Future climate changes under different scenarios and their effects on runoff in the upper Taohe River Basin

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Abstract

Climate changes may pose challenges to water management. Simulation and projection of climate-runoff processes through hydrological models are essential means to assess the impact of global climate change on runoff variations. This study focuses on the upper Taohe River Basin which is an important water sources for arid and semi-arid regions in Northwest China. In order to assess the impacts of environmental changes, outputs from a regional climate model and the SWAT hydrological model were used to analyze the future climate change scenarios to water resources quantitatively. The examined climate changes scenarios results showed that average annual temperature from 2020 to 2099 in this area exhibits a consistent warming trend with different warming rates, at rates of 0.10°C/10a, 0.20°C /10a and 0.54°C /10a under RCP2.6, RCP4.5 and RCP8.5(Representative Concentration Pathways, RCPs), The value of precipitation experiences different trends under different emission scenarios. Under the RCP2.6, average precipitation would decrease at a rate of 3.69 mm/10a, while under the RCP4.5 and RCP8.5, it would increase at rates of 4.97 mm/10a and 12.28 mm/10a, respectively. The calibration and validation results in three in-site observations (Luqu, Xiabagou and Minxian) in the upper Taohe River Basin showed that SWAT hydrological model is able to produce an acceptable simulation of runoff at monthly time-step. In response to future climate changes, projected runoff change would present different decreasing trends. Under RCP2.6, annual average runoff would experience a progress of fluctuating trend, with a rate of-$0.6\times10^8m^3$ by 5-year moving average method; Under the RCP4.5 and RCP8.5, annual average runoff would show steadily increasing trends, with rates of $0.23\times10^8m^3$ and $0.16\times10^8m^3$ by 5-year moving average method. The total runoff in the future would prone to drought and flood disasters. Overall, this research results would provide a scientific reference for reginal water resources management on the long term.

Key Words: Future climate change; Emission scenario; Runoff projection; SWAT; Upper Taohe River Basin

1. Introduction

Water resources problem has become a primary problem of global resources and environment in the 21st century, and is also an essential aspect of the development of international earth science (Yang et al.,2019; Wang et al., 2010; Liu et al., 2003; Jia et al., 2001). Globally, temperatures rise due to continuous greenhouse gas emissions have exerted an irreversible impact on climate change, water resources, agriculture, health, energy, and natural system, in the meantime, it also has increased the risk of future ecological environment, economic and social development (Young et al., 2020; Mo et al., 2017; Ge et al., 2014; Aich et al., 2016; Lindner et al., 2010; Piao et al., 2010). How to scientifically assess the impact of future climate change on regional hydrological processes quantitatively has become a hot topic for meteorological and hydrological researchers. Generally, the most scientific approach to predict climate change is based on physical assumptions that describe future global or regional climate change, or climate change scenarios (Moss et al., 2008).

Coupled Model Intercomparison Project 5 (CMIP5) of the 5th Assessment Report (AR5) as the most successful products of General Circulation Models (GCMs), which has four future scenarios, that is, Representative Concentration Pathways (RCP): 2.6, 4.5, 6.0, and 8.5. These scenarios are based on the expected differences in radiation forcing for the future climate. In RCP2.6, scenarios can be found with a year 2100 radiative forcing from as low as 3 W/m^2. In RCP4.5 and RCP6.0, assuming the stabilization of radiative forcing. However, RCP8.5 assumes an increasing radiative forcing to 8.5 $W \cdot m^{-2}$ even after 2100(Kawase et al.,2011, Fisher et al. 2007; Van Vuuren and Riahi 2011). Compared with the global models, the regional climate models (RCMs) with higher resolutions, can not only describe the characteristics of large-scale circulation, but also accurately capture the characteristics of climate change at the regional scale, (Kim et al., 2010; Giorgi et al., 1994 Wang et al., 2016, 2018). Different scenarios generate different prediction trends for future climate change and have been widely used in the studies of global and regional climate change.

