Science of the Total Environment 592 (2017) 639–648

Contents lists available at ScienceDirect

Science of the Total Environment

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

Increasing trends in rainfall-runoff erosivity in the Source Region of the Three Rivers, 1961–2012

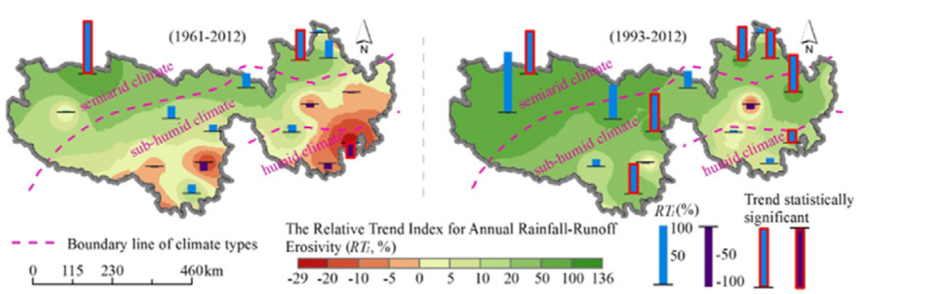
Yousheng Wang [a,b], Congcong Cheng [a,b], Yun Xie [a,b,*], Baoyuan Liu [a,b], Shuiqing Yin [a,b], Yingna Liu [a], Yanfang Hao [a,b]

[a] *State Key Laboratory of Earth Surface Processes and Resources Ecology, 100875 Beijing, China*
[b] *School of Geography, Beijing Normal University, 100875 Beijing, China*

HIGHLIGHTS

- Mean increase in rainfall-runoff erosivity for the whole period was 12.1%.
- The increasing trend was more pronounced in the latest two decades.
- The increase in erosivity mainly resulted from the high-intensity precipitation.
- Rising trends of sediment yield supported increase in erosivity.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 24 July 2015
Received in revised form 28 February 2017
Accepted 28 February 2017
Available online 22 March 2017

Editor: D. Barcelo

Keywords:
Trend
Rainfall-runoff erosivity
Precipitation
Erosive rainfall
Sediment yield
Source Region of the Three Rivers

ABSTRACT

As the head source of the two longest rivers in China and the longest river in Southeast Asia, the East Qinghai-Tibetan Plateau (QTP) is experiencing increasing thaw snowmelt and more heavy precipitation events under global warming, which might lead to soil erosion risk. To understand the potential driving force of soil erosion and its relationship with precipitation in the context of climate change, this study analyzed long-term variations in annual rainfall-runoff erosivity, a climatic index of soil erosion, by using the Mann-Kendall statistical test and Theil and Sen's approach in the Source Region of the Three Rivers during 1961–2012. The results showed the followings: (i) increasing annual rainfall-runoff erosivity was observed over the past 52 years, with a mean relative trend index (RT_1) value of 12.1%. The increasing trend was more obvious for the latest two decades: RT_1 was nearly three times larger than that over the entire period; (ii) more precipitation events and a higher precipitation amount were the major forces for the increasing rainfall-runoff erosivity; (iii) similar rising trends in sediment yields, which corresponded to rainfall-runoff erosivity under slightly increasing vegetation coverage in the study area, implied a large contribution of rainfall-runoff erosivity to the increasing sediment yields; and (iv) high warming rates increased the risk of soil destruction, soil erosion and sediment yields. Conservation measures, such as enclosing grassland, returning grazing land to grassland and rotation grazing since the 1980s, have maintained vegetation coverage and should be continued and strengthened.

1. Introduction

Global warming has become a heavily discussed issue around the world in recent years (Easterling et al., 2000; Stocker et al., 2013) and

* Corresponding author at: State Key Laboratory of Earth Surface Processes and Resources Ecology, 100875 Beijing, China.
E-mail address: xieyun@bnu.edu.cn (Y. Xie).

http://dx.doi.org/10.1016/j.scitotenv.2017.02.235
0048-9697/

has been shown to exacerbate and trigger heavy precipitation events in a number of areas (Cao and Pan, 2014), which may increase the risk of soil erosion, especially in semi-arid and sub-humid climate zones.

