IMPACT OF CHANGES IN LAND USE AND CLIMATE ON THE RUNOFF BASED ON SWAT MODEL IN DAWEN RIVER BASIN, CHINA

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Abstract. A distributed hydrological model (SWAT), which is widely used both domestically and internationally, was selected to quantitatively analyze the impact of land use and climate change on runoff in this paper in Dawen River Basin, China. The calibration and validation results obtained at Daicunba and Laiwu hydrological stations yield R^2 values of 0.83 and 0.80 and 0.73 and 0.69 and the Ens values of 0.79 and 0.76 and 0.71 and 0.72, respectively. Taking 1980-1990 as the reference period, the annual runoff increased by 288 million m^3, which was caused by changes in the land use of basin from 1991 to 2004, whereas the annual runoff decreased by 132 million m^3 due to climate change. Land use changed from 2005 to 2015, which resulted in an increase in annual runoff of 13 million m^3, and annual changes in climate caused a decrease in annual runoff of 61 million m^3. An extreme land use scenario simulation analysis shows that, compared to the current land use simulation in 2000, the runoff of cultivated land scenarios and forest land scenarios was reduced by 38.3% and 19.8%, respectively, and the runoff of grassland scenarios increased by 4.3%. Climate change simulation analysis revealed that there was a positive correlation between runoff changes and precipitation changes in the river basin. The annual total runoff in the basin decreases with rising temperatures and decreases with decreasing temperatures, which showed that the impact of precipitation variability was stronger than that of change in air temperature.
Keywords: *SWAT model; arbitrary scenario method; calibration and validation; runoff simulation*

Introduction

Climate and land use are two important factors that influence the hydrological responses of a river. Climate variability can impact flow routing time, peak-flows and volume by affecting the amount and distribution of regional precipitation and temperature (Sahoo et al., 2018; Kalogeropoulos and Chalkias, 2013; Zuo et al., 2015a), whereas land-use changes can cause changes in baseflow, annual mean discharge, and flood frequency and severity (Lin et al., 2015; Anand et al., 2018; Memarian et al., 2014). In the context of climate change, drastic human activities have a great influence on watershed hydrology. Among these activities, land-use change is the most direct manifestation of human impact (Zou et al., 2018; Zeng et al., 2015). The impact of climate change on hydrology has become more and more serious in recent years, including quantity, quality, spatial and temporal distribution of water resources, and the degree of development and utilization of water resources. The impact of climate change on water resources has been the focus of a significant amount of current research (Sunde et al., 2018). The distributed hydrological model not only considers spacial heterogeneity but also has the advantage of portraying hydrological and physical processes (Uniyal et al., 2015; Zhang et al., 2018). In recent years, distributed hydrological models have been widely used to evaluate the hydrological effects of

climate and land use changes. In many distributed hydrological models, the SWAT (Soil and Water Assessment Tool) model has been widely used in the simulation of basin water balance, long-term surface runoff and daily average runoff (Gyamfi et al., 2016). A large number of domestic studies have adopted models to simulate the effects of climate and land-use changes on the hydrological cycle of a river basin; in particular, these models have provided a basis for large-scale complex basin applications (e.g., the Haihe River Basin (Zhang and Chen, 2009), Yellow River Basin (Wang and Zheng, 2014), and Huaihe River Basin (Yang and Chen, 2017).

International research on climate change in the hydrological field began in the 1970s (Bull and Schick, 1979; Ruddiman et al., 1977; Lettenmaier and Burges, 1978), and studies on the impact of climate change on the water cycle began in the late 1980s in China (Wu et al., 2016; Lin et al., 2015; Zeng et al., 2013; Zhang and Yang, 2014). Based on global meteorological data from 1900 to 1998 and using RS and GIS technologies, Sanjay K. Jain conducted a simulation study on the effects of land-use/cover changes on the process of runoff and sediment production in the Satluj Watershed in the Himalayas (Jain et al., 2010). Prokop found that land-use change was an important factor of hydrological changes in the Himalayas from 1930 to 2010 (Prokop and Sarkar, 2012). Wei Chao quantitatively studied the dynamic change of land use in Taian based on RS technology (Wei et al., 2016). In this paper, the SWAT model is used to simulate runoff in Dawen River Basin. Through the simulation of watershed runoff in a changing environment, the tendency and rules of runoff under the background of climate change and land use are discussed, and the impacts of climate change and land use change on water resources in the river basin can be assessed. The results of the research provide effective means for the simulation, evaluation and analysis of water resources in the basin and the optimal allocation of water resources, which is of great significance for regional economic development and sustainable development.

Materials and methods

Study area

The Dawen River is located between 35°37′30″-36°32′30″N and 116°11′15″-118°0′0″E in Shandong Province, China. The Dawen River flows from east to west and passes along Laiwu, Taian, Pingyin, and Wuyuan. The northern part of Dawen River Basin is mainly constrained by the Taishan Mountain Range and the Xiaoqing River; the eastern part is bounded by Lushan; the south is bordered by Mengshan, Yumai and Huaihe River basins; and the west is bordered by the Yellow River Basin. The east-west distance of the Dawen River Basin is approximately 176.6 km; the north-south distance is approximately 102 km; and the basin area is approximately 8726 km^2 (*Fig. 1*).

