Catena 124 (2015) 68–76

Contents lists available at ScienceDirect

Catena

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

Rates of soil erosion in China: A study based on runoff plot data

Qiankun Guo, Yanfang Hao, Baoyuan Liu *

State Key Laboratory of Earth Surface Processes and Resources Ecology, School of Geography, Beijing Normal University, 100875, Beijing, China

ARTICLE INFO

Article history:
Received 17 December 2013
Received in revised form 14 August 2014
Accepted 18 August 2014
Available online 29 September 2014

Keywords:
Runoff plots
Soil loss rates
Land use
Runoff
China

ABSTRACT

Soil erosion has been a major environmental issue in China. However, the overall rate and the variability in runoff and soil loss of different regions and land uses in China have not been reported in the literature. In this study, an extensive database of runoff plots in China was compiled. Runoff and soil loss rates of sheet and rill erosion under natural conditions based on plot studies, are reviewed. The history of plot studies in China is briefly introduced, and basic information, such as the geographic distribution of soil erosion monitoring sites, the distribution of slope length and the slope gradient of runoff plots, is described. The runoff and soil loss rates of five water erosion regions in China were analyzed in terms of the main land use types. The soil loss rate was 30.87–107.44 t ha^{-1} a^{-1} on fallow land and 7.65–49.38 t ha^{-1} a^{-1} on farmland under conventional tillage. The land use types with permanent cover experienced the lowest soil loss rates, which were 0–1.89, 0.28–8.06 and 3.98–1.57 t ha^{-1} a^{-1} for forest, shrub and grassland, respectively. In China, the regional differences in the soil loss rate were mainly observed on fallow land and farmland, whereas almost no differences were observed on forest, shrub and grasslands. The soil loss rates of forest, shrub and grasslands showed no significant differences worldwide. However, the soil loss rates of farmland with conventional tillage in northwest and southwest China were much higher than in most other countries. This indicated that farmlands in China are still suffering from a very serious erosion problem that requires additional future attention. This study provided a broad assessment of sheet and rill erosion for prioritizing problems and selecting the appropriate erosion control practices.

1. Introduction

Soil erosion causes significant problems, both on-site and off-site. The on-site effects include a loss of productivity from a shift in soil texture and breakdown of soil structure resulting from loss of fines and organic matter, among other problems. The off-site problems arise from sedimentation downstream, which reduces the capacity of rivers and drainage ditches, enhances the risk of flooding and shortens the design life of reservoirs. Such sediment problems result in huge economic costs (Morgan, 2005). Therefore, the protection of soil resources has been identified as an important objective of environmental policy (CEC, 2006). This requires a correct assessment of erosion rates and their distribution (Cerdan et al., 2010). In the United States, this assessment has been conducted as a national erosion inventory (Holeman, 1981), which was part of national resources inventory (NRI) (Nusser and Goebel, 1997). NRI was conducted since 1977 and much valuable data was acquired. The soil loss rates were calculated by USLE and RUSLE, which were developed on the basis of field plot data. Satellite remote sensing was also widely used during the past 30 years for regional-scale water erosion assessments. However, the main concern with this methodology is the lack of validation data or ground truthing (Vrieling, 2006). Field measured data are necessary to support the interpretation and model calculation of an erosion assessment. The USLE-type runoff plots seem to be the only standard method for field measurements because this quantification technique enables the comparison of results from different areas and different studies (Visser et al., 2004).

Extensive assessments of soil loss over large areas were conducted in different nations or continents by adopting field-measured data from runoff plots. The United States has collected soil erosion data over a long period of time and has used a standardized methodology to analyze the data, which led to the development of the Universal Soil Loss Equation (Wischmeier and Smith, 1965, 1978) and the Revised Universal Soil Loss Equation (Renard et al., 1997). These two equations are used worldwide. Various erosion assessment models have also been developed for Europe (Goblin et al., 2004; Kirkby et al., 2008). Soil loss rates were reported in Europe (Cerdan et al., 2010), Africa (Stocking, 1984; Roose, 1976) and Australia (Lu et al., 2003). These data provided a basic magnitude of soil erosion for

* Corresponding author at: State Key Laboratory of Earth Surface Processes and Resources Ecology, School of Geography, Beijing Normal University, Xinjiekou Wai St. 19, Haidian, 100875, Beijing, China. Tel.: +86 10 58809959.
E-mail address: baoyuan@bnu.edu.cn (B. Liu).

http://dx.doi.org/10.1016/j.catena.2014.08.013
0341-8162/

different countries or continents. However, few data were reported from China. This information could be used as a reference for a national soil conservation strategy.

