Simulation of Daily Runflow in the Mainstream Tarim River under Future Climate Scenarios (Postprint)

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Abstract

Taking the mainstream of the Tarim River as the study area, this study employed the distributed MIKE SHE hydrological model to identify various underlying surface parameters at the daily scale. Observed meteorological data from six meteorological stations (Alar, Baicheng, Kuqa, Luntai, Korla, and Tikanlik) within the mainstream from 1998 to 2007 were selected, and the model was calibrated and validated using observed data from three hydrological stations (Xinqiman, Yingbaza, and Qiala) along the mainstream from 1998 to 2007. Combined with temperature and precipitation data from the HadGEM2-ES climate model, the evolution characteristics of runoff in the Tarim River mainstream under future climate scenarios (2021–2050) were projected. The results indicate:
The MIKE SHE model was used to simulate the daily runoff process in the Tarim River mainstream, with model efficiency coefficients all exceeding 0.72, indicating strong model applicability. Over the next 30 years, the multi-year monthly average temperature in the Tarim River mainstream will increase by 1.7–2.2°C compared to the baseline period (1981–2004), with greater warming in summer and autumn; precipitation will show an overall increasing trend, with larger increases in spring and smaller increases in autumn. Under future climate scenarios, the annual average runoff at each hydrological station shows a decreasing trend, most significantly in summer and autumn ($P < 0.01$). Among them, the Qiala hydrological station in the lower reaches shows the largest reduction in average runoff (5.04%), while the Xinqiman hydrological station in the upper reaches shows the smallest reduction (0.6%). Across the climate emission scenarios, the reductions at each hydrological station are smallest under RCP2.6 (low emission scenario) and largest under the RCP8.5 high emission scenario. Under future climate scenarios, the decreasing trend of annual runoff in the Tarim River mainstream will pose greater difficulties for regional water resource allocation, greater threats to ecological security, and will also intensify conflicts in the regional human-land relationship.

Full Text

Abstract

Taking the mainstream of the Tarim River as the research area, this study applies the distributed hydrological model MIKE SHE to identify various underlying surface parameters of the river' s mainstream under daily-value dimensions. Observed data from six meteorological stations (Alar, Baicheng, Kuche, Luntai, Kuerle, and Tiegianlike) from 1998-2007 were utilized, along with observed discharge data from three hydrometric stations (XinQiman, Yingbazha, and Chara) for model calibration and validation. Combining air temperature and rainfall data from the HadGEM2-ES climate model, the study estimates future runoff evolution features (2021-2050) of the Tarim River mainstream under climate scenarios. The results indicate that: (1) The MIKE SHE model was adopted to simulate runoff processes, with model efficiency coefficients exceeding 0.72, demonstrating strong applicability; (2) In the next 30 years, the monthly average temperature of the Tarim River mainstream will increase by 1.7-2.2°C compared with the baseline period (1981-2004), with obvious temperature rises in summer and autumn, while rainfall overall shows an increasing trend with higher increases in spring and lower increases in autumn; (3) Under future climate scenarios, annual runoff volume at various hydrometric stations shows a decreasing trend, with obvious decreases in summer and autumn ($P < 0.01$). The downstream Chara station has the largest decrease rate (5.04%), while the upstream XinQiman station shows the opposite trend (0.6%). Under various climate emission scenarios, RCP2.6 shows the smallest decrease rate compared with RCP8.5 at various hydrometric stations. The annual runoff of the Tarim River mainstream under future climate scenarios shows a decreasing tendency, causing greater difficulties in allocating regional water resources and posing greater threats to ecological security. Meanwhile, contradictions in regional man-earth relationships will also be aggravated.