The SWAT hydrologic model

The SWAT model is a basin-scale model that was developed by the Agricultural Research Service (ARS) of the United States Department of Agriculture (USDA). It is mainly used for the simulation of water quantity and quality of surface water and groundwater (Kiniry et al., 2005). This model has been widely used in different regions around the world and mainly used for the direct evaluation of the effects of human

activities, climate variability or other factors related to large-scale precipitation (Wang et al., 2015).
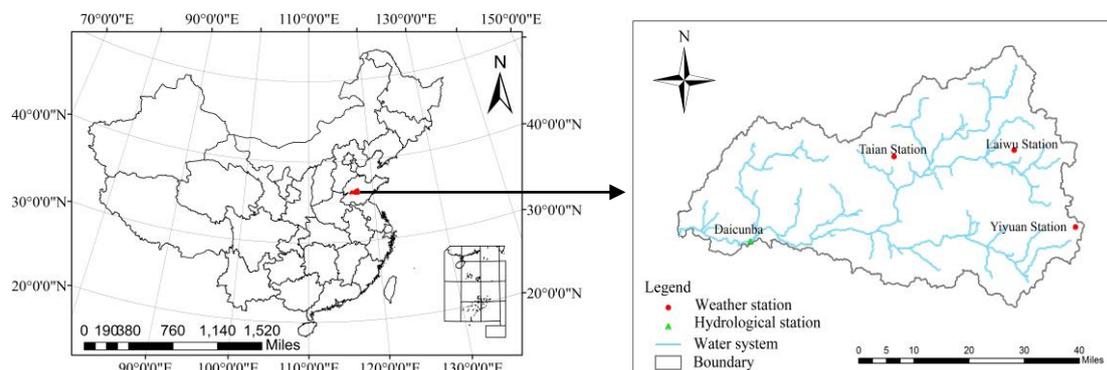
Figure 1. Dawen River Basin location map

The SWAT model partitions a watershed into sub-basins connected by a stream network and further delineates hydrologic response units (HRUs). By using data such as precipitation, soil properties, topography, land cover, and management, the surface runoff generated from each HRU can be calculated in each sub-watershed. The hydrologic cycle, as simulated by SWAT, is based on the water balance equation (*Eq. 1*), and the simulated processes include vadose zone processes and groundwater flow (Zhang et al., 2017).

$$SW_t = SW_o + \sum_{i=1}^{t} (R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw})_i \qquad \text{(Eq.1)}$$

where SW_t is the final soil water content, SW_0 is the initial soil water content, t (days) is the time, R_{day} is the precipitation on day i, Q_{surf} is the surface runoff on day i, E_a is the evapotranspiration on day i, W_{seep} is the amount of water entering the vadose zone from the soil profile on day i (soil interflow), and Q_{gw} is the amount of return flow on day i.

