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Effects of topographic factors on runoff and soil loss in Southwest China

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ABSTRACT

Soil erosion is a threat to sustainable agricultural and regional development in karst regions. In this study, field plot observation method was used to estimate the effects of slope gradient and length on runoff and soil loss in Guizhou, Southwest China. The results showed that runoff and soil loss is nonlinearly related to slope gradient. The increasing trends of runoff and soil loss declined after the slope gradient of 15°. This turning point was affected by both slope gradient and rock outcrops on the 20°–25° slopes, hence it is still unknown whether the slope gradient of 15° is a critical value. Runoff showed a trend of decrease-increase-decrease as slope length increased, and soil loss rate showed an increasing trend as slope length increased. There is a significantly positive linear relationship between soil loss and slope length ($P < 0.01$). Runoff and soil loss were significantly correlated with rainfall amount (P) and the maximum 30 or 60 min rainfall intensity (I_{30} or I_{60}), which had power function with PI_{30} on gradient-changed slopes and PI_{60} on length-changed slopes. Moreover, soil loss has a power function relationship with slope gradient/length and runoff depth. This study is helpful to elucidate the effect of topographic factors on soil erosion and to take effective soil conservation measures in karst regions.

1. Introduction

Soil erosion is a worldwide challenge to achieve a sustainable development (Pimental, 2006). Soil erosion is driven by the interactions between climate, soils, topography, land use and socio-economic factors. The consequences of soil erosion are both on-site including soil degradation, soil fertility decreasing, desertification, and reduce in infiltration and water storage capacities, and off-site including siltation of dams, reservoirs and rivers, water pollution, destruction of wildlife habitats, and increase in floods.

Slope gradient and length are main topographic factors affecting soil erosion (Liu et al., 1994; Liu et al., 2000). The effects of slope gradient and length on soil loss have been evaluated by different methods, for example the Universal Soil Loss Equation (USLE) and the Revised Universal Soil Loss Equation (RUSLE) (Hickey, 2000; Kinnell, 2001). Several studies found runoff/soil loss increased with the growing slope gradient (Fox and Bryan, 2000; Nord and Esteves, 2010). However, runoff/soil loss is not always linearly positively related to slope gradient. Other studies showed that soil erosion started to decline when slope reached a critical gradient (Jin, 1995; Liu and Singh, 2004). In addition, many studies on the relationship between runoff/soil loss and slope length found runoff and soil loss are complicatedly affected by slope length. With the increasing slope length, there are three changes of soil erosion. 1) decrease (Joel et al., 2002; Yair and Raz-Yassif, 2004; Laws and Parsons, 1943; Stomph et al., 2002; Giesen et al., 2005; Xu et al., 2009; Kara et al., 2010); 2) increase (Zingg, 1940; Wischmeier et al., 1958; Rejman and Brodowski, 2005); 3) and no remarkable change (Wischmeier et al., 1958). Furthermore, rainfall characteristics play important roles in the effects of slope gradient and length on runoff and soil loss (Assouline and Ben-Hur, 2006; Liu et al., 2000).

Due to the extensive karst landscape, around 73% of the land area, Southwest China is one of the most severely eroded regions in the country (Guo et al., 2015; M.X. Liu et al., 2014; Y. Liu et al., 2014; Jiang et al., 2014). It has a subtropical monsoon climate, characterized by strong spatiotemporal variability of precipitation. Due to the high population density and the variable terrain conditions, the cropland parcels are characterized by steep slopes, short slope lengths and thin topsoil. More than 80% of its farmland is on slopes over 6°. Soil profiles in this mountainous karst area are generally undeveloped. Usually without the C-horizon, both adhesion and affinity between the topsoil and bedrock are substantially decreased. And therefore heavy rainstorm can easily cause soil erosion and exacerbate the rocky desertification

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(Yuan, 1993).

As a kind of serious land degradation, karst rocky desertification heavily constrains the sustainable development in this region and it has received increasing attentions from both the governments and academic community (Wang et al., 2004; Yan and Cai, 2015). Several studies have researched the relationship between topographic factors and soil erosion in this region. For example, Xu et al. (2008, 2011) applied RUSLE model and GIS/RS techniques to research the relationship between land use and soil erosion. They found that dry farmlands with a slope from 6° to 25° were most seriously impacted and they were the key contributor to soil erosion in Maotiao river watershed in Guizhou. In addition, some studies used large runoff plot method to evaluate the effects of land use and land cover change, and rainfall regimes on the runoff and soil erosion on karst slopes (*e.g.* Peng and Wang, 2012). With more frequently extreme weather (M.X. Liu et al., 2014), there is an increasing demand for researches on soil erosion in this karst area. However, to the best of our knowledge, there is a lack of field observation in the effects of topographic factors on surface runoff generation and soil loss; and the understanding of the relationship between topographic factors and soil erosion is also far from satisfactory.

