Comparative analysis of two distributed soil erosion and sediment yield models in Sichuan Basin, China

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Abstract Based on data from two watershed outlets, and three runoff plots in the purple soil hilly areas of Sichuan Basin, two distributed soil erosion and sediment yield models were constructed. One is based on a grid with 20-m resolution in Hemingguan Watershed, with an area of 0.419 km^2, and the other is based on a land plot in Lizikou Watershed with an area of 19.63 km^2. Comparison of these two models shows that the simulation based on the high precision grid is more accurate. When the area of a watershed is larger than 10 km^2, the accuracy of the model will be increased if a high-resolution grid is adopted, whereas if the resolution of the grid is low, the grid will generalize too much information, such as different land-use patterns in the same grid. On the other hand, a distributed model based on a land plot can substantially reduce the computational complexity because the land-use means are uniform. The two models basically have the same structure, but the Hemingguan model is more accurate than the Lizikou model.

Key words distributed soil erosion and sediment yield model; Sichuan Basin; comparison

INTRODUCTION

In recent decades, many non-Chinese distributed soil erosion and sediment yield models have been constructed for flood, soil erosion, and rainfall–runoff predictions. Examples include ANSWERS (Area Nonpoint Source Watershed Environment Response Simulation; Beasley *et al*., 1982), SHE (System Hydrologique European; Abbott *et al*., 1986), WEPP (Water Erosion Prediction Project; Nearing *et al*., 1989), EUROSEM (European Soil Erosion Model; Morgan *et al*., 1998), SEMMED (Soil Erosion Model for Mediterranean Regions; De Jong *et al*., 1999), AGNPS (Agricultural Nonpoint Source; Perrone *et al*., 1999), etc. In China, Tang (1996) established a sediment yield model for small watersheds in hilly loess-dominated regions. Wang (2001) developed a distributed runoff model for single rainfall events using Matlab language, and Qi (2004) built a distributed soil erosion and sediment yield model for small watersheds for single rainfall events. However, most Chinese models are mainly limited to the Loess Plateau region, and it requires substantial effort to extend them to other areas. Along with the development of computer and geographic information system (GIS) techniques, distributed soil erosion and sediment yield models have been widely recognized and used in the fields of hydrology and sediment.

Soil erosion is a serious problem in the Sichuan Basin. It impacts the regional environment and causes cultivation problems (Zhu *et al*., 2002). Available erosion models for this area are very limited (Chen *et al*., 2003). As a result, research on soil erosion problems and the construction of simulated models to predict erosion in this region are needed.

METHODOLOGY

Description of the study area

The study area is located in Nanchong city, Nanbu county, Sichuan Province, (Fig. 1). The Hemingguan Watershed is composed of three branches, covers approx. 1.7 km^2, and has an elevation ranging from 394 m at the outlet to a maximum of 681 m. The average basin slope is 32.5%. The Lizikou Watershed is composed of seven branches and covers approx. 19.63 km^2. The two watersheds are adjacent. The dominant soil type in both watersheds is calcareous purple soil with a low organic content. The soil is easily dispersed and suspended by water, and its erosion-resisting characteristics are poor. The climate in this region is subtropical monsoon, with a mean annual temperature of 17.8°. Average annual precipitation is about 957 mm; however, it has a non-uniform distribution throughout the year, with 73.5% of the total rainfall occurring between May and October. Rainfall intensity in the region is always low (the average intensity of a major event is about 0.085 mm min^{-1}), but event duration tends to be relatively long (average duration is about 7.8 h).