Using hydrological models to simulate and predict the mechanism of climate-runoff processes is an important means to assess the impact of global climate change on runoff.。As a typical method of the distributed hydrological model, SWAT (Soil and Water Assessment Tool) model has been successfully applied to the study of major watershed changes worldwide by its mature and stable physical basis, and has become an important tool for the study of water resources utilization and management (Arnold et al., 2012; Srinivasan et al., 1998). The impact of future climate change on regional runoff in China has also become a hot issue of common concern to many domestic scholars (Zhang et al., 2016; Zhou et al., 2015; Gao et al., 2010). For example, Wang et al.(2017) found the annual runoff gradually increases as the area of cultivated land converted to forest land increases in middle and upper reaches of the Weihe River using the SWAT model. Zubaida's study of Urumqi River using SWAT model found the impact of climate change on runoff was more significant than the impact of land use changes (Zubaida et al.,2018). Wang and Liu (2013) used statistical downscaling model to drive SWAT hydrological model to predict runoff of Zamu River in Northwest China. The results showed that the change rates of runoff in SRES A2 and B2 climate scenarios were -10.6 %, 1.17 % and -4 %, 13 %, respectively. Jin et al. (2016) studied the future changes of water resources in Haihe River Basin and found that the water resources will increase slightly from 2021 to 2050, especially in the north zone. In recent years, many researchers have used SWAT model driven by various climate models to study the runoff response of various typical regions, such as the source area of the Yellow River, Yangtze River Basin and other major rivers. These studies, by projecting the future change in regional runoff, have made a great contribution to the understanding of the regional water resources change

Taohe River, a large tributary of the upper reaches of the Yellow River, undertakes the task of water diversion for water scarcity areas in central Gansu Province through the *Taohe River Diversion Project*, and has an key strategic position for the sustainable development of regional social economy. In this study, the middle and upper reaches of Taohe River Basin is selected as the study area. Based on the in-site observations of meteorological and hydrological stations, along with the output data of future climate change scenarios and SWAT hydrological model, the future regional climate changes and their impacts on runoff change are comprehensively analyzed. This research aims at optimizing water resources scheduling and improving water use efficiency, which would promote ecological protection and high-quality development of the Yellow River Basin. and can provide a scientific reference for regional long-term water resources management.

2. Study area

<Fig. 1 is near here>

Taohe River (101°36′–104°20′E, 34°03′–36°01′N) is located in arid and semi-arid areas of northwest China, and is a main tributary of the upper Yellow River. Its total length is about 678 km, and its area is about 25,500 km^2.Taohe River Basin is located in the transitions of Tibetan Plateau and Loess Plateau, which also is a transition area from alpine humid area to warm arid area (Fig. 1(a).(b)).

The upper Taohe river basin is an important water concentration in Northwest China. Its slopes which is susceptible to the influence of the southwest monsoon originated from the Indian Ocean, with an abundant precipitation of 400~600 mm per year. Therefore, the natural runoff gradually occupies more than 68.8% of the whole basin, which is the main runoff generation area and important water supply area of the Tao River Basin (Cheng et al., 2020; Qi et al., 2015; Zhang et al., 2006; Ma et al., 2009). The water systems in the study area are well developed with many symmetrical tributaries (Fig. 1(c)). Generally, the middle and upper reaches of the Tao River is an important ecological barrier in the upper reaches of the Yellow River and plays an important role in maintaining water resources and ecological security in the Yellow River Basin.

