Climate Change in Ganjiang River Basin and Its Impact on Runoff

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Abstract. Predicting the change of runoff in the future is significant to the management of regional water resources. In order to estimate future climate change of Ganjiang river basin and explore its impact on runoff, the changes of precipitation and temperature under the three representative concentration pathways (RCP2.6, RCP4.5 and RCP8.5) were analyzed and the Soil and Water Assessment Tool (SWAT) hydrological model was established to simulate the corresponding runoff in the Basin. The statistical relationship between the factors and the predictor in the Ganjiang river basin was built based on Statistical Downscaling Model (SDSM). For three scenarios, the precipitation showed slight increase trends under RCP2.6 and RCP4.5, but a significant increase under RCP8.5; and generally decreased from July to October while increased from January to April. The temperature exhibited a rising trend under three scenarios, of which the rank was RCP8.5>RCP4.5>RCP2.6. The runoff had an increasing trend and the rank for the three scenarios was RCP8.5>RCP4.5>RCP2.6. Generally, runoff had a strong positive correlation with precipitation while a weak correlation with temperature. The flood risk in Ganjiang river may increase significantly in the future.

Keywords: SWAT model; Climate changes; Runoff; Ganjiang river.

1. Introduction

As the most effective tool for studying global climate change, the global circulation models (GCMs) has been used in the worldwide. The model has shown ability of simulation in some regions, but there are still uncertainties due to different dynamic systems, grid size, and parameterization of physics processes. Precision and resolution of the model have improved in the past few decades. In recent years, the high-resolution atmospheric model have received considerable attention[1].

The research area in this paper is Ganjiang river basin. The Ganjiang river (113.58° to 116.63° east longitude and 24.52° to 28.75° north latitude) is located in the south of Yangtze River Basin and it is the seventh largest branch of the Yangtze River. It belongs to the water system of the Poyang Lake Basin with the area of 83,500 km². The basin covers Nanchang, Yichun, Xinyu, Pingxiang, Jian and Gangzhou from north to south, accounting for 51.5% of the total land area of Poyang Lake Basin. As the largest river basin in Jiangxi Province, the high-precision downscaling future climate prediction and runoff simulation of Ganjiang river basin has far-reaching significance for the national economy, ecosystem, sustainable development strategy, agriculture and food security, flood and drought prevention. To study future climate change and the impact of climate change on the runoff in Ganjiang river are conducive to a deeper understanding of the response mechanism of lake basin system to climate change, and to provide a scientific basis for adjusting water consumption structure, flood and drought prevention, especially for making the countermeasures for mitigating the impact of change on climate and runoff.
The CMIP5 model in this study is CanESM2 from Canada, and SDSM statistical downscaling model is selected to simulate temperature and precipitation. It uses MLR technology to establish statistical function relationship between factors and regional predictors. According to the assumption that the statistical relationships is still applicable in future climate change scenarios, the statistical relation was applied to the GCM future data of factors by using SWG technology. SDSM has a better simulation of temperature and evaporation, but a worse simulation of precipitation. In many areas of China, it has good application. SWAT model is a kind of distributed hydro-model. Compared with others, the distributed hydro-model takes climate and underlying surface as input factors, which can describe runoff process more reasonably and accurately. SWAT model is not suitable for China in some modules. For example, soil classification in China is different from that in the United States, so it cannot be directly applied. For application, Chinese scholars have improved the model. In 2002, Wang Zhonggen, Liu Changming, etc. verified the runoff simulation function of SWAT model according to the statistics of Heihe River from 1959 to 1993, based on the meteorological data and runoff data, which is more suitable for the northwest cold region of China, but not for the simulation of single event flood process. Li Hongliang proved the applicability of SWAT Model in Daqing River Basin; Jin Cong verified the applicability of the model in Xinxing river.

2. Methodology

2.1. Data Sources

CMIP5 model adopted CanESM2 data that is from the Canadian Environment and Climate Change Network (https://www.canada.ca/en.html). The World Soil Database (HWSD) is derived from the FAO and the Vienna International Institute for Applied Systems. It is currently the most widely used soil data in the world. China's soil data is the 1:1000000 raster data provided by the second national land survey in Nanjing. The landuse data is the raw data downloaded from the “Western China Environmental and Ecological Science Data Center”. The 1Km landuse raster data is converted from China's 2000s, 1:100,000 landuse data. The meteorological data comes from China Meteorological Science Data Sharing Network from 1961 to 2005. The stations such as Ji'an, Yushu, Yichun, Guangchuan, and Nanchang were selected, the data including 50-year data of 19 elements such as pressure, relative humidity, precipitation, evaporation, wind speed, sunshine. The observed runoff data of Waizhou Station from 1961 to 2005 is from the Waizhou Hydrological Station.

