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Original Research Paper

The Terraced Fields Environmental Impact Assessment in Data-Scarce Areas Based on the Embedded Terraced Module SWAT Model

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ABSTRACT

The terraced field widely distributed in Loess Plateau where serious soil and water loss happens, has a significant influence on watershed hydrological environment. At present, for the deficiency of watershed scale terraced fields hydrological environment impact assessment model and lacking of measured data, the terraced fields environmental impact assessment has attracted many attentions of the researchers. This paper adopts the hydrologic analogy combined with a scale physical model method, to infer the runoff and sediments in data-scarce area. Using the embedded terraced module SWAT model to assessment of terraced fields environmental impact, the results show that was a new way to conjecture the hydrologic data in data-scarce area. And the terraced field module can meet the accuracy requirement, the NS sufficient were both above 0.5 in calibration and verifying period. The soil erosion modulus of terraced fields contained in and removed from the watershed, was respectively 5.3% and 16.2% greater than the real. This indicates that the embedded terraced module SWAT model could be used in terraced fields environmental impact assessment in Loess Plateau small watershed.

INTRODUCTION

As an important soil and water conservation measure, the terraced field was widely distributed in the Loess Plateau. Its area has reached to 6050000 hectares (Tang 2004), accounts for 16% of the total region area. The most significant influence of the terraced fields to the watershed hydrological environment, is changing the microtopography of the underlying surface, creating a good condition for the agricultural cultivation and increasing the rainfall, runoff and nutrients, and then impacting the whole watershed runoff, sediments and nutrient substance recycle process. Only by completely simulating the terraced fields effects on the environment, soil water infiltration, slope crop growth and groundwater recharge, can researchers make the correct estimation of its ecological and economic benefits. But the international broadly applied models needs to be improved on the watershed scale terraced fields environmental impact assessment. In addition, the hydrological stations distribution in Loess Plateau was relatively disperse, and numerous terraced field widely distributed as small watersheds lack measured data. Simulating the watershed terraced fields hydrological process in these areas has become a difficulty.

The hydrologic process researching in data-scarce area is the focus of the study of the international hydrology and water resources organization (Xia et al. 2002). Many important international research organizations, for example the IHDP, WCRP, IHP, TGBP, BAHC, etc. have paid more attention to research the weather and hydrological process in these areas. And the IAHS has already started an international hydrological plan PUB, in order to carry out the hydrological forecasting in data-scarce areas. At present, hydrological process researching in these areas usually adopts the regional method, utilizing the measured data calibrated model parameters to infer the parameters in data-scarce area. Currently, widely used models were the SWAT model and the VIC model (Huang et al. 2009).

This paper, utilizing the hydrologic analogy combined with a scale physical model method, infer the hydrological data in data-scare areas. Based on the embedded terraced module SWAT model evaluate the terraced fields environmental impact.

MATERIALS AND METHODS

Overview of the watershed: YanGou watershed is located between the 36°21'~36°22'N and 109°20'~109°35'E; its multi-years average precipitation is 549.9mm **[1]**. The total area of the watershed is 47 sq. km and the soil erosion area is

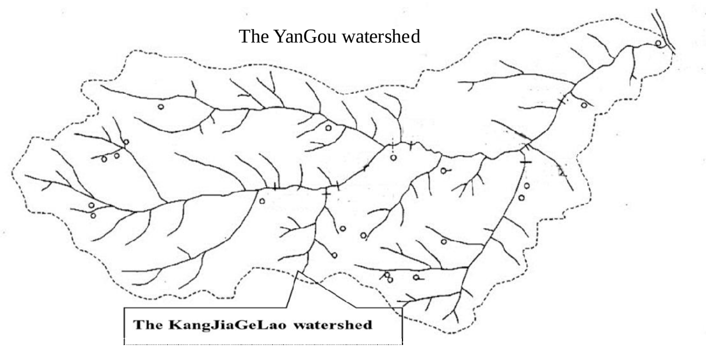

Fig. 1: Location of the Kangjiagelao watershed.