The hydrologic model of the Dawen River Basin

SWAT model and database establishment

The topographic, soil, land use and hydro-meteorological data were collected or generated as follows (*Table 1*). The 90*90 DEM downloaded data is geometrically corrected by using a binomial formula. The error must be less than 0.5 pixel units to meet the requirements of the model river network division and sub-basin extraction. The soil data were sourced from the soil database of the Harmonized World Soil Database (HWSD) and the HWSD by using the USDA standard. The soil data was corrected and interpreted by ENVI 5.1. The land use map obtained by processing the classification is converted into a land use type map in a format supported by the SWAT model, get the land use map of the study area in 1985 and 2000 and 2015 (*Fig. 2*). This study used the weather observation data of three traditional meteorological stations from 1980 to 2015 (the Taian, Yiyuan and Laiwu stations).
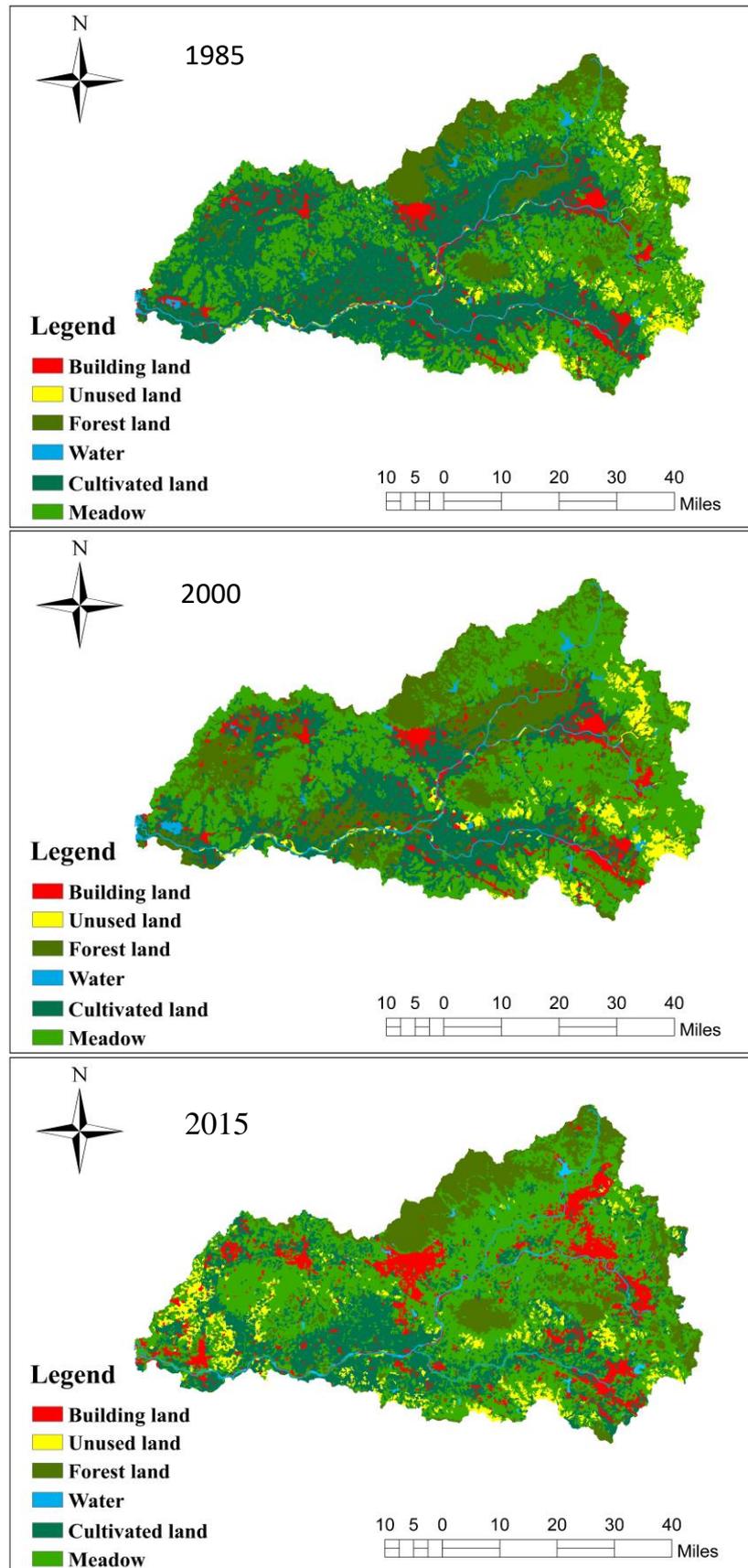
Figure 2. *Land use of the Dawen River Valley in 1985, 2000 and 2015*

Table 1. *Data sources and basic information*

Data	Accuracy	Formatting	Source
DEM	90 m × 90 m	GRID	Geospatial Data Cloud
Land Use Map in 2000	1 km × 1 km	GRID	Chinese Research Academy of Environmental Sciences
Soil type map	1:1000000	Shapefile Feature Class	Harmonized World Soil Database
Meteorological data	Day	txt	Weather Data Sharing Network
Hydrological data	Year, Month	txt	Taian and Laiwu City Hydrographic Bureau

SWAT calibration and validation

Based on the land use data and meteorological data in 2000 and the meteorological data from 1980 to 2015, the global sensitivity analysis module in SWAT-CUP was used to analyze the sensitivity of the parameters. The value of T provides the degree of sensitivity; the greater the absolute value is, the more sensitive it is. The P value indicates that the closer the significance value of sensitivity is to 0, the more significant it is. Based on the measured data of the hydrological station, the sensitivity analysis of the parameters was performed, and parameters with strong sensitivity were selected to adjust the parameters. By using the official SWAT-CUP software, the parameters were adjusted (Khalid et al., 2018; Zhang et al., 2013). The SUFI-2 algorithm was used to determine the optimal value of the parameters by iteration (Zhang et al., 2013), and the best values of the parameters were introduced to the model through the internal tuning parameters of SWAT modelfor simulation verification. In this paper, the effective evaluation method defined by Karuse (Krause et al., 2005) is used to applicability of the simulated value of the SWAT model in Dawen River Basin was evaluated by using two indicators of correlation coefficient (R^2) and Nash-Sutcliffe efficiency coefficient (Ens). Scenarios were established to quantitatively analyze the impact of both of these indicators on river basin runoff and to separately analyze the impact of single land use type and different climate change scenarios on the runoff of the river basin. This provided an important scientific basis for water resource management and land-use planning under the influence of climate change and human activities. Relevant studies have suggested that simulations have significant effects when $R^2 > 0.6$ and $Ens > 0.5$ (Zuo et al., 2015b; Lotz et al., 2017).

Scenario development and model analysis

After verifying the accuracy of the model simulations, the response of the Dawen River basin to land use and climate change was analyzed by establishing five scenarios. The specific settings of these scenarios were presented in *Table 2*. In the simulation process, the parameters of the vegetation module and the soil hydraulic parameters were changed accordingly: Scenario 1 was used as the base period and compared to scenarios 4 and 5 to obtain the impact of both land use and climate change on production flows. Scenarios 2 and 3 were compared with scenario 1, and the impact of climate change on production flow was obtained. Then, scenarios 4 and 5 were compared with scenarios 2 and 3, respectively, to obtain the impact of land-use change on production flow during the corresponding period. Finally, the impact of land use and climate change at different periods on the runoff of the entire river basin were quantitatively analyzed.