3. Data and methods

3.1. Climate change scenario data

The future climate change scenario data used in this paper were derived from the RegCM4.6- based future climate prediction dataset of Northwest China of the National Tibetan plateau Science Data Center(http://data.tpdc.ac.cn/zh-hans/data/). This dataset is based on four different greenhouse gas emission concentrations (RCP2.6, RCP4.5, RCP6.0 and RCP8.5) of HadGEM2-ES of regional climate model RegCM4.6 and global climate model CMIP5, which can simulate and predict the average temperature and precipitation in Northwest China from 2007 to 2099 (Pan et al., 2019).The future climate change output data set has a spatial resolution of 0.25° × 0.25°and temporal intervals of 3 h, daily and yearly covering the northwest China (Gansu, Ningxia, Qinghai, Xinjiang, and Shaanxi Provinces).This study selected climate variables during the period 2007 to 2099 under three different emission scenarios (RCP2.6, RCP4.5 and RCP8.5) in the middle and upper reaches of the Tao River basin/UTB as the forcing data of SWAT model to project future runoff changes.

3.2. Meteorological and hydrological data

<Table 1 is near here>

The data of eight major meteorological stations in the middle and upper reaches of the Tao River and its surrounding areas are selected as the input data of the hydrological model. Information on major weather stations is shown in Table 1. The meteorological station data, during1986-2018, were obtained from the China National Meteorological Data Sharing Website (http://data.cma.cn/). The meteorological elements include wind speed, evaporation, atmospheric pressure, temperature (average temperature, maximum temperature, minimum temperature), average vapor pressure, average relative humidity, precipitation, sunshine hours.

<Table 2 is near here>

The monthly runoff data of representative hydrological stations (Luqu, Xiabagou and Minxianin)the middle and upper reaches of the Tao River(Table 2) from 1986 to 2014 were provided by Gansu Hydrology and Water Resources Bureau.

3.3. SWAT model construction data

The upper Tao River Basin can be extracted and divided into 28 sub-basins and 388 hydrological response units (HRUs) from DEM. The monthly runoff data of three hydrological stations from 1986 to 2010 are regarded as the calibration period and the period from 2011 to 2014 are used to verify. SWAT-CUP is used for parameter sensitivity analysis and uncertainty analysis.

The land use data used in this research are from Resource and Environmental Science Data Center of the Chinese Academy of Sciences (http://www.resdc.cn). There are some differences between China ' s land use classification system and SWAT model, it is necessary to reclassify regional land use data. After reclassification, there are 6 first-level types and 19 second-level types of land use can be procuted in in upper Taohe River Basin. They are divided into 9 new land types (Table 3) to highlight the main land use distribution characteristics of the basin.

<Table 3 is near here>

Data on spatial distribution of soil types were derived from the HWSD(China Soil Map Based Harmonized World Soil Database) Soil Database (http://www.fao.org) jointly issued by the Food and Agriculture Organization of the United Nations (FAO) and the Vienna International Institute for Applied Systems (IIASA) in 2009. Soil type data (China Soil Map Based Harmonized World Soil

Database) from Nanjing Soil Research Institute, Chinese Academy of Sciences, version v1.1 with 1 km resolution, was used to provide reliable soil parameters for SWAT.

<Table 4 is near here>

Note : Calibration method : r_means that the existing parameters will be multiplied by 1 (given value), a_means that the given value will be added to the existing parameters, v_means that the existing parameters will be replaced by the given value.

3.4. Evaluation indicators

The calibration and verification of SWAT model used Nash efficiency coefficient (*NSE*), certainty coefficient R^2 and relative deviation (*RE*) as evaluation indexes to evaluate the simulation results with the measured values. The *NSE* coefficient reflects the fitting degree between the observed and the simulated values. The closer the NSE coefficient is to 1, the better the simulation effect is. If the *NSE* coefficient is greater than 0.5, the simulation of the model is considered to be successful. R^2 is used to characterize the correlation degree of variables, which is used to evaluate the consistency of the change trend between the simulated value and the measured value. The calculated value tends to 1, indicating that the simulation effect is better. It is generally considered that $R^2 > 0.6$ can be used as a criterion for evaluating the correlation between simulated and measured runoff values. *Re* represents the relative deviation between the simulated value and the measured value. The more the calculated value tends to 0, the better the effect is. It is generally believed that Re < 20 %, and the simulation results can be accepted (Xiao, 2010).The formulas for evaluation indicators are presented as Equations (1) – (3).

