Catena 121 (2014) 151–163

Contents lists available at ScienceDirect

Catena

journal homepage: www.elsevier.com/locate/catena

Assessing the effects of land use and topography on soil erosion on the Loess Plateau in China

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ARTICLE INFO

Article history:
Received 6 January 2014
Received in revised form 5 May 2014
Accepted 8 May 2014
Available online 2 June 2014

Keywords:
Soil erosion
Loess Plateau
Land use
Topography

ABSTRACT

The Revised Universal Soil Loss Equation (RUSLE) was used in conjunction with geographic information system (GIS) mapping to determine the influence of land use and topography on soil erosion on the Loess Plateau during the period 2000 to 2010. The average soil erosion on the Loess Plateau was 15.2 t ha^{-1} yr^{-1} in 2000–2010. Most of the Loess Plateau fell within the minimal and low erosion categories during 2000 to 2010. Forest, shrub and dense grassland provided the best protection from erosion, but the decadal trend of reduced soil erosion was greater for the lower vegetation cover of woodland and moderate and sparse grassland. Midslopes and valleys were the major topographical contributors to soil erosion. With slope gradient increased, soil erosion significantly increased under the same land use type, however, significant differences in soil erosion responding to slope gradients differed from land uses. The results indicate that the vegetation restoration as part of the Grain-to-Green Program on the Loess Plateau has been effective.

1. Introduction

Soil erosion is a widespread and major environmental threat to our terrestrial ecosystems (Singer and Warkentin, 1996; Yang et al., 2003). During the last 40 years, nearly one-third of the world's arable land has been lost to erosion, with loss continuing at the rate of more than 10 million ha per year (Pimental et al., 1995). Soil erosion is directly related to reduced agricultural productivity and to water pollution, and it may reduce the ability of soil to mitigate the greenhouse effect (Lal and Bruce, 1999; Nearing et al., 2005; Weltzin et al., 2003). Soil erosion by water is considered one of the most severe types of erosion and has attracted considerable attention in the past, mainly due to its destructive effects, including eutrophication, non-point pollution and, eventually, land degradation (Asselman et al., 2003; Jin et al., 2008; Singer and Shainberg, 2004).

Several models have been developed to assess soil erosion caused by water, including the Universal Soil Loss Equation—USLE (Wischmeier and Smith, 1978), Revised Universal Soil Loss Equation—RUSLE (Renard et al., 1997), Erosion Productivity Impact Calculator—EPIC (Williams, 1985) and Water Erosion Prediction Project—WEPP (Flanagan and Laflen, 1997). The USLE, or the lateral RUSLE model, is a universally accepted method that can be used as the best fitted model for monitoring soil erosion because its applicability has been proven over the last decades, and the reliability of the results are indisputable (Lee, 2004; Lu et al., 2004). Supported by GIS and remote sensing technologies, the RUSLE model has been used as a distributed model in estimating soil loss for its application not only in areas with relatively lower slope but also on topographically complex landscape units (Desmet and Govers, 1996). In recent years, RUSLE has been applied in the study of soil erosion in the Chinese Loess Plateau. The model has been further developed to work with complex terrain and to permit the quantitative assessment of precipitation, vegetation cover and soil erosion. For example, Fu et al. (2011) predicted soil erosion on the Loess Plateau using the RUSLE model and assessed the possible influences of land-use policy on soil erosion. Similar applications reported for some areas on the Loess Plateau have indicated a good representation of soil erosion (Liu and Liu, 2010; Zhang et al., 2008).

RUSLE predicts soil loss due to water erosion as a function of climate erosivity (influenced by amount and intensity of rainfall), topography, soil erodibility, and vegetation cover/management (Renard et al., 1997). Studies on the variation of water erosion with reference to rainfall, soil properties, topography, land use and vegetation cover will help further the understanding of erosion phenomena. Soil and topography have a strong influence on water erosion, but they are relatively stable. Therefore, scientists attribute increased soil erosion mainly to rainstorms, inappropriate land use and degraded vegetation (Alatorre et al., 2012; Mohammad and Adam, 2010). However, due to their interactions, the relationships among precipitation, vegetation and erosion

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http://dx.doi.org/10.1016/j.catena.2014.05.009
0341-8162/

are uncertain and complex (Xu, 2005). Vegetation mitigates soil erosion by its canopy, roots, and litter components, and the effect on soil erosion is influenced by the composition, structure, and growth pattern of the plant community providing the cover (Bakker et al., 2005; Gyssels et al., 2005). Thus, a positive or negative correlation between precipitation and erosivity mainly depends on the land use and vegetation cover conditions. Soil erosion in the hilly and gully regions on the Loess Plateau showed an evident erosion-resistance due to increase in the vegetation cover (Sun et al., 2013). Plant cover and land uses are considered the most important influences and, to some extent, exceed the influence of rainfall intensity and slope gradient (Kosmas et al., 1997; Thornes, 1990). Often, a loss of vegetation cover leads to increasing runoff and erosion (Al-Seikh, 2006; Singer and Le Bissonnais, 1998).

The Chinese Loess Plateau is one of the most severely eroded regions in the world. It has been calculated that the average erosion modulus for the region is 5000–10,000 t km^{-2}, even reaching a peak of 20–30,000 t km^{-2} in some regions (Liu and Liu, 2010), yielding a vast quantity of sediment that is carried by the Yellow River (Huang He) and its tributaries. Approximately 90% of the sediment in the Yellow River originates from soil erosion on the Loess Plateau (Tang, 2004). Severe soil erosion has led to the impoverishment of cultivated land, and thus poverty of the local people, and to desertification, which destroys land conditions crucial for human survival. Field monitoring and investigations have confirmed the reduction of soil erosion on hill slopes and in small catchments of the Loess Plateau (Zheng, 2006; Zhou et al., 2006). Soil erosion on the Loess Plateau in the latest study showed a significantly declining trend as a result of the improved vegetation cover and ecological construction (Sun et al., 2013). Only a limited amount of research has been undertaken on the actual or potential effects of land uses or topographies on soil erosion and how this might relate to human modification of vegetation cover initiated by policies such as the "Grain-to-Green" Program (Fu et al., 2011). Therefore, a quantitative assessment is needed for scientific support for the ongoing implementation and evaluation of ecological construction and environmental management programs.

