Assessing the impact of human-induced land-use change on water cycle based on land surface model

Tohoku University　Student Member　○Linghao Meng
Tohoku University　Regular Member　Daisuke Komori

Abstract

Human activities have become one of the most crucial factors of the natural water cycle. This research is to assess the impact of human activities, especially land use and vegetation changes on the natural hydrological factors in the Loess Plateau Region (LPR), a region suffered the most severe soil erosion over the world. From 1999 the water conservation project, forest and grass land increased significantly to replace most of the field land to more than 25%. three stations at the watershed are used to analyze water cycle parameter changes. Climate and land use data are divided into three parts and thus nine cases for simulation. The model calibration shows good accuracy of H08 used in the region.

１． Introduction

Rapidly expanding human activities have profoundly affected various biophysical and biogeochemical processes of the Earth system over a broad range of scales, and freshwater systems are now amongst the most extensively altered ecosystems (Carpenter et al. 2011). Apart from urbanization, human activities also apparently altered the natural water cycle, with both positive and negative impacts simultaneously. So, it is significant to assess the effects of human activities as a way of nature environment protection project.

So far, various researches about the relationship between water and the environment as well as human activities have been carried out. For example, Gorman (2015) found climate change increased the runoff in Mississippi River Basin and Hanasaki (2014) pointed out that the role that forest plays depends on specific catchment and so on. However, most are focus on climate change; for land use changes the dominant point lies on urbanization and deforestation, human-induced afforestation is rarely being researched. Therefore, this research aims using land surface model to physically simulate the water cycle changes under human afforestation at large watershed scale.

２． Materials and Methods

2.1 Data Preparation

We used the downscale daily climate data in 5-arc minute resolution from three observation datasets provided by H08 (Hanasaki, 2008): 1) the Water and Global Change (WATCH) forcing data for 1980 –1989 (hereafter H for history), 2) the Second Global Soil Wetness Project for 1996 – 2005 (hereafter P for past), 3) the WATCH Forcing Data methodology applied to ERA-Interim data for 2005 – 2014 (hereafter C for current). DEM data and River discharge data from three observation stations (Figure 1) in the Loess Plateau Region were obtained from National Earth System Science Data Sharing Platform (NESSDSP) and used to calibrate and validate the models.

The LPR is one of the most severe soil erosion area. Chinese government started its water and soil conservation project by reducing the area of field crops into forest. Land use data of 1985, 2000, 2012, were obtained from CGSSP (Figure 2).

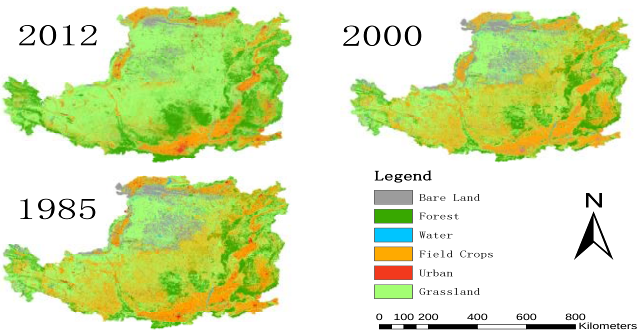

Figure 1. Land use in LPR of 1985, 2000, and 2012

Table 1. Details of nine simulation

Case	Data		Case	Data		Case	Data	
	Climate	Land Use		Climate	Land Use		Climate	Land Use
H-H	1980-1989	1985	P-H	1996-2005	1985	C-H	2005-2014	1985
H-P	1980-1989	2000	P-P	1996-2005	2000	C-P	2005-2014	2000
H-C	1980-1989	2012	P-C	1996-2005	2012	C-C	2005-2014	2012

2.2 Analysis Methods

A land surface model called H08 is used to analyze water cycle under different land use scenarios in the LPR. This module is based on a bucket model (Manabe, 1969) with improvements. The soil water balance and runoff were expressed as follows:

$$\frac{dW}{dt}=Rainf+Q_{sm}-E-Q_s-Q_{sb} \qquad Q_s=\begin{cases} W-W_f & W_f<W \\ 0 & W_f\geq W \end{cases} \qquad Q_{sb}=\frac{\omega_f}{\tau}\left(\frac{w}{\omega_f}\right)^{\gamma}$$

Where Q_{sm} is the snow melt rate; Q_s is the surface runoff, Q_{sb} is the subsurface runoff, τ is a time constant and the γ is a shape parameter. (Hanasaki, 2008) Nine simulation will be conducted in this research as shown in table 1.

Keywords　Loess Plateau Region, land surface model, land use change, water cycle
Address　〒980-8579　6-6-06 Aramaki Aza Aoba, Aoba-ku, Sendai, Miyagi, Tohoku University
Department of Civil and Environmental Engineering, Hydro-Environment System Lab　ＴＥＬ　022-795-5007

2.3 Model Calibration and Calibration

Observed daily discharge of three stations in the LPR was used for model calibration. Parameters of the H08 model that are susceptible to river discharge and related to land use (Mateo et al., 2012) are soil depth (SD), bulk transfer coefficient (CD), time constant for daily maximum subsurface runoff (τ), and a shape parameter (γ) that is related to subsurface flow (Hanasaki et al., 2014). The model can be calibrated by changing the values of the parameters based on land use type and evaluated using the Nash-Sutcliffe Efficiency Coefficient (NSE). The C-C case of each station is used to calibrate the model. By changing the 4 parameters to find the optimal match of the parameter sets. Another two cases were used for model validation.