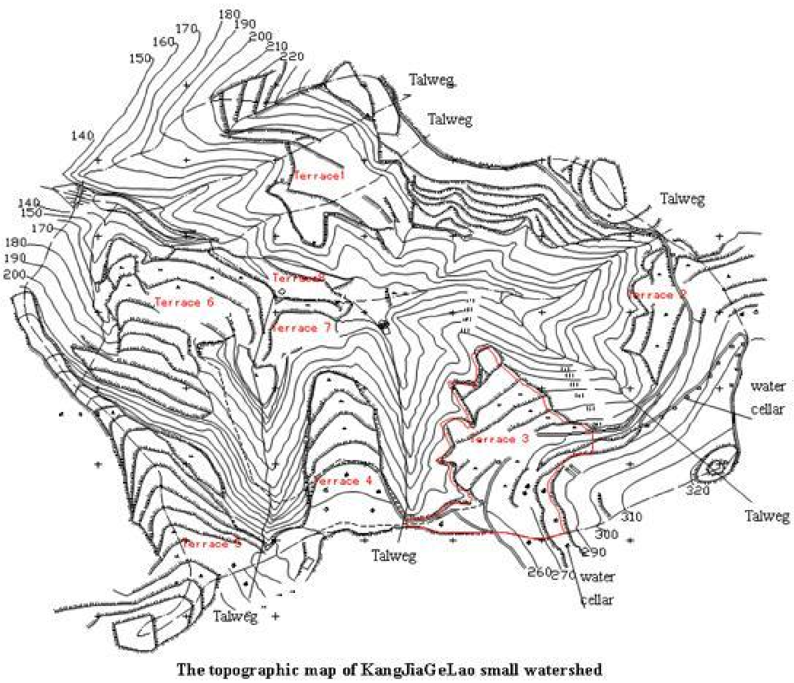

Fig. 2: Terraced fields distribution map of the Kangjiagelao small watershed.

35.7 sq. km taking 76.2% of the total region. The soil erosion modulus is 9000t/km^2/a, belonging to the intensity of soil erosion type area. The study area is KangJiaGeLao watershed, a sub basin of YanGou watershed, located in the southwest of the YanGou watershed (Fig. 1). Its areas is 0.34 sq. km, and terraced fields takes more than 47% of the total area (Fig. 2) (Gao et al. 2005, 2006, Pute et al. 2006). Up to now there is no hydrological monitoring of cross section in KangJiaGeLao watershed.

Inferring the hydrological data: Based on the similarity theory and the request of the geometrically similar, motion similar and dynamic similar of the water erosion simulation, a systemic research program for simulating the rainfall, runoff and sediment processes in the small watershed was proposed, and the scale relations of the small watershed physical model are listed in Table 1. Under the normality condition, the 1:100 (the model: the prototype) physical model of the KangJiaGeLao watershed (Fig. 3) was designed based on the watershed topographic map (Gao et al. 2005, Gao et al. 2006, Pute et al. 2006, Zhang et al. 2011).

Since 2003, a large number of terraced fields was constructed in the watershed. Utilizing artificial rainfall experiment in the small watershed physical model to acquire the erosion modulus after terraced fields was constructed. The experimental results revealed that the erosion modules reduced to 2900t/a (Pute et al. 2006).

Table 1: The scale of the small watershed physical model (Gao et al. 2005)

name		Symbol of the scale	The scale Value
Geometric simulation	Horizon scale	λ_l	100
	Vertical scale	λ_h	100
Rainfall simulation	Raininess scale	$\lambda_i = \lambda_V = \lambda_l^{1/2}$	10
	Precipitation scale	$\lambda_P = \lambda_i \lambda_{t_1}$	33.3
	Rainfall time scale	λ_{t1}	3.3
hydraulic Simulation	Flow velocity scale	$\lambda_V = \lambda_l^{1/2}$	10
	Flow quantity scale	$\lambda_Q = \lambda_l^{5/2}$	100000
	Roughness scale	$\lambda_n = \lambda_l^{1/6}$	1.47
	Flow time scale	$\lambda_{t1} = \lambda^{1/2}_l$	10
Erosioned Sediments simulation	Suspended load scale	$\lambda_d = \frac{\lambda_l^{1/4} \lambda_\nu^{1/2}}{\lambda^{1/2}_{\frac{\rho_s - \rho}{\rho}}}$	3.16
	Start simulation	$\lambda_V = \lambda_l^{1/2}$	10
	Sediment concentration scale	λ_s	3
	Deformation time scale	$\lambda_{t'}$	3.3
	Sediment discharge scale	λ_G	300000
Soil water simulation	Soil moisture content scale	λ_θ	1
	Infiltration rate scale	$\lambda_f = \lambda_V = \lambda_l^{1/2}$	10

