

## Runoff Simulation in the Qingshui River Basin of Ningxia under Climate and Land Use Change (Postprint)

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### Abstract

Climate and land use change are the most direct factors affecting water resources variation. The SWAT model was applied to conduct multi-scenario simulation and prediction of runoff in the Qingshui River Basin, a small watershed in the arid and semi-arid region of Ningxia. Future climate and land use change scenarios were established based on historical climate element variation trends and the CA-Markov model, respectively. The coefficient of determination  $R^2$  and the Nash-Sutcliffe efficiency coefficient  $Ens$  (Nash-Sutcliffe efficiency coefficient) were employed to measure the goodness-of-fit between simulated and observed values and to evaluate the model's applicability in the Qingshui River Basin. The results demonstrated that at the Hanfuwan station,  $R^2$  values were 0.80 and 0.71, and  $Ens$  values were 0.77 and 0.69 during the calibration and validation periods, respectively; at the Quanyanshan station,  $R^2$  values were 0.66 and 0.63, and  $Ens$  values were 0.62 and 0.56 during the calibration and validation periods, respectively, indicating that the constructed SWAT model is suitable for runoff simulation in the Qingshui River Basin. Simulation results of runoff under future climate and land use change scenarios revealed that runoff variation is primarily dominated by precipitation changes, and the combined effect of precipitation reduction and temperature increase exerts the most significant impact on watershed runoff variation. Due to increases in cultivated land and construction land, watershed runoff will show a significant increasing trend under all three future land use scenarios. Compared with 2010, runoff will increase by 17.04% under the natural growth scenario, 14.44% under the forest protection scenario, and 13.98% under the planning scenario by 2020. Integrated scenarios combining changes in precipitation, temperature, and land use indicate that future watershed runoff will decline to varying degrees, with the combined planning scenario and climate change scenario showing the most

pronounced runoff decrease, while the forest protection scenario, which intentionally increases forest area and strengthens ecological conservation, plays a certain role in mitigating the decline in watershed runoff. Against the backdrop of climate change, according to water resources utilization and management objectives, negative impacts of climate change on watershed water resources can be mitigated by adjusting watershed management measures, particularly land use changes and improving regional microclimate, thereby improving watershed runoff and ecological environmental conditions.

## Full Text

### Preamble

#### Runoff Prediction for Ningxia Qingshui River Basin Under Scenarios of Climate and Land Use Changes

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**Abstract:** Climate and land use changes are critical factors that directly influence water resources. To predict runoff under these changes in the Ningxia Qingshui River Basin—a typical arid and semi-arid basin in the Yellow River Valley—we calibrated and validated the distributed hydrologic SWAT model using the coefficient of determination ( $R^2$ ) and Nash-Sutcliffe efficiency coefficient (Ens) at the Hanfuwan and Quanyanshan hydrological stations. Future climate and land use change scenarios for 2020 were developed based on historical climate trends and the CA-Markov model. The calibration and validation results showed that at Hanfuwan station,  $R^2$  values were 0.80 and 0.71, and Ens values were 0.77 and 0.69 for the calibration and validation periods, respectively. At Quanyanshan station,  $R^2$  values were 0.66 and 0.63, and Ens values were 0.62 and 0.56, respectively. These results indicate that the SWAT model can be applied to simulate runoff in the Qingshui River Basin under climate and land use changes.

Our findings demonstrate that runoff is dominated by precipitation, with the combined scenario of reduced precipitation and increased temperature having the most significant impact. Runoff is expected to increase under future land use scenarios due to expanding farmland and built-up areas. Compared to 2010, runoff in 2020 would increase by 17.04%, 14.44%, and 13.98% under natural

growth, planned development, and woodland/ecological protection scenarios, respectively. However, when combining land use and climate change scenarios, runoff is projected to decrease under all combinations. The most substantial decrease occurs under the combination of planned development and climate change scenarios, while woodland/ecological protection measures help slow the rate of runoff decline under all climate change scenarios. Therefore, in the context of climate change, ecologically prudent construction and land-use management are necessary to address the severe challenges of runoff change in the Qingshui River Basin.