$$NSE=1-\frac{\Sigma_{i=1}^{n}(Q_{sim}-Q_{obs})^2}{\Sigma_{i=1}^{n}(Q_{obs}-\overline{Q_{obs}})^2} \quad (1)$$

$$R^2=\frac{\left(\Sigma_{i=1}^{n}\left(Q_{obs}-\overline{Q}_{obs}\right)\left(Q_{sim}-\overline{Q}_{sim}\right)\right)^2}{\Sigma_{i=1}^{n}\left(Q_{obs}-\overline{Q}_{obs}\right)^2\Sigma_{i=1}^{n}\left(Q_{sim}-\overline{Q}_{sim}\right)^2} \quad (2)$$

$$Re=\frac{Q_{sim}-Q_{obs}}{Q_{obs}}\times 100\% \quad (3)$$

n represents the length of simulation time; $\overline{Q}_{obs}$ and $\overline{Q}_{sim}$ represent the average values of runoff observation and simulation values in the simulation period, respectively; Q_{obs} and Q_{sim} represent the runoff observation and simulation values in the research time, respectively.

4. Result analysis

4.1. Climate change prediction under different scenarios

4.1.1. Evaluation and Correction of Climate Model Output

Products from Reg CM4.6 driven by HadGEM2-ES have been used to simulate the future climate change in northwest China. Pan et al. (2020) found that the temperature bias of HadGEM2-ES is generally within ±2.5 °C in the southeast and south during the historical period 1985-2004. This article has evaluated and revised the temperature output values under the RCP4.5 scenario based on observed meteorological in the upper Tao River Basin based om historical period during 2007-2018. The deviation between the simulated value and the measured value was exhibited in Fig.2. The deviation between the simulated value and the measured value is small in summer and large in winter. The maximum temperature deviation can reach 7.5 °C, but the temperature variation is consistent with the observed value (Fig. 2). According to the relationship between altitude and temperature in each site, the average observed temperature from 2007 to 2018 is about 0.8℃. By comparison, the simulated annual average temperature and the observed multi-year average is about consistent under climate change scenarios. Corrections through inverse deduction between the linear equation and the vertical decline rate of temperature, the average temperature and the maximum/minimum temperature are adjusted separately. Therefore, the corrected data are more in line with the actual situation of the study area and meet the research need of future climate change.

<Fig. 2 is near here>

4.1.2. Projection of Future Temperature Change in upper Taohe River Basin

Under the three greenhouse gas emission scenarios, the average annual temperature in the study area shows a consistent warming trend in the future period (Fig. 3). The average temperature in the future study area would be about 2.83 °C, 3.32 °C, and 4.24 °C under RCP2.6, RCP4.5, and RCP8.5 scenarios during 2007-2100, and the change rates may be 0.10 °C / 10a, 0.20 °C / 10a, and 0.52 °C / 10a. The average temperature in the next 2080s would be about 0.54 °C, 1.14 °C, and 3.44 °C higher than the average temperature in 1956-1997 (Cheng et al., 2019), which may be consistent with global warming trend. Overall, the temperature in upper Taohe River Basin will increase with the increase in emission scenarios.

<**Fig. 3** is near here>

At the same time, the possible future temperature changes in this basin are also analyzed from the two aspects of maximum and minimum temperatures. The annual average maximum and minimum temperature changes in the upper and middle reaches of the Tao River under three greenhouse gas emission scenarios were set for four stages: 2007-2018, 2020s (2019-2039), 2050s (2040-2079) and 2080s (2080-2099) (Fig. 4).