Table 2. Model simulation scenario settings

Scenarios	Land use	Climate data
1	1985	1980-1990
2	1985	1991-2004
3	1985	2005-2015
4	2000	1991-2004
5	2015	2005-2015

Based on the land use data in 2000, all of the land use types in the basin were set to farmland, forest land and grassland scenarios, and the corresponding soil hydrological parameters and vegetation module parameters were changed. The annual runoff under different land use scenarios was simulated from 2000 to 2015.

Based on a hypothetical climate plan (Yao et al., 2017), land use in 2000 and the possible scope of climate change, the values of the precipitation and temperature changes were obtained by using any scenario approach, and under the conditions of constant temperature and precipitation, the temperature increased by 1 °C and 2 °C, and decreased by 1 °C and 2 °C, respectively, the precipitation changes increased by 10% and 20% and decreased by 10% and 20%, respectively. 25 climate change scenarios were established. The response of runoff to climate variability was simulated through different climate variability schemes. The annual change in runoff b is solved as follows (*Eq. 2*):

$$b = (y_i - y_0) / y_0 \times 100\% \tag{Eq.2}$$

where y_i is the average annual runoff under the i climate scenario (m³/s); and y_0 is the annual average runoff under a real scenario (m³/s).

Results and analysis

Correction and verification results

According to the natural river network and topography of the basin, the study area was divided into 35 sub-basins, as shown in *Figure 3*. To obtain a reasonable resolution to assess soil properties, land uses, and management practices, the threshold values of land use, soil type and slope were chosen as 10%, 15% and 10%, respectively. These sub-basins were then further divided into 326 HRUs.

Through analysis, the first six sensitivity parameters were selected to adjust the parameters (*Table 3*). At the calibration period (*Table 4; Figs. 4, 5* and *6*), the simulated peak values in the flood season were lower than the measured values in 1999 and 2002, and higher than the measured values in 2000, 2005, and 2007; the R^2 and Ens values in Daicunba were 0.83 and 0.79, respectively. The simulated peak values in the flood season were lower than the measured values in 1985 and 1991, and higher than the measured values in 1982, 1987, 1988, and 1992; the R^2 and Ens values in Laiwu station were 0.73 and 0.71, respectively. The runoff simulation values of the two stations during the correction period have high precision.
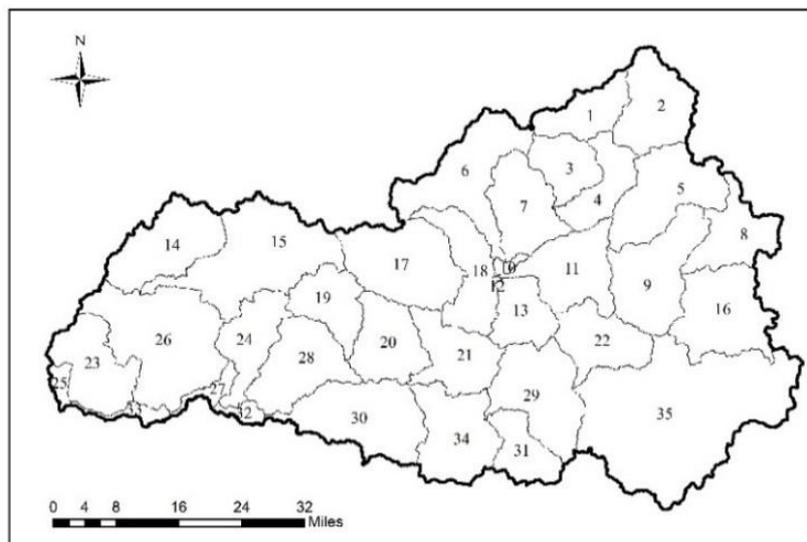
Figure 3. *Sub-basins in the Dawen River Basin delineated by the SWAT*

Table 3. *Dawen River Basin runoff sensitivity parameters*

Parameter name	Variable name	Rank	T value	P value	Ranges	The most suitable value
CN2	Curve number	1	-18.133	0	0-15	12.1687
ALPHA_BF	Base-flow recession constant	2	-2.578	0.012	0-1	0.5364
SOL_K	Saturated hydraulic conductivity	3	-2.519	0.013	0-2.0	0.6696
SOL_AWC	Available water capacity of the soil layer	4	-3.09	0.02	0.5-1.4	0.6765
ESCO	Soil evaporation compensation coefficient	5	1.8	0.08	0.3-0.9	0.5713
GWQMN	Threshold depth of water in the shallow aquifer required for return flow to occur	6	-1.463	0.147	0-5000	1763.47

Table 4. *Dawen River Basin monthly runoff simulation correction and verification*

Period	Site	R^2	Ens
Regular rate	Daicunba	0.83	0.79
	Laiwu Station	0.73	0.71
Verification period	Daicunba	0.80	0.76
	Laiwu Station	0.69	0.72

