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Original Research Article

Estimating soil erosion response to land use/cover change in a catchment of the Loess Plateau, China

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ABSTRACT

The vegetation restoration project, named the Grain to Green Program, has been operating for more than ten years in the upper reaches of the Beiluo River basin, located in the Loess Plateau of China. It is significant to be able to estimate the success of preventing soil erosion. In this study, the Revised Universal Soil Loss Equation (RUSLE) and the Sediment Distributed Delivery (SEDD) model were used to assess the annual soil loss derived from water erosion. The results showed that the study area suffered from primary land use changes, with increasing grassland and forest and decreasing farmland from 1990 to 2010. Based on that, the average soil erosion modulus decreased from 18,189.72 t/(km^2 a) in 1990–7408.93 t/(km^2 a) in 2000 and 2857.76 t/(km^2 a) in 2010. Compared with 1990, the average soil erosion modulus decreased by 59.0% and 84.3% for 2000 and 2010, respectively. Benefiting from the increased vegetation coverage and improved ecological environment, the soil erosion in this study area clearly declined. This research also found that the distribution of the three years of soil erosion was similarly based on topographic factors. The soil erosion modulus varied with different land use types and decreased in the order of residential area > farmland > grassland > forest. The average soil erosion modulus gradually increased with the increase of the slope gradient, and 76.08% of the total soil erosion was concentrated in the region with a gradient more than 15 degrees. The soil erosion modulus also varied with slope aspects in the order of sunny slope > half-sunny slope > half-shady slope > shady slope. This research provides useful reference for soil and water conservation and utilization in this area and offers a technical basis for using the RUSLE to estimate soil erosion in the Loess Plateau of China.

1. Introduction

Soil erosion, a widespread form of soil degradation, is one of the most severe threats to the terrestrial ecosystems in the world (Pimental, Harvey, & Resosudarmo, 1995). It is directly related to decreased agriculture productivity and water pollution, and it has many negative effects on nature, such as degradation of soil structure, depletion of soil fertility, reducing the effective rooting depth, and ruining the most fundamental of all natural resources (Fitton, Saffouri, & Blair, 1995; Lal & Bruce, 1999; Nearing, 2005).

The Chinese Loess Plateau is the most heavily eroded area in the world (Fu, 1989), and the soil erosion modulus with 5000–10,000 mg km^{-2} per year were larger than other areas (Chen, Wang, Fu, & Qiu, 2001). Since the 1950s, to control severe soil erosion, improve agriculture production and reduce sediment loads in the Yellow River, there has been implemented a lot of soil and water conservation projects in the Loess Plateau catchments. In order to promote sustainable development in the Loess Plateau, the Grain for Green project was implemented in 1999. These conservation efforts, including terracing, afforestation and vegetation restoration, reduced the sediment yield from hill slopes and sediment delivery to rivers by increasing hydrologic surface roughness, and the vegetation coverage gradually increased (Chen, Ma, & Zhang, 2016; Yan, Zhang, Yan, & Zhao, 2016). Generally, the more the vegetation restoration implemented in the region, and the lower the soil erosion modulus (Ritsema, 2003).

Soil erosion caused by water has been assessed by some developed models, including the Water Erosion Prediction Project (WEPP), Universal Soil Loss Equation (USLE), the Revised Universal Soil Loss Equation (RUSLE), and the Erosion Productivity Impact Calculator (EPIC) (Flanagan & Laflen, 1997; Renard, Foster, & Weesies, 1997; Williams, Renard, & Dyke, 1983; Wischmeier & Smith, 1978). The USLE model considers most of the factors to assess long term soil erosion from interrill and rill areas

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(Wischmeier & Smith, 1978). Compared to the USLE, the RUSLE has become available during the last 40 years with the characteristics of easily to parameterize and requiring less data (Lee, 2004). The combination of erosion models with GIS was an effective method to assess the temporal and spatial distribution of erosion (Mitasova, Hofierka, Zlocha, & Iverson, 1996; Qin & Zhu, 2009). Ferro and Porto (2000) used the USLE combined with the travel time concept and assessed the erosion in a watershed.

There have many researches to investigate soil erosion either in plot or watershed scale in the Loess Plateau of China (Fu, Wang, & Lu, 2009; Sun, Shao, & Liu, 2013; Zhao, Kondolf, Mu, & Han, 2016). Fu, Zhao, and Chen (2005), based on the RUSLE to assess soil loss in the Yanhe watershed of the Loess Plateau, found that the annual average soil erosion was 14,458 mg km^{-2} per year. Sun, Shao, and Liu (2014) used the RUSLE to analyze the influence of land cover change on soil erosion in the Loess Plateau from 2000 to 2010. The results found that the steadily increased vegetation cover lead to gradually decreased soil erosion rates from 2000 to 2010. Zhao, Kondolf, Mu, and Han (2017) found that the sediment yield also decreased in the Huangfuchuan catchment of the Loess Plateau from 1990 to 2006. A series of previous studies demonstrated that these measures have obtained success to some extent.

