

# Soil erosion assessment in the core area of the Loess Plateau

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**Abstract** In order to explore the spatiotemporal evolution of erosion and sediment yield before and after Grain for Green Project in the Loess Plateau. The soil loss of Yulin is estimated by Chinese Water Erosion on Hill Slope Prediction Model. The result shows that the spatiotemporal variations of soil erosion are largely related to rainfall erosion distribution, slope, and land use type. The overall soil erosion categories in the south region are higher than that of the northwest. Mid slopes and valleys are the major topographical contributors to soil erosion. With the growth of slope gradient, soil erosion significantly increased. The soil loss has a decreasing tendency after Grain for Green Project. The results indicate that the vegetation restoration as part of the Grain for Green Project on the Loess Plateau is effective.

## 1. Introduction

The Loess Plateau is one of the most serious soil erosion regions, and the severe water erosion area is about  $3.67 \times 10^4$  km<sup>2</sup>, accounting for 89% in China. In response to the environmental crisis, the government has launched the "Grain for Green" (GFG) Project in 1999. In the Loess Plateau, the reforestation has significantly improved the NDVI and retarded soil erosion, increasing soil organic and carbon storage, as well as environmental quality since 1999<sup>[1]</sup>. However, the contribution of Grain for Green Project for reducing soil loss is not clear in the core region of the Loess Plateau. So, quantitative simulation assessment of soil erosion under the influence of climate change and reforestation is an important work.

The empirical statistical model is simple, needs less data and reliable result<sup>[2]</sup>. The Revised Universal Soil Loss Equation (RUSLE) model is regarded as one of the best empirical model to assess soil erosion. However, the related studying achievement has proved that the assessment of soil erosion by RUSLE is not perfect in the Loess Plateau<sup>[3]</sup>. The characteristic of the Loess Plateau is complex, steep terrain conditions and soft soil, and shallow gully erosion has a significant impact on slope erosion. Therefore, it is necessary to consider the effects of shallow gully erosion. Jiang added the *G* factor (shallow gully erosion factor) to RUSLE model.<sup>[4]</sup> This new model is called China Water Erosion on Hill Slope Prediction model (CWEHP), which increases assessment accuracy of soil loss in the Loess Plateau.<sup>[5]</sup>

This study, taking Yulin in the Loess Plateau as a case study, aims to estimate *K*, *SL*, *C*, *P*, *R* and *G* factors supported by GIS and RS, and the objectives of this paper are: (1) to estimate soil loss from 2000 to 2013; (2) to calculate and analyze soil loss change under slope and elevation; (3) to simulate NDVI contribution for reducing soil loss and assess the benefits of soil and water conservation after GFG; (4) to discuss measures for soil conservation planning in Yulin.



## 2 Materials and methods

### 2.1 Study area

The study region is Yulin (Fig. 1) located at 36°57'-39°34'N, 107°28'-111°15'E, which is situated at the northern of Shaanxi province, being bounded by Gansu province, the Ningxia Hui Autonomous Region, the Inner Mongolia Autonomous Region, and Shanxi province, and belonging to transitional terrain from Mu Us desert to northern Shaanxi Loess Plateau and being a typical crisscross zone of farming and animal husbandry as well [6]. Its terrain slope is from northwest to southeast, and it is arid and semiarid temperate zone with continental monsoon climate. Climate characteristic is a typical temperate monsoon climate zone: dry and rainless in winter, and significant rainfall in summer (more than 60 % of rainfall occurs from June to September in the flood season), with a mean annual temperature of 14.5 C°, annual average relative humidity of about 69 % and annual precipitation varying between 472 and 1504 mm (annual average rainfall is 885 mm). [7].

