Streamflow and soil erosion simulation using SWAT model in Lower-Middle Reaches of Lancang River

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***Abstract*—Using SWAT model, the soil erosion and streamflow in the watersheds of Lower-Middle Reaches of Lancang River were assessed. The dam effect on the streamflow in the inlet and outlet of the watersheds was evaluated. At the same time, we explored the impacts of land use change on soil erosion by calculating the land use dynamic degree. Results showed that there was no significant difference between the pre-dam and post-dam construction period both in the inlet and outlet of the watershed. The soil erosion simulation revealed the temporal and spatial variation and distributions in the watershed. Correlation analysis was used to relate soil erosion to land use dynamics. The results revealed significant correlation between soil erosion and land use dynamics of forest land (Spearman's rs=0.227) and grassland (Spearman's rs= -0.138), which indicated farmland and grassland have key impacts on soil erosion process in each sub-basin.**

***Key Words*—Streamflow; Soil erosion; SWAT; Dam effect; Land use dynamics**

I. INTRODUCTION

Hydroelectric dams significantly disturbed the original river ecosystem, they regulate streamflow, alters hydraulic force, and reduces the sediment transport to downstream [1,2]. Studies have shown that the dams changed water discharge and disturbed alluvial sand [3].

On the other hand, soil erosion has become a serious global problem and its importance in affecting sustainability of regional development make it an issue we should never ignore [4,5]. According to Bakker [6], land cover change would affect the amount of soil erosion initiation and transportation to the water body, so it's necessary to understand the spatial distribution and long-term dynamic principles of soil erosion for the land use management and soil erosion prevention [7].

The key objectives in this paper are to: (i) reveal the streamflow variation in different periods; (ii) assess long-term soil erosion dynamics in the Lower-Middle Reaches of Lancang River; (iii) explore the response of soil erosion to the land use variation.

II. MATERIAL AND METHODS

A. Study watershed description

The Lower-Middle Reaches of Lancang River watershed in Yunnan lies between 21.1–29.3 °N and 98.7–102.3 °E; with an area of about 88,655 km^2 across 39 counties. The average rainfall is about 500mm. In addition, the river gorge is steep with slopes ranging from 0.8‰ to 1.0‰ in the middle and lower parts, with the average elevation about 2000 m. Together with the complex climate and topography and various forms of human activities, soil erosion has become main environmental concern in this region.

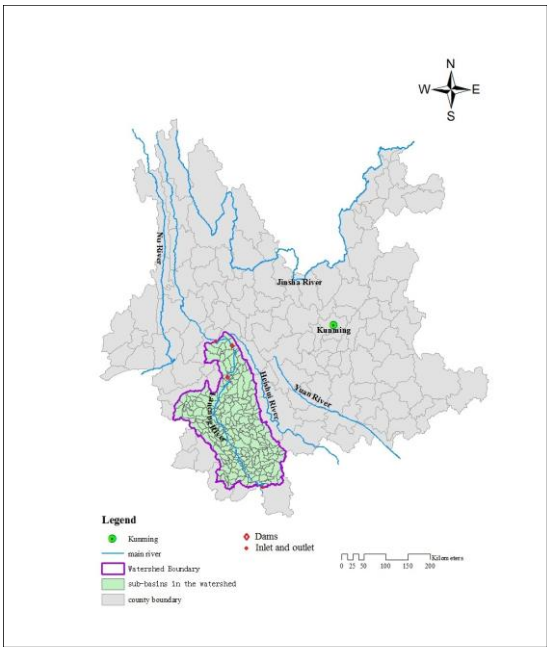

Fig.1 Location of study area.

B. Model description

The SWAT model is suitable for predicting long-term impacts of land management practices on water, sediment and agriculture chemical yields in large complex watersheds [8]. SWAT was used to simulate the soil erosion and the streamflow in the Lower-Middle Reaches of Lancang River. Each sub-watershed is parameterized using a series of hydrologic response units (HRUs). A HRU is a particular combination of land use, soil type and slope range. In this study, the watershed was divided into 258 sub-basins. And the soil erosion load is based on the Modified Universal Soil Loss Equation (MUSLE).