Rainfall-runoff erosivity, which couples raindrop energy and rainfall intensity, is a comprehensive measure of the erosive force for precipitation and surface runoff (Wischmeier and Smith, 1958, 1965). This factor can quantitatively reflect the potential of precipitation to erode soil (Davison et al., 2005; Panagos et al., 2015) and is one basic factor in the widely used soil erosion model Universal Soil Loss Equation (Wischmeier and Smith, 1978) and its successors (Foster, 2004; Renard et al., 1997). Rainfall-runoff erosivity is designated as the R-factor in the Universal Soil Loss Equation and equals the average annual summation of EI_{30}, the total rainfall energy (E) in a storm multiplied by its maximum 30-min rainfall intensity (I_{30}) (Wischmeier and Smith, 1958). EI_{30} has been calculated by using detailed pluviograph rainfall data. In view of the importance of runoff from snowmelt, thaw and light rain in the early spring in cold areas, erosivity from thaw and snowmelt has also been considered in the Revised Universal Soil Loss Equation (Wischmeier and Smith, 1978). Because of the unavailability of pluviograph rainfall, studies that estimate rainfall-runoff erosivity use more readily available data, such as daily (Yu and Rosewell, 1996a; Yin et al., 2013), monthly (Ferro et al., 1999; Yu and Rosewell, 1996) and annual rainfall data (Bonilla and Vidal, 2011; Lee and Heo, 2011).

Studies on variations in rainfall-runoff erosivity require long-term rainfall data and thus have only been reported in some places and with different scales. According to the current set of studies, rainfall-runoff erosivity increases in humid areas but decreases in semi-arid areas. In Europe, increasing trends have been observed in humid regions, including Ukkel in Belgium (Verstraeten et al., 2006), the Central Ruhr region in Germany (Fiener et al., 2013), lower Austria (Klik and Konecny, 2013), the Algarve in Portugal (de Santos Loureiroa and de Azevedo Coutinho, 1995), the Iberian Peninsula (de Luis et al., 2010) and southern Italy (Diodato and Bellocchi, 2009). However, decreasing trends were identified in the semi-arid southern Europe, such as Sicily in Italy (D'Asaro et al., 2007) and northeastern Spain (Angulo-Martinez and Begueria, 2012). In the dry North Africa, decreasing trends were also reported in the hyper-arid regions of Sudan (Elagib, 2011), southern Nigeria (Salako, 2008) and the central Rift Valley of Ethiopia (Meshesha et al., 2015). In China, studies focused on the two largest basins of the Yangtze River in the wet south and the Yellow River in the dry north. Increasing trends were obvious for the Yangtze River basin (Huang et al., 2013), but decreasing trends were significant for the middle Yellow River basin, where the Loess Plateau is located (Xin et al., 2011; Yang and Lu, 2015; Yue et al., 2014). No previous changes were studied in the United States, but increasing predictions were given in wet areas of the United States for future scenarios (Nearing, 2001; Segura et al., 2014). A case in the eastern humid region of Australia, Sydney, also showed a significant increasing trend (Yu, 1995). Obviously, rainfall-runoff erosivity varies among locations or zones around the world.

