Quaternary International xxx (2016) 1–11

Contents lists available at ScienceDirect

Quaternary International

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

Impacts of topography on sediment discharge in Loess Plateau, China

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ARTICLE INFO

Article history:
Received 26 February 2016
Received in revised form
30 November 2016
Accepted 8 December 2016
Available online xxx

Keywords:
Principal components analysis
Linear regression
Soil erosion
Sediment discharge
Topographic characteristics
Loess plateau

ABSTRACT

Geomorphologic characteristics of a basin affect mass movement, water and sediment transport. The purpose of this study is to examine coupling relationship between topography and soil erosion in Loess Plateau during past 50 years (1960–2011). We firstly describe the distribution patterns of topographic characteristics and sediment discharge in specific river basins. By using mathematical methods (PCA method, linear regression and ANOVA analysis) and topographic variables, we build a comprehensive index – Erosion Topography Index (ETI). According to the research, the following findings are obtained. Firstly, average sediment discharge varies from 0.13×10^8 t to 7.56×10^8 t along the Yellow River from the upper-stream to down-stream. The sediment discharge of this region decreased 60%–90% since the year of 1980, and decrease tendency is more obvious after the year 2000 compared to the period of 1980–2011. Secondly, topographic characteristics and the Erosion Topography Index has similar distribution pattern. Thirdly, there is no significant linear correlation between ETI and all four sediment discharge variables (average sediment, total sediment, sediment of 1980–2011, and sediment of 2000–2011), but there are significant positive linear correlations ($p < 0.05$) between ETI and each sediment discharge variable. Furthermore, the correlation between ETI and sediment of 2000–2011 is stronger ($p = 0.035$) than other variables, and the gradient coefficient of them is higher ($k = 0.667$) than other variables too. Except the topographic characteristics, the vegetation coverage and human activities should be other factors that can influence the variations of sediment discharge in Loss Plateau.

1. Introduction

Soil erosion is one of the most important force in process of affecting much of the Earth's landscape, including detachment, transport and deposition, and has attracted much attention throughout the world. Soil erosion can deteriorate natural environment and socioeconomic properties, such as soil quality, agricultural production, ecosystem stability (Gafur et al., 2003; Singer and Shainberg, 2004; Ulén and Kalisky, 2005). Sediment is detached by rainfall and transported by runoff, and the sediment discharge is influenced by many contributors, such as climate, topography, land use cover and human activities. Moreover, drainage network systems are key elements that forcing landscape change because they transport water and sediment (Fryirs, 2013). Providing reliable tools for determining and quantifying sediment discharge and its dominant contributors is of considerable importance (Zhang et al., 2015; Pareta and Pareta, 2011).

In previous studies of sediment discharge and its influencing factors, researchers have found that sediment discharge is sensitive to various factors, including climate change (e.g. precipitation and temperature), human activities (e.g. dam construction, land-use change, and other forms of land disturbance) and watershed topography (e.g. elevation, basin length, slope etc.) (He et al., 2008; He et al., 2012, 2015a,b; Zhao et al., 2013; Cheng et al., 2015), such as in the upper Yangtze River, the decrease of sediment yield in Jialing River were due to revegetation and soil and water conservation and land degradation, engineering and channel activities were responsible for the increase of sediment yield in Jinsha River (Zhang and Anban, 2004). Moreover, climate change and human activities have significant influence on watershed geomorphologic characteristics and connectivity (Zhu et al., 2008; Fryirs, 2013; Lu et al.,

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http://dx.doi.org/10.1016/j.quaint.2016.12.005
1040-6182/

2013), such as in Yangze river, both natural and anthropogenic factors have impacts on sediment load (Dai and Lu, 2014). Soil and water conservation measurements, such as construction of dams and reservoirs, can cause decrease of soil erosion and sediment discharge. On the hand, over grazing, over exploitation and mining activities can also destroy land surface and intensify soil losses, and then increase the sediment load of rivers (He et al., 2015a,b). It has been estimated that an additional 4% of global runoff could arise from an increase of 1 °C in global temperature (Miao et al., 2011). Therefore, with the increase of runoff, the sediment transport capacity could increase, which cause increase of sediment discharge. During 1990s in Weihe River basin, precipitation has decreased 10.4% which contributes 68.2% of the runoff reduction (Su et al., 2007). In upper reaches of Yellow River, precipitation changes have significant impacts on streamflow, and the contributions were 10%–20% since 1990s (Wang et al., 2004). Construction of dams and reservoirs causes the reduction of sediment discharge, while deforestation and mining activities reduce land surface resistance and enhance the effectiveness of runoff on sediment, hence increasing sediment discharge (Walling and Fang, 2003). Contribution rate of human activities is 61%–93% to decrease of sediment discharge in 10 tributaries of Yellow River's middle reach (Xin et al., 2009). Land cover is considered as an important method to protect soil erosion because it can increase surface roughness and infiltration rate, improve soil structure and break landscape connectivity (Hudek et al., 2010; Ouyang et al., 2010; Rey and Burylo, 2014). Soil and water conservation measurements can change underlying surface and have obvious influence on runoff and sediment discharge, and they also can reduce sediment transport to river channels. Understanding characteristics of drainage system morphology is crucial because it controls the relationship between runoff, sediment discharge and rainfall (Cowton et al., 2013). Drainage network systems are key elements that drive landscape change because they convey most of the global fluxes of water and sediment from land to ocean (Fryirs, 2013). Moreover, geomorphic characteristics of drainage systems can affect energy fluxes, mass movement, and sediment and water dispersion in watersheds (Bertoldi et al., 2006; Zhang et al., 2015). Numerous topographic indices have been proposed to represent the geomorphologic characteristics of a river basin. The geographic and geomorphologic characteristics of a drainage basin are significant for hydrological researches involving watershed management, soil erosion risk assessment and environmental development. Evaluating drainage features can provide quantitative explanations of basin geometry to reveal geological and geomorphologic history of each river basin (Magesh et al., 2011). Hydrologists and geomorphologists have recognized that there important relations between hydrologic characteristics, and geographic and geomorphic characteristics of drainage basin systems, such as area, slope, gully density, stream order and length (Sreedevi et al., 2009). Analyzing drainage variables, such as basin area and perimeter, channel length, gully density, basin relief, and stream orders, to investigate coupling relationship between soil erosion and drainage system under the influence of different intensity rainfall. In Loess Plateau of China, watershed shape and relief parameters have large influence on the sediment yield, such as plan curvature, hypsometric integral, basin relief and slope (Zhang et al., 2015).

