Assessing impacts of different land use scenarios on water budget of Fuhe River, China using SWAT model

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Abstract: The Soil and Water Assessment Tool (SWAT) model was used to assess the impacts of different land use scenarios on hydrological processes in the Fuhe watershed in Poyang Lake Basin, East China. A total of 12 model parameters were calibrated with observed monthly runoff data for 1982-1988 and validated for 1991-1998 for baseline conditions. The baseline test results of R^2 and Nash-Sutcliffe model efficiency (NSE) values ranged between 0.88 and 0.94 across the calibration and validation periods, indicating that SWAT accurately replicated the Fuhe watershed streamflow. Several different land use scenarios were then simulated with the model, focusing on the impacts of land use change on the hydrology of the watershed. The results of hypothetical scenario simulations revealed that surface runoff declined while groundwater recharge and evapotranspiration (ET) increased, as forest land, agriculture land and/or grassland areas increased, as well as when paddy field and urban areas decreased. These results further showed that forest land has a higher capacity to conserve the water as compared to pasture land. The results of the real scenario simulations revealed that urbanization is the strongest contributor to changes in surface runoff, water yield, and ET. Urbanization can be considered as a potential major environmental stressor controlling hydrological components.

Keywords: SWAT model, land use, streamflow, water budget, scenario simulation, Poyang Lake, Fuhe watershed
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1 Introduction

Land use/land cover change (LULC) within a region can impact both hydrologic landscape functions and the habitat quality, and thus the biodiversity of a landscape. Additionally, LULC can affect the water quality of a stream system and receiving water bodies due to decreases or increases in soil erosion or other pollutants within a watershed system. According to some studies, vegetation cover is the key factor affecting surface runoff

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and soil erosion in mountainous regions[1,2]. The presence of vegetation intercepts rainfall, increases infiltration, reduces surface runoff, and thus significantly prevents sheet erosion[3,4]. Li et al.[5] found that water quality was significantly correlated with vegetation cover in the Han River basin in central China, and that in-stream environmental indicators were generally improved for subwatersheds with higher vegetation cover.

The Soil and Water Assessment Tool (SWAT) ecohydrological model[6] has been tested for a wide range of watershed scales and environmental conditions worldwide[7-11] and has been used extensively to evaluate the impacts of LULC changes on watershed hydrology and water quality. Example results of such studies conducted in the United States, Europe and Asia, including large decreases in runoff for hypothetical total conversions of a semi-arid watershed in Arizona to forest, grassland, or other types of vegetation[12], increased runoff in response to four scenarios of increasing urbanization relative to baseline conditions dominated by forest for a watershed in Texas[13], increased runoff due to hypothetical increases in grassland for two different forested watersheds in Germany using a modified version of SWAT called SWAT-G[14], and sediment increases equal to 200% or more when 50% of the pasture or grassland area was converted to cropland in a watershed in the southern Philippines[15].

Similar LULC change impact assessments have also been conducted for several SWAT-based studies in China. Chen[16] found that runoff depth decreased when land use cover was converted from unvegetated to vegetated conditions. Qiu et al.[17] reported that evapotranspiration and runoff decreased, and that overall utilization of water and environmental conditions improved, in response to increased forest land implemented with the “Conversion of Cropland to Forest and Grassland Program” (CCFGP, a nationwide ecological recovery program, to minimize wide-scale soil erosion and vegetation degradation as well as to improve water budgeting, in 1999 China) in the Jinghe River watershed in the Loess Plateau region. Runoff was also predicted to decrease in LULC change scenarios performed by Luo et al.[18] for the Xiangjiang River watershed in south central China, in which they simultaneously simulated increases in forest and grassland areas versus decreases in the amounts of agricultural and urban land. Cai et al.[19] reported runoff and sediment loss results, respectively, for the Upper Huaihe River basin in northeast China, and found that runoff and sediment losses were the least for woodland areas as compared to rice paddy and farmland production areas.

The influence of LULC change is a critical issue for the source region of water draining to Poyang Lake in northeast China, which is the largest fresh water lake in China. Fuhe River is the second largest source of discharge to Poyang Lake and thus has a very important impact on the water level, environmental conditions, and animal and plant habitat of the lake. At the same time, the middle and lower Fuhe River is a populous and developed region in Jiangxi Province, and is also the main grain production base of China. Changes in land-cover and vegetation in the region have affected surface and groundwater hydrology and streamflow at the catchment scale and have also altered the hydrological cycle and flood vulnerability of the Fuhe River system. Therefore, there is a need to investigate the impacts of LULC change on the hydrology and water quality of Fuhe River as well as on Poyang Lake, using comprehensive water quality models such as SWAT. Thus, the specific objectives of this study are: (1) to calibrate and validate SWAT based on measured streamflow data collected for Fuhe River, (2) to evaluate the impact of several Land use/land cover change scenarios on the hydrology and sediment movement for the Fuhe River system including potential changes in forested, agricultural and urban areas, and (3) to evaluate the impact of the implementation of the “Conversion of Cropland to Forest and Grassland Program” on regional water budget.

2 Materials and methods

2.1 Study area description

The Fuhe River basin is located in the east of Jiangxi Province, China (Figure 1). It has a drainage area of 14 778 km², and situated between latitudes 31°34′-32°10′N and between longitudes118°39′-119°19′E. The length of the main stream is 348 km and the mean annual runoff is approximately 126×10^8 m^3. The stream network and elevation ranges are shown in Figure 1.