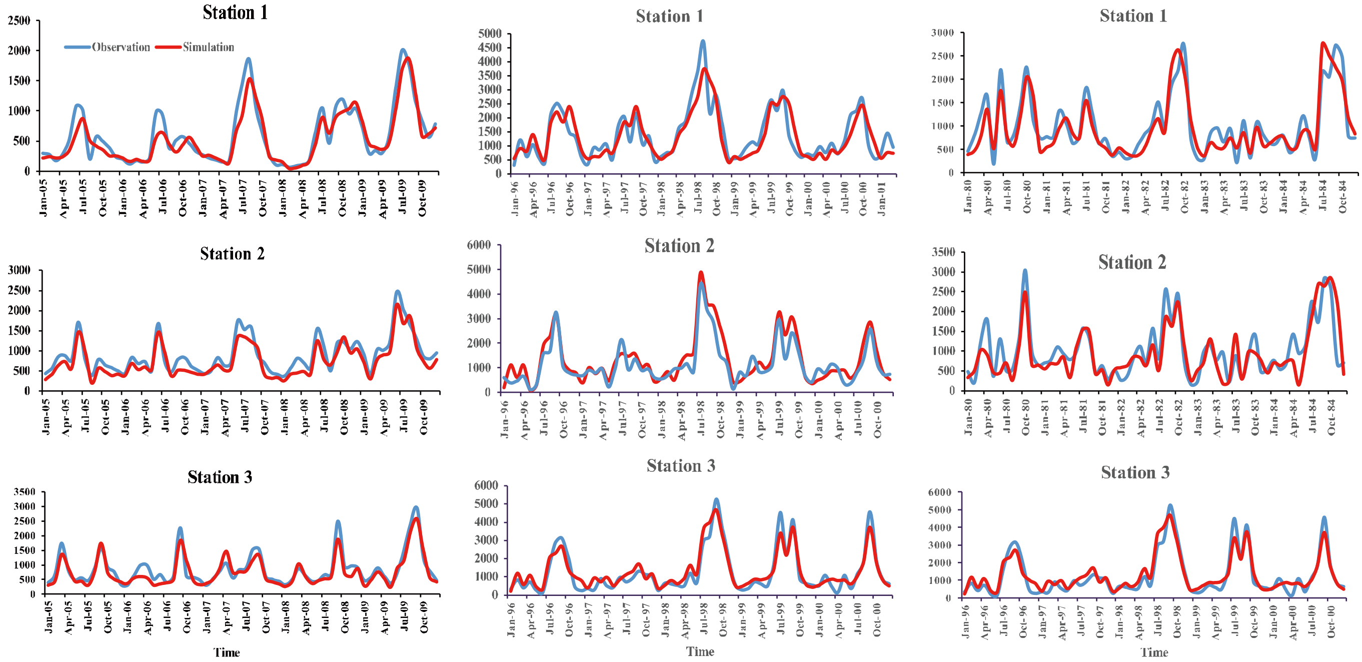

Figure 2. Model calibration (Left) and validation (Middle and Right) of three stations

４. Results and discussion

As shown in figure 1, forest and grassland increased significantly while crop field dramatically decreased because of the Water and Soil Conservation Project. By calculation, the total ratio of forest and grassland increased from 53% to 80% while field crops deceased from 33% to 12%.

Figure 2 shows the result of model calibration and validation. The NSE of each station is 0.84, 0.78, 0.88, which means the H08 has high accuracy when applying to LPR. Then the optimized parameters were used to validate the model by using past and history cases. As shown in the middle and right part of figure 2, the simulated results match the observation data.

Currently, the simulation of first stage of C-C case is being conducted. The result shows that by government's Water Conservation Project the discharge at the land use of 2012 is both delayed and declined in comparison of that at the land use of 2000 and 1985.

５. Conclusion

(1) Human-induced afforestation have exerted great changes in the land use pattern of the LPR. Forest and grassland have greatly replaced the crop fields which used to be the dominant land use type.

(2) The simulation of 3 selected stations shows satisfactory accuracy in calibrating the models, which means it can be applied to simulate the water cycle in the studied area. The H-H and P-P case also shows high consistence in the model validation process and governance of further simulations.

(3) The human-induced transition from field crops to grass and forest increase the ability to constraint the water resource and thus can decrease as well as delay the flood peak in the research region.

６. References

Carpenter SR, Stanley EH, Vander Zanden MJ (2011) State of the world's freshwater ecosystems: physical, chemical, and biological changes. Annu Rev Environ Resour 36(1):75–99.

O'Gorman, P. A. (2015). Precipitation extremes under climate change. Current climate change reports, 1(2), 49-59.

Hanasaki N., (2008). An integrated model for the assessment of global water resources–Part 1: Model description and input meteorological forcing. Hydrology and Earth System Sciences, 12(4), 1007-1025.

Hanasaki N., (2014). A quasi-real-time hydrological simulation of the Chao Phraya River using meteorological data from the Thai Meteorological Department Automatic Weather Stations. *Hydrological Research Letters*, *8*(1), 9-14.

Manabe, S. (1969). Climate and the ocean circulation: I. The atmospheric circulation and the hydrology of the earth's surface. Monthly Weather Review, 97(11), 739-774.

Mateo, C. M. R., Hanasaki, N., Komori, D., Tanaka, K., Yoshimura, K., Kiguchi, M., & Oki, T. (2012). Optimization of H08 land surface model parameters in the Chao Phraya River basin to reproduce the 2011 river discharge. In Annual Conference of Japan Society of Hydrology and Water Resources (pp. 78-79).