C. Model description

The data needed for SWAT including vegetation cover data, soil property data, meteorological data and hydrological data belong to the attribute data. In SWAT, spatial database should have the same geographic coordinate and projection. In this paper, the spatial data were converted to Transverse Mercator projection.

To compare the streamflow flux after the emergence of the dams, the monthly average streamflow in 1990–1993 was considered as the original hydrological profile. The data in 2004–2009 was treated as the profile after the emergence. We selected 1995 and 2000 land cover data to representative the variation, which were based on data availability. The land cover data was made from classified Landsat imagery and the accuracy has been checked. The scale of DEM used in this paper was 1:100,000. Soil type map, provided by Institute of Soil Science, Chinese Academy of Sciences, was input into the model after being clipped and reclassified. The meteorological data were obtained from the daily monitoring data from seven weather stations in the Lower-Middle Reaches of Lancang River from 1990 to 2009.

D. Model description

Using the data prepared for the model, topography, soil properties and land cover database were constructed. Watershed climate condition was simulated with daily monitoring data obtained from the weather stations.

The average monthly runoff and sediment data of Mengsheng Hydrological Station and Menghai Hydrological Station from 1990 to 1992 were utilized to calibrate the model, and the data in 1993 were used for the validation. Uncertainty analysis was performed using Sequential Uncertainty Fitting (SUFI-2) in the SWAT-CUP software. We selected thirteen hydrological and sediment parameters to calibrate. Nash-Suttcliffe efficiency, E_{NS} and Person efficiency R^2 were selected to evaluate the fitness of the model. The results for calibration and validation are listed in Table 1. From Table 1, we can conclude that the simulation results are satisfactory and have certain applicability; the validation results reach the requirements of the model, though they are not perfect as the calibration results.

TABLE I. CLALIBARATION AND VALIDATION RESULTS

Hydrological station		Calibration		Validation	
		NS Coefficient	R^2	NS Coefficient	R^2
Mengsheng	runoff	0.72	0.78	0.68	0.71
	sediment	0.69	0.72	0.64	0.69
Menghai	runoff	0.63	0.73	0.61	0.70
	sediment	0.60	0.70	0.58	0.66

E. Model description

A formula was used to quantify the degree of land use variation. The degree of individual land use dynamics is calculated through the numerical change in particular land use dynamics multiplied by the length of time of the study. The formula is:

$$LC = \frac{Ub - Ua}{Ua} \times \frac{1}{T} \times 100\% \qquad (1)$$

In the formula, LC represents the degree of land use change, U_a the amount of the particular land use at beginning of year a, U_b the amount at the end of year b and T represents the length of time. When the unit of T is set as a year, LC indicates the degree of annual individual land use dynamics. Using data in 1995 and 2000, we calculated LC of each land use type in each sub-basin. Then we correlated the soil erosion yield and LC of each sub-basin in SPSS software to explore the soil erosion dynamics response to the land use variation.

III. RESULTS AND DISCUSSION

A. Streamflow variation in different periods

The streamflow characteristics at the inlet and outlet of the studied section, before and after the dams' construction, were shown in Table 2. It revealed that the streamflow volume from upper catchments showed some variation in the simulation period due to weather and demand variation. The hydrological difference in the inlet of two sections was analyzed to ascertain the impact of the dams. The significance (Sig.) value of inlet streamflow in the simulation period was 0.689, but the Sig. value of outlet streamflow was 0.641, indicating little significant difference in different periods. The statistical analysis indicated that no significant disturbance occurred in both the inlet and the outlet, which could be partly related to the variability of the climate in the simulation period.