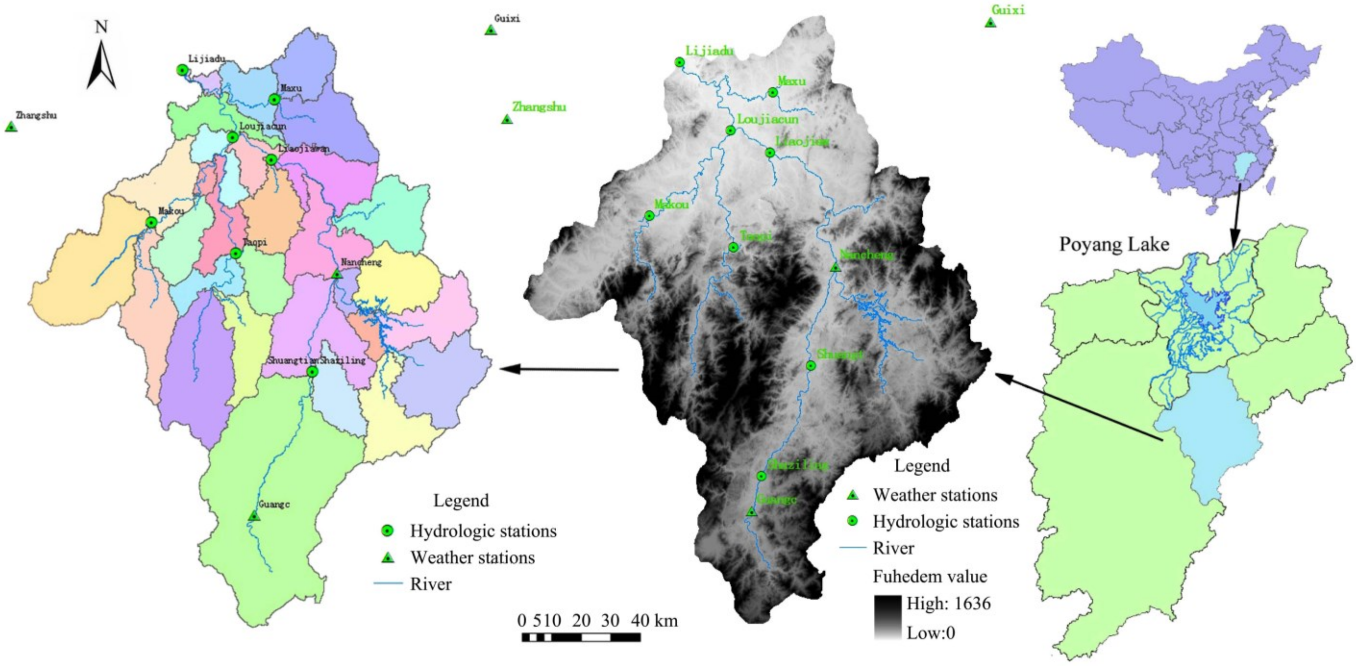

Figure 1 Map of Fuhe River watershed showing relative locations of meteorological, hydrologic stations and stream network

This area is dominated by a subtropical humid monsoon climate. The mean annual temperature is about 16.9°C to 18.2°C, the mean annual humidity is around 80% and the mean annual number of rainy days is approximately 170 d. The mean annual precipitation ranges from 1 200 mm to 2 000 mm of which 50% to 60% of the annual rainfall is received from April to July. Because of the impact of high solar radiation and the circulation of monsoon weather patterns, the streamflow in Fuhe River varies significantly by season. The region is frequently threatened by floods during the monsoon period each year. However, less precipitation occurs in late autumn and winter.

The main soil type in the Fuhe River basin is the krasnozem, comprising 65.9% of the whole Fuhe River basin area. Krasnozems in good physical condition have: (1) loose and friable tilth, (2) high permeability of both air and water, (3) reasonably plant-available water content, and (4) low soil strength when moist. Because of its high permeability, the river discharge supplied by groundwater recharge and surface runoff is limited.

2.2 Input data

Key SWAT input data layers include a Digital Elevation Model (DEM), land use map, soil map and weather data (Table 1). There are four weather stations (Nancheng, Zhangshu, Guixi and Guangchang) that are located in or near the watershed (Figure 1). There are also eight streamflow monitoring stations (Shaziling, Shuangtian, Taopi, Makou, Liaojiawan, Loujiacun, Maxu, and Lijiadu) located within the watershed (Figure 1) which were obtained from the Jiangxi provincial water conservancy department (Table 1). Monthly discharge data were acquired from 1982 to 1998 for the Lijiadu station near the watershed outlet and 2010 for the other seven stations to test SWAT during the baseline calibration and/or validation phases.

Table 1 Key spatial model input data, and monitoring data used to test SWAT, for Fuhe River watershed

Data	Resolution	Source
Digital Elevation Model (DEM) map	30 m	The Global Land One kilometer Base Elevation database[20]
Weather	Four stations (Figure 1)	The China Meteorological Data Sharing Service System website[21]
Soil map	100 m	Harmonized World Soil Database (HWSD), assembled by the Food and Agriculture Organization of the United Nations (FAO) and International Institute for Applied Systems Analysis (IIASA)[22]
Land use map	30 m	Landsat TM/ETM, three time periods (1990, 2000, and 2009)[23]
Water discharge data	Eight stations (Figure 1)	The website of Jiangxi provincial water conservancy department[24]

Fifty years of daily meteorological data (1960-2010) were analyzed and processed into mean monthly meteorological statistics to create data that was representative of the study area for the SWAT weather generator[25]. Daily minimum and maximum air temperature, wind speed, solar radiation and relative humidity obtained for the four climate stations shown in Figure 1 were used for the SWAT simulations. These data were also used to simulate reference evapotranspiration in the model by Priestley-Taylor method[25].

An unsupervised classification method with maximum likelihood clustering and DEM data were employed for image classification as a hybrid method to generate land use maps[26]. Land use categories included paddy fields, agricultural land, forest, pasture, urban, water, wetland and bare land. All crops, except paddy fields, were all classified as agricultural land. Rice paddies (Figure 2) were separated out and simulated specifically as "rice", per the rice crop parameters provided with the SWAT model, because the Fuhe River basin is a major rice production area in China. Detailed land use maps are shown in Figure 2 for 1990, 2000 and 2009 which form the basis for the baseline and two historical land use scenarios described below.

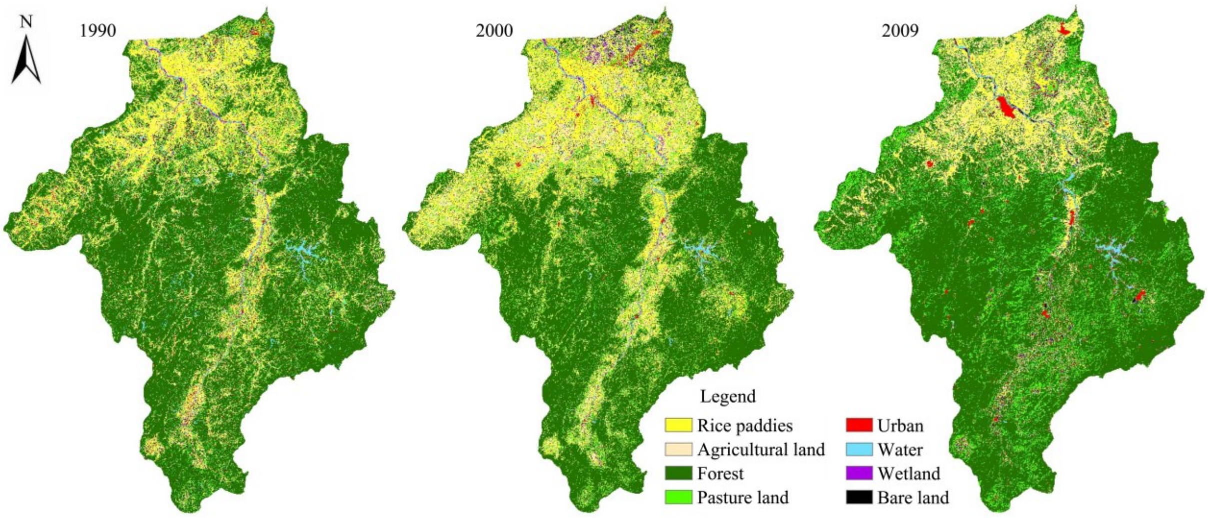

Figure 2 Land use maps of Fuhe River basin for 1990 (left), 2000 (middle) and 2009 (right)

2.3 Description of SWAT model

The hydrologic cycle of a watershed simulated by SWAT can be separated into two major divisions. The first division is the land phase of the hydrologic cycle, which controls the quantity of water and sediment and the nutrient load input into receiving waters. The second division is the water routing phase, which simulates movement through the channel network. The model considers both natural sources (e.g. mineralization of organic matter and N fixation) and anthropogenic contributions (fertilizers, manures, and point sources) as nutrient inputs. The model delineates watersheds into sub-basins interconnected by a stream network. Each subwatershed is divided further into hydrological response units (HRUs) based on unique soil/land class characteristics without any specified location in the subwatershed. Flow, sediment, and nutrient loading from each HRU in a subwatershed are summed, and the resulting loads are then routed through channels, ponds, and reservoirs to the watershed outlet[27].