During the verification period (*Table 4; Figs. 4, 5* and *6*), the simulated peak value in the flood season was lower than the measured value in 2013, and higher than the measured values in 2009, 2012 and 2015; the R^2 and Ens values in Daicunba were 0.80 and 0.76, respectively. The simulated peak values in the flood season were lower than the measured values in 1999, and higher than the measured values in 1996 and 2001; the R^2 and Ens values in Laiwu Station were 0.69 and 0.72, respectively. The accuracy of the runoff simulation values at the two stations during the verification period is thus adequate.
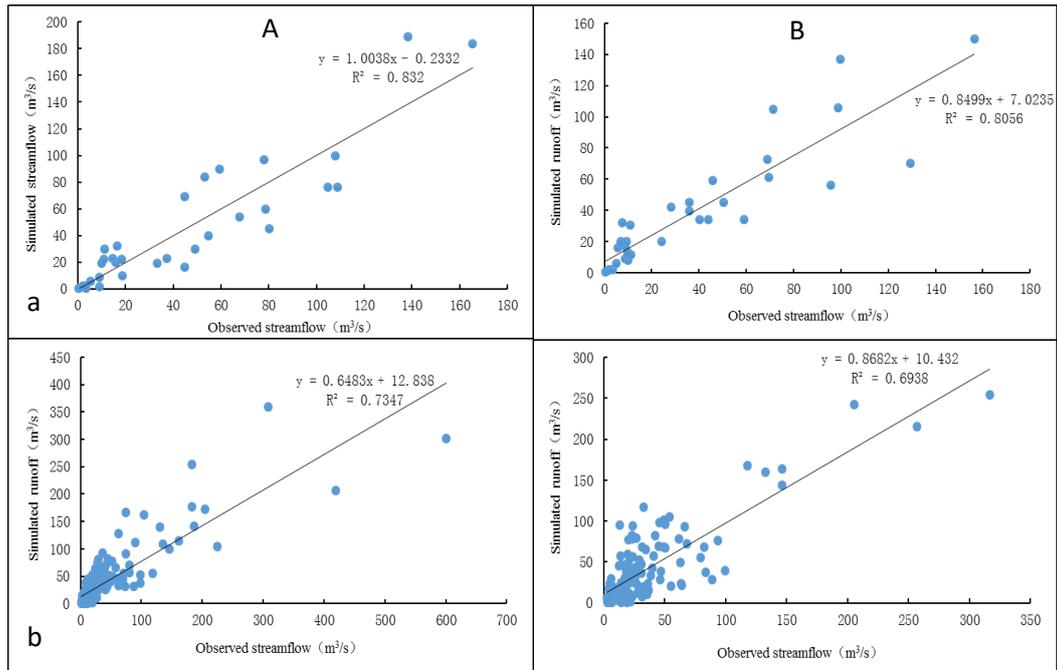
Figure 4. Correlation between simulated and measured values of monthly runoff in the hydrological stations A: Rate period; B: Validated period; a) Daicunba; and b) Laiwu station
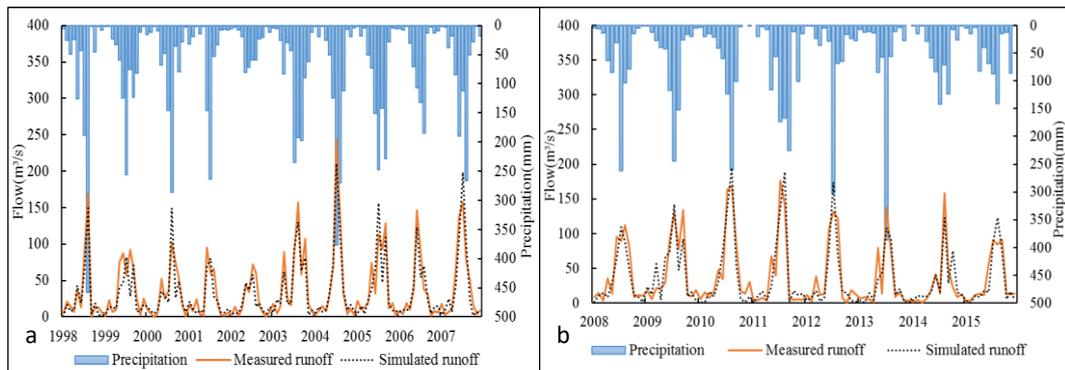
Figure 5. Daicunba hydrological station monthly runoff simulation and actual measurement comparison chart. a: Rate period; b: Validated period
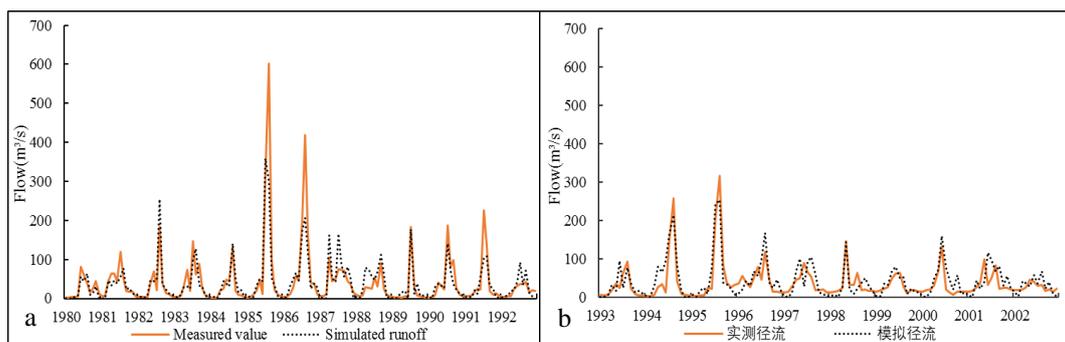
Figure 6. Laiwu hydrological station monthly runoff simulation and actual measurement comparison chart. a: Rate period; b: Validated period

For the determination and verification of monthly runoff, the deterministics coefficient of the measured and simulated values of runoff are $R^2 > 0.6$ and Ens > 0.6. This shows that the measured values of runoff are in good agreement with the simulated values and that the SWAT model has good applicability in the study area.