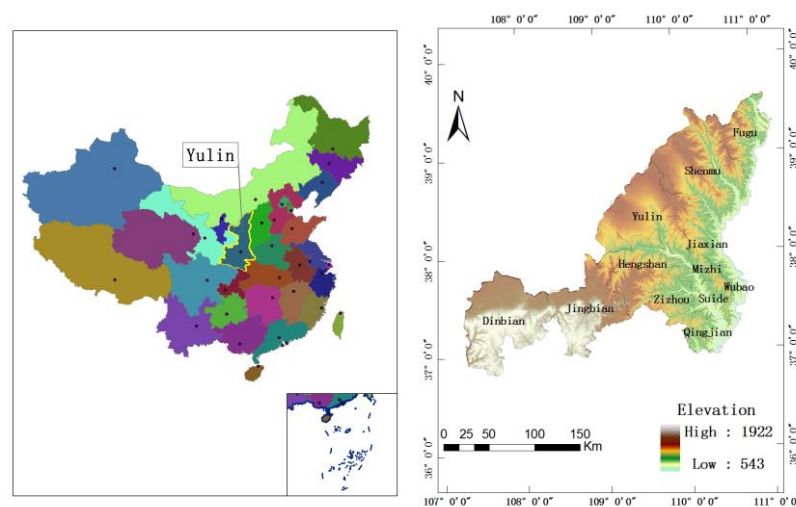


Fig. 1 The location of Yulin, Shaanxi Province, China

### 2.2 Data collection

The related GIS spatial data and soil data are downloaded from scientific websites. The 30m ASTER GDEM made by NASA and annual mean MODIS 250m NDVI from 2000 to 2013 are downloaded from the Geospatial Data Cloud (<http://www.gscloud.cn>). Daily precipitation data are from China Meteorological Data Sharing Service System (<http://cdc.nmic.cn/home.do>) and Data Sharing Infrastructure of Earth System Science (<http://loess.data.ac.cn>). One part of soil data is Harmonized World Soil Database version 1.1) (HWSD) from (<http://westdc.westgis.ac.cn/>), the other soil data are from the Second Soil Census in Shaanxi Province. The 30m resolution DEM data, the 1:1,00,000 land use type maps of 2000, 2005 and 2013, precipitation, NDVI data and soil type map are used for separate computation  $SL$ ,  $G$ ,  $P$ ,  $R$ ,  $C$ , and  $K$  factors.

### 2.3 Model description

The China Water Erosion on Hill Slope Prediction Model (CWEHP) has 7 factors, and this model can be described as Eq. 1, [4].

$$A = R \cdot L \cdot S \cdot K \cdot C \cdot P \cdot G \quad (1)$$

In the Eq. 1,  $A$  is the average soil loss due to water erosion ( $\text{ha}^{-1} \text{ year}^{-1}$ ),  $R$  is the rainfall erosivity factor ( $\text{MJ} \cdot \text{mm} \cdot \text{h} \cdot \text{m}^{-2} \cdot \text{h}^{-1}$ ),  $K$  is the soil erodibility factor ( $\text{t} \cdot \text{h} \cdot \text{m}^2 / (\text{h} \cdot \text{m}^2 \cdot \text{MJ} \cdot \text{mm})$ ),  $S$  is the slope steepness factor,  $L$  is the slope length factor,  $C$  is the cover and management practice factor, and  $P$  is the conservation support practice factor,  $G$  is rill erosion factor. The  $LS$ ,  $C$ ,  $P$  and  $G$  factors are dimensionless. The  $K$ ,  $SL$ ,  $C$ ,  $P$ ,  $R$  and  $G$  factors are accepted by relevant literatures [8,9,10,11,3,4].