The East Qinghai-Tibetan Plateau (QTP) contains the head sources of three famous rivers, including the two longest rivers in China (the Yangtze River and the Yellow River), and the longest river in Southeast Asia (the Langcang-Mekong River). The region is called the Source Region of the Three Rivers (SRTR) in China. The average elevation of the SRTR is over 4000 m, with snow covering the entire year. The warming rate over the past 50 years has been 1.6 °C, which is more than double the values of 0.59 °C for the entire QTP and 0.65 °C for the Northern Hemisphere since 1870 (Ding et al., 2006), so the SRTR is an area that is sensitive to climate warming. As the source area with high elevations for three large rivers, the SRTR contains very little human activity. This region was listed by the government as a key protected area for water and soil conservation (Shao et al., 2013), therefore the natural factor of rainfall-runoff erosivity under warming conditions might be an important driving force to increase soil erosion risk in the study area. In recent years, a greater frequency of extreme precipitation events (Cao and Pan, 2014; Li et al., 2012) and much more glacier melt runoff (Yao et al., 2013; Zhang et al., 2012) have been reported. These events would undoubtedly cause rainfall-runoff variations and increase soil erosion risk, but the limited observations of precipitation and soil loss in this high-altitude area have restricted soil erosion research. Little has been known about the variations in rainfall-runoff erosivity in this area. The objectives of this study are as follows: (i) to analyze the long-term trends in rainfall-runoff erosivity over the past 52 years from 1961 to 2012 and their spatial patterns in the SRTR, (ii) to analyze the contributions of seasonal precipitation amounts and intensity to the variations in rainfall-runoff erosivity, and (iii) to assess the effect of variations in rainfall-runoff erosivity and vegetation coverage on sediment yields. This study will be useful for identifying the vulnerable eroded areas in response to climate change and providing information on soil conservation.

2. Data and methods

2.1. Study area and data

The SRTR is located between 31°36′N–36°33′N and 90°31′E–102°52′E and covers an area of 32.36×10^5 km^2, 12.13% of the total area of the QTP (Fig. 1). This region has a complex mountainous landform and continuous and steep terrain, with elevation widely ranging from 2179 m to 6575 m with an average of 4435 m. Three zones, namely, a humid climate, sub-humid climate, and semi-arid climate, could be classified from the southeast to the northwest, with the average annual precipitation decreasing from 772.8 mm to 262.2 mm. Greater than 70–80% of the annual precipitation occurs during the summer. The temperatures in January (the coldest month) and July (the warmest month) are −12.6 °C and 11.8 °C, −17.3 °C and 12.7 °C, −16.7 °C and 13.4 °C for the humid, sub-humid and semi-arid climates, respectively (Wang, 2004). The regional soil is characterized by shallow depth and a high amount of rock fragments and exhibits pronounced vertical zonal divisions, from alpine meadow soil in the southeast to alpine steppe soil in the high-altitude northwest. The grassland types change from high-cold scrub meadows to high-cold steppes (Zhang et al., 2013). The population density in the SRTR is two people per km^2 (Yi et al., 2013).

Daily precipitation data from 1 October 1960 to 31 December 2012 for a total of 37 stations were collected from the National Meteorological Information Center of the China Meteorological Administration (National Meteorological Infomation Center, 2015) and are listed in Table 1. 16 weather stations were present in the SRTR. 21 stations surrounding the SRTR were also selected to spatially interpolate the rainfall-runoff erosivity, with the criteria that these stations were inside the QTP and the shortest distance from the station to the boundary of the SRTR was no greater than 150 km. All the issued weather data has been quality-controlled by the National Meteorological Information Center of the China Meteorological Administration. In addition, both the double-mass curve method (Kohler, 1949; Tabari et al., 2011) and autocorrelation analysis (Yue et al., 2002) were used to assess the quality of the 52-year series of daily precipitation data for each station. Although the starting observations were from the 1950s for the majority of the stations, no missing data existed since the 1960s for any of the stations. The points that were plotted for all 37 stations in the double-mass curve were almost straight lines. The average correlation coefficients were between 0.91 and 0.95, indicating the good quality of the collected data.

2.2. Estimation of rainfall-runoff erosivity

Nearly all the erosive rainfall events in the SRTR occur during the warm season (May to September). The main form of precipitation during the cold season (end of October to April) is snowfall, which usually accumulates and melts during the late spring and early summer.