2.2. Models

The SWAT model is a distributed hydrological model with strong physical mechanism, which can be used for hydrological response research in a basin simulation. It has been applied in many regions such as Asia, Europe, Australia, America, etc. It is suitable for different climatic conditions and soil or landuse types. In this study the distributed hydrological model was established by SWAT based on the daily values of surface climate data from 1961 to 2005 of six climate stations and the data of soil, landuse, topography, the daily runoff from 1961 to 2005 at Waizhou Hydrological Station and NCEP. According to the data of soil, landuse and slope, 164 sub-basins were divided and 2441 Hydrological Response Units (HRU) were obtained.

In the SWAT model, the equation of water balance was given as follows:

\[
SW_t = SW_0 + \sum_{i=1}^{t} (R_a - Q_{surf} - E_a - W_{seep} - Q_{gw})
\]

where \(SW_t\) and \(SW_0\) are the initial and final runoff of the day \(i\), mm; \(t\) is the number of days; \(Q_{surf}\) is the surface runoff of the day \(i\), mm; \(R_a\) is the precipitation of the day \(i\), mm; \(E_a\) is the evapotranspiration of the day \(i\), mm; \(Q_{gw}\) is the return flow of groundwater at the day \(i\), mm. \(W_{seep}\) is the amount of water infiltrated from the soil surface into the unsaturated zone, mm.

SDSM statistical downscaling model was selected, which is more categorized as a downscaling method with a coupling function coupled with a random weather generator. The model is widely used in many research fields currently. The fundamental principle was as follows:
\[ w_i = \alpha_0 + \sum_{j=1}^{n} \alpha_j P_{ij} \; ; \; R_i^{0.25} = \beta_0 + \sum_{j=1}^{n} \beta_j P_{ij} + e_i \]  
\[ T_i = \gamma_0 + \sum_{j=1}^{n} \gamma_j P_{ij} + e_i \]

\( w_i \) is the probability of precipitation at day \( i \); \( \alpha, \beta, \gamma \) is the mode parameter; \( R_i \) is the precipitation; \( T_i \) is the temperature; \( e_i \) is the error.

3. Results and Discussion

3.1. Calibration and Verification of SWAT Model

SUFI-2 algorithm was used to calibrate the parameters, and the results showed there were four most sensitive parameters that were GW_DELAY, ALPHA_BF, CN2 and GWQMN (Table 1).

| Parameter      | Types | Best Fitted Value | t-Stat | p-Value |
|----------------|-------|-------------------|--------|---------|
| GW_DELAY       | V     | 43.13             | -21.32 | <0.01   |
| ALPHA_BF       | V     | 0.61              | 4.22   | <0.01   |
| CN2            | R     | 0.07              | 1.98   | 0.05    |
| GWQMN          | V     | 0.36              | 1.12   | 0.27    |

The observation sequence was divided into two parts. The first part was the calibration period (1961–1990) used to establish the statistical relationship, and the second part was the verification period (1990-2005) to test the reliability of the model. The determination coefficient \( R^2 \) and Nash-Sutcliffe Efficiency \( E_{\text{na}} \) values of the model were 0.88 and 0.84 in calibration period, while 0.89 and 0.87 in verification period, which proved the high applicability of SWAT model in the Ganjiang river basin. As shown in Figure 1, the simulation of monthly runoff in the period of calibration and verification was accurate. The maximum simulated runoff was slightly higher than the observed, the minimum simulated runoff was slightly lower than the observed.

![Figure 1](image)

**Figure 1.** Monthly simulation values and observed values of Waizhou station during the calibration and validation periods.

3.2. Future Temperature Change

As shown in Figure 2, in the calibration period, the simulations of the monthly maximum temperature, minimum temperature and average temperature of the basin were close to the observed values, and the simulation of maximum temperature was closest to the observed values. The forecast data for 2006-2100 were divided into three stages: 2020S (2006-2035), 2050S (2036-2065) and 2080S (2066-2100). As shown in Table 2, in the three scenarios, the temperature under RCP 8.5 showed a maximum increase, followed by RCP 4.5 and RCP 2.6. The maximum temperature under RCP 2.6 increased by 1.6 °C in 2030S, 2.5 °C in 2050S and 2.51 °C
in 2080S; under RCP 4.5, the maximum temperature increased by 1.3 °C in 2030S, 2.8 °C in 2050S and 3.1 °C in 2080S; under RCP 8.5, the maximum temperature increased by 1.7 °C in 2030S, 2.7 °C in 2050S and 4.1 °C in 2080S. The temperature had an obvious rising trend in September and October, and a slight rising trend in January and February.

### Figure 2. The comparison between observed temperature and downscaled temperature in Ganjiang river basin.

The minimum temperature under RCP 2.6 increased by 0.9 °C in 2030S, 1.7 °C in 2050S and 1.7 °C in 2080S; under RCP 4.5 the minimum temperature increased by 0.7 °C in 2030S, 2.1 °C in 2050S and 2.3 °C in 2080S; under RCP 8.5, the minimum temperature increased by 1.2 °C in 2030S, 2.3 °C in 2050S and 3.6 °C in 2080S.

