Severe erosion	>20,000	1,258	3.83	0.48
Total		32,835	100	12.5

5. Conclusion

The calculated results are close to those calculated on the scale of the Loess Plateau. In addition, compared with Google high-definition image sampling, soil erosion is more serious in the exposed slope farmland area, and less erosion is woodland and grassland, indicating that using RUSLE model, GIS and RS technology to estimate the soil erosion of Loess Plateau area is a feasible method and technical approach[12,13]. Soil erosion estimation model is still in the theoretical trial stage. USLE, which is used to calculate the annual average soil erosion, is difficult to accurately reflect the soil loss due to rainfall processes. In theory, the interaction between some factors, such as *C*, *R*, *L* and *P*, is double-calculated in this equation, thus ignoring the interaction between the factors. This is also the shortcoming of using this model in this study, because the Loess Plateau region has complex terrain and large slope, and there are some gaps with the basic conditions of equation establishment. Therefore, there are still some problems to be further studied, such as the influence of spatial resolution on the results, the influence of vector and raster data conversion process on the data accuracy. In addition, the influence of human activities should be considered in the later research, such as the construction of flat hills and renovation of terraced fields.

Conflict of interest

The authors declare that they have no conflict of interest.

Acknowledgements

Project: Gansu Provincial Natural Science Foundation (1610RJYA013).

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