The KangJiaGeLao watershed is the sub basin of the YanGou watershed, the weather conditions are very similar. Both the soil parent material in the two watersheds is loess, the main soil type is loessal soil. And also the vegetation composition of the two watersheds is made up of robinia, aspen and caragana etc. The gully density of YanGou watershed and KangJiaGeLao watershed respectively are 4.8km/km^2 and 3~4km/km^2. According to the above analysis, the two watersheds were similar with each other in hydrological and geographical conditions. So the YanGou watershed runoff data were chosen as the reference variable (Li et al. 2012, Xu et al. 2012), the KangJiaGeLao watershed runoff data were calculated out according to the hydrologic analogy method (Liu 1989).

Watershed SWAT model construction: In the SWAT model, the rainfall-runoff parameter CN was usually adjusted to simulate the terraced fields. But this method did not have a unify standard, and cannot completely response the terraced fields effect on the water quantity and quality. According to the terraced fields influence on the watershed water environment process, Shao Hui (2012) developed the terraced module and successfully embedded into the SWAT model (Fig. 4). The newly developed module needs to define a terraced construction percent, and to describe the percentage, the terraced fields takes in the HRU. Otherwise, a runoff-percent needs to be defined, in order to ensure the runoff flow into the terraced fields from the other areas in the HRU. This parameter allows the runoff flow into the terraced fields from the other area higher than the terraced fields. And also the parameter reflected the location of the terraced fields in the HRU in some degree. In addition, the slope and length of the terraced fields need to be declared. Fig. 1 describes the terraced fields location and the runoff directions in the HRU.

This paper constructs the KangJiaGeLao watershed SWAT model based on the DEM data, soil map, LUCC data, and weather data. The DEM data were downloaded from the website, http://datamirror.csdb.cn/admin/productdemMain.jsp. The LUCC data were from 1:250000 land cover remote sensing investigation and monitoring database of China. The soil map was delivered from the 1:500000 Loess Plateau soil map. The weather data came from Yan'An weather station, containing the daily precipitation data, daily temperature data, daily wind speed data and daily relative humidity data from 1998 to 2009.

The KangJiaGeLao watershed SWAT model was constructed on the ArcSWAT2009.93.7b based on the platform ArcGIS software of the ESRI company. The extract threshold was setting as 0.81 ha when dividing the sub basin, and 34 sub basins were produced totally. Dominant method was chosen to divide HRU in the sub basins, that means every sub basin was divided into one HRU.

RESULTS AND DISCUSSION

The SWAT model simulates from 1998 to 2009. The warm-up period was set from 1998 to 2001, that prompts that the starting condition can be more closer to the actual of the watershed. The model parameter (Table 2) calibration period was set from 2002 to 2004, and the model parameter verifying period was set from 2005 to 2008.

Through the map geometric registration, labelling terraced location and dividing the sub basin based on the ArcGIS software, the area of the terraced fields, distributed in every sub basin, was computed. The runoff flow into the terraced fields from the no terraced fields set as 50% of the terraced area in every sub basin.

The terraced fields were all set as level terrace, and the slope and length of the terraced fields were got from the average value of the topographic map. The average width of the terraced fields perpendicular to slope direction was

Fig. 3: The 1:100 (the model: the prototype) physical model of the KangJiaGeLao watershed.

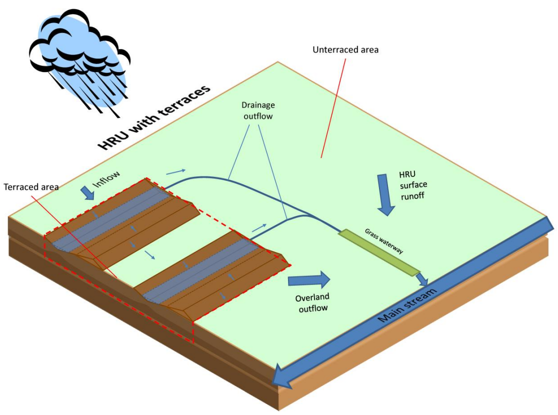

Fig. 4: Sketch map of an HRU in SWAT with a terraced area (Hui et al. 2012).

set as 20m, and the length of the slope parallel to the slope direction was set as 150m. The height of terraced ridge was set as 20cm, and the side slope was set as 75°. There was no drainage facility and channel, and the terraced field was assumed as the newly constructed with no sediment deposit. The soil type, land use and vegetation composition was same to the HRU.