The hydrologic cycle simulated by SWAT is based on the following water budget equation:

$$SW_t = SW_0 + \sum_{i=1}^{t}(R_{day} - Q_{surf} - E_a - Q_{lat} - Q_{gw}) \quad (1)$$

where, SW_t is the final soil water content (mm H_2O); SW_0 is the initial soil water content on day i (mm H_2O); t is the time (days); R_{day} is the amount of precipitation on day i (mm H_2O); Q_{surf} is the amount of surface runoff on day i (mm H_2O); E_a is the amount of Evapotranspiration (ET) on day i (mm H_2O); Q_{lat} is the lateral flow loss from soil to streams on day i (mm H_2O); and Q_{gw} is the amount of groundwater recharge on day i (mm H_2O). Precipitation, surface runoff, ET and groundwater recharge constitute the main part of this hydrologic cycle and were key inputs or outputs that were analyzed in this study.

2.4 Model evaluation method

The performance of the model was evaluated by the coefficient of determination (R^2), the Nash-Sutcliffe efficiency (E_{NS}) index[26-28] and the percent bias (PBIAS)[29]. The R^2 is the square of correlation coefficient and can range from 0 to 1. An R^2 value of 1 indicates a perfect alignment between simulated and observed values while an R^2 value of 0 indicates no alignment between simulated and observed values. The weakness of using the R^2 statistic is that model predictions can be consistently wrong and still result in a R^2 value close to 1, due to systematic over- or under-prediction, pointing to the need to use additional evaluation statistics such as the E_{NS} in order to more accurately determine the accuracy of model results[28]. The R^2 is calculated as:

$$R^2 = \frac{\left[\sum_{i=1}^{n}(Q_{obsi} - Q_{obsave})(Q_{simi} - Q_{simave})\right]^2}{\sum_{i=1}^{n}(Q_{obsi} - Q_{obsave})^2 \sum_{i=1}^{n}(Q_{simi} - Q_{simave})^2} \quad (2)$$

where, n is the number of events; Q_{simi} and Q_{obsi} the simulated and observed runoff at event i; Q_{simave} and Q_{obsave} the average simulated and observed runoff over the validation period.

Values for E_{NS} can range from $-\infty$ to 1. In most typical applications, E_{NS} values should exceed 0.5 in order for model results to be judged satisfactory for hydrologic and pollutant loss evaluations performed on a monthly time step basis[30]. Further suggested E_{NS} criteria[30] include: values between 0.5-0.65 are acceptable; values between 0.65-0.75 are good, and values that exceed 0.75 are very good. The Nash–Sutcliffe coefficient is calculated as:

$$E_{NS} = 1 - \frac{\sum_{i=1}^{n}(Q_{simi} - Q_{obsi})^2}{\sum_{i=1}^{n}(Q_{obsi} - Q_{obsave})^2} \quad (3)$$

where, n is the number of time steps; Q_{simi} and Q_{obsi} are the simulated and observed streamflow at time step i, and Q_{obsave} is the average observed streamflow over the simulation period.

Percent bias (PBIAS) measures the average tendency of the simulated data to be larger or smaller than their observed counterparts[28,31]. The optimal value of PBIAS is 0.0, with low-magnitude values indicating accurate model simulation. Positive values indicate model underestimation bias, and negative values indicate model overestimation bias[26,29]. PBIAS is calculated as:

$$PBIAS = \left[\frac{\sum_{i=1}^{n}100\ (Q_{obsi} - Q_{simi})}{\sum_{i=1}^{n}Q_{obsi}}\right] \quad (4)$$

where, $PBIAS$ is the deviation of data being evaluated, expressed as a percentage.

2.5 Model setup

ArcSWAT version 2009.93.3 was used in this research[32] which is one the major releases of SWAT version 2009 (SWAT2009). The basin was divided into 31 subwatersheds (Figure 1) and 476 HRUs, which were created as a function of nine land use classes, 33 soil classes and four slope classes (0 to 3%, 3% to 5%, 5% to 8% and >8%). This discretization respected the original distribution of soil and land use, while maintaining the number of HRUs at a reasonable number. Meteorological data were introduced into the model, and databases of soil and land use properties were edited to provide the required data for our study area.

The SWAT model involves a large number of parameters which describe the different hydrological conditions and characteristics across the study basin. During the calibration process, the first step was to determine which model parameters are the most influential in matching the simulated model results to the observed results. This can eliminate or at least reduce some of the limitations of manual calibration. To help accomplish this goal, the Automated Sensitivity Analysis tool provided by SWAT was used, which employs the LH-OAT (Latin Hypercube Sampling-One at A Time) analysis method[33]. Historical streamflow and meteorological data for the period 1982 to 1988 were used for sensitivity analysis.

Typically, testing of SWAT and similar models is performed by splitting the available observed monitoring data into two time periods: one for calibration, and another for validation[34]. In our study, one year (1981) was chosen as a warm-up period in which SWAT was allowed to initialize and approach reasonable starting values for model state variables. The model was then initially calibrated using a manual calibration method for the 1982-1988 period at Lijiadu station. The manual calibration process was divided into two steps: (1) surface runoff calibration, and (2) streamflow calibration. The proportion of groundwater recharge versus surface runoff was determined as a function of the observed total daily streamflow using a baseflow filter[32]. Following the manual calibration process, the SWAT-CUP software package was then used to perform an additional automatic calibration of SWAT[32]. Finally, validation was conducted for the 1991 to 1998 period. Figure 3 shows a flow chart of the calibration and scenario setting process.