Simulation scenarios

Responses of streamflow to different land use scenarios

To understand the impact of land-use changes on streamflow in this basin, the calibrated SWAT model was run under scenarios S1 S4 and S5. The percentages of land-use change rates and the changes in land use area in kilometers under these three scenarios are shown in *Figure 7* and *Table 5*. In scenario S1, the status of land use in Dawen River was mainly meadow (27.69%), forest land (19.07%), cultivated land (28.18%), and building land (12.17%). Compared to scenario S1, the area of forest land increased by 23.66%, the area of building land increased by 11.08%, and the area of cultivated land and unused land decreased by 24.38% and 6.93%, respectively, in scenario S4. Compared to scenario S4, the area of forest land decreased by 27.66% and that of unused land decreased by 3.57%, the area of the meadow increased by 10.64%, and the area of building land increased by 17.27% in scenario S5. From 1985 to 2015, the meadow area increased by 17.85% and the cultivated land area decreased by 18.3%. The water area did not change much.
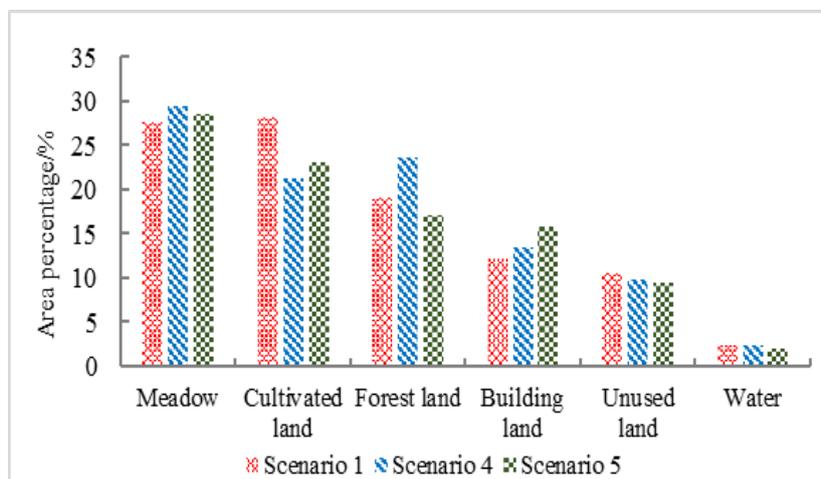
Figure 7. *Percentages of land uses under three scenarios*

Table 5. *Proportion of land use in the Dawen River Basin in 1985, 2000 and 2015*

Year	Meadow (%)	Cultivated land (%)	Forest land (%)	Building land (%)	Unused land (%)	Water (%)
1985	27.69	28.18	19.07	12.17	10.56	2.33
2000	29.49	21.31	23.59	13.51	9.83	2.27
2015	28.51	23.02	17.06	15.85	9.48	1.96

Based on the situational settings, a quantitative study was conducted on the runoff response to land use and climate change in Dawen River Basin (*Table 6*). The results

show that the average annual runoff values in scenarios 1, 2, 3, 4 and 5 are 9.21, 7.89, 7.28, 8.17, and 7.41 million m^3, respectively. Scenarios 2 and 3 are compared to Scenario 1. Climate change caused an annual average runoff reduction of 1.32 and 0.61 million m^3. The comparison between Scenario 2 and Scenario 4 results in an increase of 28 million m^3 in average annual runoff due to the change in land use. The comparison between Scenario 3 and Scenario 5 results in an increase of 13 million m^3 in average annual runoff due to land use change.

Table 6. Simulation results of land use and climate change impact on runoff in the Dawen River Basin

Scenario	Annual precipitation (mm)	Annual average temperature (°C)	Average annual flow (10^9m^3)	Impact of land use change on runoff (10^9m^3)	Impact of climate change on runoff (10^9m^3)
1	-	-	9.21	-	-
2	755.7	13.4	7.89	-	-1.32
3			7.28	-	-0.61
4	-	-	8.17	0.28	-
5	-	-	7.41	0.13	-

