Science of the Total Environment 642 (2018) 591–600

Contents lists available at ScienceDirect

Science of the Total Environment

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

Reduced sediment transport in the Chinese Loess Plateau due to climate change and human activities

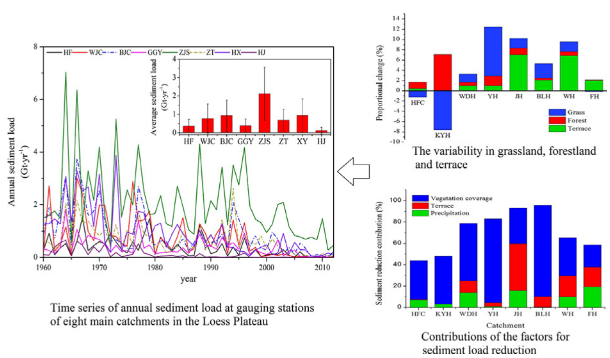
Xiaonan Yang [a], Wenyi Sun [a,b,*], Pengfei Li [c], Xingmin Mu [a,b,*], Peng Gao [a,b], Guangju Zhao [a,b]

[a] State Key Laboratory of Soil Erosion and Dryland Farming on the Loess Plateau, Northwest A&F University, Yangling, China
[b] Institute of Soil and Water Conservation, Chinese Academy of Sciences and Ministry of Water Resources, Yangling, China
[c] College of Geomatics, Xi'an University of Science and Technology, Xi'an, China

HIGHLIGHTS

- The sediment discharge in eight catchments located in the Loess Plateau showed a significant decrease since the 1960s.
- Sediment discharge in most tributaries had shown abrupt changes since 1996.
- The contribution of runoff reduction was greater than the sediment concentration change to the reduced sediment load.
- Increasing vegetation coverage was the primary factor driving the reductions in sediment loads.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 27 April 2018
Received in revised form 5 June 2018
Accepted 6 June 2018
Available online xxxx

Editor: Ouyang Wei

Keywords:
Sediment discharge
Climate change
Terrace construction
Vegetation coverage
Loess Plateau

ABSTRACT

The sediment load on the Chinese Loess Plateau has sharply decreased in recent years. However, the contribution of terrace construction and vegetation restoration projects to sediment discharge reduction remains uncertain. In this paper, eight catchments located in the Loess Plateau were chosen to explore the effects of different driving factors on sediment discharge changes during the period from the 1960s to 2012. Attribution approaches were applied to evaluate the effects of climate, terrace, and vegetation coverage changes on sediment discharge. The results showed that the annual sediment discharge decreased significantly in all catchments ranging from -0.007 to -0.039 $Gt \cdot yr^{-1}$. Sediment discharge in most tributaries has shown abrupt changes since 1996, and the total sediment discharge was reduced by 60.1% during 1997–2012. We determined that increasing vegetation coverage was the primary factor driving the reductions in sediment loads since 1996 and accounted for 47.7% of the total reduction. Climate variability and terrace construction accounted for 9.1% and 18.6% of sediment discharge reductions, respectively.

1. Introduction

Soil erosion and the resulting river sediment transport are globally widespread and constitute a major environmental threat to human-managed ecosystems (Pimentel and Kounang, 1998). Soil erosion causes water pollution, water storage capacity reduction, and regional poverty, which is a challenge for sustainable social-economic

* Corresponding authors at: State Key Laboratory of Soil Erosion and Dryland Farming on the Loess Plateau, Northwest A&F University, Yangling, China.
E-mail addresses: sunwy@ms.iswc.ac.cn, (W. Sun), xmmu@ms.iswc.ac.cn (X. Mu).

https://doi.org/10.1016/j.scitotenv.2018.06.061
0048-9697/

development (Munodawafa, 2007; Zhao et al., 2013; Rickson, 2014). In recent decades, significant decreasing trends in river sediment loads have been observed in different parts of the world (Walling and Fang, 2003; Wang et al., 2015). A better understanding of the changes in river sediment loads over time and the driving mechanisms are thus of paramount importance for decision makers and planners to take appropriate sustainability measures. In general, climate change and human activities are two primary factors that affect soil erosion and the terrestrial hydrological cycle (Syvitski et al., 2005; Li and Fang, 2016; Li et al., 2016).

The impacts of climate change on soil erosion have been observed since the 1940s (Bryan and Albritton, 1943; Schumm and Langbein, 1958; Li and Fang, 2016). Mainly, the variety of rainfall amounts, intensities, and spatial distributions directly alter the erosion process. Lu et al. (2013) found that every 1% change in precipitation could result in a 2% change in sediment loads. Zhang (2007) suggested that a 4–18% increase in precipitation would lead to a 31–167% increase in soil loss. These findings show that soil erosion increases with increased precipitation when other factors remain unchanged. However, decreased soil erosion under increased precipitation has occurred in different areas of the world (Li and Fang, 2016), which may be attributed to land use/cover changes, reservoir and dam construction, and other human activities (Gao et al., 2011; Nunes et al., 2013).