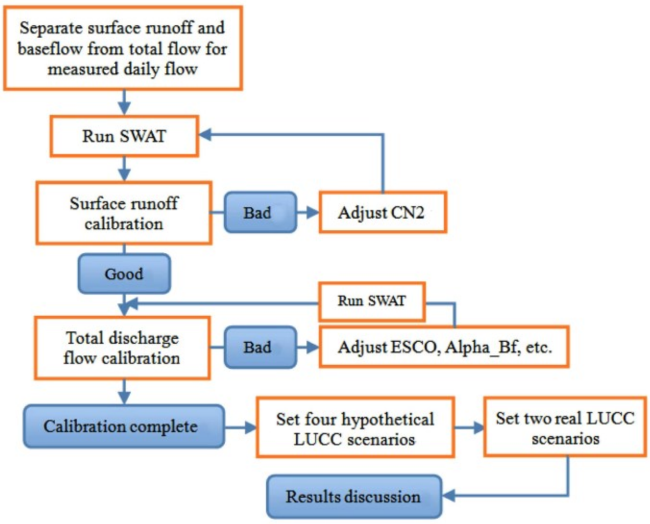

Figure 3 Flowchart of calibration and scenario setting process

2.6 Description of land-cover change scenarios

This study investigated six different scenarios to access the effects of LULC on the hydrology of the Fuhe River Basin (Table 2). The calibrated parameters, meteorological data, landscape characteristics and soil data used for the baseline simulation were also used for the six scenarios to provide a consistent basis for comparison between the baseline and these LULC scenarios for the simulation period of 1982 to 1998, which was the time period used for the baseline model testing. Table 2 shows the proportions of land use change for each scenario including the five land use classes that were of primary interest for this study: forest (FRST), pasture land (PAST), urban (URBN), agriculture land (AGRL) and rice paddies (RICE). Scenarios 1 and 2 replicate the actual land use change that had occurred by either 2000 or 2009, based on the land use maps for those two different years (Figure 2).

The historical scenarios 1 and 2 capture the local effects of the "Conversion of Cropland to Forest and Grassland Program" (CCFGP), a nationwide ecological recovery program adopted by China in 1999, to minimize wide-scale soil erosion and vegetation degradation as well as to improve water budgeting results. Over 100 000 km^2 of cropland and bare land was converted to forest land in the first decade of the CCFGP; however, the impact of the program on the hydrology of affected watersheds in China such as the Fuhe River watershed has not been researched extensively[17].

Table 2 The area and percentage of land use types that were simulated in different land use scenarios

Land use type		AGRL	RICE	FRST	PAST	URBN	WATR	WETL	BARE
Baseline Scenario (Historical, 1990)	Area/km²	1680	2863	8270	1361	211	201	93	99
	Percentage/%	11.4	19.4	56.0	9.2	1.4	1.4	0.6	0.7
Scenario 1 (Historical, 2000)	Area/km²	1595	2140	8441	1566	361	293	33	352
	Percentage/%	10.8	14.5	57.1	10.6	2.4	2.0	0.2	2.4
Scenario 2 (Historical, 2009)	Area/km²	1247	2231	8960	1342	516	173	37	272
	Percentage/%	8.4	15.1	60.6	9.1	3.5	1.2	0.3	1.8
Scenario 3 (Hypothetical)	Area/km²	1680	0	11133	1361	211	201	93	99
	Percentage/%	11.4	0	75.3	9.2	1.4	1.4	0.6	0.7
Scenario 4 (Hypothetical)	Area/km²	0	2863	9950	1361	211	201	93	99
	Percentage/%	0	19.4	67.3	9.2	1.4	1.4	0.6	0.7
Scenario 5 (hypothetical)	Area/km²	1680	0	8270	4224	211	201	93	99
	Percentage/%	11.4	0	56.0	28.6	1.4	1.4	0.6	0.7
Scenario 6 (hypothetical)	Area/km²	0	2863	8270	3041	211	201	93	99
	Percentage/%	0	19.4	56.0	20.6	1.4	1.4	0.6	0.7

Remote sensing data indicated that the overall effect of the CCFGP on the proportion of forest land in the Fuhe River watershed was moderate, resulting in an increase in forest of 56% to 57.1% from 1990 to 2000 and then from 57.1% to 60.6% from 2000 to 2009. Agricultural land and rice paddies decreased from 11.4% to 10.8% and 19.4% to 14.5%, respectively, during 1990 to 2000. The amount of agricultural land decreased further from 10.8% to 8.4% during 2000 to 2009 but a slight increase (14.6% to 15.1%) in rice paddies occurred during the same time period. The total pasture land area followed an opposite pattern compared to the rice paddies, with an initial increase from 9.2% to 10.6% of the overall land area during 1990 to 2000 followed by a decrease (10.6% to 9.1%) during 2000 to 2009. The remote sensing data further suggested that the proportion of residential area increased at approximately 0.1% annually over the total twenty year period and that the total proportion of urban areas gradually expanded from 1.4% to 3.5% between 1990 and 2009.

Scenarios 3 through 6 represent hypothetical scenarios that reflect larger land use changes, relative to the historical scenarios 1 and 2, which provide further insight on the effects of different land use changes on the Fuhe River watershed water budget. Specifically, areas of agriculture land (Scenarios 4 and 6) or paddy fields (scenarios 3 or 5) were changed to forest land or pasture land to compare the influence of different land uses on the water budget (Table 2). To account for potential effects of a "more extreme CCFGP approach" on the Fuhe River catchment water budget, the baseline rice paddy area (2 863 km^2) and the baseline agricultural area (1 680 km^2) were completely converted to forest in scenarios 3 and 4, respectively. This resulted in an increase of forested area from 56.0% to 75.3% and 56.0% to 67.3% for scenarios 3 and 4, respectively. For scenario 5, the baseline paddy fields were eliminated and the pasture area was correspondingly increased from 9.2% to 28.6% (Table 2). Likewise, the baseline agricultural land was totally converted to pasture land for scenario 6, resulting in an increase of pasture area from 9.2% to 20.6%.

3 Results and discussion

3.1 Parameters calibration results

Table 3 shows the rank of parameters. The initial curve number for moisture condition II (CN2) was the most influential parameter for surface runoff, which is consistent with a summary reported in a previous review which found that CN2 was the most used calibration parameter for surface runoff (36 out of 64 studies)[34]. The CN2 is a function of soil permeability, land use, and the antecedent soil water conditions. This parameter is important for estimating surface runoff[35]. Similar results were reported in a previous SWAT study, in which the sensitivity analysis results demonstrated that the most influential parameters governing surface runoff and groundwater recharge are CN2 and GWQMN[36]. In addition, the previous review noted above[34] found that GWQMN was an important calibration parameter in 12 out of the 64 SWAT studies that were reviewed.

Table 3 The rank of parameters determined from sensitivity analysis

Parameters (Definition)	Rank	Calibrated results
CN2 (Initial SCS runoff curve number for moisture condition II)	1	multiply original values by 1.09
ESCO (Soil evaporation compensation factor)	2	0.02
GWQMN (Threshold depth of water for return flow)	3	748.17
SOL_AWC (Available water capacity of the soil layer)	4	multiply original values by 1.21
ALPHA_BF (Groundwater recharge alpha factor)	5	0.16

3.2 SWAT performance

The observed and simulated streamflow for 1982 to 1988 (calibration) and 1991 to 1998 (validation) are shown for the Lijiadu gauging station (Figures 1) on a monthly basis in Figures 4 and 5, respectively. Although the model obviously underestimated or overestimated streamflow during several time periods, overall it performed well for the entire simulation period. During the calibration period, the E_{NS} and R^2 were both computed to be 0.89 for the aggregated monthly time step (Figure 4). The corresponding E_{NS} and R^2 values were determined to be 0.89 and 0.94 during the validation period (Figure 5). The PBIAS was computed to be 0.22% (Figure 4) during the calibration period and -9.5%

(Figure 5) during the validation period. These results showed that the estimated streamflow was very accurate during the calibration period but slightly overestimated the measured streamflow during the validation period.