Annual average runoff changes under different extreme land use scenarios

The runoff variation under three different extreme scenarios was compared to simulated runoff under the land use scenario in 2000 (*Fig. 8*). The runoff in the cultivated land scenario decreased by 38.3%, and the runoff decreased by 19.8% in the forest land scenario. However, the runoff increased by 4.3% in the grassland scenario. These results show that grassland can increase the runoff and water supply in the basin to conserve water resources. The increase in cultivated land will lead to a large reduction in runoff. Because cultivated land has the effect of inhibiting the increase of runoff, human activities have a greater impact on hydrology.
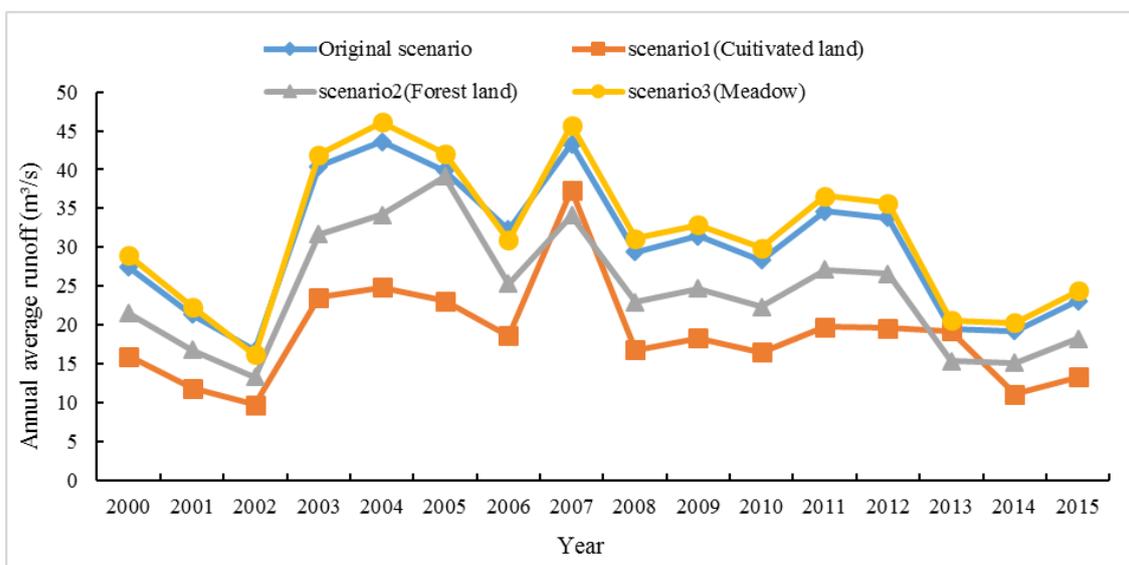
Figure 8. Simulated runoff changes in extreme land use scenarios

Influence of temperature and rainfall on average runoff in the basin

It can be seen from the annual average temperature and precipitation cumulative anomaly curve in the Dawen River Basin (*Fig. 9*). From 1990 to 1995, the temperature accumulation anomaly curve showed a downward trend, which was a period of low temperature. From 1995 to 2009, the temperature accumulation anomaly curve showed an upward trend, which was a period of higher temperature. Then, the temperature accumulation anomaly curve began to rise after a short decline until 2015, and the overall situation was relatively stable. The average temperature over 26 years is approximately 13.4 °C and is growing at a speed of 0.47 °C/10a. The cumulative anomaly curve of precipitation in the Dawen River Basin from 1990 to 1998 showed a downward trend, which was a period of low rainfall. The cumulative anomaly curve of precipitation in 1998-2002 experienced a short stage of rising and falling, and the overall situation was relatively stable. From 2002 to 2015, the cumulative anomaly curve of precipitation showed an upward trend, which was a rainy period. According to this analysis, the average precipitation in Dawen River Basin during the past 26 years is 755.7 mm, and the annual average precipitation has decreased overall. The reduction rate is approximately 54.9 mm/10a.
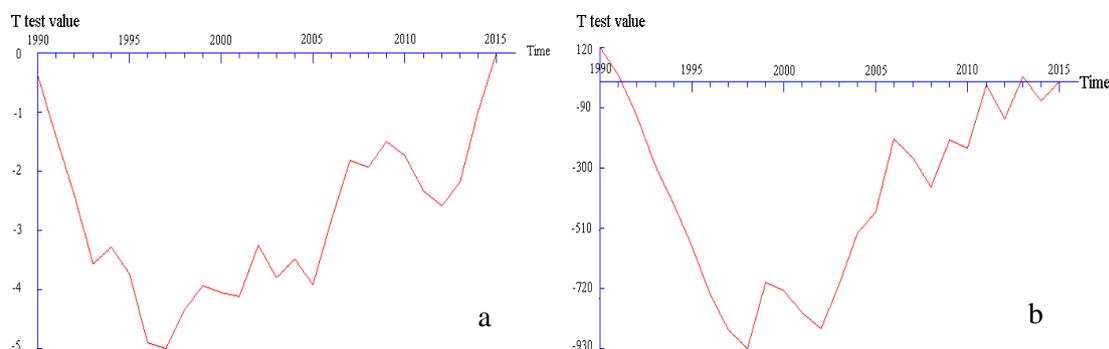
Figure 9. *Cumulative anomaly curve. a: Temperature; b: Precipitation*