TABLE II. STATISTICAL ANALYSIS OF STREAMFLOW BEFORE AND AFTER DAM'S APPEARANCE

	Year	Min (m3/s)	Max (m3/s)	Mean (m3/s)	Standard Deviation	t	Sig.
Outlet	1990-1993	219.8	3365.1	1416.6	880.2	0.219	0.641
Inlet		1.1	15.5	5.9	3.7	0.161	0.689
Difference		218.7	3349.6	1410.7	-	-	-
Outlet	2004-2009	176.2	3723.9	1499.3	857.8	-	-
Inlet		1.2	15.6	6.1	3.5	-	-
Difference		175	3708.3	1493.2	-	-	-

B. Watershed yearly soil erosion

The simulated distribution of annual soil erosion loads revealed soil erosion dynamics in the watershed. The highest soil erosion load occurred in 1990, 1995, 2000, and 2009 was 85, 126, 109, 64 t/km^2/y, respectively. Figure 2 indicated that the northern part of the watershed experienced relatively severe soil erosion and the central part experienced relatively slight soil erosion during the whole study interval. The soil erosion of the western and southeastern part was lightened as time passed by. The simulations showed that the watershed averaged soil erosion loads were 32, 32, 34, 16 t/km^2/y, respectively.

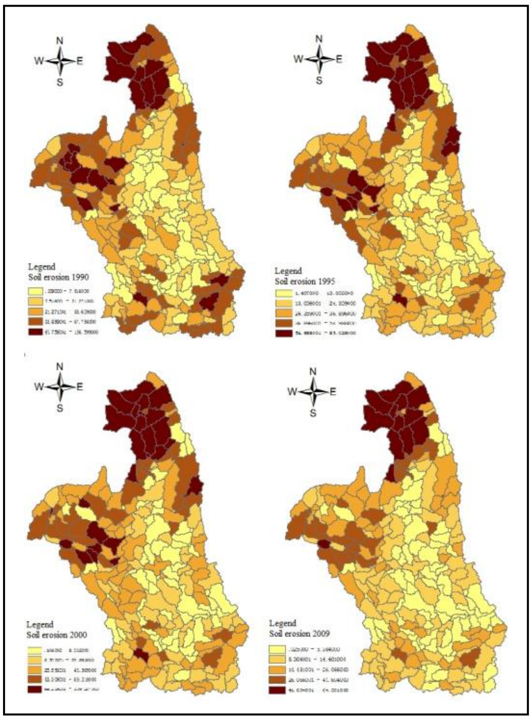

Fig.2 Soil erosion load in each sub-basin in study area.

C. Soil erosion dynamics under land use variations

We tested for correlation between soil erosion and individual land use dynamics resulting that the individual land use dynamics of grass land and forest land revealed significant correlation with soil erosion load in each sub-basin, while the individual land use dynamics of water land, crop land and arid land revealed no significant correlation with the soil erosion load (Table 3).

Differentiations exist in soil erosion dynamics response to individual land use dynamics. According to Huang et al. [9], the less human disturbances on the grass land soil and higher community coverage would reduce the soil erosion in the sub-basin. Forest lands are dominant land use in the study, and the roots of forests extend to a relatively wide range, which is good for soil and water conservation. The nature of correlation of land use and soil erosion is the consequences of land use variation on soil erosion exports. The results indicated that grass land and forset land are the key land use type for soil erosion in the sub-basin at watershed scale, which lays a foundation for further study of soil conservation.

TABLE III. SPEARMAN RANK CORRELATION OF INDIVIDUAL LAND USE DYNAMICS AND SOIL EROSION LOAD IN EACH SUB-BASIN.

LC of each land use type	Soil erosion load
Crop land	0.116
Grass land	-0.138*
Forest land	0.227**
Water land	-0.172
Arid land	-0.99

*Significance at p<=0.05, **Significance at p<=0.01

IV. SUMMARY AND CONCLUSIONS

We explored the temporal-spatial feature of soil erosion variation at watershed scale in the Lower-Middle Reaches of Lancang River. Using correlation analysis, we attempted to explore the relationship between soil erosion and land use variation. The main conclusions of the study are listed below:T-test results showed that there were no significant differences between the pre-dam and post-dam construction periods both in the inlet and outlet of the watershed. The sub-basins with high soil erosion load mostly distributed in the northern parts of the study region and sub-basins with relatively low soil erosion mainly located in the central parts. The significant correlation between soil erosion load and individual land use dynamics of each land use type in each sub-basin indicated that the grass land and forset land are key land use types that affected the soil erosion process.

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