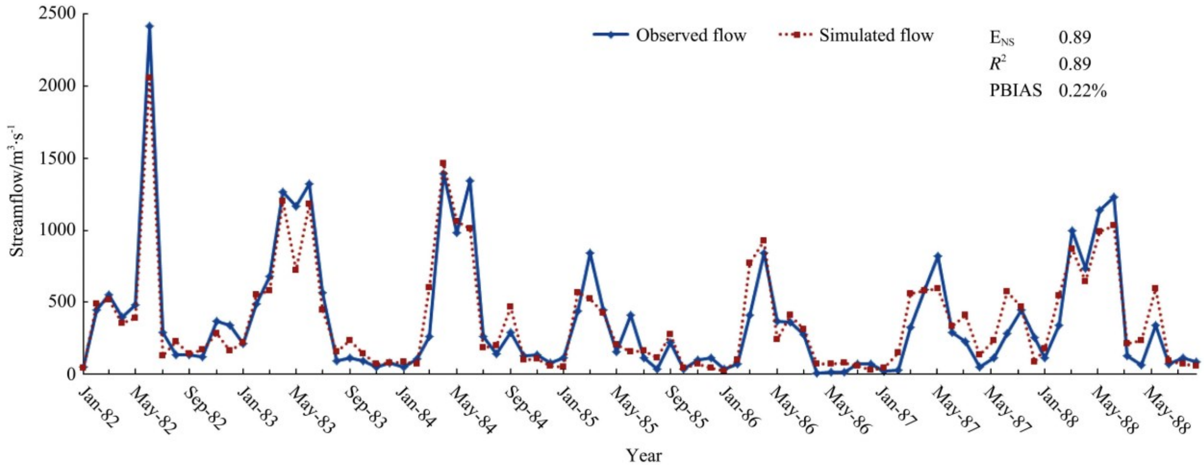

Figure 4 Time series of the observed and simulated monthly streamflow for Lijiadu hydrologic station from 1982 to 1988 (Calibration period)

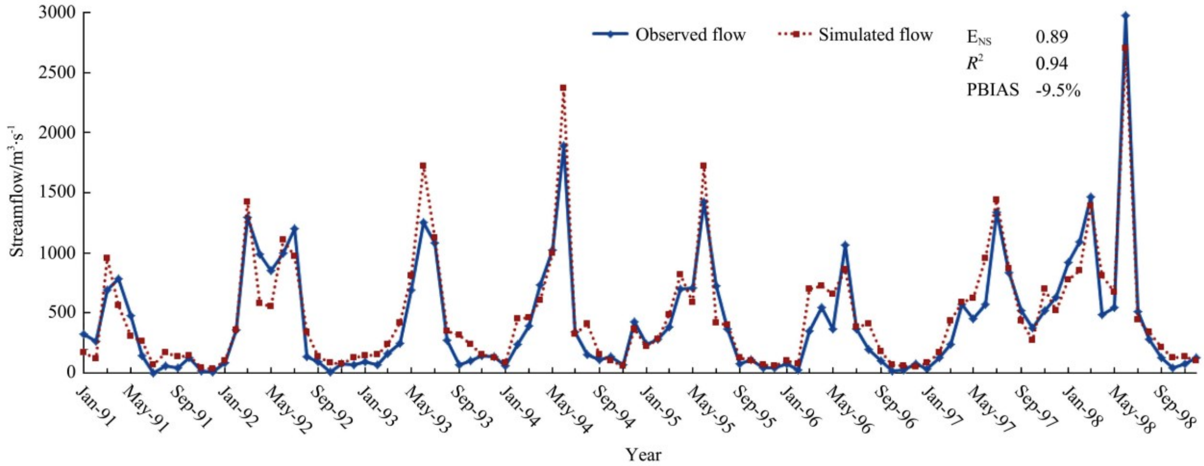

Figure 5 Time series of observed and simulated monthly streamflow for Lijiadu hydrologic station from 1991 to 1998 (Validation period)

The additional spatial cross-validation between observed and simulated monthly streamflows for 2010 at the other seven monitoring gages is presented in Figure 6. Except for the Taopi station, the E_{NS} and R^2 values are all above 0.85. These results, coupled with the results described above at the Lijiadu gauging station near the watershed outlet, suggest that the overall results of the calibrated model were very strong per the previously described criteria[30] and additional extrapolation of those suggested criteria for the R^2 statistic[10]. The results further indicate that SWAT can be used to analyze the relationship between LULC and the Fuhe River watershed water budget.

3.3 Response of water budget to real LULC scenarios

The effects of the implementation of the CCFGP are shown in Figure 4 via plots of aggregated annual surface runoff, groundwater recharge and ET over 1982 to 1998, and long-term average monthly values of the same three water balance components in Table 4, for the baseline and two historical scenarios. The plots of the water balance components in Figure 4 reveal that very slight impacts were predicted between the 1990 baseline and the 2000 historical land use (scenario 1), and that somewhat larger impacts occurred between 2000 and 2009 (scenario 1 versus scenario 2). Based on the monthly averages listed in Table 4, the scenario 1 surface runoff increased 3.5%, ET decreased 0.7%, and groundwater recharge decreased 2.5 relative to the baseline. Larger impacts were predicted for the CCFGP changes that occurred during the second decade, as evidenced by an increase in the surface runoff of 5.8%, a decrease in the groundwater recharge of 8.5%, and an ET decrease of 0.9% between scenario 2 and scenario 1. These results are consistent with the existing research[37] that also showed that moderate land use changes resulted in minor changes in the water budget.

