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Simulation of surface runoff and sediment yield under different land-use in a Taihang Mountains watershed, North China

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ABSTRACT

The maintenance of water and soil resources has attracted the attention of governments and scientists world-wide. The loss of these resources is a serious problem in the Taihang Mountains, and the emerging issue with water has threatened the livelihoods of local residents and the sustainability of this region. A simple distributed soil erosion and sediment yield model (DSESYM) has been developed based on WetSpa extension. The effect of land-use change on surface runoff and sediment yield was then analyzed through applying the model in the Chongling watershed. Taking the land-use distribution of the watershed in 2000 as the baseline, fourteen scenarios were performed to characterize the effect of land-use change on surface runoff and sediment load relative to the baseline condition. These scenarios involved converting the mixed land-use to 93.89% of the area being forestland (scenario 1), shrubland (scenario 2), grassland (scenario 3), cropland (scenario 4), mixed crop/forest land (scenarios 5 and 6), mixed crop/shrub land (scenarios 7 and 8), mixed crop/grass land (scenarios 9 and 10), mixed crop/shrub/forest land (scenarios 11 and 12), and mixed crop/grass/forest land (scenarios 13 and 14). The scenario analysis revealed that when land-use was changed to 93.89% of the respective land-use in scenarios 4, 5, 7 and 9, an increase in runoff and sediment yield for single rain events compared to the baseline whereas a change to forest and shrubland caused a decrease (scenarios 1 and 2). Slope is an important factor in soil erosion, but in the study area, when the slope is more than 10°, the difference of stream flow and sediment between forest, shrub and grass was not obvious (scenarios 5, 7 and 9). The model can be used to predict surface runoff, erosion, deposition and sediment yield of each grid cell and the whole watershed in response to land-use scenarios for single rain events in the Taihang Mountains. It is easy to execute if the precipitation process data, the relationships of water and sediment for different land-use, and GIS maps of the study area are available, which makes it suitable for widespread application.

1. Introduction

Soil erosion and sediment export to rivers and lakes cause important environmental problems. Soil erosion irreversibly deteriorates soil quality, which often results in reduced soil productivity and may even drive land-use change (Bakker et al., 2004, 2005). Eroded sediment is often polluted with fertilizers, leading to eutrophication and the disturbance of fragile aquatic ecosystems. Increased sediment loading to rivers can lead to excessive sedimentation in lakes and reservoirs, thereby threatening aquatic biota and hydroelectric power generation (Douglas, 1995; Vanacker et al., 2003; Wilkinson et al., 2009).

Land-use changes can have a large impact on watershed hydrology and erosion, and soil erosion is often affected by the cultivation of arable land and, depending on climate, on intensive grazing, especially in sloping areas. To a large extent, soil erosion is determined by the absence of protective vegetative land cover. The rapid abandonment of traditional agricultural practices and the large extent of areas affected by vegetation recovery have changed the hydrological response and sediment delivery dynamics (Gallart and Llorens, 2004; Lopez-Moreno et al., 2006). Many studies have illustrated the importance of human-induced land-use changes on the fluxes of water and sediment (McIntyre, 1993; Slaymaker, 2001; Van Oost et al., 2000; Boix-Fayos et al., 2008; García-Ruiz

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et al., 2008; Fiener et al., 2011; Manuel et al., 2011; Yan et al., 2013; Shi et al., 2014).

Some erosion models have been used to analyze the impacts of land-use changes on hydrology, stream stability and sediment yield (Fohrer et al., 2001; Mishra et al., 2007; Bakker et al., 2008; Verstraeten and Prosser, 2008; Dymond et al., 2010). However, most of the erosion models suffer from problems including unrealistic input requirements, over-parameterisation, parameter values to local conditions. Most of the models focus on the mean annual sediment yield rather than the event sediment yield, which are inappropriate for providing event-based predictions of sediment load (Merritt et al., 2003). Event-based studies of soil erosion may help to better understand sediment yield processes (Zheng et al., 2008). Many more studies have attempted to investigate the effect of land-use and land-cover change on watershed hydrology and soil erosion (Bari and Smettem, 2006; Ashagrie et al., 2006; Nyakatawa et al., 2007; Ward et al., 2008; Gómez et al., 2009; Alkharabsheh et al., 2013). Changes in flow and sediment discharges can influence sedimentation in reservoirs, which rapidly decreases storage capacities (Bonora et al., 2002). This problem is currently taking place in the Taihang Mountains in North China, where sedimentation patterns in downstream areas have significantly changed mainly due to land-use change. In addition, seasonal, extreme meteorological phenomena have caused significant soil losses, and sediment deposited in reservoirs has increased the inadequacy of freshwater supplies in this region.