### 3 Results and Discussion

#### 3.1 The spatial-temporal distribution characteristic of soil loss

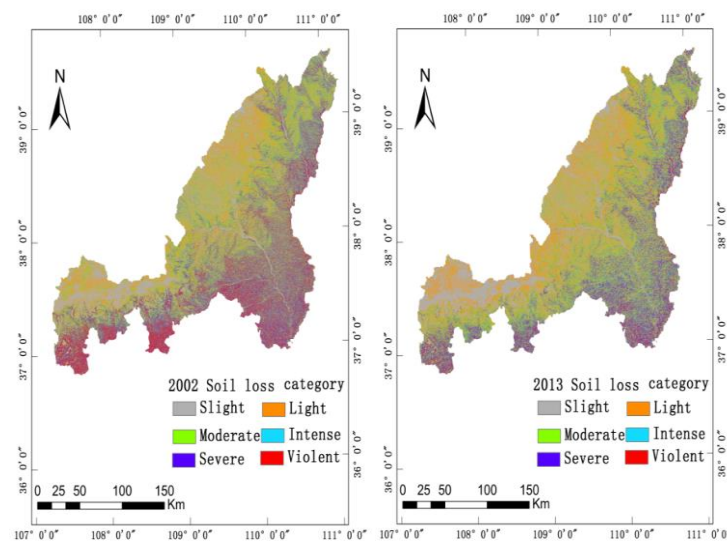
According to the Standard for Classification and Gradation of Soil Erosion SL190-2007 (Ministry of Water Resources of PR China, 2008) [12], predicated soil erosion rate is classified into soil erosion risk classes. The soil erosion category maps are shown in Fig. 2. and Table 1.

**Tab 1** Statistics of soil erosion categories

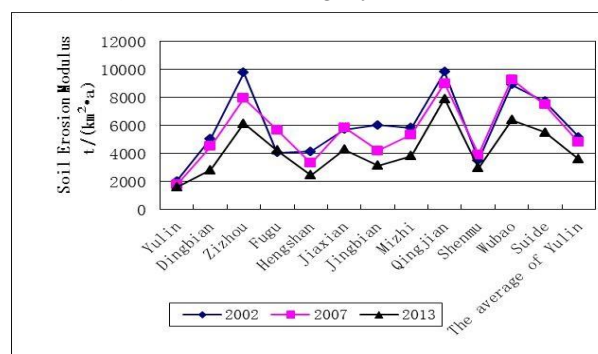
Erosion statistics	2000	2001	2002	2007	2008	2013
slight	46.67%	25.40%	29.71%	30.31%	29.88%	33.17%
light	29.15%	16.58%	24.97%	24.27%	23.87%	28.12%
Category moderate	11.22%	13.58%	14.71%	14.98%	16.47%	15.23%
intense	5.89%	10.17%	9.99%	10.76%	12.00%	9.78%
severe	4.70%	13.60%	11.55%	12.02%	11.57%	9.21%
violent	2.38%	20.67%	9.06%	7.66%	6.21%	4.49%
Soil loss t/(km <sup>2</sup> ·a)	2238.81	9611.88	5132.86	4775.34	4454.3	3575.94
Annual rainfall erosivity factor (MJ·mm·hm <sup>-2</sup> ·h <sup>-1</sup> )	437.93	2384.58	1463.45	1212.78	1368.98	1272.59

From 2000 to 2013, the annual mean  $R$  factor is 1163.64 MJ·mm·hm<sup>-2</sup>·h<sup>-1</sup>. There is a significant gap among  $R$  factor in different years, with the highest value of 2384.58 MJ·mm·hm<sup>-2</sup>·h<sup>-1</sup> in 2001 and the lowest value of 437.93 MJ·mm·hm<sup>-2</sup>·h<sup>-1</sup> in 2000, corresponding soil loss was 9611.88 t and 2238.81 t / (km<sup>2</sup>·a). The soil loss are close related with  $R$  factor, the  $R$  factor in other years are similar. The soil loss in 2002, 2007, and 2013 are 4778.90, 4131.92 and 3350.09 t / (km<sup>2</sup>·a), respectively. In 2002, about 30.15% soil erosion is in the intensity to violent category, and total soil loss is 202 million tons. In 2007, about 29.81% soil erosion is in the intensity to violent category, and total soil loss is 165 million tons. In 2013, about 22.77% soil erosion is in the intensity to violent class, and total soil loss is 151 million tons. Compared with 2002, the average soil loss and total erosion decreased by 1428.81 t / (km<sup>2</sup>·a) and 60.4 million tons in 2013. The soil loss has showed a declining tendency since 2000.