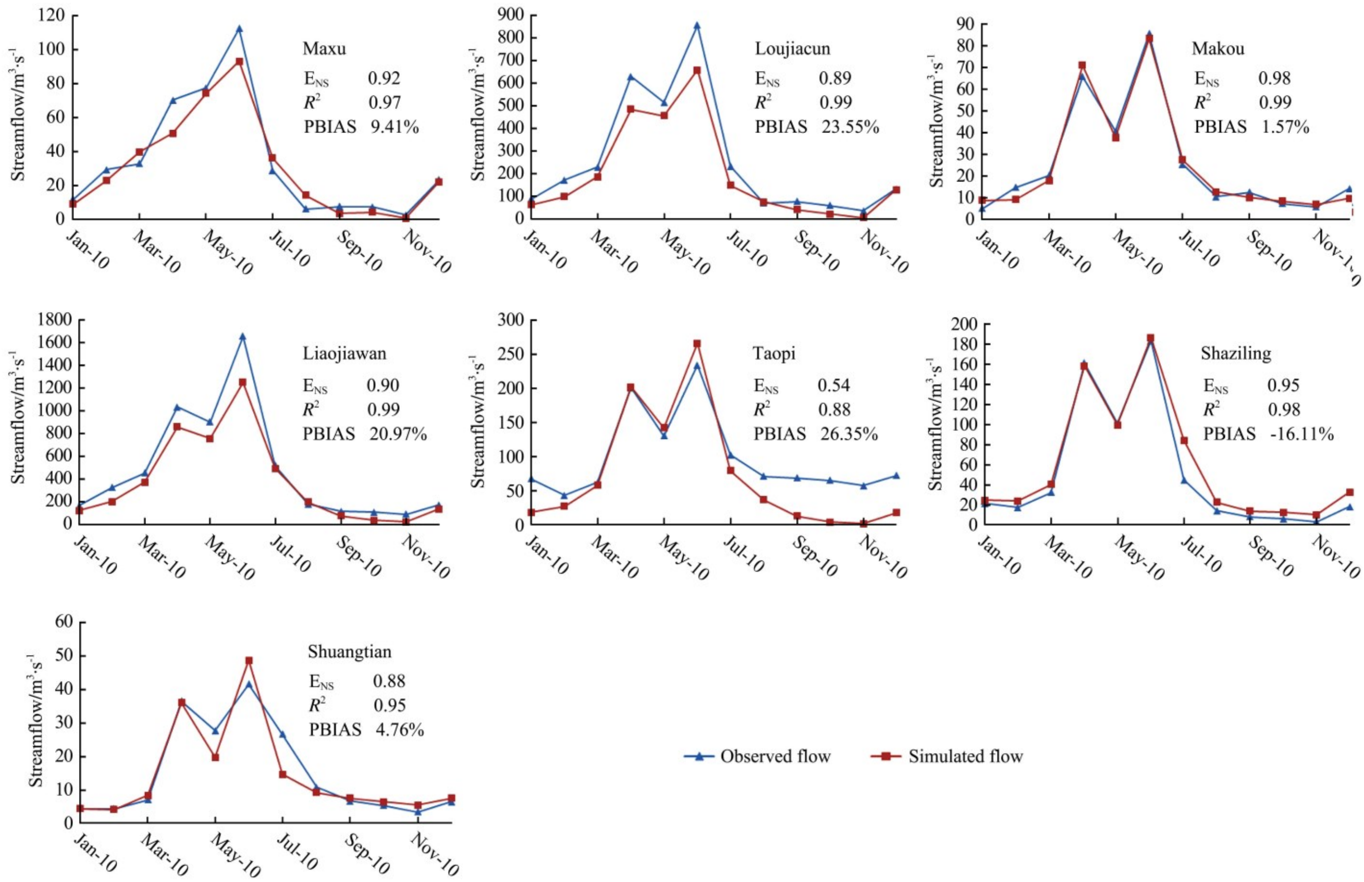

Figure 6 Validation results for other 7 hydrologic stations (Figure 1) based on comparisons between observed and simulated streamflows in 2010

Table 4 Simulated average monthly water components for scenarios 1 and 2 at Lijiadu hydrologic station for 1982 to 1998

Scenario	Surface runoff /mm	Groundwater recharge /mm	Evapotranspiration /mm
Baseline	49.0	23.5	77.2
Scenario 1	50.7	22.9	76.6
Scenario 2	53.6	21.0	75.9

China adopted the "Conversion of Cropland to Forest and Grassland Program" (CCFGP) to minimize wide-scale soil erosion and vegetation degradation. Table 2 shows that afforestation projects were in progress over a period of two decades as a result of this program, which resulted in a conversion of about 1% of the paddy field area into forest by the year 2000. However, almost 4% of the paddy field area was transformed into bare and urban land during that same time period and the urban area expanded by a rate of about 1% per decade. Thus, the increase in surface runoff shown in Figure 7 for scenario 1 can be mainly attributed to the expansion of urban area between 1990 and 2000. These results further underscore that much of the water budget improvements that occurred due to the afforestation efforts during the first decade were likely offset by the increased of urban land. Similar impacts are implied by the stronger responses predicted for scenario 2 (2009 land use) as shown in Figure 7. The continuing afforestation projects again likely resulted in some improvement of overall the water budget status in the Fuhe River watershed, including some reduction of surface runoff. However, the fast-paced residential and commercial developments appear to have had an overall greater influence on the water budget as compared to CCFGP efforts.