Keywords: Daily runoff model; Mainstream of Tarim River; Climate change; MIKE SHE

1. Study Area and Data

[FIGURE 1] Boundary, river network and rainfall stations in mainstream of Tarim River

2. Data and Methods

2.1 Data Sources and Processing

Meteorological data from six stations (Alar, Baicheng, Kuche, Luntai, Kuerle, and Tiegianlike) for the period 1998-2007 were collected. Hydrometric discharge data from three stations (XinQiman, Yingbazha, and Chara) for 1998-2007 were used for model calibration and validation. The Delta method [?] was applied to correct the HadGEM2-ES climate model data. The correction results of HadGEM2-ES data are shown in [TABLE 1].

Soil type data were obtained from the Harmonized World Soil Database at 1 km × 1 km resolution, including five soil types: sand clay loam, silt loam, loam clay, sand, and clay loam. Land use data were also acquired at 1 km × 1 km resolution. A 1:250,000 DEM was used for topographic information. The Penman-Monteith equation [?] was employed to calculate reference evapotranspiration (ET) for the 1998–2007 period:

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$$

where ET_0 is reference evapotranspiration (mm · d ¹); R_n is net radiation at the crop surface (MJ · m ² · d ¹); G is soil heat flux density (MJ · m ² · d ¹); T is mean daily air temperature at 2 m height (°C); u_2 is wind speed at 2 m height (m · s ¹); e_s is saturation vapor pressure (kPa); e_a is actual vapor pressure (kPa); Δ is slope of the vapor pressure curve (kPa · °C ¹); and γ is the psychrometric constant (kPa · °C ¹).

[TABLE 2] Data list of the MIKE SHE model of mainstream of Tarim River

Model performance was evaluated using the correlation coefficient (CORR) and Nash-Sutcliffe efficiency coefficient (NS) [?]:

$$CORR = \frac{\sum_{i=1}^{n}(O_i - \bar{O})(S_i - \bar{S})}{\sqrt{\sum_{i=1}^{n}(O_i - \bar{O})^2 \sum_{i=1}^{n}(S_i - \bar{S})^2}}$$

$$NS = 1 - \frac{\sum_{i=1}^{n}(O_i - S_i)^2}{\sum_{i=1}^{n}(O_i - \bar{O})^2}$$

where O_i represents observed discharge (m³ · s ¹); S_i represents simulated discharge (m³ · s ¹); $\bar{O}$ is the mean observed discharge; and $\bar{S}$ is the mean simulated discharge.

3. Model Calibration and Validation

3.1 Parameter Calibration

Following Refsgaard [?, ?], the MIKE SHE model parameters were calibrated considering: (1) the physical meaning of parameters and their reasonable ranges, including soil hydraulic parameters, Manning' s roughness coefficients, and land use parameters; and (2) parameter sensitivity and uncertainty. The model was calibrated using 1998–2003 data, with 2004–2007 data used for validation. Calibration focused on daily runoff processes at the three hydrometric stations.

[TABLE 3] Result of values of the calibrated parameters

3.2 Validation Results

The validation results demonstrate that the MIKE SHE model effectively simulates daily runoff processes in the Tarim River mainstream. Model efficiency coefficients exceed 0.72 for all stations, indicating strong applicability. The simulated and observed daily runoff comparisons are shown in [FIGURE 2] and [FIGURE 3].

[TABLE 4] Results of MIKE SHE model validation

4. Future Runoff Simulation Under Climate Change Scenarios

Using the calibrated MIKE SHE model, future runoff (2021–2050) was simulated under three RCP scenarios (RCP2.6, RCP4.5, and RCP8.5) based on HadGEM2-ES climate projections. The multi-annual monthly mean runoff changes relative to the baseline period are shown in [FIGURE 5].

The results indicate that under future climate scenarios: (1) Annual runoff shows a decreasing trend at all stations, with significant reductions in summer and autumn ($P < 0.01$); (2) The downstream Chara station exhibits the largest decrease rate at 5.04%, while the upstream XinQiman station shows the smallest decrease at 0.6%; (3) Under different emission scenarios, RCP2.6 shows the smallest decrease rate, while RCP8.5 shows the largest decrease rate; (4) The contradiction between water supply and demand will intensify, particularly affecting ecological security.

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