The geomorphic features of Yulin may be roughly divided into the north sand and the southern hilly and gully district. The north windy desert region is flat, including Fugu, Shenmu, Dingbian, Jingbian country and Yuyang district. The southern hilly and gully district contains Zizhou, Suide, Qingjian, Mizhi, Wubu, Jia and Henshan countries. So, the soil loss shows evident spatial distribution characteristic, that the south region is much larger than the west and north region. The soil erosion category from slight to moderate is mainly located in the west and north sand region. Areas suffering from intense erosion rates higher than 5000 t / (km<sup>2</sup>·a) included the gully and hilly regions in the southern parts. The rainfall erosivity of 2002, 2007 and 2013 are similar, corresponding estimated soil loss of 13 countries are shown in Fig. 6. In 2002, there are 8 countries the soil loss over 5000 t / (km<sup>2</sup>·a), including Qingjian (9807.52 t / (km<sup>2</sup>·a)), Zizhou (9745.63 t / (km<sup>2</sup>·a)), Wubu (8871.47 t / (km<sup>2</sup>·a)), Suide (7697.39 t / (km<sup>2</sup>·a)), Jingbian (6008.27 t / (km<sup>2</sup>·a)), Mizhi (5804.42 t / (km<sup>2</sup>·a)), Jiaxian (5686.19 t / (km<sup>2</sup>·a)) and Dingbian (5014.85 t / (km<sup>2</sup>·a)). In 2013, the soil loss over 5000 t / (km<sup>2</sup>·a) countries decrease to 4, such as Qingjian (7888.82 t / (km<sup>2</sup>·a)), Wubu (6360.55 t / (km<sup>2</sup>·a)), Zizhou (6108.54 t / (km<sup>2</sup>·a)), Suide (5482.03 t / (km<sup>2</sup>·a)). The average soil loss in the hill and gully region reduced by 2277.75 t / (km<sup>2</sup>·a). The soil loss of 13 countries are all reduced after 2002, the maximum and minimum decrease countries are Zihou with 3637.09 t / (km<sup>2</sup>·a) and Shengmu with 532.39 t / (km<sup>2</sup>·a). The vegetation coverage steadily increased on the Loess Plateau, which appears to have effectively reduced the susceptibility of the Plateau to soil erosion.



**Fig. 2** Soil loss category in 2002 and 2013



**Fig. 3** The soil loss of each country 2002, 2007 and 2013

### 3.2 Change analysis of soil erosion on different slope and elevation

Soil loss has a positive correlation under critical slope in the Loess Plateau. In the study area, More than 68% slope is less than 40 degree. In the hilly and gully region, the ravines and fragmented landform are widely distributed, all of them can accelerate soil erosion. In order to identify the soil loss change in different slope, slope is classified into six classes: the first ( $1^{\circ}$ - $5^{\circ}$ ), the second( $5^{\circ}$ - $8^{\circ}$ ), the third( $8^{\circ}$ - $15^{\circ}$ ), the forth( $15^{\circ}$ - $20^{\circ}$ ), the fifth( $20^{\circ}$ - $35^{\circ}$ )and the sixth( $>35^{\circ}$ ).The map of soil loss in different slope is shown in (Fig. 4).Soil loss increased rapidly over the second slope degree ( $5^{\circ}$ - $8^{\circ}$ ), reaching the max value in the fifth slope degree( $20^{\circ}$ - $35^{\circ}$ ), then reducing quickly over the sixth slope degree ( $>35^{\circ}$ ).The soil loss of 2002, 2007, and 2013 have reached the peak values of 15371.02, 13368.04, and 9855.55  $t/(km^2 \cdot a)$  in the fifth slope classes ( $20^{\circ}$ - $35^{\circ}$ ). Compared with 2002, the soil loss in all different slope classes are declining, especially in the fifth slope degree( $20^{\circ}$ - $35^{\circ}$ ), reduced by 5515.5  $t/(km^2 \cdot a)$ . According to regulations of reforestation, the major slope cultivated land to reforestation is over  $25^{\circ}$ . The vegetation recovering relieves the direct washing of rain to soil, on the contrary, the accumulated nutrition from saved water and soil promote growth of vegetation.