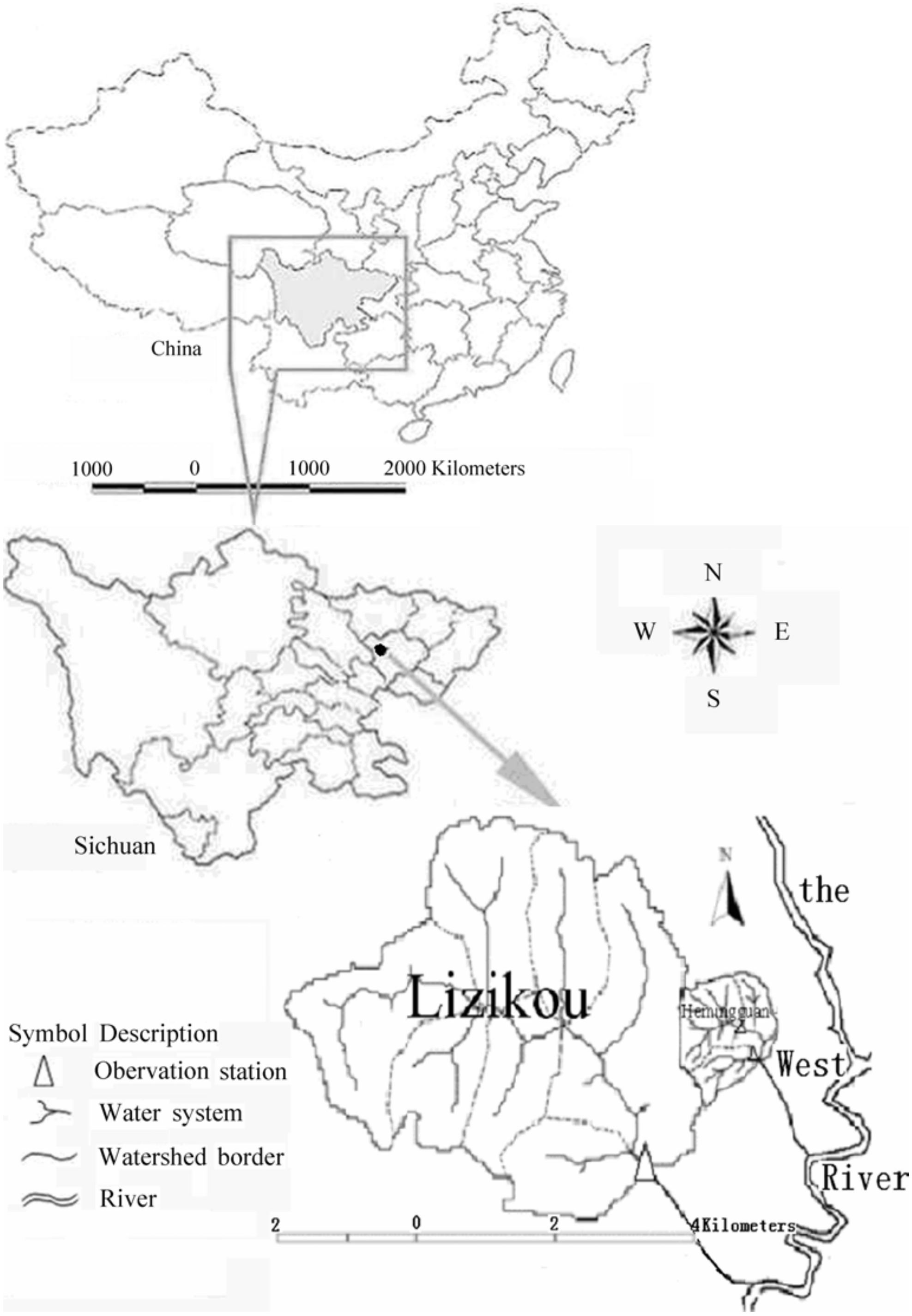

Fig.1 Location map of the study area.

Data collection

In order to study the erosion characteristics of the purple soil in Sichuan Basin, two observation stations were established at the outlet of the branches of the Hemingguan Watershed. Further, three experimental runoff plots (Table 1) were constructed in a branch hillside. Runoff and erosion data for single rainfall events have been collected at these sites since 1985. In May 2005, an observation station at the outlet of the Lizikou Watershed was set up to collect water and sediment data. Hence, the available data for this study consist of observation data at the outlets of the two watersheds and the three runoff plots.

Table 1 Characteristics of the three runoff plots.

No.	Experimentation Establishment	Slope/Aspect	Slope length (horizon)	Area(horizon/oblique)	Soil thickness
I	Catch basin	22–25°/South	13.91 m	205.93 m^2/264.92 m^2	10–15 cm
II	Sand basin		13.66 m	201.18 m^2/262.89 m^2	8–12 cm
III	Runoff tank		14.82 m	215.44 m^2/261.50 m^2	15–20 cm

Comparative analysis of the two models

Two distributed soil erosion and sediment yield models, one for Hemingguan, and the other for Lizikou have been constructed (Yuan, 2007).

(1) The structure and framework for the two models are the same, and both employ a 10-min timestep. The following equation was constructed to estimate the depth of surface runoff based on a natural storage model (Zhao, 1984; Yuan, 2007):

$$H_s = P - E - Z - (W_m - W_o) - FC \tag{1}$$

where H_s is the depth of surface runoff (mm); P is time-interval rainfall (mm); E is evaporation capacity (mm); Z is vegetation interception (mm); W_m is field moisture capacity (mm); W_0 is soil impoundment before a rainfall event (mm); and FC is time-interval soil stable infiltration (mm).

In this model, evaporative capacity was ignored for the 10-min timestep, but was considered for the entire rainfall event.