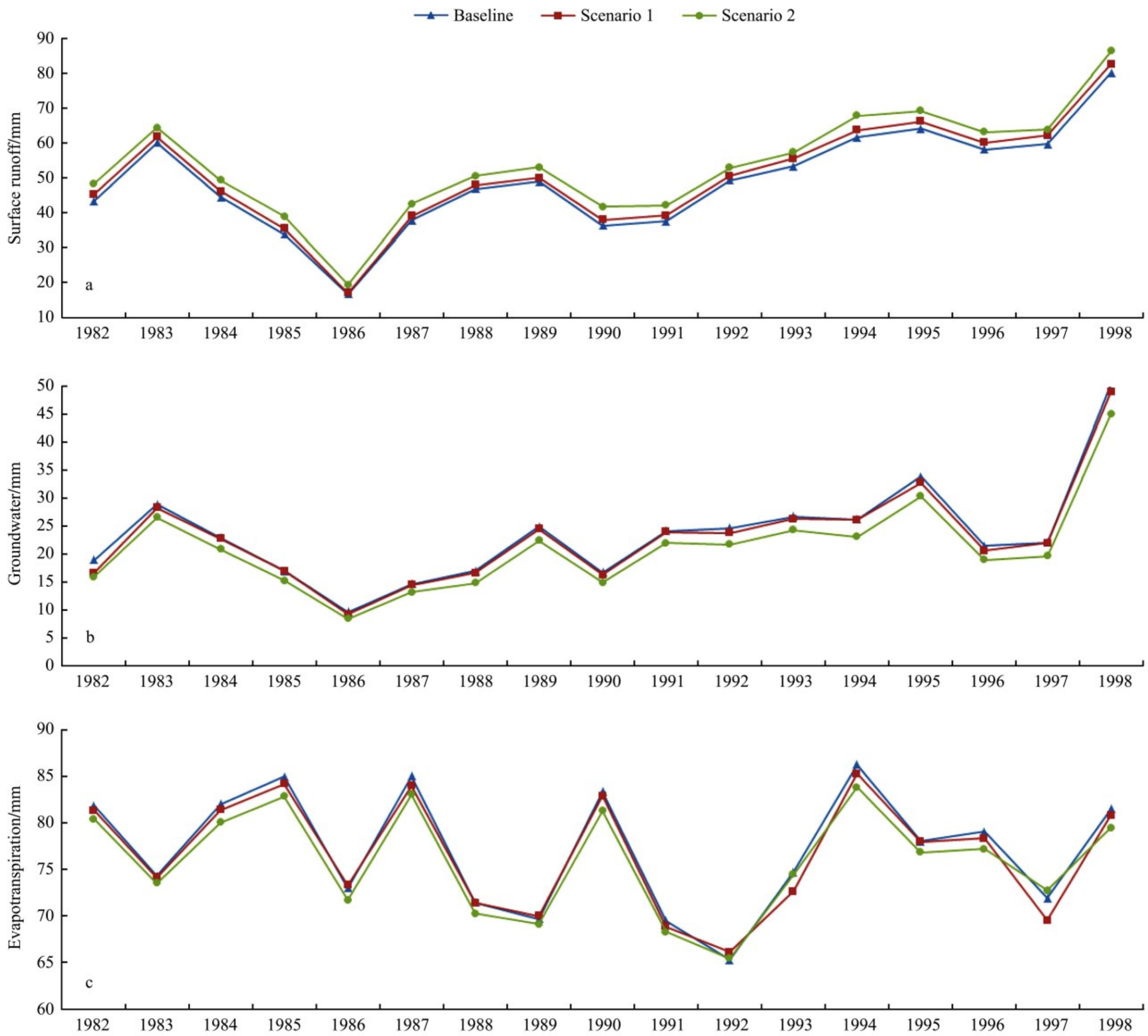

Figure 7 Comparison of (a) surface runoff, (b) groundwater recharge, and (c) evapotranspiration results between the baseline and scenarios 1 and 2

3.4 The responsiveness of the water budget to hypothetical LULC scenarios

Graphical comparisons of the annual water budget components over the 1982 to 1998 simulation period for the baseline and the four hypothetical scenarios (scenarios 3 to 6; Table 2) are shown in Figure 8 and the long-term average monthly water component values for the baseline and four hypothetical scenarios are listed in Table 5. The predicted impacts were generally linear relative to the baseline levels (Figure 8). Surface runoff decreased 26.5%, 5.5% and 6.1%, groundwater recharge increased 41%, 9.5% and 11%, and ET increased 42%, 0.6% and 1.8% across scenarios 3 to 5, based on the long-term average monthly values shown in Table 5. Surface runoff increased 10.5%, groundwater recharge decreased 8.5%, and ET decreased 3.8% in scenario 6. The total conversion of rice paddy area to forest (scenario 3) resulted in by far the largest impacts of any of the hydrological scenarios and reveals the potential overall impact on the Fuhe watershed water budget in response to an "extreme CCFGP scenario."

The scenario 4 and 5 results (Figure 8 and Table 5) were greater than hydrological impacts predicted for the first decade of historical change (scenario 1; Figure 7 and Table 4) but were similar to the impacts predicted for the second decade of historical change (scenario 2; Figure 7 and Table 4). However, the overall hydrologic impacts of scenarios 3 and 6 (Figure 8 and Table 5) were greater than hydrological impacts estimated for scenario 2.

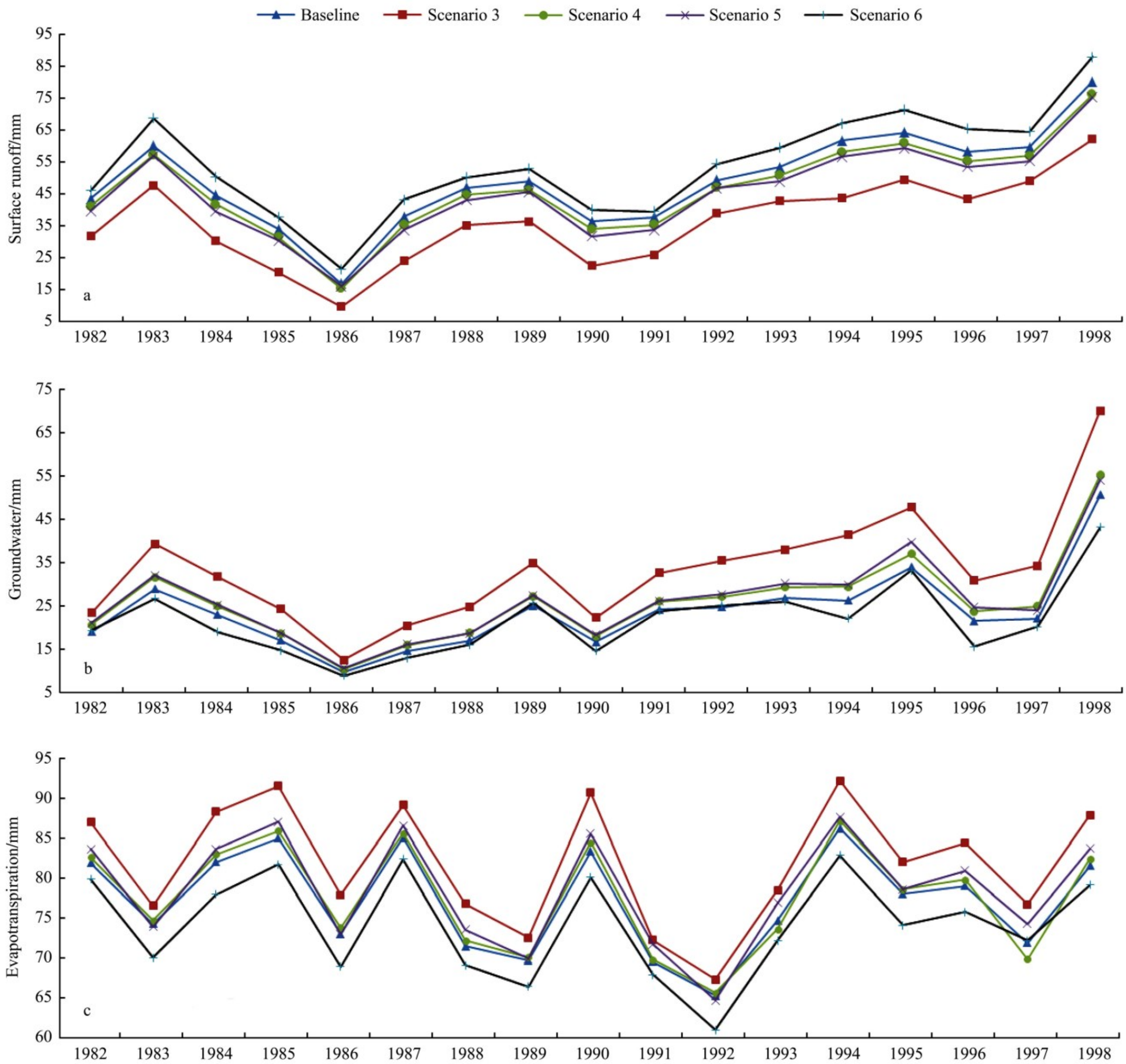

Figure 8 Comparison of key hydrologic component results between the baseline scenario and scenarios 3-6 for (a) surface runoff, (b) groundwater recharge, and (c) evapotranspiration

Table 5 Simulated average monthly water components under hypothetical scenarios at the Lijiadu hydrologic station

Scenarios	Surface runoff/mm	Groundwater Recharge/mm	Evapotranspiration /mm
Baseline	49.0	23.5	77.2
Scenario 3	36.0	33.1	81.9
Scenario 4	46.3	25.7	77.6
Scenario 5	45.0	26.1	78.6
Scenario 6	54.1	21.5	74.2

Comparing the scenario 3 and scenario 5 results, it can be inferred that forest lands and pasture lands amplify soil infiltration as compared with paddy fields, resulting in more groundwater recharge. In addition, pasture lands have lower transpiration and interception rates as compared with forested areas. The increase of ET can be explained by the increase of forested areas, which results in an increased evaporation effect from leaves. Only from the result in scenario 4, more forest also results in less surface runoff, more groundwater recharge, and less ET than agricultural land. It means that forest has a greater capacity to conserve water than does pasture and agricultural land.