Over the last 80 years, numerous experimental studies of runoff and soil loss have been conducted in China using runoff plots. Despite the considerable differences in plot size, conservation measures and length of the measurement period, the runoff plot data provided valuable information about runoff and soil loss rates in China. Various local erosion assessment models have been developed in China from these data (Zhang et al., 1992; Zhou et al., 1995; Lin et al., 1997; Wu et al., 1998; Yang, 2002; Bi et al., 2006). However, few studies were conducted that comprehensively and quantitatively explored the national scale of soil erosion.

Consequently, a large dataset of runoff and soil loss rates measured on runoff plots under natural rainfall conditions across the country was compiled, and this database was used to provide a comprehensive assessment of both runoff and soil loss rates measured at the plot scale. The specific objectives of this paper are as follows: 1) to briefly introduce the history of plot studies in China; 2) to develop a database of soil erosion under various land use types in different erosion regions; and 3) to assess the variability of both runoff and soil loss rates of sheet and rill erosion among regions, land uses and soils. The soil loss rates obtained in this study will be compared with other regions of the world and used to provide an important reference for further erosion studies and the application of erosion control programs at a regional scale.

Table 1
Data sources used for the database compilation.

Region	Provinces	Reference
Northeast	Heilongjiang	Chen et al., 2006; Zhao and Wei, 2009; *Nenjiang;*
	Inner Mongolia	Chen et al., 2006; Central experimental station of soil and water conservation in Hulunbuir, 1994;
	Jilin	Chen et al., 2006; Han et al., 2007;
North	Liaoning	Chen et al., 2006; Han et al., 2007; Lin et al., 1997; Sun et al., 1997;
	Beijing	*Miyun, Fangshan, Huairou, Mentougou and Yanqing;*
	Hebei	Gu et al., 1994; Lv et al., 1999; Wang and Xie, 1999;
	Henan	Huang et al., 2000;
	Shandong	Han and Guo, 1991; Liu et al., 2007;
	Jiangsu	Zhang et al., 2009;
Northwest	Inner Mongolia	Zhungeer banner (Personnel communication);
	Shaanxi	Hou and Cao, 1990; Lu et al., 1988; Soil and water conservation committee in the middle reach of Yellow River, 1965; Zhang and Lu, 1993;
	Gansu	He et al., 1992; Soil and water conservation committee in the middle reach of Yellow River, 1965;
	Henan	Li et al., 1992;
	Qinghai	Xu et al., 2007; Zhu et al., 2008a;
Southwest	Hubei	Gao et al., 2004; Huang et al., 1998; Xiang et al., 2001; Yong, 2011; Zheng and Zhang, 2006;
	Hunan	Liu and Tan, 1992; Zhang and Zhong, 1999; Zhou et al., 2009, 2010;
	Sichuan	Chen et al., 2002, 2009; Li et al., 2005; Lin et al., 2007a, b; Lv et al., 2000; Soil and water conservation committee of Sichuan Province, 1991; Wu et al., 2007;
	Chongqing	Jiang et al., 2011; Li and Li, 1991;
	Guizhou	Zhang et al., 2000, 2001a; Zhu et al., 2008b;
	Yunnan	Mi et al., 2006; Wang et al., 1982; Yang, 1999;
South	Zhejiang	Jin and Wang, 2000; Li and Zhang, 2000; Yang et al., 2004; Yuan et al., 2001;
	Jiangxi	Fan et al., 2005; He, 1995; Liu, 2006; Liu and Cheng, 2003; Wang et al., 2008; Xie et al., 2004; Zhang et al., 2001b; Zuo et al., 2003;
	Fujian	Chen, 1999, 2006; Ding et al., 2006; Huang et al., 2007; Lin et al., 1998; Zhou et al., 1995; Zhu et al., 2003;
	Guangdong	Chen and Wang, 1992; Liu et al., 2000;
	Guangxi	Huang et al., 2010, 2012; Huang and Liang, 1999;
	Hainan	Yi et al., 2004;

