Soil erosion assessment in the core area of the Loss Plateau

Bo Yang 1, 2 · Quanjiu Wang 1

1 Institute of Water Resources and hydro-electric Engineering, Xi’an University of Technology, Xi’an 700048, Shaanxi, People’s Republic of China
2. Institute of Natural Resources Environment and historical culture, Xian Yang Normal University, Xian Yang, 712000, Shaanxi, People’s Republic of China

Abstract In order to explore the spatiotemporal evolution of erosion and sediment yield before and after Grain for Green Project in the Loss 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 3.67×10⁴ km², 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 Loss 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[1]. However, the contribution of Grain for Green Project for reducing soil loss is not clear in the core region of the Loss 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 [2]. 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 [3]. 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. [4] 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. [5]

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 \cite{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). \cite{7}.

![Fig. 1 The location of Yulin, Shaanxi Province, China](image)

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, \cite{8}.

\begin{equation}
A = R \cdot L \cdot S \cdot K \cdot C \cdot P \cdot G
\end{equation}

In the Eq. 1, $A$ is the average soil loss due to water erosion (ha$^{-1}$ year$^{-1}$), $R$ is the rainfall erosivity factor (MJ·mm·hm$^{-2}$·h$^{-1}$), $K$ is the soil erodibility factor (t·hm$^{-2}$·h/(hm$^{-2}$·MJ·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 \cite{8,8,9,10,11,12,13,14}.
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], predicted soil erosion rate is classified into soil erosion risk classes. The soil erosion category maps are shown in Fig. 2 and Table 1.

| Erosion category | 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%     |
| moderate         |            |            |            |            |            |            |
| severe           | 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%      |
| violent          | 4.70%      | 13.60%     | 11.55%     | 12.02%     | 11.57%     | 9.21%      |
| Soil loss (t/(km²·a)) | 2238.81   | 9611.88    | 5132.86    | 4775.34    | 4454.3     | 3575.94    |
| Annual rainfall erosivity factor (MJ·mm·hm⁻²·h⁻¹) | 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⁻²·h⁻¹. There is a significant gap among R factor in different years, with the highest value of 2384.58 MJ·mm·hm⁻²·h⁻¹ in 2001 and the lowest value of 437.93 MJ·mm·hm⁻²·h⁻¹ in 2000, corresponding soil loss was 9611.88 t and 2238.81 t/(km²·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/(km²·a), respectively. In 2002, about 30.15% soil erosion is in the intensity to severe category, and total soil loss is 202 million tons. In 2007, about 29.81% soil erosion is in the intensity to slight category, and total soil loss is 165 million tons. In 2013, about 22.77% soil erosion is in the intensity to violent category, and total soil loss is 151 million tons. Compared with 2002, the average soil loss and total erosion decreased by 1428.81 t/(km²·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 county 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/(km²·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/(km²·a), including Qingjian(9807.52 t/(km²·a)), Zizhou (9745.63 t/(km²·a)), Wubu (8871.47 t/(km²·a)), Suide (7697.39 t/(km²·a))Jingbian (6008.27 t/(km²·a)), Mizhi (5804.42 t/(km²·a)), Jiaxian (5686.19 t/(km²·a)) and Dingbian (5014.85 t/(km²·a)). In 2013, the soil loss over 5000 t/(km²·a) countries decrease to 4, such as Qingjian(7888.82 t/(km²·a)), Wubu (6360.55 t/(km²·a)), Zizhou (6108.54 t/(km²·a)), Suide (5482.03 t/(km²·a)). The average soil loss in the hill and gully region reduced by 2277.75 t/(km²·a). The soil loss of 13 countries are all reduced after 2002, the maximum and minimum decrease countries are Zizhou with 3637.09 t/(km²·a) and Shengmu with 532.39 t/(km²·a). The vegetation coverage steadily increased on the Loess Plateau, which appears to have effectively reduced the susceptibility of the Plateau to soil erosion.
corresponding increase of soil loss of landforms in different slope, especially 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°-5°), the second(5°-8°), the third(8°-15°), the forth(15°-20°), the fifth(20°-35°) and the sixth(>35°). The map of soil loss in different slope is shown in (Fig. 4). Soil loss increased rapidly over the second slope degree (5°-8°), reaching the max value in the fifth slope degree(20°-35°), then reducing quickly over the sixth slope degree (>35°). The soil loss of 2002, 2007, and 2013 have reached the peak values of 15371.02, 13368.04, and 9855.55 t/(km²·a) in the fifth slope classes (20°-35°). Compared with 2002, the soil loss in all different slope classes are declining, especially in the fifth slope degree(20°-35°), reduced by 5515.5 t/(km²·a). According to regulations of reforestation, the major slope cultivated land to reforestation is over 25°. 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/(km²·a) in 2002, corresponding, 1500-1700m and 1300-1500m. While in 2013, the max and min soil loss values change 4514.88 and 1703.61t/(km²·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/(km²·a), while the decreased soil erosion modulus was 1375.279 t/(km²·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.

4. Conclusion
By selecting 13 countries of Yulin on the Loss 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.

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References
[1]. Song F, Xing K, Liu Y, et al. Monitoring and assessment of vegetation variation in Northern Shaanxi based on MODIS/NDVI 2011 J. Acta Ecologica Sinica, 31 354.
[2]. Sun WY, Shao, QQ, Liu, JY. Soil erosion and its response to the changes of precipitation and vegetation cover on the Loess Plateau 2013 Journal of Geographical Sciences 23 1091
[3]. Fu B J, Zhao W W, Chen L D, et al. Assessment of soil erosion at large watershed scale using RUSLE and GIS: a case study in the Loess Plateau of China 2005 J. Land Degradation & Development 16 73 .
[4]. Jiang Z.S, Zheng F L, Min W U. Prediction model of water erosion on hillslopes 2005 J. Journal of Sediment Research 4 1
[5]. Qian J, Zhang L P, Wang W Y, et al. Effects of vegetation cover and slope length on nitrogen and phosphorus loss from a sloping land under simulated rainfall 2014 J.Polish Journal of 23 835.
[6]. Zha Y, Liu Y, Deng X. A landscape approach to quantifying land cover changes in Yulin, Northwest China 2008 J. Environmental Monitoring & Assessment 138 139.
[7]. Liu Y, Gao J. Trend Analysis of Land Degradation in the Zone along the Great Wall in Northern Shaanxi 2002 Acta Geographica Sinica 57 443
[8]. Zhang W B, Fu J S. Rainfall erosivity estimation under different rainfall amount 2003 J. Resources
Science 25 35

[9]. Rick D. Van Remortel, Matthew E. Hamilton, Robert J. Hickey. Estimating the LS Factor for RUSLE through Iterative Slope Length Processing of Digital Elevation Data within ArcInfo Grid 2001 J. Cartography, 30 27

[10]. Wang B, Zheng F L, Mathias J. M. Römkens. Comparison of soil erodibility factors in USLE, RUSLE2, EPIC and Dg models based on a Chinese soil erodibility database 2013 Acta Agriculturae Scandinavica 63 69

[11]. Cai C F, Ding S W, Shi Z H, et al. Study of applying USLE and geographical information system IDRISI to predict soil erosion in small watershed 2000 Journal of Soil Water Conservation, 14 19