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Modeling runoff and soil erosion in the Three-Gorge Reservoir drainage area of China using limited plot data

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SUMMARY

This paper presents a modeling approach to simulate runoff and soil erosion at the small watersheds of the Three-Gorge Reservoir drainage area in China by using limited plot data on runoff-soil erosion. The approach coupled the empirical relationships between soil loss and runoff. This relationship is derived from the experimental plots under different land use types with a spatially distributed hydrological model, WetSpa Extension, to calculate soil loss in grid cells. A topographic factor was also developed to account for the impacts of topography on soil loss. Finally, a constant Sediment Delivery Ratio (SDR) was applied to calculate sediment yields transported to the catchment outlet from grid cells. The coupled model was first calibrated for the study areas using the observed continuous discharge data and event-based sediment data over the period from May 1st through October 31st of 2001 in a small sub-catchment in Sichuan, China. The calibrated model was then applied to the same sub-catchment over the same period of every year from 1993 to 2000 as well as the neighboring catchments to assess the performance and stability of the model. A comparison of observed and simulated stream flows indicates that the model performance was acceptable in six (1993, 1994, 1996, 1998, 1999 and 2000) of the 8 years with Nash–Sutcliffe Efficiency (NSE) of 0.654 and 0.729 for weekly and monthly flow discharges, respectively. A comparison between the observed and simulated sediment yields showed that the simulation of sediment yields was very satisfactory (NSE = 0.88) and the spatial variability of soil erosion rates within the catchments was predominantly controlled by land use types. Finally, the model was applied to assess the efficacy of soil conservation through land use changes in Sub-catchment No. 2. The results clearly indicated that land use changes after 1990s have been very effective in reducing both runoff and sediment. This study suggests that experimental plot data is an effective supplement to modeling spatial variation of soil erosion, albeit their various limitations.

1. Introduction

Soil erosion remains one of the world's biggest environmental problems, threatening both developed and developing countries (ISCO, 2002). Erosion by water not only strips the fertile topsoil on site, but also degrades water quality and clogs streams, rivers, and reservoirs with transported sediments off site. Sedimentation in reservoirs has become an increasing concern around the world. MahMood (1987) estimated that around 50 km^3 of sediment – or 1% of global reservoir storage capacity – is trapped behind the world's dams every year. Large reservoirs in the US lose storage capacity at an average rate of around 0.2% per year whereas major reservoirs in China lose capacity at an annual rate of 2.3% (McCully, 1996). As an extreme example, the reservoir behind the SanMenXia Dam constructed on the Yellow River of China in 1960 lost 40 percent of the initial storage capacity in the first 4 years due to the massive load of sediments eroded from the Loess Plateau. The Three-Gorge Reservoir (TGR), formed behind the Three-Gorge Dam (TGD) on the Yangtzi River, is over 600 km long and more than 1000 km^2 of water area. It is estimated that TGR trapped about 162 million tons of sediment annually in 2003–2007 after the Three-Gorge Dam (TGD), the world's largest hydro dam, began to operate in 2003,which represents 84% of sediment discharge in the pre-TGD period (1986–2002) (Hu et al., 2009). Sedimentation in the reservoir behind the TGD results in a progressive reduction of the storage capacity and triggers a series of physical, chemical