<**Fig. 4** is near here>

The maximum temperature and minimum temperature would show increase trends under the three scenarios. The change in maximum temperature under the RCP2.6 scenario would be steadily increasing and the increments under the three stages would be 0.13 °C, 0.44 °C and 0.44 °C higher than those from 2007 to 2018, respectively, which was consistent with the change trend of average temperature. Under the RCP4.5 scenario, the maximum temperature would increase significantly, and temperature could be 0.63 °C, 1.02 °C and 1.42 °C in the three stages higher than 2007-2018, respectively, with maximum change range of 13%-17%. The future maximum temperature changes most significantly under RCP8.5 scenario, which would increase to 0.49 °C, 1.64 °C and 3.34 °C, which could be higher than those in 2007-2018, respectively, with a maximum range of 33 %. The results indicate that the highest temperature in the 21st century would be gradually increasing.

Compared with the change of the maximum temperature, the change range of the minimum temperature in different scenarios is consistent with the maximum temperature in the future. Under the RCP2.6 scenario, the minimum temperature in the three stages would increase to 0.26 °C, 0.61 °C and 0.60 °C, which would be slightly higher than that in 2007–2018, respectively. The change under RCP4.5 scenario would be significantly enhanced, and the three stages would increase to 0.71 °C, 1.12 °C and 1.59 °C, which would be higher than those from 2007 to 2018, respectively. Under the RCP8.5 scenario, the minimum temperature changes most significantly, which would be 0.64 °C, 1.79 °C and 3.57 °C in the three stages and higher than the reference period, respectively. The results indicate that the minimum temperature would be gradually increasing from the 21 st century, and the minimum temperature change would be more significant than the maximum temperature change, which indicates that minimum temperature changes would contribute greatly to the future regional warming.

4.1.3. Projection of Future Precipitation Change in upper Taohe River Basin

<**Fig. 5** is near here>

According to Pan et al.'s (2020) analysis of the precipitation data outputs by the climate model in the historical period (1985~2015) in the northwest region, the simulation effect at the eastern of Qinghai-Tibet Plateau is poor, which may be due to the influence of the Qinghai-Tibet Plateau monsoon circulation, resulting in a false high-value precipitation center in climate model. Compared with the observed precipitation from 2007 to 2018, it is found that the simulated precipitation from climate model is similarly overestimated in the eastern part of the middle and upper reaches of the

Tao River. Therefore, the seriously overestimated stations are removed and compared with the precipitation changes of all stations in the region. Fig.5 shows the future multi-year precipitation changes in the middle and upper reaches of the Tao River from 2007 to 2099, comparing the not-removed and removed gridded precipitation. The results shows the 5-year moving average curve could be presented the precipitation change trend well.

Under the RCP2.6 scenario, the average precipitation in the study area would be about 658 mm in 2020-2099 with an insignificant decreasing trend (-3.69 mm/10a), and the average precipitation after excluding abnormal stations would be 620 mm, which is closer to the measured precipitation. The precipitation would be fluctuated greatly in the 2030 s, while the precipitation would reach to least level in the 2080 s. Under the RCP4.5 scenario, the average precipitation in the future would be 677.5 mm, and the average precipitation after excluding abnormal stations would be 638.5 mm with an insignificant increasing trend (4.97 mm/10a). The precipitation would reach the most value in the 2070s (689 mm), and would reach the least value in the 2020s (591.3 mm). The future average precipitation under RCP8.5 scenario would reach 693.2 mm, and the average precipitation after excluding abnormal stations would be 653.9 mm with an increasing trend (12.28 mm/10a). The average precipitation would have an insignificant change before the 2080s, but it would be the most abundant after the 2080s.

4.2. Applicability evaluation of SWAT model

The results of hydrological process curves during the calibration period and verification periods (Fig. 6) showed that SWAT model can well capture the time and flow of flood peaks in the three hydrological stations. The simulated value in the dry season is also consistent with the basic flow of the basin, but the simulation abilities among the three the stations are different. Luqu, Xiabagou, Minxian and other three hydrological stations are the main outlets of the source area of the Tao River. The overall runoff simulation values of the determination coefficient R^2, the Nash efficiency coefficient *NSE* and the relative error *Re* of the monthly runoff simulation at regular rates fall within a small uncertainty interval (Table 5).

