Geomorphology 234 (2015) 19–27

Contents lists available at ScienceDirect

Geomorphology

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

Linking watershed geomorphic characteristics to sediment yield: Evidence from the Loess Plateau of China

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ARTICLE INFO

Article history:
Received 23 June 2014
Received in revised form 11 January 2015
Accepted 18 January 2015
Available online 24 January 2015

Keywords:
soil erosion
Sediment yield
Geomorphic characteristics
Partial least-squares regression (PLSR)

ABSTRACT

The geomorphic characteristics of a watershed affect the energy fluxes, mass movement, and water and sediment dispersion within the watershed. This paper examines how watershed complexity affects sediment yield in terms of rainfall and geomorphic characteristics. The geomorphic characteristics include primary, secondary and compound topographic attributes; watershed shape characteristics; relief parameters; and stream network characteristics. Because of the high co-dependence among these characteristics, partial least-squares regression (PLSR) was used to identify the relationships between the sediment yield and 29 selected watershed characteristics. The PLSR combines the features of a principal component analysis and multiple linear regression and is a robust multivariate regression method that is appropriate when the predictors exhibit multiple co-linearity. The first-order factors were determined by calculating the variable importance for the projection (VIP). Those variables with high VIP values are the most relevant for explaining the dependent variable. The results showed that the watershed shape and relief parameters have large influences on the sediment yield. The VIP values revealed that the sediment yield is primarily controlled by the plan curvature (VIP = 1.87) and the highest order channel length (VIP = 1.53), followed by the hypsometric integral (VIP = 1.49), rainfall (VIP = 1.44), basin relief (VIP = 1.19), slope (VIP = 1.15), sediment transport capacity index (VIP = 1.13), length ratio (VIP = 1.06), profile curvature (VIP = 1.01) and divide average relief (VIP = 1.00). This paper quantified the effects and relative importance of different geomorphic attributes on sediment yield. The insight provided by these results can be used in the selection of appropriate geomorphic variables for watershed erosion and hydrological models. Thus, this study is intended to elucidate the internal dynamics of sediment transport and storage in a watershed and provide a guide for watershed management.

1. Introduction

Soil erosion is the dominant geomorphic process on much of the Earth's land surface (Toy et al., 2002) and includes the detachment, transport and storage of soil particles. Sediment is detached from the soil surface by raindrop impacts and by the shearing force of runoff (Jain and Kothyari, 2000). If the sediment that is available for transport is greater than the transport capacity, storage results in the accumulation of sediment on the soil surface (Trimble, 1975; Toy et al., 2002). The amount of sediment that passes through the outlet of a watershed comprises the sediment yield of the watershed (Glymph, 1954; Parsons et al., 2006; Fryirs, 2013; Vanmaercke et al., 2014). This yield is determined by the environmental conditions of the watershed, such as climate, soil, topography, land use, and various forms of human disturbance, which can affect the sediment supply, transport, storage, residence time, as well as the connectivity of sediment sources to the watershed outlet (Trimble, 1983; Zheng et al., 2008; Fryirs, 2013; Shi et al., 2013; Yan et al., 2013). Providing reliable tools for determining and quantifying sediment yield and its determinant factors is of essential importance for sustainable catchment management (Parsons et al., 2006).

In a study of global sediment yields and their controlling factors, Walling and Fang (2003) found that sediment yields are sensitive to many factors, including reservoir construction, land clearance and land-use change as well as other forms of land disturbance, such as mining activity, soil and water conservation measures, sediment control programs, and climate change. Human activities and climate change have a profound impact on watershed geomorphic characteristics and connectivity (Fryirs, 2013). Watershed longitudinal linkages are weakened with the construction of dams and reservoirs, which causes the sediment yield to decrease, whereas natural vegetation clearance and mining activity reduce the resistance of land surfaces and enhance the effectiveness of flow on sediments, thus increasing sediment yield (Renschler and Harbor, 2002; Gobin et al., 2003). The importance of

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http://dx.doi.org/10.1016/j.geomorph.2015.01.014
0169-555X/

land cover in preventing soil erosion is well known (Walling and Fang, 2003; Gyssels et al., 2005; Rey and Burylo, 2014). Land cover is considered to be a major factor that reduces soil erosion because land cover can improve soil structure, increase the surface roughness and infiltration rate, trap and retain sediment and break landscape connectivity (Burylo et al., 2007; Hudek et al., 2010; Ouyang et al., 2010; Preti et al., 2011; Lü et al., 2012; Rey and Burylo, 2014). Watershed management for soil and water conservation is primarily designed to increase water retention and reduce the on-site effects of soil erosion (Walling and Fang, 2003; Chen et al., 2007). Watershed management for soil and water conservation also reduces sediment transfer to river channels and sediment loads in rivers by increasing sediment storage and reducing sediment mobilization and watershed connectivity (Walling and Fang, 2003; Chen et al., 2007). Connectivity in geomorphic system was defined as the water-mediated transfer of sediment between two different compartments of the watershed sediment cascade (Fryirs, 2013). Watershed connectivity can be used to examine watershed internal structures and quantify the sediment cascade over a range of

