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Application of the PRMS model in the Zhenjiangguan watershed in the Upper Minjiang River basin

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Abstract The PRMS model was established for Zhenjiangguan watershed in the upper reach of the Minjiang River basin, China. The results showed that PRMS had an acceptable performance in simulating monthly runoff in the study area. The analysis on the impacts of precipitation changes on hydrological processes indicated that both runoff and evapotranspiration increased with the increase of precipitation. Moreover, evapotranspiration had larger sensitivity to the change of precipitation than runoff.

Key words Zhenjiangguan watershed; PRMS model; precipitation change; runoff; evapotranspiration

INTRODUCTION

The Minjiang River is the largest tributary in terms of mean runoff in the Upper Yangtze basin, and very important for the environment of the Chengdu plain (Zhang *et al.*, 2012). Since the 1930s, however, water shortage has become a problem in the Chengdu plain. Climate is an important factor influencing hydrological conditions (Li *et al.*, 2009). Understanding the impacts of climate change on hydrological process such as runoff and evapotranspiration (ET) in a typical watershed of this region is critical for the sound management and development of water resources. Zhenjiangguan watershed is the source area of the Minjiang River which has strategic significance for the environment, economy and social well-being of the Chengdu plain downstream (Zhang *et al.*, 2012). In recent years, both precipitation and runoff have had decreasing trends, and climate change has obviously influenced hydrological processes in this watershed. It is necessary to study the hydrological response to climate change for this region.

A physically-based hydrologic model is useful for identifying the cause of runoff change at basin scale (Praskievicz and Chang, 2009; Chang and Jung, 2010). The US Geological Survey's (USGS) Precipitation–Runoff Modeling System (PRMS) is a hydrologic model suited for analysing the effect of climate change on runoff (Leavesley *et al.*, 1983; Leavesley and Stannard, 1995; Leavesley *et al.*, 2005). This model can be used to simulate the land-surface hydrologic processes of ET, runoff, infiltration, and interflow by balancing the energy and mass budgets of the plant canopy, snowpack, and soil zone on the basis of distributed climate information, and has a modular design that allows for selection of alternative hydrologic process algorithms among existing or easily added modules. However, few studies on the application of PRMS in the mountain regions in southwest of China have been reported.

This paper aims to assess the applicability of PRMS in Zhenjiangguan watershed, which is a typical watershed in the Upper Minjiang River basin in the southwest mountain region in China, and to study the impacts of precipitation change on runoff and ET at the monthly scale.

METHODS

Study area

Zhenjiangguan watershed (Fig. 1), is located in the Upper Reach of the Minjiang River, which lies between longitude 103°11'–103°54'E and latitude 32°9'–33°9'N. The study area is about 4455 km^2 and the length of main stream is about 103.7 km. The climate is a typical alpine climate, and more than 80% of precipitation occurs from May to October. The elevation of Zhenjiangguan watershed ranges from 2500 to 5541 m, with an average of 3871 m.

There are three main soils: Mollic Leptosols, Haplic Luvisols and Calcaric Cambisols, which cover 47.3%, 21.6% and 17.6% of the whole watershed, respectively. Grass, forest and brush are the main three land use types, and cover 64.2%, 28.3% and 4.9% of the study area, respectively.
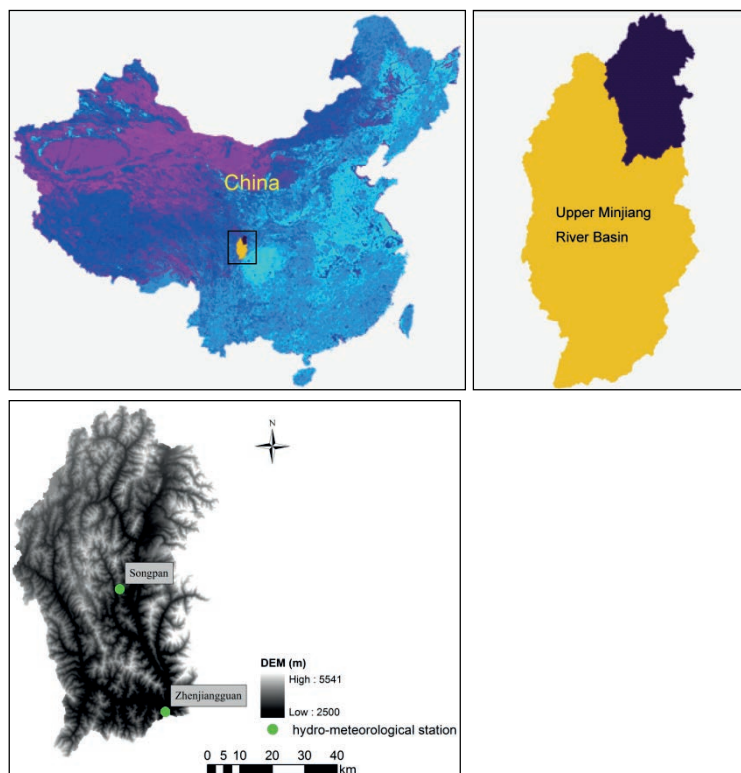
Fig. 1 Location of Zhenjiangguan watershed.