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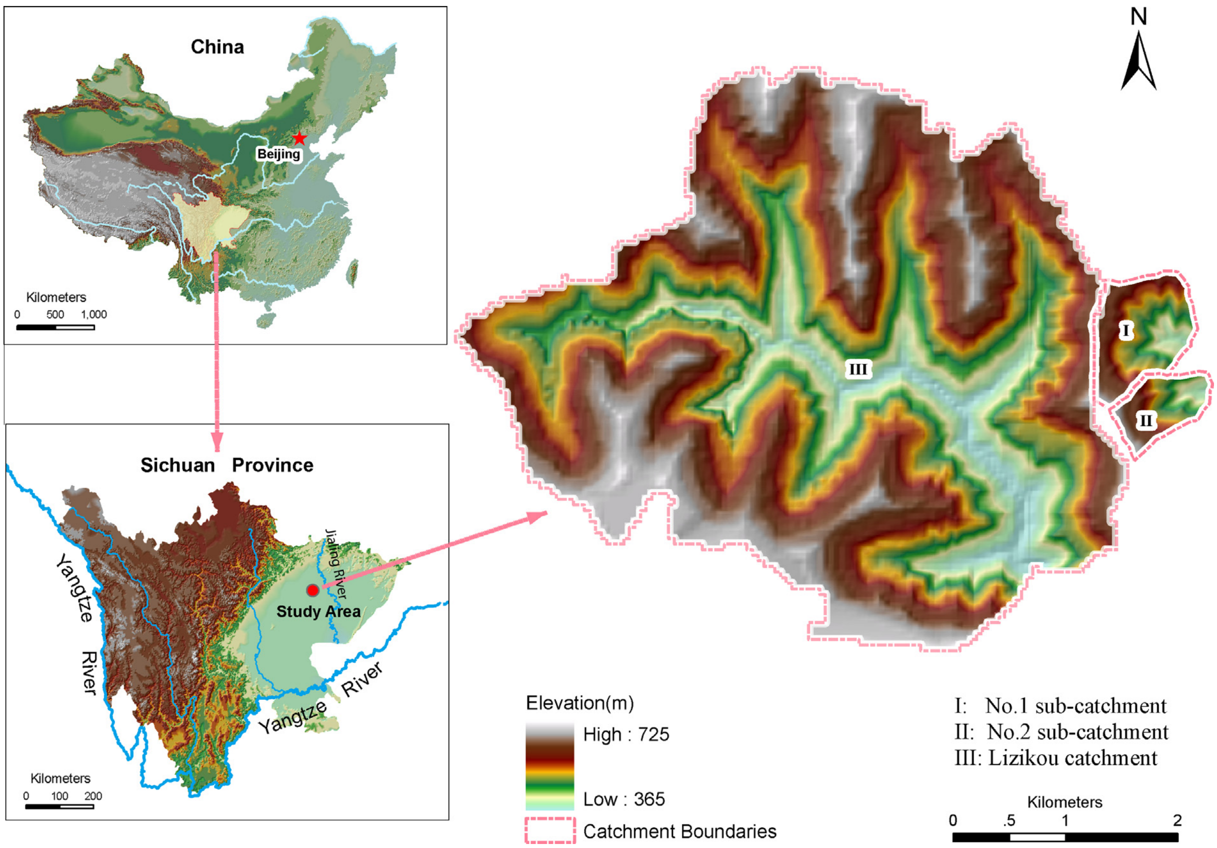

Fig. 1. Map and DEM of study area.

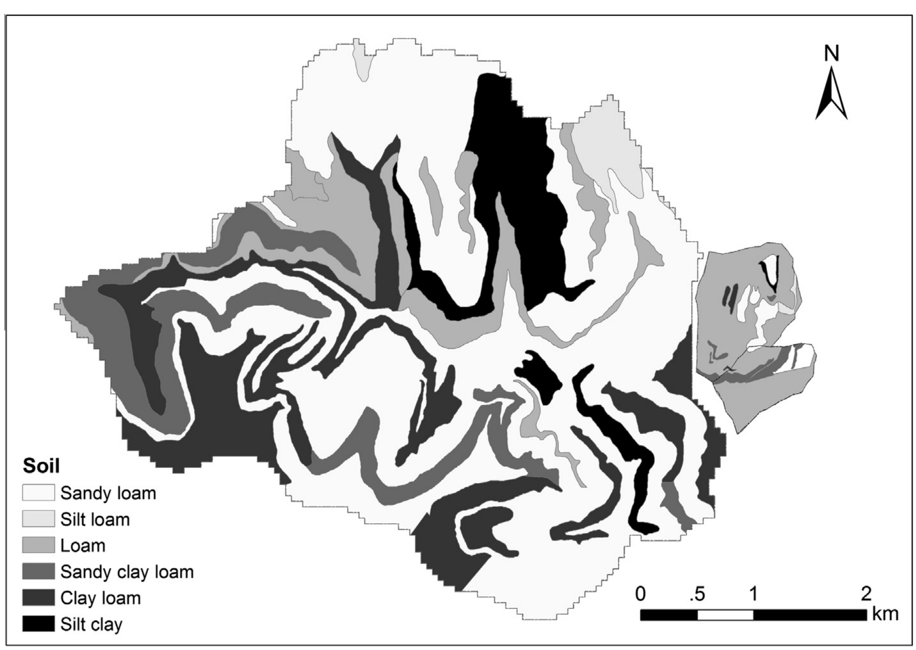

Fig. 2. Soils in HeMingGuan and LiZiKou catchments.

and ecological impact on the environment (Lu and Higgitt, 2000). The fundamental solution to sedimentation is to reduce sediments transported into the reservoir. The TGR has a drainage area of about 1 million km^2. Integrated small watershed management (ISWM) that aims to control soil erosion through implementing comprehensive measures (e.g. changing inappropriate land use, terracing slope lands, planting trees and grasses) has developed rapidly in the area since the 1990s. The ISWM has been conducted in more than 5000 small watersheds with an area of 96,000 km^2 (Shi et al., 2012; Liao, 2010). The small watersheds refer to those