<**Fig. 6** is near here>

The simulated performance in Luqu station as the main water outlet in the source of Tao River Basin showed well, with R^2, *NSE* and *Re* in monthly runoff simulation rate of 0.79, 0.89, and 2.39% respectively. In the verification period, R^2, *NSE* and *Re* also reached 0.89, 0.95, and -8.9%, respectively. R^2, *NSE* and *Re* of monthly runoff simulation in Xiabagou station were 0.77, 0.88, and -3.86%, respectively, and 0.89, 0.96, -5.07% in the verification period. Minxian station serves as the total outlet of the upper Tao River Basin. The results showed that R^2, *NSE* and *Re* in monthly runoff simulation rate were 0.83, 0.91, -14.6%, respectively, and the verification period, R^2, *NSE* and *Re* also reached 0.87, 0.94, -8.6% respectively. The above evaluation results show that SWAT model is able to well capture runoff change in upper Tao River Basin, which indicated the capability for the subsequent study on the response of water resources in the Tao River Basin to future climate change.

<**Table 5** is near here>

4.3. Projection of Future Runoff Change in the middle and upper reaches of the Tao River

Based on the good application of SWAT model, the annual runoff changes under three greenhouse gas emission scenarios in the middle and upper reaches of the Tao River could be predicted from 2020 to 2099 by inputting the corrected RCPs temperature and eliminated abnormal precipitation data from grids, as shown in Figure 7. In order to compare the long-term runoff changes, this research takes the average runoff trend from 1956 to 2014 as the historical period, the runoff changes in different future periods could be analyzed intuitively.

Under the RCP2.6 scenario, the annual average runoff would be about $30.9\times10^8m^3$, and the overall change trend is similar to the runoff from 2003 to 2014. Among the whole period, the relative maximum and minimum runoff would appear in the 1930s alternately, while the overall minimum runoff would appear in the mid-1980s as low as $17.1\times10^8m^3$. Comparably, the overall average runoff would be the highest in the 1950s with an annual average runoff of $35.2\times10^8m^3$, and the lowest in the 1980s at $24.6\times10^8m^3$. Drought risk might be estimated in the future. Under the RCP4.5 emission scenario, the annual average runoff would be about $32.5\times10^8m^3$ steadily, and the overall change trend is lower 15% than the period of 1956-1985. The runoff during 2040s and 2070s might be the highest value. Under the RCP8.5 emission scenario, the annual average runoff would be about $32.2\times10^8m^3$， with no significant increase trend. The maximum runoff would appear in the mid-2080s and the minimum appeared in the mid-2060s as low as $14.8\times10^8m^3$.

<**Fig. 7** is near here>

Table 6 shows the change of projected runoff in each season. Under the RCP2.6 emission scenario, runoff would decrease most significantly in summer, and insignificant change the other seasons. Under the RCP4.5 emission scenario, the runoff in the all seasons would show a trend of increasing-decreasing fluctuantly. Under the RCP8.5 emission scenario, the runoff in spring and summer would also show a fluctuant trend. In general, the future runoff in upper Tao River Basin would show a decreasing trend in summer and increasing in autumn, with insignificant change in other seasons.

<**Table 6** is near here>

5. Discussion

5.1. Uncertainty analysis of SWAT model

SWAT model has complex structure and involves many equations and variables (Wang et al, 2003; Cheng et al., 2006). Due to the complexity and randomness of hydrological process, there are many uncertain factors in the process of hydrological model simulation, which could cause interference to the simulation effect. According to the observed situation in upper Tao River Basin and relative literatures, 23 parameters in the SWAT model (Table 4) were selected for preliminary overall sensitivity analysis. The calibration number was set to 500 times and the iteration number was set to 10 times. The parameters suitable for the hydrological process change in the study area were obtained through sensitivity layer-by-layer screening. The contribution of different parameters to calibration and validation of the model in different study areas are also different, which can have a varying degree impact on the model results (Rui et al., 2002; Yang et al., 2013).