According to the results (Fig. 5), it is indicated that the embedded terraced module SWAT model can reflect the runoff changing tendency of KangJiaGeLao watershed well. But in dry seasons, the model may overestimate the runoff in some degree.

The KangJiaGeLao watershed monthly runoff simulation accuracy index is listed in Table 3. The statistical result shows that in both calibration period and verifying period, the simulation results can meet the accuracy requirements. That means the embedded terraced module SWAT model can be used in Loess Plateau small watershed runoff simulation.

Table 2: Runoff parameters calibration result in the Kangjiagelao watershed.

Parameter	Calibration range	Calibration result
CN2	80~90	86
SOL_AWC	±0.04	+0.04
SLSUBBSN	-95%~+400%	+400%
ESCO	0~1.0	0.2
SOL_K	-50%~+50%	-50%

Table 3: Runoff simulation statistical result of Kangjiagelao small watershed.

Indicators	Calibration	Validation
NS[a]	0.60	0.70
r^2[b]	0.60	0.72
PBIAS[c]	-12.73%	11.21%

Note: [a]Nash-Sutcliff coefficient, [b]Square of correlation coefficient, [c]Percent bias.

Based on the above calibrated and verified parameters, monthly runoff and sediments were computed, and again at the scenario terraced fields were removed from the watershed to research the terraced fields effects on the watershed. From the results, it can be inferred that the existence of terraced fields can effectively reduce water generation, and bring down the peak discharge. But the influence in dry seasons was relatively less than in flood seasons.

The Fig. 6 compares the simulated runoff with and without terraced fields in different seasons from 2002 to 2008, and Fig. 7 the runoff statistical result of the Kangjiagelao watershed with and without terrace. It indicates that the percentage terraced fields reducing runoff can reach up to 47.16% in summer, but in spring, autumn and winter the percentage was totally 25.47. The terraced fields can reduce the runoff 37.92% a year averagely in the KangJiaGeLao watershed.

Utilizing the small watershed 1:100 scale mode artificial rainfall experiment measured data to verify the SWAT model sediment data. For comparing, terraced field was removed from watershed simulation erosion modulus with the real data, and it can be inferred that the embedded terraced module SWAT model can simulate the watershed soil erosion process well in both terraced fields exist in and removed from the watershed conditions. In the scenario, when the terraced fields were removed from the watershed, the artificial rainfall experiment measured erosion modulus as 2900t/ km^2/a, and the SWAT model simulation result was 3054 t/ km^2/a. The simulation result was 5.3% greater than the measured data. Under terraced fields existed in the water-

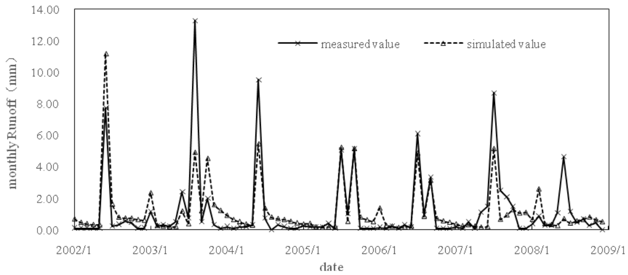

Fig. 5: Monthly runoff simulation result of the Kangjiagelao small watershed.

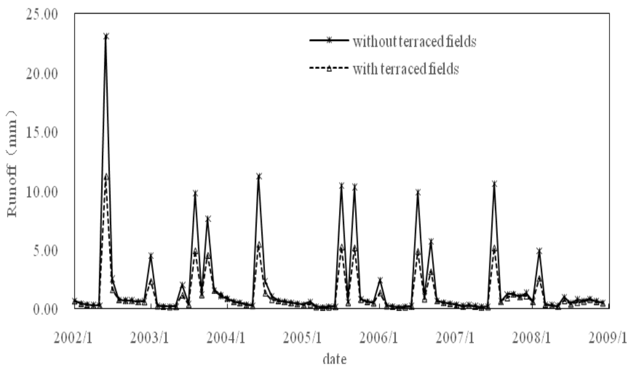

Fig. 6: Monthly runoff simulation result of the Kangjiagelao watershed with and without terrace.