Elevation is another key factor for soil loss. DEM is also classified into seven classes by interval 200m. Soil loss of 2000, 2007 and 2013 in different elevation zones are elaborated in (Fig. 5). The fifth elevation zone (from 1300 to 1500m) is a turning point, below or above this elevation zone, soil loss increases with elevation. The max and min soil loss value are 8149.46 and 3078.89  $t/(km^2 \cdot a)$  in 2002, corresponding, 1500-1700m and 1300-1500m. While in 2013, the max and min soil loss values change 4514.88 and 1703.61 $t/(km^2 \cdot a)$ . As for the comparison of the slope gradient distribution in 2002, 2007

and 2013, it is obvious that the soil loss in 1500–1700m elevation zone decreases significantly, reducing about 3634.58 t/(km<sup>2</sup>·a), while the decreased soil erosion modulus was 1375.279 t/(km<sup>2</sup>·a) in 1300–1500m elevation zone. In fact, soil loss in different elevation zones embodies relationship of geomorphology and soil loss. As a whole, the average soil loss of each slope and elevation degrees are all decreased from 2002 to 2013.

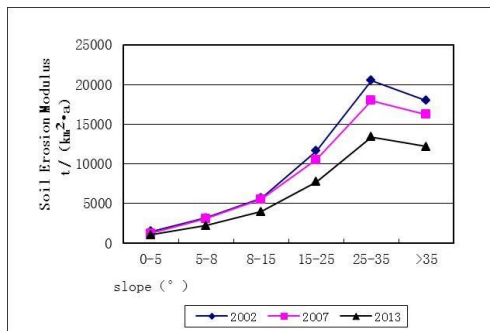


Fig.4 Comparison of soil loss in slope

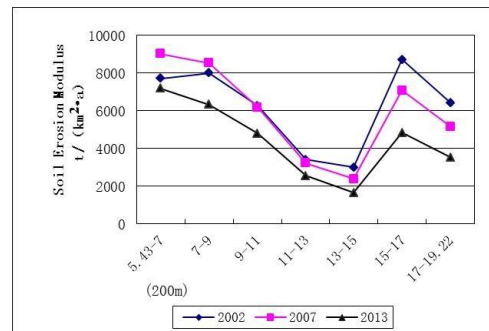


Fig.5 Comparison of soil loss in elevation

#### 4. Conclusion

By selecting 13 counties of Yulin on the Loess Plateau, a vulnerable and sensitive ecological region, as the study area, this research synthesizes GIS and RS techniques and analysing the vegetation cover change, slope gradient, elevation and land use. Then, a qualitative assessment method was used to assess water erosion (rill and sheet erosion) and the dynamic change trend of spatial and temporal distribution in erosion status and intensity between 2000 and 2013. The simulation rainfall method was also accepted to estimate the contribution of Grain for Green Project. The research demonstrates the Chinese Water Erosion on Hill Slope Prediction model could rapid and effective assessment soil loss and change trend over a large area. The continual increased woodland and grassland have made great contribution to reduce soil loss. The control of soil and water loss of Yulin has already obvious achievement.

#### Acknowledgements

This study is supported by the National Natural Science Foundation of China (No.51239009, 51179150), the Science Foundation of Shaanxi Province Education Department (No.14JZ063, No.16JZ089), the Science Foundation of Xianyang Normal University Historical Geography (No. Szxky1409 and Szxky1407).

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