To mitigate negative consequences of management, the impact of land-use on stream flow and sediment dynamics in the Taihang Mountains needs to be studied. Due to the regional limitations of other erosion models and the difficulties of parameterising these models, this study built a simple distributed soil erosion and sediment yield model based on WetSpa extension for simulating surface runoff and sediment yield of single rain events. The objectives of this study were:

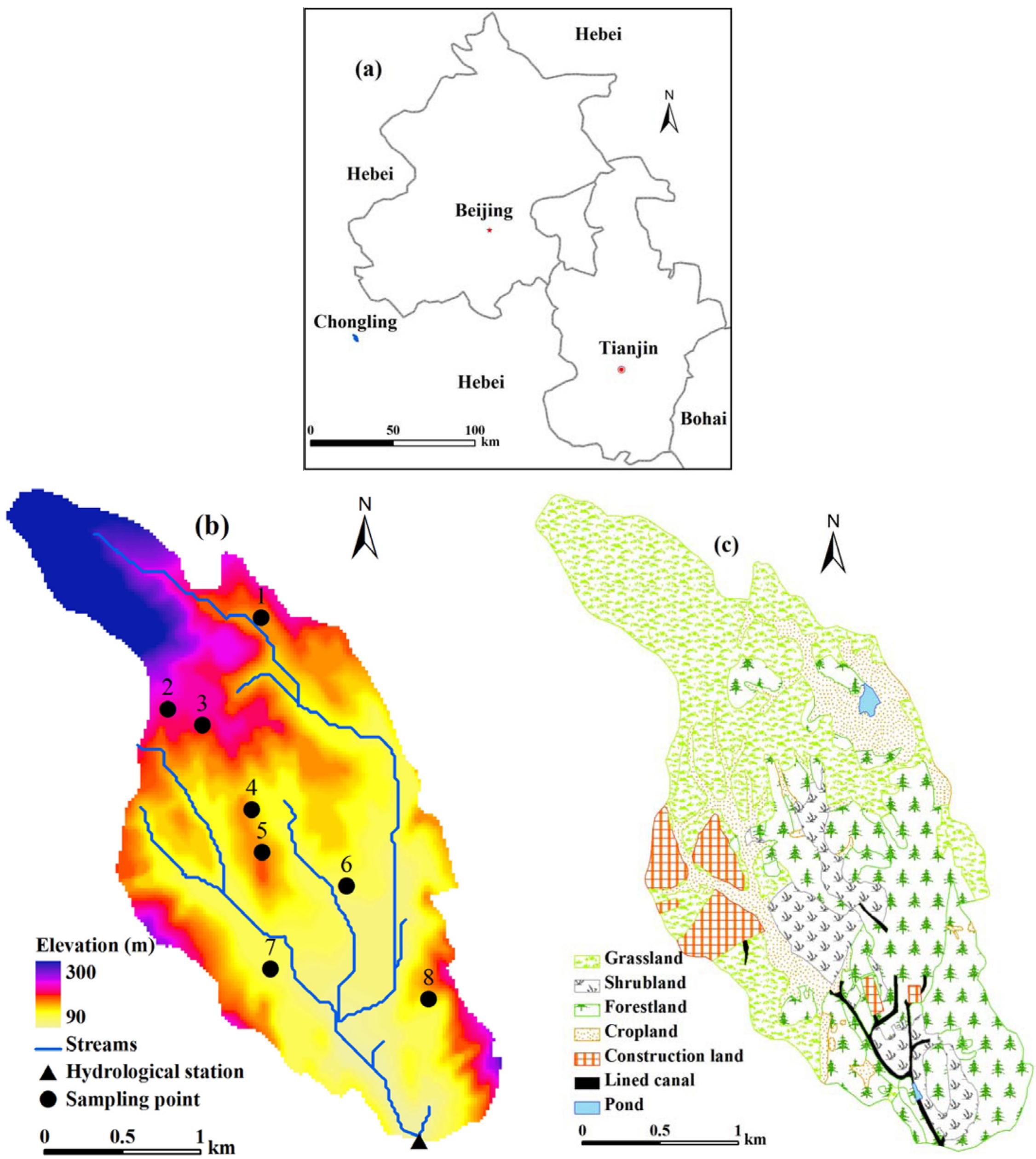

Fig. 1. Location of the study area: (a) the location of the Chongling watershed in China, (b) DEM of the Chongling watershed and the eight commonly used soil sampling locations indicated by solid circles, and (c) Land-use map of the Chongling watershed.