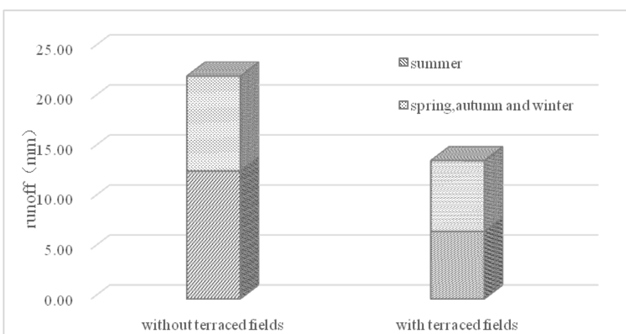

Fig. 7: Seasonal runoff statistical result of the Kangjiagelao watershed with and without terrace.

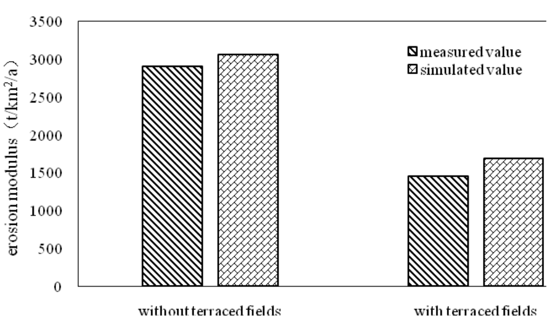

Fig. 8: Erosion modulus comparison of the Kangjiagelao small watershed with and without terrace.

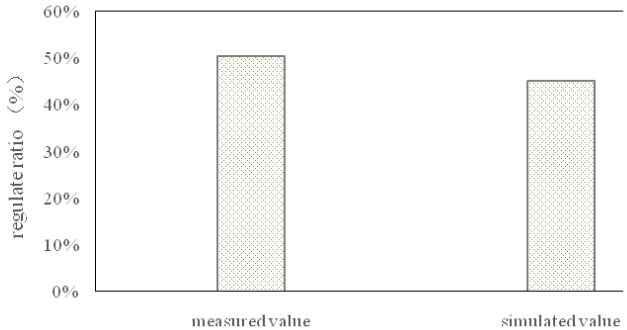

Fig. 9: Terrace erosion regulation fraction comparison of the Kangjiagelao small watershed.

shed condition, the artificial rainfall experiment erosion data were 1445 t/km^2/a, and the SWAT model simulation results was 1679 t/km^2/a. The simulation result was 16.2% greater than the measured data. Considering the allowed error of measured erosion and sediment transport data as relative greater, the embedded terraced module SWAT model can be used to simulate the erosion and sediment transport in Loess Plateau small watershed.

The Fig. 8 contrast experimental measured erosion decrease ratio with the simulation data, and Fig. 9 terrace erosion regulation fraction comparison of the Kangjiagelao small watershed. According to the artificial rainfall experiment on the watershed physical model, the terraced fields can obviously reduce about 50% of erosion sediments. And the simulation result showed the erosion sediments decreased to about 45%, very close to the measured data. At the same time, taking the topographic map conversion errors into consideration, the simulation result was reasonable.

CONCLUSIONS

This paper adopts the hydrologic analogy combined with a scale physical model method to infer the runoff and sediments in data-scarce area. Using the embedded terraced module SWAT model simulate the KangJiaGeLao watershed with and without terraced fields.

1. Based on the verified results of the KangJiaGeLao watershed hydrological process simulation, the terraced field module can meet the accuracy requirement in simulating the watershed runoff. The NS coefficient was both above 0.5 in calibration and verifying period. The soil erosion modulus of terraced fields contained in and removed from the watershed, was respectively 5.3% and 16.2% greater than the real. This indicates the embedded terraced module SWAT model could be used in the hydrological process simulation in Loess Plateau small watershed, and also can be used to evaluate the terraced fields water environmental effects.

2. Using the embedded terraced module SWAT model simulate runoff and sediments at the supposed scenario terraced fields were removed from the watershed, and results indicate that the terraced fields can reduce runoff and sediments obviously, and the influence was rather lower in dry seasons. The terraced fields runoff-reducing effect in summer (47.16%) was higher than the total in spring, autumn and winter (25.47%), and the average runoff-reducing effect was 37.92%.

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