**Keywords:** climate change; land use change; Ningxia Qingshui River Basin; SWAT model; runoff prediction

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## 1. Study Area Overview

The Qingshui River in Ningxia originates from Heicigounao, Kai Town, Yuanzhou District, Guyuan City, at the eastern foothills of the Liupan Mountains. It flows northward through Yuanzhou District in Guyuan City, Tongxin County in Wuzhong City, and Zhongning County, eventually joining the Yellow River west of Quanyanshan. The river spans 303 km with a basin area of 13,511 km<sup>2</sup>. The basin's geographical location ranges from 105°12 E to 106°38 E and 35°53 N to 37°28 N. Topographically, the basin is higher in the south and lower in the north, characterized by complex terrain dominated by loess hills. The western side consists of loess hills, the middle and upper reaches form alluvial-pluvial plains, the middle-eastern section comprises loess hill regions, and the lower reaches are valley plains. The basin experiences a temperate semi-arid climate with uneven spatiotemporal precipitation distribution, concentrated in summer. The multi-year average precipitation is 335 mm, decreasing from 600 mm upstream to 1400 mm downstream, while the multi-year average evaporation is 1400 mm and the average temperature is 6.2°C.

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## 2. SWAT Model Construction for the Study Area

### 2.1 Model Input Data

Model input data included: (1) DEM data at 90 m × 90 m resolution from the International Scientific Data Service Platform; (2) Land use data derived from Landsat TM imagery; (3) Soil data comprising spatial distribution and physical properties, with soil mechanical composition converted from international to U.S. standards; (4) Meteorological data from six stations within and around the basin, including daily observations from 1995-2011; and (5) Hydrological data comprising monthly runoff measurements from 2001-2011 at the Hanfuwan (midstream) and Quanyanshan (downstream) hydrological stations.

## 2.2 Model Calibration and Validation

ArcSWAT was used to build the Qingshui River Basin model. The calibration and validation were performed using SWAT-CUP, as the built-in parameter sensitivity analysis and calibration tools in SWAT are relatively weak. Following the top-down calibration principle, 2000 served as the warm-up period, 2001-2005 as the calibration period, and 2006-2011 as the validation period. Parameter sensitivity analysis and calibration were first conducted for the section above Hanfuwan station, then for the Hanfuwan-to-Quanyanshan reach.

## 2.3 Model Applicability Evaluation

The coefficient of determination ( $R^2$ ) and Nash-Sutcliffe efficiency coefficient (Ens) were selected to evaluate model performance.  $R^2$  indicates the agreement between simulated and observed values, with values above 0.70 considered accurate and above 0.50 acceptable. Ens assesses hydrological model performance, with ranges of 0.75-1.00 indicating very good fit, 0.65-0.75 good, and 0.50-0.65 satisfactory.

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## 3. Scenario Development

### 3.1 Climate Change Scenarios

Based on Ningxia climate zoning and basin characteristics, the Qingshui River Basin was divided into northern, central, and southern sub-regions. Using 2010 as the baseline and analyzing precipitation and temperature trends from 1960-2011, three climate scenarios were developed:

- **C1 (Precipitation change only):** Northern region: +10.05 mm in flood season, -2.57 mm non-flood; Central: -11.84 mm flood, -4.68 mm non-flood; Southern: -0.87 mm flood, -2.34 mm non-flood.
- **C2 (Temperature change only):** Northern: +0.49°C max, +0.59°C min; Central: +0.38°C max, +0.59°C min; Southern: +0.39°C max, +0.71°C min.
- **C3 (Combined precipitation and temperature change):** Simultaneous application of C1 and C2.

### 3.2 Land Use Change Scenarios

Based on historical land use changes and future development plans, the CA-Markov model simulated 2020 land use patterns. Three scenarios were established relative to 2010 baseline (S0):

- **S1 (Natural growth):** Land use evolves according to existing trends.
- **S2 (Planning scenario):** Follows 2020 land use master plan, strictly limiting encroachment on woodland and water areas.
- **S3 (Woodland protection):** Based on S2, all farmland is converted to forest through the Grain-for-Green program.

[Figure 2: see original paper] Distribution of land use types in Qingshui River basin of 2020

### 3.3 Combined Climate and Land Use Change Scenarios

Since climate and land use changes act synergistically on runoff, nine combined scenarios were developed (Table 1).

Scenarios of climate and land use combination

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## 4. Results and Analysis

### 4.1 Model Calibration and Validation

Twelve runoff-related parameters were selected for sensitivity analysis. The most sensitive parameters for the Qingshui River Basin were: CN2 (SCS runoff curve number), CH\_N2 (Manning's  $n$  for main channel), CANMX (maximum canopy storage), and ALPHA\_BNK (baseflow alpha factor for bank storage). These indicate that runoff generation is significantly influenced by vegetation cover and channel storage capacity.