The average temperature under RCP 2.6 had an increasing trend with 1.2 °C in 2030S, 1.5 °C in 2050S and 1.6 °C in 2080S; under RCP 4.5 scenario, the average temperature had an increasing trend with 0.7 °C in 2030S, 1.7 °C in 2050S and 2 °C in 2080S; under RCP 8.5, the average temperature had an increasing trend with 1 °C in 2030S, 2 °C in 2050S and 3.1 °C in 2080S, and it increased obviously from April to October under RCP 8.5.

### Table 2. Future temperature change in the Ganjiang river basin.

| Period | Minimum temperature increase(°C) | Maximum temperature increase(°C) | Average temperature increase(°C) |
|--------|---------------------------------|----------------------------------|----------------------------------|
|        | RCP2.6 | RCP4.5 | RCP8.5 | RCP2.6 | RCP4.5 | RCP8.5 | RCP2.6 | RCP4.5 | RCP8.5 |
| 2020S  | 0.9    | 0.67   | 1.2    | 1.63   | 2.5    | 2.51   | 1.2    | 1.55   | 1.57   |
| 2050S  | 1.68   | 2.06   | 2.29   | 1.4    | 2.82   | 3.16   | 0.66   | 1.67   | 1.97   |
| 2080S  | 1.68   | 2.33   | 3.58   | 1.7    | 2.73   | 4.16   | 1.03   | 1.98   | 3.06   |

### 3.3. Future Precipitation Change

The future precipitation in the Ganjiang river basin was shown in Figure 3. It showed that under the three climate scenarios, the simulated precipitation in the Ganjiang river basin would generally decrease from July to October, and decrease by about 20 mm per month; the precipitation would increase from January to April. Precipitation increased from RCP2.6, RCP4.5 to RCP8.5. Compared with the average annual precipitation, RCP2.6 had a fluctuating trend in 2020S, 2050S and 2080S, and the average annual precipitation was 1653mm, which had a small gap with the baseline period. The change of RCP4.5 was more complicated, and it fluctuated in 2020S and 2050S. The annual precipitation increased by 150mm in 2080S; under RCP8.5 the precipitation fluctuated in 2020S, and increased in both 2050S and 2080S, the monthly average increase was up to 10%, about 200mm.

### Figure 3. Comparison of monthly mean precipitation between observation and RCP data in Ganjiang river basin.
### 3.4. Future Runoff Change

Figure 4 shows the monthly value of runoff change for the three scenarios in three periods. The maximum of runoff appeared in April under the RCP8.5 compared with the average annual runoff, and the minimum value appeared in October under the RCP8.5. It indicated that the extreme climate was more likely to appear under the RCP8.5. In 2020S, the changes in the three scenarios were not obvious, the change of runoff was very unstable, but it was in a small increase or decrease overall; in 2050S, the runoff gradually decreased in January to March, the annual average runoff increased by 1140 m$^3$/s compared with the average annual runoff, and increased more obviously under RCP8.5. The annual average runoff increased by 1291 m$^3$/s; in 2080S, under RCP2.6, the runoff still had no clear increase or decrease trend. Under the RCP4.5, the runoff of simulation increased by 1137 m$^3$/s compared with the annual average runoff. Under RCP8.5, the runoff of simulation had an increasing trend.

![Runoff Change Graph](image)

**Figure 4.** The simulated runoff of Waizhou station from 2009 to 2100.

**Table 3.** Annual runoff variation of Ganjiang river basin.

| Month | Baseline Period | RCP2.6 | RCP4.5 | RCP8.5 | Change in Runoff (%) |
|-------|-----------------|--------|--------|--------|----------------------|
|       | Runoff (m$^3$/s) |        |        |        |                      |
| 1     | 273.08          | 664.78 | 638.11 | 704.67 | 143                  |
| 2     | 462.41          | 987.12 | 1177.88| 1213.17| 113                  |
| 3     | 835.41          | 1101.09| 1148.9 | 1197.73| 32                   |
| 4     | 1258.27         | 1462.51| 1598.65| 1652.02| 16                   |
| 5     | 1389            | 1030.38| 1057.52| 1053.49| -26                  |
| 6     | 1684.77         | 1055.29| 1070.52| 1219.93| -37                  |
| 7     | 1251.82         | 834.25 | 809.54 | 848.01 | -33                  |
| 8     | 740.18          | 721.08 | 699.74 | 750.22 | -3                   |
| 9     | 604.78          | 411.22 | 312.38 | 357.27 | -32                  |
| 10    | 431.34          | 361.42 | 276.69 | 318.89 | -16                  |
| 11    | 346.86          | 520.91 | 528.1  | 514.27 | 50                   |
| 12    | 256.24          | 537.65 | 564.8  | 584.76 | 110                  |
| Max   | 1684.77         | 1462.51| 1598.65| 1652.02|                      |
| Min   | 256.24          | 361.42 | 276.69 | 318.89 |                      |
| Mean  | 794.51          | 807.31 | 823.57 | 867.87 |                      |
| CV    | 0.29            | 0.18   | 0.18   | 0.19   |                      |
As shown in Table 3, the runoff increased from January to April and November to December, among which the runoff increased the most in January, February and December, with the maximum increase rate of 162%; the runoff decreased in May to October, and the runoff in June and July decreased the most, reaching 37%. In 2009-2100, the maximum runoff appeared in April, the minimum in October under RCP4.5, with the value of 276.69 m$^3$/s.