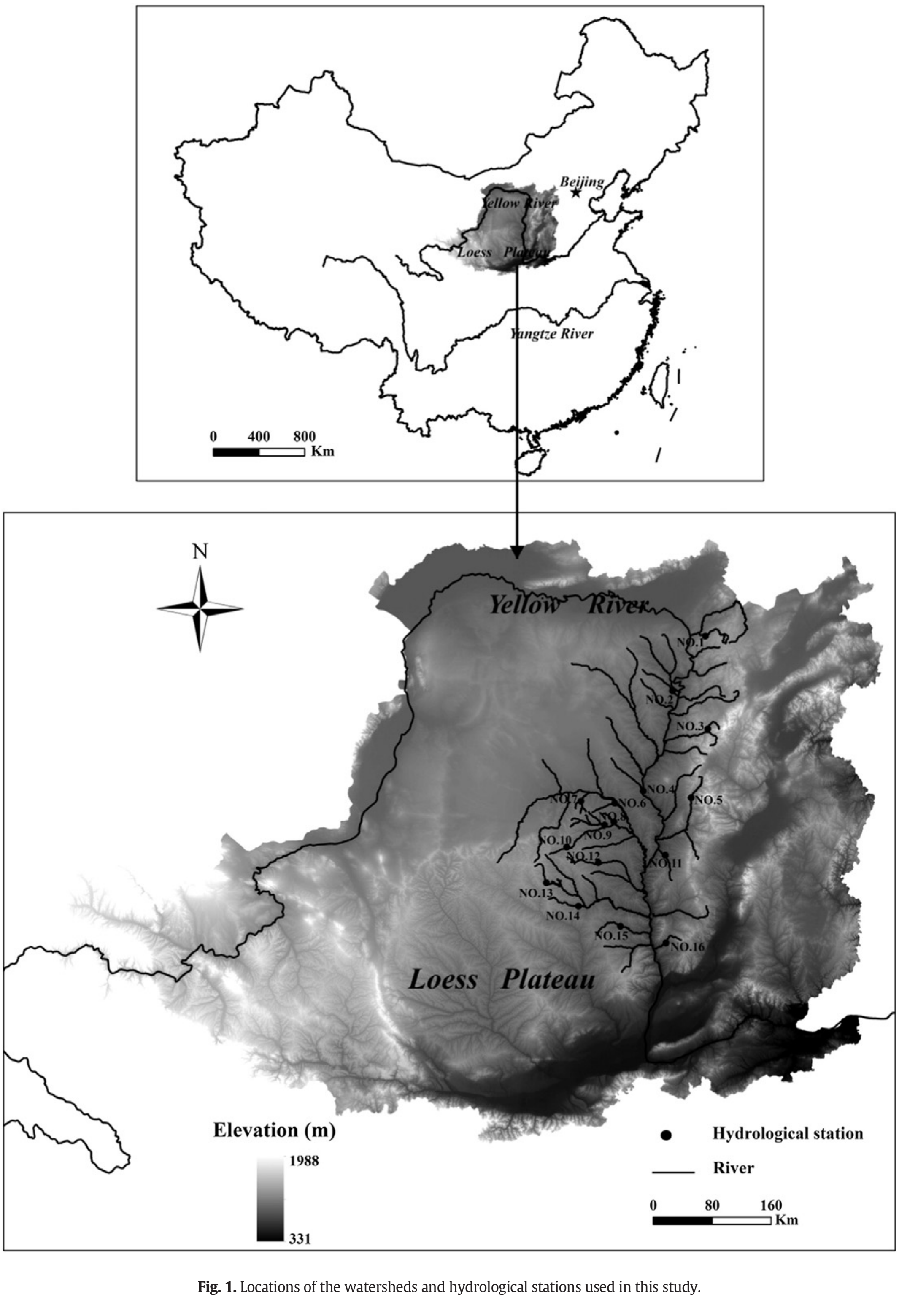

Fig. 1. Locations of the watersheds and hydrological stations used in this study.