It can be seen from *Figure 10* and *Table 7* that the multi-year average runoff variation in Dawen River Basin is mainly related to rainfall and temperature in the basin. First, the annual total runoff of the basin decreases with increasing temperature and decreases with decreasing temperature. The annual runoff decreased by 4.1% when the temperature increased by every 1 °C; the annual runoff decreased by approximately 3.0% when the temperature decreased every by 1 °C. This indicates that temperature is one of the main sensitive factors affecting runoff in the basin. Second, there is a positive correlation between rainfall and annual runoff in the basin. The annual runoff of the basin increases with the increase in annual rainfall, and the increase in runoff is greater than the increase in rainfall. When the annual rainfall in the basin increases by every 10%, the annual total runoff increases by approximately 18.3%. The average annual runoff of the basin decreases with the decrease of precipitation, but its reduction of rainfall is smaller than its increase of rainfall. When the annual rainfall decreases by every 10%, the annual average runoff decreases by 15.1%. Precipitation is an important factor affecting runoff in the basin. Compared to the change of temperature, the annual runoff of the basin is more affected by rainfall.

Table 7. *Simulation results of different climate change scenarios*

Precipitation change Temperature changes	-20%	-10%	0	+10%	+20%
T-2	-29.7	-18.2	-3.3	11.2	33.1
T-1	-29.1	-19.4	-3.0	10.7	34.4
0	-27.1	-15.1	0	18.3	30.7
T+1	-30.6	-20.2	-4.1	11.1	32.5
T+2	-30.3	-21.5	-4.7	12.2	31.8
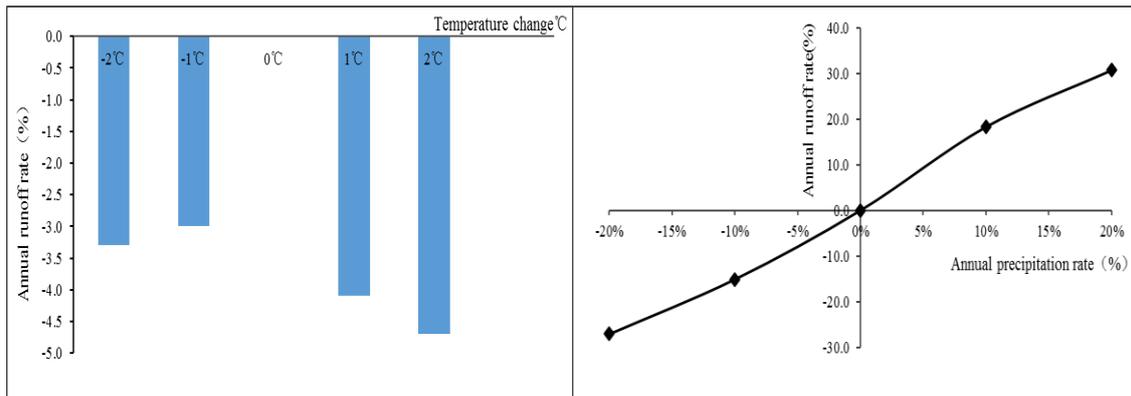
Figure 10. *Annual runoff rate of the Dawen River Basin under changes in temperature and precipitation*

Conclusion

In this paper, the distributed hydrological model (SWAT) is applied to quantitatively simulate the impact of land use and climate change on water production in Dawen River Basin through multi-site calibration and verification. The results are shown as follows:

(1) The calibration and validation at two hydrological stations showed that the R^2 values were 0.83 and 0.80 and 0.73 and 0.69, and the Ens values were 0.79 and 0.76 and 0.71 and 0.72, respectively, which satisfied the SWAT model simulation accuracy evaluation criteria. Therefore, the SWAT model was suitable for this research basin. The parametric model can be applied directly to the actual situation in the basin.

(2) Land use and climate change in different periods have different effects on water yield in the basin. Scenarios 2 and 3 are compared to Scenario 1, indicating that climate change caused annual average runoff reductions of 1.32 and 0.61 billion m^3, respectively. The comparison between Scenario 2 and Scenario 4 results in an increase of 28 million m^3 in annual average runoff due to the change in land use. The comparison between Scenario 3 and 5 shows an increase of 13 million m^3 in average annual runoff due to land-use change.

(3) The simulation results of different land use types showed that the runoff in cultivated land decreased by 38.3%, the runoff in forest land decreased by 19.8%, and the runoff in grassland increased by 4.3%. Therefore, in the future watershed management process of Dawen River Basin, the type of land use will be adjusted to meet the water demand in the basin, increase the water output of the basin and ensure water use downstream of the basin.

(4) By analyzing the rate of runoff change in the basin under various climate scenarios, the annual total runoff in the basin decreases with the increase of temperature, and decreases with the decrease of temperature. The annual runoff increased with the increase of annual rainfall and the increase of runoff was greater than the increase of rainfall. The annual average runoff of the basin decreased with the decrease of precipitation, but its degree of decrease of rainfall was smaller than its degree of increase of rainfall.

(5) Runoff is not only affected by changes in land use but also by climate change. If the change in runoff is mainly caused by land use, the water resources planning and management policy can still be formulated based on current hydrology and meteorological data; If the main factor causing the change in runoff is climate change, then it is necessary to focus on the impact of future climate change on hydrology and water resources, and the research can also provide a reference for water resources planning management.

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