* Field data of "*Nenjiang, Miyun, Fangshan, Huairou, Mentougou and Yanqing*" were measured by the soil conservation research group at Beijing Normal University (BNU).

2. Materials and methods

2.1. Plot database: selection criteria and compilation

The database was mainly compiled from Soil Conservation Station bulletins, journal papers and PhD dissertations (Table 1). Three soil erosion regions in China were divided according to the dominant erosive agents: water erosion region, wind erosion region and frozen-thaw erosion region. For water erosion, five water erosion regions were established for China: the northeast (NE) black soil region; the northern (N) rocky and earth mountain region; the northwest (NW) Loess Plateau region; the southwest (SW) purple soil region; and the southern (S) red soil hilly region. The five regions were decided by synthesis analysis of factors affecting soil erosion, such as soil types, topography, climate, and so on. They are widely used in China for soil erosion research, soil erosion inventory and soil conservation planning.

Plot data were selected according to the following criteria: (i) only data obtained from direct measurements were selected, (ii) only data with clear site, management, and plot-data descriptions for interpretation were selected. The data recorded for analysis included the plot length and slope gradient, the measurement period, and the land use and conservation measures. If a site's data base was not sufficiently detailed, the plot data were excluded from the database. Fallow land was included in the database because this type of land has often been used in soil erosion studies as a reference, representing maximum soil loss; however, this was not a common land management practice. Plots under conservation management were also included in the database because this was a widely used land use practice, especially on farmland.

Every record corresponded to a unique combination of land use, plot length, slope gradient, conservation measure and measurement period. For each plot, the runoff and soil loss rate for each year were recorded. However, some studies did not present values of runoff and soil loss rates for each year but reported the mean or total data for the measurement period. In this case, the mean runoff and soil loss rate were counted as one record for each plot. Most records of runoff and soil loss rates were reported annually, and few of them were averaged over several years.

A total of 2823 plot-year data were collected for analysis from 73 different sites, which were widely distributed in China (Fig. 1). This database for China is currently one of the largest compilations of runoff and soil loss rates on a plot scale. The statistics for the compiled data from the five different regions are shown in Table 2.

The earliest record in this database is from 1945 in Tianshui, Gansu Province. The number of plot years increased in the 1950s, declined in the 1960s to the point that no data was collected during much of the 1970s. The number of plot years boomed in the next decade, reaching a peak of 144 plot years in the late 1980s. The number of plot-years subsequently started to slightly decline, which is possibly attributed to the fact that some ongoing research has not yet been reported (Fig. 2).

The data used in this study varied in terms of slope gradient, slope length and land use. Six land use types were classified, including fallow (no vegetation), farmland, forest, shrub, grassland and orchard. The slope length of the plots ranged from 0 to 300 m. However, only the plots with slope length of more than 5 m were used in the study because plots with length less than 5 m were considered to be not representative. Most of the data were collected from plots between 5–40 m lengths with a peak in plot years at the length of 10–20 m. The slope gradient varied from 0° to 40°, with a peak in plot years at a slope gradient of 10° to 20°. For all of the land use types, the largest numbers of plot-years were on 10–20 m long slopes and the second and third largest number of plot-years were on 5–10 m long slopes and 20–40 m long slopes (Fig. 3). Very few plots were constructed on slopes less than 5 m or longer than 40 m, and these plots were mainly used for quantifying the slope length factor. A frequency distribution of the slope length for all of the land use types revealed a similar trend. For the slope gradient, the largest number of plot-