The current study was carried out on experimental field plots in Guizhou Province, a karst mountainous region in Southwest China. The objectives of this study were 1) to evaluate the effects of slope gradient and length on runoff generation and soil loss rate; and 2) to expand our understanding of the soil erosion mechanism on hillslope in subtropical monsoon climate. The findings are helpful to make policies for sustainable land use management and soil conservation in the similar karst areas.

2. Material and methods

2.1. Study area

The study was carried out in the Shiqiao watershed located in Bijie City, Guizhou Province, China (Fig. 1). The watershed, with the area of 8.19 km^2, is a tributary of the Wujiang River basin belonging to the Yangtze River basin. The altitude of the study area ranges from 1400 to 1743 m asl. The watershed has a subtropical humid monsoon climate. The annual temperature is 14 °C and average annual rainfall is 863 mm. About 80% of annual rainfall is concentrated from May to September (rainy season). Due to low cover of vegetation and the wide distribution of limestone, the study area presents typical rocky desertification and severe soil erosion area in Guizhou Province. Soils are composed of different particle sizes: 32.7% of size < 0.002 mm, 56.3% of size 0.002–0.05 mm, and 11% of size > 0.05 mm. The main land use types include forest, farmland, and grass land. The representative crops are maize, beans, potatoes, rapes, and peppers. Around 16.3%, 38.9%, 28.8% and 16% of farmlands are on slopes of < 6°, 6–15°, 15–25°, and > 25°, respectively.

2.2. Plots layout

Experiment was set up in the study area. Two set of plots were used to analyze the effects of slope gradient and slope length on runoff and soil loss (Fig. 2 and Table 1). Slope gradient-changed plots include 5°, 10°, 15°, 20° and 25° with the same slope length of 10 m. Slope length-changed plots include 5, 10, 15, 20 and 25 m with the same slope gradient of 15°. Soils have a thickness of 0.21–0.30 m. To minimize the effects of vegetation coverage on runoff generation and soil loss on plots, the vegetation coverage rate on plots was controlled to < 5% by weeding the plots properly during the observation periods. In addition, there are rock outcrops on 20° and 25° slopes (Fig. 2).

2.3. Data collection and analyses

Rainfall, runoff and soil losses data were obtained from field observation during the period of 2012–2014. Rainfall was recorded by an auto-recording rainfall gauge at 5-min intervals. Runoff and soil losses data were obtained from the field plots experiments.

Runoff and sediment were collected using collecting tanks installed in the outlet of each plot. Each collecting tank was connected to a diversion tank which accounted for one-ninth of the total runoff generated on a plot in the heavy rainfalls. The depth of the runoff water in the collecting tanks was measured after each rainfall. When the rainfalls

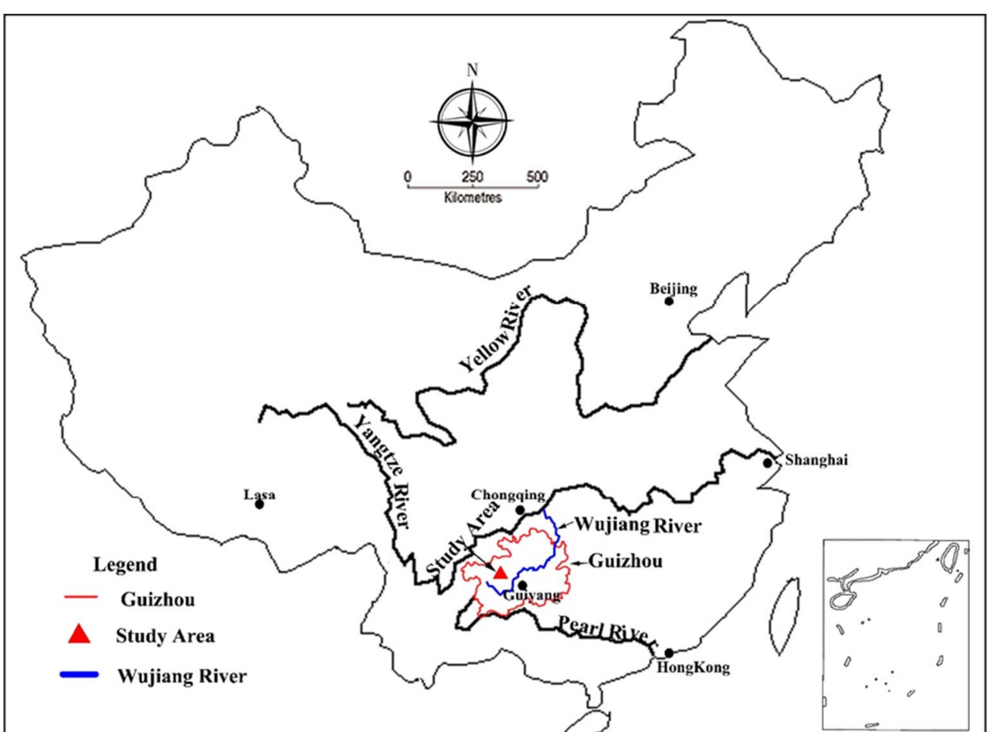

Fig. 1. Location of the study area in Guizhou Province, Southwest China.