The objectives of this study were the following:

1. Estimate and map the rates of soil loss by water erosion of the Loess Plateau for the decade 2000 to 2010.
2. Assess the influences of different land uses and covers, and topographical positions and slope gradients on the soil erosion of the Loess Plateau.

2. Materials and methods

2.1. Location and description

The Loess Plateau is located in the middle reaches of the Yellow River basin, north China (Fig. 1), and lies roughly within 100°54′–114°33′ E and 33°43′–41°16′ N. The Plateau covers an area of more than 600,000 km^2, extending to the Yinshan Mountains in the north, the Qingling Mountains in the south, the Wuqiaoling–Riyue Mountains in the west and the Taihang Mountains in the east. Most of the Plateau has sub-humid and semi-arid climates, with an average annual temperature of 4.3 °C in the northwest and 14.3 °C in the southeast. The average annual precipitation ranges from 200 mm in the northwest to 750 mm in the southeast and mostly falls as high intensity rainstorms (Li et al., 2009). The Plateau surface is covered by highly erodible loess layers averaging 100 m deep. The surface soil types vary from northwest to southeast in the order of Eolian sand, sandy loess, typical loess and

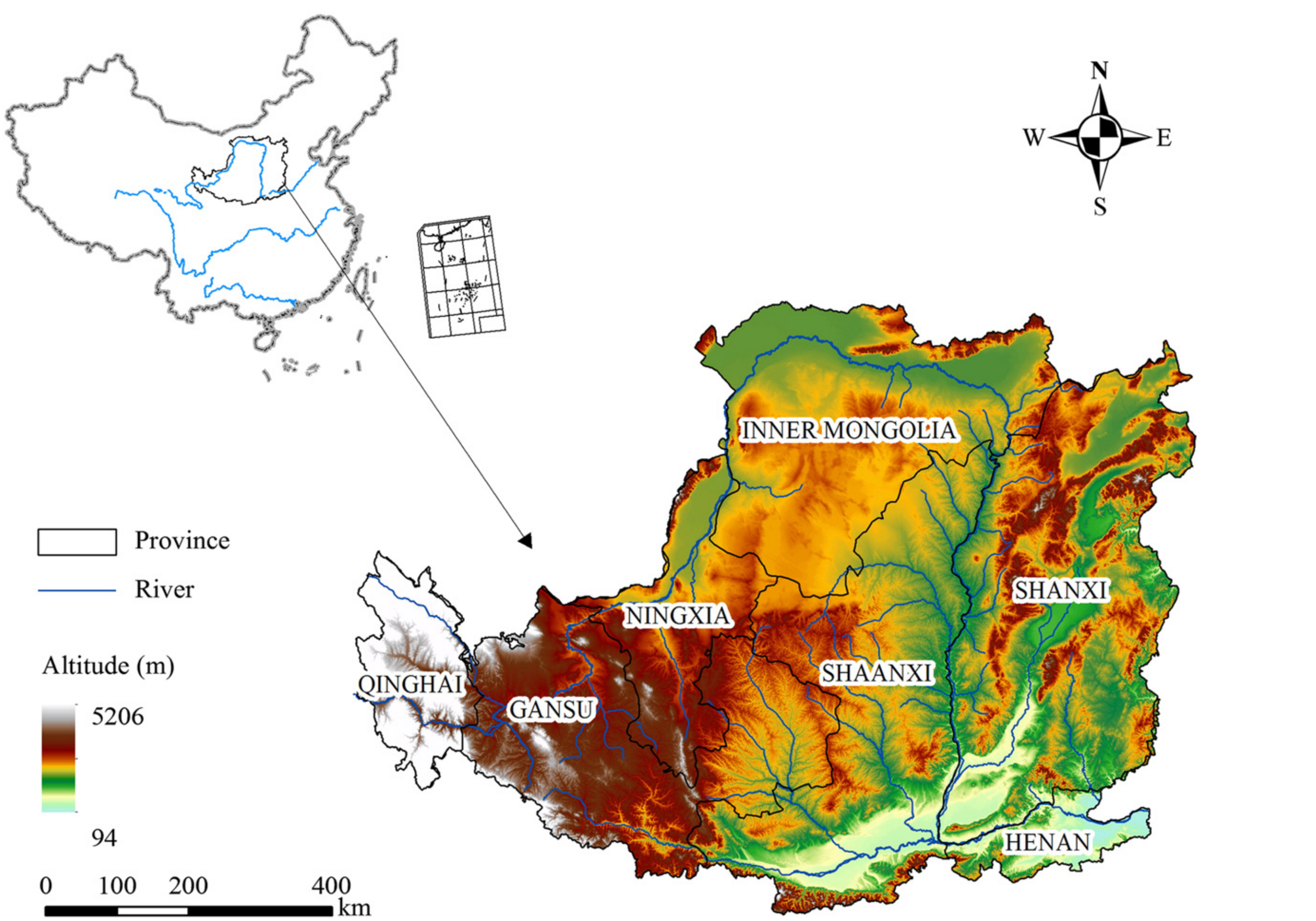

Fig. 1. Location, provincial boundaries and range of altitudinal variation of the Loess Plateau, China.