During the past decades, various researches and methodologies have been implied and introduced to investigate correlation of geomorphology and sediment discharge. Researchers have developed multiple methods and models to estimate soil erosion process and risks, including the Revised Universal Soil Loss Equation (RUSLE), Soil and Water Assessment Tool (SWAT), Water Erosion Prediction Project (WEPP) and so on. Some researchers utilized digital elevation data (DEM) to investigate geomorphic characteristics (slope, aspect, gully density etc.), and describe correlations between geomorphology and soil erosion through statistical method and mathematical models (Kang et al., 2001; Wei et al. 2010a,b; Cheng et al., 2015; Zhang et al., 2015). A couple of investigations have assessed geomorphic characteristics' impacts on sediment yield and soil erosion through regression analysis, Geographic Information System (GIS) and hydrological models (Manoj and Umesh, 2000; Sreedevi et al., 2009; Zhang et al., 2015; Cheng et al., 2015). Moreover, using digital elevation data (DEM) and GIS techniques is a fast, precise, convenient and inexpensive method to extract and compute morphologic parameters, and it's practical to investigate relationships between morphology and hydrology (Sreedevi et al., 2009). Loess Plateau is one of the most serious soil erosion place in the world, and there are abundant researches to study erosion process, how to control soil erosion, and their contributors through existed methods and models. However, not many studies focus on the coupling relationship between geomorphology and sediment discharge within basins, and analyzing their correlations through comprehensive index.

This paper aims to analyzing impacts of topographic characteristics on sediment discharge in Loess Plateau by investigating several key basins of this region (Weihe River Basin, Beiluohe River Basin, and Jinghe river Basin etc.). In summary, the objectives of this research is: (1) quantitatively analyze topographic variables and sediment discharge of key basins in Loess Plateau; (2) build comprehensive index of topography to study its impacts on sediment discharge; (3) investigate correlations of the comprehensive geomorphologic index and soil erosion. These objectives will deepen understanding of how geomorphology affect soil erosion, and help to provide scientific support for sustainable development.

2. Study areas

Loess Plateau is located in the upper and middle reach of Yellow River (100°54′ to 114°33′E and 33°43′ to 41°16′N) which is one of the most serious soil erosion regions in the world. Loess plateau is continental monsoon climate, and the average precipitation of this region ranges from 250 mm/a to 600 mm/a, increasing from northwest to southeast (Fig. 1). Furthermore, approximately 60–70% of the annual precipitation occurs in rainy season (June to September).

Ten basins are key study area (Weihe River Basin, Wudinghe River Basin, Jinghe River Basin, Beiluohe River Basin, and Fenhe River Basin, Qinhe River Basin, Yanhe River Basin, Taohe River Basin, Kuyehe River Basin and Huangfuchuan River Basin), which locate in the middle reach of Yellow River. Weihe River is the biggest tributary of Yellow River, originating form Gansu province and joining to Yellow River at Tongguan, and the length of the main stream is 818 km ad the area is 134766km^2. Drainage system of Weihe River presents the plume asymmetric distribution, and drainage area and stream length and of north tributary is larger than that of south tributary. Topography of this Weihe River basin is complex because of geological structure, showing high elevation in the west and low in the east and north-south mountain region sloping like stair-step. Main landforms include loess hill, tableland, mountain region, terrace and alluvial plain. Hill region mainly distributes in upper stream and accounts more than 70% of Weihe River basin area (Zhao, 2014). Jinghe River and Beiluohe River are the two biggest tributary of Weihe River, which originate in the northern bank. Area of Jinghe River basin is 45,421 km^2, and terrain displays northwest high and southeast low. Drainage system presents palmation and has obvious fractal feature. Average runoff modulus is 43,296 m^3 km^{-2}·a^{-1} and sediment transport modulus is 5845 t km^{-2}·a^{-1} (Wen, 2008). The length of Beiluohe River is 680 km, and the control hydrological station is Zhuangtou whose

Please cite this article in press as: Cheng, N.N., et al., Impacts of topography on sediment discharge in Loess Plateau, China, Quaternary International (2016), http://dx.doi.org/10.1016/j.quaint.2016.12.005