Data

Daily runoff data of Zhenjiangguan station (at the outlet of Zhenjiangguan watershed) were collected for 1984 to 1987. Daily precipitation, daily maximum and minimum temperatures were also collected from Zhenjiangguan and Songpan stations. Potential evapotranspiration (PET) for model input was calculated by the FAO Penman-Monteith equation (Allen *et al.*, 1998) using daily maximum and minimum temperatures, wind speed, relative humidity, and atmospheric pressure from Songpan station. The DEM (digital elevation model), soil and land use information are shown in Table 1.

Table 1 Geo-spatial data used in PRMS model.

Data	Source	Resolution
DEM	CNIC, (http://www.cnic.cn)	90 m×90 m
Land use data	Institute of Geographic Sciences and Natural Resources Research, CAS	1:100000
Soil data	Harmonized World Soil Database established by the Food and Agriculture Organization of the United Nations (FAO) and International Institute for Applied Systems Analysis (IIASA), (http://www.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/)	1:1000000

Hydrological model and input

The PRMS model was developed to analyse the effects of climate and land-use changes on water resources. PRMS has been applied to study the impacts of climate change on water resources in different regions with a variety of climatic and physiographic characteristics (Burlando and Rosso, 2002; Dagnachew *et al*., 2003; Jung and Chang, 2011).

In this study, the ArcGIS tool was used to define Hydrologic Response Units (HRUs) based on the DEM, land use and soil data of the study area (Fig. 2). There are totally 86 HRUs for the whole study area. Based on the DEM, soil and land use data, parameter information required by PRMS was prepared for each HRU according to the required format, such as area (hru_area), average elevation (hru_elev), average slope (hru_slope), hru major vegetation types (cove-type), and so on.

Calibration and validation

Monthly runoff was used to calibrate manually the PRMS model set up for Zhenjiangguan watershed for the period 1984–1986, and to validate the model for 1987. The performance of PRMS model was assessed by using the coefficient of determination (R^2), relative error (RE) and Nash-Sutcliffe (NS) efficiency coefficient (Nash and Sutcliffe, 1970). The parameters of PRMS model selected for calibration and validation include smidx_coef, hru_percent_imperv, smidx_exp, and carea_max. The part calibrated parameters and their descriptions are shown in Table 2.

Table 2 Part calibrated parameters and their description.

Parameter	Description	Calibrated value
smidx_coef	Coefficient in non-linear contributing area algorithm	0.2
hru_percent_imperv	Decimal fraction of HRU area that is impervious	0.03
gwflow_coef	Linear coefficient to route water in ground-water	0.015
smidx_exp	Exponent in non-linear contributing area algorithm	0.3
carea_max	Maximum possible area contributing surface runoff, expressed as decimal fraction of HRU area	0.4
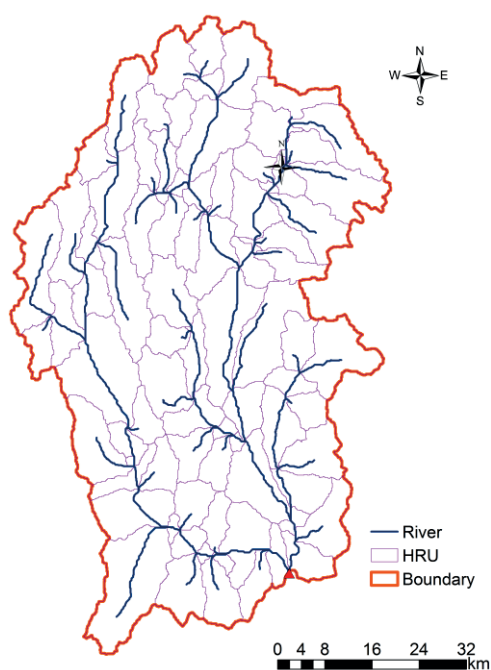
Fig. 2 Hydrologic response units (HRUs) of Zhenjiangguan watershed.

RESULTS AND DISCUSSION

Calibrated and validated results

Monthly runoff at Zhenjiangguan station from 1984 to 1986 was used to calibrate the parameters of PRMS, and that from 1987 was used for validation. Figures 3 and 4 show the comparison of the simulated and observed runoff in the calibration and validation periods. The simulated values