The runoff increased the most under RCP 8.5 by 10%. Under RCP 2.6, the runoff fluctuated, and the change of runoff was not obvious. The change of runoff under the RCP 4.5 was similar to that under the RCP 2.6 with a larger increase of 350 m$^3$/s; the increase under RCP 8.5 was much larger than the first two scenarios, especially in April and June, with an increase of 880 m$^3$/s. Maximum and minimum values were more likely to appear in RCP 4.5 and RCP 8.5. It possibly indicated that extreme climate was more likely to appear in these two scenarios, and low emissions were undoubtedly safer, which also reflected the importance of reducing emissions.

3.5. Runoff Response to Climate Change

Figure 5 was the diagrams of runoff and precipitation change at Waizhou Hydrological Station in the periods of 2020S, 2050S and 2080S. By comparing the precipitation and runoff of the same period, the relationship between runoff and precipitation was very close. The change of runoff was consisting with the change of precipitation. The annual runoff had no obvious change in 2020S. The annual runoff in 2050S and 2080S increased with the increase of precipitation, and increased the most in 2080S. The increase of runoff was 2080S > 2050S > 2020S under three scenarios, and the increase of runoff was RCP8.5 > RCP4.5 > RCP2.6 in three periods.

| Frequency(%) | Baseline Period | RCP2.6 | RCP4.5 | RCP8.5 |
|--------------|----------------|--------|--------|--------|
| 10           | 13132.53       | 13684.48 | 14953.47 | 15801.99 |
| 20           | 11714.47       | 12060.71 | 12961.75 | 13258.81 |
| 30           | 10750.21       | 10636.64 | 10959.49 | 11699.23 |
| 50           | 9260.7         | 8981.75  | 9138.26 | 9247.17 |
| 75           | 8530.5         | 8221.35  | 8116.94 | 8103.88 |
| 90           | 6744.59        | 6412.58  | 6539.46 | 6740.31 |
| 95           | 6389.63        | 5981.1   | 6025.01 | 6149.91 |

**Figure 5.** Runoff and rainfall of Waizhou Station under three scenarios.

Table 4 shows the design values of runoff at different frequencies (10%, 20%, 30%, 50%, 75%, 90%, 95%) in Ganjiang River Basin. Sample mean value of observed data was 9490.55, and variation coefficient ($C_v$) was 0.29. For three emission scenarios, the mean value under RCP 2.6 scenario was 10083.20 with $C_v$=0.12; The mean value under RCP 4.5 scenario was 10434.49 with $C_v$=0.12; Under RCP 8.5 scenario the mean value was 10964.51, and $C_v$ was 0.13. It can be seen that the mean values of runoff increased according to the order of RCP2.6, RCP4.5 and RCP8.5. The prediction of future runoff had significance for preventing flood or drought in the future.

**Table 4.** Design values of runoff in Ganjiang river basin.
4. Summary and Conclusions
(1) Using SDSM model to simulate the climate in Ganjiang river basin, the temperature had a good simulation result with the explained variance of more than 70%, but the simulation of precipitation in April-June was worse than that in other months with the explained variance of 20%-40%. The future temperature of the Ganjiang river basin was overall on the rise, while the precipitation was in a fluctuating rising trend.

(2) The $E_a$ and $R^2$ of the SWAT model in the calibration and validation period were all over 0.8, which proved the model was applicable to Ganjiang river basin.

(3) The response of runoff to precipitation was much greater than the response to temperature. Runoff had a positive correlation with precipitation, and had a weak correlation with temperature. This is mainly because the Ganjiang river basin is an inland basin, and precipitation is the main source of recharge. The decrease of precipitation leads to a decrease of runoff directly.

(4) Compared with the annual average runoff, April was the month in which runoff and precipitation got their maximum value, October was the month in which the minimum value appeared, and all occurred under RCP 8.5 scenario, which proves that the extreme climate more likely occurred under RCP8.5. The flood risk in Ganjiang river may increase significantly in the future.

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