The total surface runoff for each calculating unit (in the Hemingguan model, it is a grid; whereas in the Lizikou model it is a land plot) was estimated using the following equation (Yuan, 2007):

$$Q_{os}(x) = Q_{is}(x) + Q_s(x) \tag{2}$$

where $Q_{os}(x)$ is total surface runoff through the outlet (m^3); $Q_{is}(x)$ is the total surface runoff through the inlet (m^3); $Q_s(x)$ is the self total surface runoff (m^3).

Neither model assessed the effect of the groundwater moving mechanism when calculating the full runoff for each unit; however, groundwater runoff was considered when calculating the total runoff for the full watershed.

Erosion for each calculating unit was affected by the runoff and erosion in adjacent units (Xiao, 2001). Erosion for each unit was estimated using the following equation (Yuan, 2007):

$$M(x) = M + \Delta M = M + (4.517(10^3 Q_i)^{-0.012} M_i^{0.757}) \tag{3}$$

where $M(x)$ is the erosion amount for the calculating unit (kg); M is the erosion amount due to runoff and is calculated by multiplying the slope factor by the gully factor (kg); ΔM is the erosion increment from other units (kg); Q_i is the runoff amount from other units (m^3); and M_i is erosion amount from other units (kg).

(2) The spatial scales for the two models differ because the area of the Lizikou watershed is much larger than the Hemingguan watershed. The Hemingguan model is based on a 20 m × 20 m grid whereas the spatial scale for the Lizikou model is a land plot having an area of tens to

thousands of square metres. The waterflow direction in each grid of the Hemingguan model is unique, whereas in the land plot for the Lizikou model, waterflow directions can be different, so the number of grids with the same waterflow direction provide a frame of reference for calculating soil erosion and sediment yield.

(3) The databases for the two models also are different. The Hemingguan model has water and sediment yields for 94 rainfall events whereas the Lizikou model has water and sediment yields for only 9 rainfall events because the observation station at the outlet of the Lizikou Watershed only was constructed in 2005.

(4) The Lizikou model takes siltation and closure by ponds and dams into account because numerous ponds are located in the watershed while there are no ponds or dams in the Hemingguan Watershed. An equation to estimate the amount of annual deposition for each pond (or dam) in the Lizikou Watershed was developed from analysing a pond siltation survey:

$$Q_{Sed} = 72.795(0.001PA)^{0.779} \quad R = 0.91, n = 10 \tag{4}$$

where Q_{Sed} is the amount of annual deposition (kg); P is the annual rainfall (mm); A is the rainwater harvesting area of the pond (or dam) (m^2); R is the linear correlation coefficient, and n is the number of ponds surveyed.

The above equation is adopted to estimate the deposition for each pond according to single rainfall events and the rainwater harvesting area of the pond.

(5) Finally, the simulation precision for the two models is different. Based on 26 rainfall events selected to verify the Hemingguan model, the results showed that runoff simulation precision is 79% and that sediment simulation precision is 76%; the simulated values are larger than the observed ones. On the other hand, for the Lizikou model, only 9 samples were available to verify the model; the results showed that runoff simulation precision is 83% and sediment simulation precision is 75%.

RESULTS AND DISCUSSION

In Sichuan Basin, at the beginning of storm events, sediment often deposits at the base of hills, in billabongs, and on the diluvial fan near the outlet of the basin. Gully erosion is weak because the basin contains numerous multi-sized gravel bed rivers and the coarse sediments cannot be transported far from their source. As watershed areas get larger, and flow distances get longer, sand-sized particles drop out first. In the Hemingguan Watershed, sediment is mainly deposited at the foot of slopes and on the edges of gullies. On the other hand, in the Lizikou Watershed, sediment is mainly deposited at the foot of slopes and in ponds and dams; hence, the Lizikou model must account for deposition in ponds and behind dams. Land-use also exercises a substantial influence on rainfall, runoff, and erosion processes, particularly for complex terrains. Changes in land use significantly affect infiltration rates, the water retention capacity of soils, and subsurface transmissivity.

Many factors affect the precision of the models such as the accuracy of the observed data, the resolution of the DEMs for each watershed, as well as slope and gully factors. The accuracy of the observed data is critical because the estimates of runoff and erosion from the equations are derived from them.

CONCLUSIONS

Two physically based distributed models were developed at the watershed scale in Sichuan Basin based on characteristic water loss and soil erosion for the purple soil regions of the basin. Model parameters based on surface slope, land use, soil type and their combinations were determined using GIS.

The Hemingguan Watershed model is capable of simulating runoff and erosion processes for each 20 m × 20 m grid over the entire watershed, whereas the Lizikou Watershed model is capable of calculating runoff and erosion for each land plot for the entire watershed. The accuracy of both models appears to be reasonable. This study shows that, grid and land-plot spatial scales can be used with distributed soil erosion models. When the area of the watershed is larger than 10 km^2, the distributed model can be based on land plot rather than on small area grids, and this tends to reduce computational complexity.

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