5.2. Uncertainty analysis of future climate change scenarios

In this study, the Reg CM4.6 driven by global climate model HadGEM2-ES was used to simulate the future climate change in northwest China. Pan et al. (2020) compared with the historical period (1986 – 2014) and found that the output results of the model had relatively large simulation errors in the middle and upper reaches of the Tao River, regardless of the average temperature or precipitation. This is because the region, located at the junction of the Tibetan Plateau and the Loess Plateau, is jointly affected by the southwest monsoon and the East Asian monsoon, as well as by the climate fluctuation of the Tibetan Plateau, the atmospheric circulation changes are complex. Together with the rugged terrain and inhomogeneous underlying surface characteristics, it is difficult to obtain accurate model simulations (Wang et al., 2009). Besides, meteorological stations in the upper and middle reaches of the Tao River and its surrounding areas are relatively scarce and the measured data are limited, which also greatly affects the reliability in the simulated values. Under the RCP4.5 emission scenario, the precipitation in the middle and upper reaches of the Tao River showed a significant decreasing trend from the late 2070s to the late 2080s, with a change rate of -8.97 mm / 10a; At the RCP8.5, the precipitation in the same period showed a significant upward trend, with a change rate of 6.50 mm / 10a. This uncertainty stems from the differences in the scenarios, which will increase the uncertainty of future precipitation trends.

The prediction of future climate change is a complex and highly uncertain increasing the uncertainty in the exploration of the impact of climate change on watershed hydrological processes. There are many sources of uncertainty in climate prediction, including uncertainty from different future greenhouse gas emission scenarios, uncertainty from natural variability within the climate system, uncertainty in methods to characterize climate processes (Duan et al., 2016; New and Hulme, 2000). Whichever scenarios or models can not completely overcome these uncertainties, but with the deepening understanding of various physical processes in the climate system, the output results of climate models will become more and more accurate.

6. Conclusion

The average temperature in upper Tao River Basin from 2020 to 2099 would show a consistent warming trend in the future period under the different greenhouse gas emission scenarios. Due to the difference in CO_2 concentration, the warming amplitude is different. From 2020 to 2099, the average temperature change rates under RCP2.6, RCP4.5 and RCP8.5 scenarios were 0.10°C/10a, 0.20°C/10a and 0.54°C/10a, respectively. In the RCP2.6 emission scenario, the average precipitation in the future study area would show a decreasing trend, with a reduction rate of 3.69 mm / 10a. Under RCP4.5 and RCP8.5 scenarios, the future precipitation showed an increasing trend, with the increase rates of 4.97 mm/10a and 12.28 mm/10a, respectively.

The calibration and validation results in three in-site observations (Luqu, Xiabagou and Minxian) in the upper Taohe River Basin showed that SWAT hydrological model is able to produce an acceptable simulation of runoff at monthly time-step. The R^2 of the calibration period and the verification period in Minxian station are 0.91 and 0.94, respectively. The *NSE* are 0.83 and 0.87, which produced a reliable result and meet the research requirements .

The future temperature and precipitation data under different emission scenarios have been input into SWAT model to predict the runoff in upper Tao River Basin. Under the RCP2.6 emission scenario, the average annual runoff in upper Tao River Basin would reach about 30.9 $\times 10^8 m^3$,with a significant change of increasing and decreasing. Under the RCP4.5 emission scenario, the average annual runoff of the study area would reach 32.5 $\times 10^8 m^3$, which would have experienced a regular periodic change of increasing and decreasing. Under the RCP8.5 scenario, the average annual runoff in the future would be about 32.2 $\times 10^8 m^3$. The overall fluctuation is weak.

Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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