Land use is one of the most important factors affecting the intensity and frequency of soil erosion (Wei et al., 2007; Garcia-Ruiz, 2010; Li et al., 2016). The main causes of soil erosion are inappropriate agricultural practices, deforestation, and urban construction. Soil erosion of agriculture land is widespread around the world (Collins et al., 2001; Garcia-Ruiz, 2010; Nunes et al., 2011). The integration of agricultural land use with shrubs, trees and grass can improve soil properties, surface roughness and evapotranspiration, thereby reducing sediment discharge into rivers (Cao et al., 2011; Wang et al., 2015; Zuo et al., 2016). Many authors have also demonstrated that in a wide range of environments, sediment loss decreases exponentially as the percentage of vegetation cover increases (Zhao et al., 2013; Wang et al., 2015). Terraces are another measure used to reduce slope erosion by weakening rainfall–runoff erosivity, conserving abundant rainwater, and increasing soil moisture. Evidence has shown that if terraces cover over 40% of a total hill slope, considerable soil load reduction could be achieved (Chen et al., 2017). Other studies have reported that terrace construction could reduce soil loss by >90% (He et al., 2009; W. Wei et al., 2016; Y. Wei et al., 2016). For decreasing the sediment load of river, check dams are another effective measure to intercept upstream sand and trap sediment, and these methods have applications in France, Italy, Spain, China and elsewhere (Boix-Fayos et al., 2007; Boix-Fayos et al., 2008; Abedini et al., 2012; Jin et al., 2012). More than 70% of the world's rivers have been reported to be intercepted by dams, and at least half of the river sediments may be trapped in artificial dams and reservoirs (Zhao et al., 2017)

The Loess Plateau, which loses approximately 5000–10,000 $t \cdot km^{-2} \cdot yr^{-1}$ of sediments in most areas and >15,000 $t \cdot km^{-2} \cdot yr^{-1}$ in some areas, is one of the most critical areas of soil erosion globally. The Yellow River is the most sediment-laden water body in the world (Pont et al., 2002; Wang et al., 2015), of which 90% of the sediment is contributed from the Loess Plateau (Zhao et al., 2013). More attention is being focused on reducing soil erosion, maintaining soil fertility, and a healthy Yellow River. Since the 1950s, a series of measures were implemented in the Loess Plateau to reduce the sediment discharge into the river (Wang et al., 2007b). Terrace and dam construction was the main measure in the 1960s and 1970s. Then, in the 1970s, integrated catchment management was applied to reduce soil erosion. At the beginning of the twenty-first century, in order to control increasingly serious soil and water loss, the Chinese government launched a large-scale ecological restoration project named "Grain for Green Program" (GfG) (Su et al., 2011). The sediment load of the Yellow River has decreased by approximately 90% over the past six decades (Wang et al., 2015). Many scholars suggest that soil and water conservation measures were responsible for the sediment load reduction in the middle reaches of the Yellow River (Zhao et al., 2014). Gao et al. (2011) estimated that the decrease in human activities accounted for 87.8% of the decrease in sediment discharge from 1982 to 2008, whereas Mu et al. (2012) showed that a decrease in human activities accounted for 81% of the sediment discharge reduction in the Yellow River basin during 1979–2008. However, the quantitative research on the causes of decreases in sediment load by each measure such as land use/cover changes and terraces still face challenges, especially at larger scales.

The main aims of the present study were to evaluate the contribution of climate change and human activities to sediment load reduction in eight catchments in the Loess Plateau. Our specific objectives were to (1) investigate the spatial and temporal variations in sediment load in the catchments and (2) quantify the anthropogenic and climatic contributions to changes in sediment load.

2. Materials and methods

2.1. Study area

The Loess Plateau lies in the upper and middle reaches of the Yellow River basin in North China (between 33°43′–41°16′N, 100°54′–114°33′E), which covers 62.4×10^4 km^2 of China's total land area with approximately 8.5% of the Chinese population distributed in this region (Zhao et al., 2013). The Loess Plateau is characterized by a temperate arid to semi-arid climate with a mean annual temperature ranging from 4.3 to 14.3 °C and an annual rainfall from 200 to 750 mm, of which 65% falls between July and September (Wang et al., 2017). The average annual evaporation was between 1400 and 2000 mm. The altitude varies between 200 and 3000 m above sea level, and the average elevation is 1212 m. The middle reaches of the Yellow River, between Toudaoguai and Huayuankou, cross the Loess Plateau (Fig. 1). There are >30 large tributaries in the Loess Plateau that contribute approximately 90% of the sediment to the Yellow River. The main tributaries from north to south, such as Huangfuchuan, Kuyehe, Wudinghe, Yanhe, Beiluohe, Jinghe, Weihe, and Fenhe, are chosen as the study region in this research (Table 1).

2.2. Data sources

The Yellow River Conservancy Commission (YRCC) provided annually observed streamflow, and sediment load data at the main gauging station along eight tributaries of the Loess Plateau (1960–2012). Meteorological data from seventy-two weather stations in the Loess Plateau from 1960 to 2012 were obtained from the China National Meteorological Information Center (http://cdc.cma.gov.cn/home.do). The interpolation method of GIDS (gradient plus inverse distance squared) for the weather station was applied to obtain the watershed climate information. Records of soil and water conservation measures at the county scale for 1990 and 2010, which include terraces, dams and reservoirs, were provided by the China water census and the National Earth System Science Data Sharing Infrastructure (http://loess.geodata.cn/). Land use data with spatial resolution of 30 m for 1990 and 2010 were provided by the Chinese Academy of Sciences Resource and Environment Science Data Center. Vegetation coverage was extracted by the normalized difference vegetation index (NDVI) derived from long-term data record (AVH13C1) at a spatial resolution of 8 km for the period of 1981–1999 and the moderate resolution imaging spectroradiometer (MOD13A3) with 1 km resolution from 2000 to 2012. The area of water soil erosion in different levels for 1990 and 2010, which are county-scale statistics, were provided by the China Water Census; Table 2 shows the different levels corresponding to the average amount of erosion and loss of depth in the Loess Plateau, which were classified according to the Standards for classification and gradation of soil erosion (MWR, 2008; Wang et al., 2016).