The trend in the result of scenario 5 shows that more paddy fields results in more surface runoff, less groundwater recharge, and less ET than pasture lands. However, it is useful to note that rice paddies were always irrigated by large quantities of water in the baseline and the scenarios, thus the soil was saturated with water most of time. Thus, less rainfall infiltrated into the soil and groundwater, resulting in much of the rainfall being transformed into runoff. Considering the main water budget components changes in the scenario 6 results, we infer that agricultural land show a better capacity to conserve water than pasture land.

The effects of the CCFGP over a 10-year period on the water budget of the Jinghe River watershed in China were investigated in a previous study[17]. After the implementation of the CCFGP, forest and grassland increased while bare land and cropland decreased, resulting in decreased surface runoff and evapotranspiration but increased streamflow of about 15% to 20% for the upstream and middle stream subwatersheds, respectively. As a result, the overall Jinghe River watershed water budget and ecological environment improved under the CCFGP policy[17]. Table 6 shows that after the implementation of the CCFGP, streamflow decreased slightly in the Fuhe River watershed. However, the results of the two historical scenarios (scenarios 1 and 2; Table 4 and Figure 7) showed that the overall trends of surface runoff increased under the CCFGP policy in the Fuhe River watershed, indicating that the ecological environment had become more degraded. Combined with the discussion pertaining to hypothetical scenarios 3-6 (Table 5 and Figure 8), it can be inferred that other factors, such as the expansion of urban area, offset the potential positive effects of the CCFGP in the Fuhe River watershed.

Table 6 Simulated average annual streamflow under different scenarios at the Lijiadu hydrologic station

Scenarios	Baseline	Scenario 1	Scenario 2
Streamflow/$m^3 \cdot s^{-1}$	426.2	422.9	422.0

These conclusions from hypothetical scenarios are consistent with some previous research from different regions around the world. The Poyang Lake watershed was chosen as the study area in another study, in which the authors evaluated different Land-cover change scenarios[38]. They concluded that ET was greater for forest land as compared to agricultural land. They inferred that the deep roots of forest plants draw moisture from soil faster than water being transpired by short rooted agricultural plants or bare soil. In addition, forest plants have larger leaf areas for transpiration. Another previous study reported similar results and inferred that forest covers the soil throughout the year with litter, and thus a high percentage of rainfall is held back by canopy storage[14]. They found that even during the dry period in autumn, the extended root system of trees is still capable of water uptake from lower soil zones, and therefore ET still proceeds at higher rates than in agricultural fields.

In another study, two different hypothetical scenarios were analyzed in which the agricultural areas were changed to coniferous forest or the coniferous forests were changed to agricultural areas[39]. The authors found that the ET increased and the surface runoff decreased due to the larger spatial amount of forested areas. They stated that the higher water consumption of coniferous forest in comparison to agricultural crops and the larger storage capacity of the soils beneath forests, resulted in less direct runoff after soil saturation is exceeded. Thus it can be concluded based on their findings as well as the results founds in this study, that more agricultural land and more pasture land leads to more runoff than forest land, and inversely, ET increases and surface runoff decreases as forest area increases.

4 Conclusions

This study shows that the effect of land use change resulting from various land use tendencies plays an important role in the changing basin hydrology of the Fuhe River basin of Poyang Lake. This paper used extreme land use scenario method based on a modeling approach, which is an important way to research how LULC impacts hydrological processes. It represents the possible range of hydrological fluctuation effects well, and also confirms the sensitivity of the model. Our research confirms that the SWAT model can be used to assess the impact of different land use scenarios on water budget characteristics in the Fuhe River basin with satisfactory accuracy.

In the historical scenario1, paddy fields were roughly converted to 1% forest land and 1% urban land. From subsection 3.4, paddy fields were found to generally produce the most runoff and forest land generally produced the least runoff, resulting in a slight increase in surface runoff of 3.5% in historical scenario 1. The decrease in paddy fields and increase in other land use types did not greatly improve the water budget. The increase of surface runoff indicates that the status in this watershed had degraded. It can be inferred that urban land had a negative impact on the regional water budget. In the historical scenario 2, the forest land increased 3.5%, meanwhile pasture land and agriculture land in total decreased 3.8%. The urban land increased by only 1%, but in this scenario, the average surface runoff increased by 5.8%, thus the water budget became more degraded than in the historical scenario 1. It can be speculated that the impact of the increase of urban land is nonlinear. Small increases in urban land are a strong environmental stressor.

Results from four hypothetical LULC scenarios showed that under the same precipitation, basin slope and soil texture conditions, paddy fields generally produced the most runoff, least groundwater recharge and the least ET. Forest land generally produced the least runoff, most groundwater recharge and the largest ET. The runoff, groundwater recharge and ET generated from agricultural land and pasture generally fell between those generated, respectively, from forest land and paddy fields.

Combined with the discussion above, we can speculate that the CCFGP policy has not greatly improved the water budget and hydrologic environment in Fuhe River, but offset the adverse effects of the increase in urban land use patterns. The approach used in this study simply determined contributions of changes for LULCs to hydrological components, providing quantitative information for stakeholders and decision makers to make better choices for land and water resource planning and management. The outputs also provide important references for the effects of CCFGP in Fuhe River. The implementation of CCFGP was not enough to improve regional water budget, controlling the population size to a reasonable level and decreasing the area of urban land should be considered in this policy. In the future work, we will continue to research the influence of urban growth and climate on water budget in this watershed, and reappraise the implementation of the CCFGP policy in Fuhe River.

One key weakness in the simulation approach used in this study was the simplistic way in which rice was simulated, which does not reflect the actual water balance dynamics that occur in actual rice production systems. The SWAT2009 user manual recommends that users simulate rice paddies using the HRU pothole function available in SWAT. However, recent research has shown that neither this recommended pothole approach or the approach used in this study (with runoff based on curve numbers) accurately capture rice paddy system dynamics[40]. Thus there is a need for further revisions in SWAT to more accurately simulate rice paddy dynamics as discussed in other recent studies[41-43].

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