generally had good agreements with the observed values at the monthly scale for the two periods. Note that there were relatively larger errors in the period from April to June for each year, which might result from the inaccuracy of the part calibrated parameters.
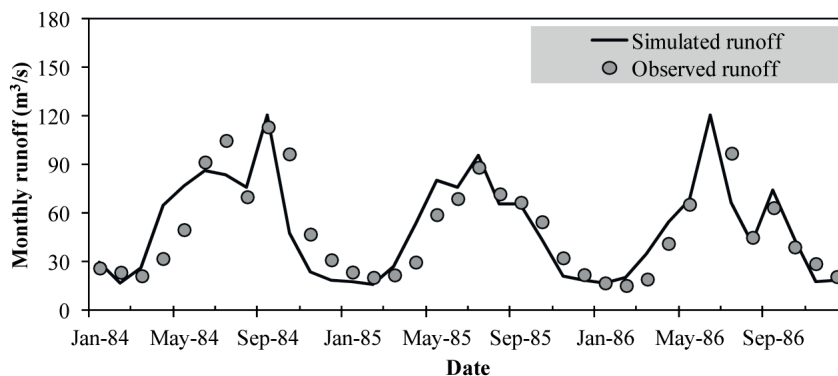

Fig. 3 Comparison of simulated and observed runoff for calibration period.
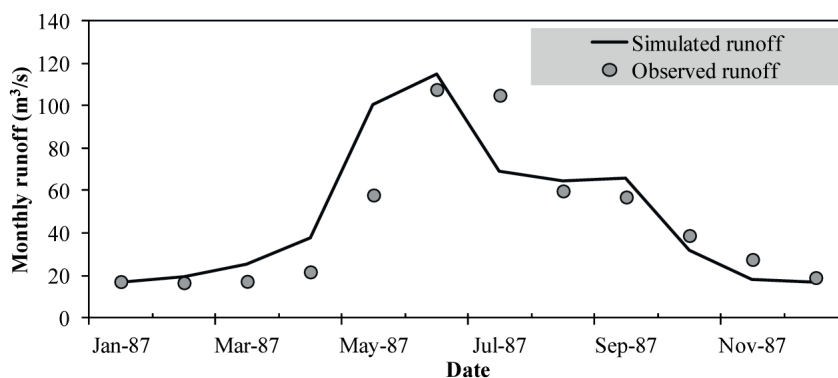

Fig. 4 Comparison of simulated and observed runoff for validation period.

The statistics also show that the model had a good performance (Table 3), although the model overestimated runoff for both the calibration and validation periods. As R^2 and NS were both larger than 0.70, and RE were less than 10%, we think that the performance of the model is acceptable.

**Table 3** Statistics of model calibration and validation.

Period	R^2	RE	NS
Calibration	0.75	2.7%	0.75
Validation	0.73	6.2%	0.70

Impact of precipitation change on runoff and ET

Two precipitation change scenarios were set up, increasing and decreasing by 20% the observed daily precipitation from 1984 to 1987. Figure 5 shows the comparison of the observed and simulated runoff for these two scenarios. The results indicated that runoff increased with the increase of the precipitation. Accordingly, ET also increased when precipitation increased. It can be seen from Table 4 that ET was more sensitive to the change of precipitation than runoff. When precipitation change increased from –20% to 20%, runoff change increased from –15.8% to 11.2%, while ET change ranged from –20.5% to 20.8%.

Table 4 Changes of Runoff and ET for precipitation scenarios.

Items	Precipitation change		
	+20%	±0%	−20%
Runoff change	11.2%	0.0%	−15.8%
ET change	20.8%	0.0%	−20.5%
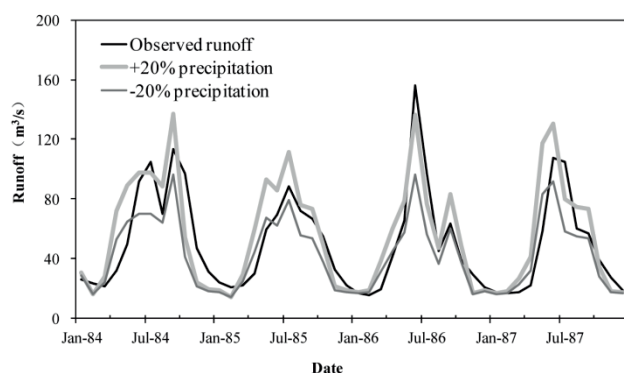
Fig. 5 Observed and simulated runoff curves.

CONCLUSION

In this study, the PRMS model was established for Zhenjiangguan watershed in the Upper Minjiang River. The assessment of calibration and validation indicated that the performance of the model was acceptable in the study area. However, the lack of weather and runoff stations had a negative influence on the quality of the simulation. Despite these limitations, the model generally reflected the variation of runoff in the calibration and validation periods.

Based on the established PRMS model, the impacts of precipitation change on runoff and ET were discussed preliminarily. Both runoff and ET increase with precipitation, and ET has a larger sensitivity for the change of precipitation. This study demonstrated that PRMS was suitable for runoff simulation and could be used to analyse the impact of climate change on hydrological processes in the typical mountain river basin in southwest China. It is recommended to collect the weather and runoff data of more stations for further validation and evaluations of PRMS in the study area, and use of more complex climate change scenarios, such as General Circulation Models (GCMs) for future studies.

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