The Beiluo River, located in the center of the Loess Plateau, is representative of the changes in vegetation coverage resulting from conservation projects. The mean annual soil erosion modulus in the catchment decreased by 90% under the implementation of projects (Chen et al., 2016). Yan et al. (2016) found that the average annual vegetation coverage in 1990, 2000 and 2010 in the upper reaches of Beiluo River basin were 15.86%, 19.20% and 35.50%, respectively, which showed a gradually increasing trend. Liu et al. (2015) also found that the annual runoff and sediment yield clearly decreased since the implementation of projects. Along with the improved ecological environment, analysis about the temporal and spatial distribution of soil erosion were limited in the upper reaches of the Beiluo River basin. To realize the effect of soil and water conservation on soil erosion and spatial distribution, we selected this basin in the Loess Plateau by combining the RUSLE with the sediment distributed delivery (SEDD) model. In this catchment, the objectives of this study are as follows:

(1) Examine the temporal and spatial variation of soil erosion and sediment yield under the background of land use changes with the SEDD model.
(2) Analyze the impacts of topographic factors including slope gradients and slope aspects on soil erosion in different years.

2. Catchment description and data collection

2.1. Catchment description

The Beiluo River basin (107°33′33″E-110°10′30″E, 34°39′55″N-37°18′22″N) is a secondary tributary of the Yellow River. The upper reaches of the Beiluo River, controlled by the Wuqi gauging station, covers an area of 3408 km^2, which accounts for 12.7% of the Beiluo River basin (Fig. 1). The studied catchment is a typical hilly gully area of the Loess Plateau and has a heavily dissected landscape with gully densities of 6–8 km/km^2. This area is located in a warm temperate semi-arid climate zone, and has clear characteristics of a continental monsoon climate with abundant sunshine and the variation of four seasons. The maximum precipitation was 797.6 mm in 1959, and the minimum precipitation was 320.2 mm in 1995. The mean annual precipitation in the flood season was approximately 391.9 mm and accounted for 76.2% of the annual total precipitation. Temperature gradually decreased from north to south, with part of the study area affected by the characteristics of topography distribution. The soil type in the basin is mainly dominated by loessial soil, dark loessial soil and gray-cinnamon soil. Loess soil is the main soil type of the catchment, and it is the youth directly forming from the Loess parent material, with the characteristics of no obvious profile differentiation. Although it has good permeability, soil erosion, drought and infertility were the prominent problems of Loess soil because of its characteristics, including steep slopes, strong evaporation and weak water

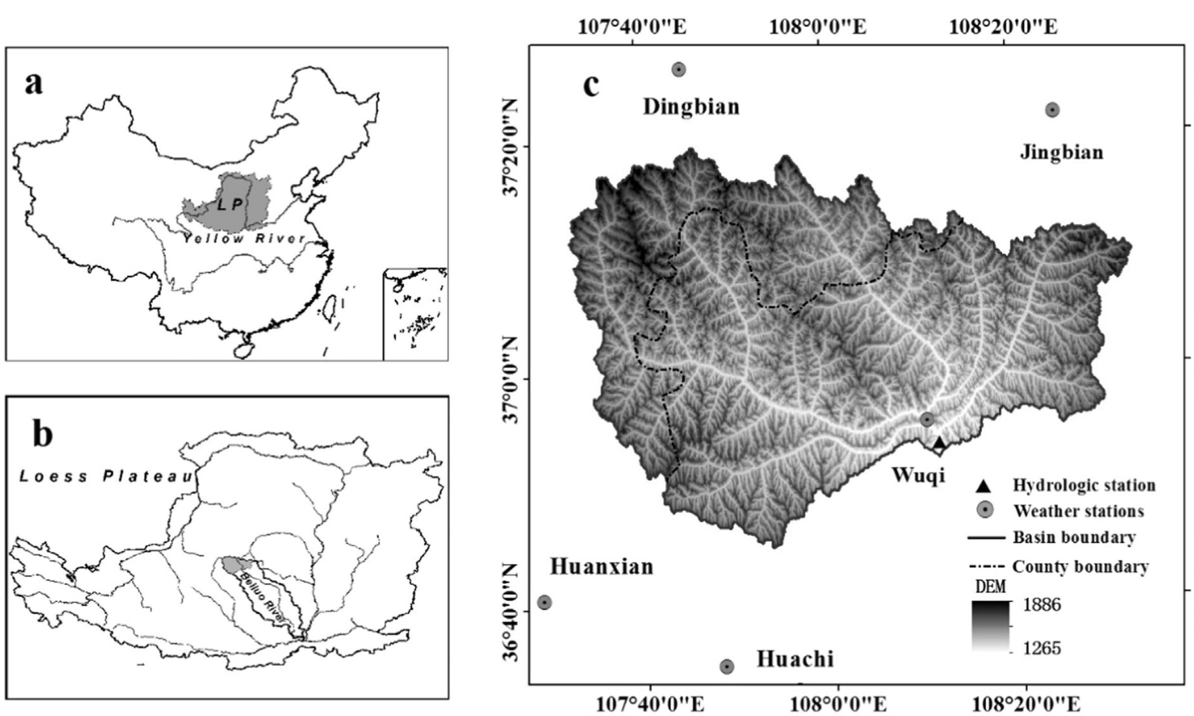

Fig. 1. The locations of the upper reaches of the Beiluo River basin (c) and the LP (Loess Plateau) (b) in China (a). Five weather stations in the studied area (c) were showed as the gray round circle with the dark point inside. The hydrological station showed as dark triangle.