Calibration results showed that for Hanfuwan station, monthly runoff  $R^2$  was 0.80 and Ens was 0.77, indicating satisfactory performance. For Quanyanshan station,  $R^2$  was 0.66 and Ens was 0.62. Validation results remained acceptable, with Hanfuwan achieving  $R^2$  of 0.71 and Ens of 0.69, and Quanyanshan achieving  $R^2$  of 0.63 and Ens of 0.56. The model performed better in the upper reaches above Hanfuwan than in the lower reaches, as the sequential calibration process propagated uncertainties downstream.

Sensitivity analysis of the parameters

Calibration and validation of SWAT model for monthly runoff in Qingshui River basin

### 4.2 Runoff Simulation Under Climate Change Scenarios

Simulations for Quanyanshan station showed that under precipitation-only changes (C1), runoff decreased by 1.82%. Under temperature-only changes (C2), runoff decreased by 3.82%. Under combined precipitation and temperature changes (C3), runoff decreased by 5.13% to 1.180 m<sup>3</sup>/s. Precipitation reduction dominated runoff changes, with temperature increase exacerbating the decline. This aligns with studies in northwest China showing precipitation as the primary driver of runoff in arid regions.

Changes of runoff under climate scenarios in Qingshui River basin

### 4.3 Runoff Simulation Under Land Use Scenarios

All three land use scenarios projected increased runoff compared to 2010 baseline (1.244 m<sup>3</sup>/s):

- **S1 (Natural growth):** 1.456 m<sup>3</sup>/s (+17.04%)
- **S2 (Planning):** 1.424 m<sup>3</sup>/s (+14.44%)
- **S3 (Woodland protection):** 1.418 m<sup>3</sup>/s (+13.98%)

The increases were driven by expanded farmland and built-up areas, particularly slope farmland in hilly regions, which significantly increases runoff. However, this may exacerbate soil erosion. Woodland protection scenarios showed that increasing ecological land can mitigate runoff decline while providing environmental benefits.

Changes of runoff under land use scenarios  
Structure of land use types in 2020

### 4.4 Runoff Simulation Under Combined Scenarios

Under combined climate and land use changes, all scenarios projected runoff decreases:

- **Precipitation reduction (C1):** Runoff changes ranged from -0.67% to -3.41%
- **Temperature increase (C2):** Changes ranged from -1.62% to -4.24%
- **Combined changes (C3):** Changes ranged from -3.87% to -5.13%

The S2+ C3 combination (planned development with climate change) showed the largest decrease (-5.13%), while S3+ C3 (woodland protection with climate change) showed the smallest (-3.87%), demonstrating that ecological protection measures can effectively buffer climate change impacts.

Changes of runoff under combination scenarios

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## 5. Conclusions and Discussion

This study developed a distributed hydrological model for the Ningxia Qingshui River Basin and evaluated its applicability. The SWAT model is suitable for runoff simulation in this basin, particularly in the upper reaches, though performance decreases downstream. Future research should focus on refining data collection to improve simulation accuracy.

Key findings include:

1. **Climate change impacts:** Runoff decreases under all climate scenarios, dominated by precipitation changes. The combined effect of reduced precipitation and increased temperature is most significant.
2. **Land use impacts:** Runoff increases under all land use scenarios due to farmland and construction expansion, with natural growth showing the largest

increase.

**3. Combined impacts:** Under realistic combined scenarios, runoff is projected to decrease, with the S2+ C3 scenario showing the most substantial decline. Woodland protection measures (S3) can effectively mitigate runoff reduction.

In the context of climate change, adjusting watershed management practices—particularly through strategic land use changes and microclimate improvement—can help alleviate negative impacts on water resources. Future watershed management should prioritize ecological protection by converting slope farmland to forest and grassland, improving soil microenvironments, and reducing evaporation. These measures can slow runoff decline and even increase water yield, providing scientific guidance for water resource management, ecological conservation, and policy development in the Qingshui River Basin and other arid/semi-arid regions.

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## References

[1] …(preserving original reference list)

*Note: Figure translations are in progress. See original paper for figures.*

*Source: ChinaXiv –Machine translation. Verify with original.*