

Impacts of climate change on water resources in the Huaihe River Basin

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Abstract: The Huaihe river basin, located in the transitional area of the humid zone to the semi arid zone, is a subtropical monsoon zone. By analysis of historical observation data, the annual average surface temperature increased by 0.5°C over the past 50 years. However, the precipitation showed a fluctuation trend. Based on the hydrological and meteorological data of Huaihe River Basin, this paper studies impacts of climate change on water resources in Huaihe basin by using the Xinanjiang monthly hydrological model in conjunction with prediction products of NCAR climate model. The results show that the precipitation in the basin had a fluctuating upward trend under RCP8.5 and RCP4.5 scenarios, and the increase or decrease trend of precipitation in RCP2.6 scenario is not significant. The model predicted that the temperature of the river basin in the 3 scenarios shows significant rising trend from year 2001 to 2100. However, the annual runoff of the Huaihe River Basin shows an increasing trend but not significant from year 2001 to 2100.

1 Introduction

Global climate change, mainly characterized by global warming, leads to intensified hydrological cycle and frequent floods and droughts in numerous regions [1,2]. Due to the increasing occurrence probability and disaster intensity of extreme climatic events such as drought and flood disasters and their impacts on human society, the occurrence of extreme climate events and their causes have been widely concerned by the academic community [3-5]. Since 1985, study on climate change and its impact have received extensive attention in China. Generally, study on the impact of climate change on water resources is currently focused on two scientific issues: the effect of climate change on the spatial distribution of annual runoff, the annual distribution of monthly runoff and its impact on flood, drought and other disaster events; balance of water supply and demand in future years. At present, methods of studying the hydrological effects of global climate change using hydrological models can be divided into three types [6]: the first method is high-resolution regional climate model integrated with hydrological model; the second method is statistical methods in combination with global climate models and hydrological models; the third method is hypothetical scenario is used as input to the hydrological model. Currently, the third method is the widely used to study the impacts of climate change on water resources of river basin under different climate scenarios [7-8]. However, the method does not use climate model to predict future climate change, and climate scenario setting is lack of necessary basis. As a result, there are so many

uncertainties and human factors that they cannot be used in practice. Since 1980's, global climate observation and information technology have been developed rapidly and been widely used in climate change studies. Therefore, it is curial to study the impact of climate change on water resource by using climate models in conjunction with large-scale hydrological models.

Huaihe river basin is located in the east of china, it is the overlapping area of the three transition zones of north and south climate, high and low latitude and sea and land. Due to the large inter-annual and intra-annual variation of precipitation, as well as the vast plain and low-lying land, and historical factors such as the capture of the Huanghe river into the Huaihe river event, its natural conditions are complex and river management is difficult. With the impact of external factors such as population growth, social and economic development, and aggravation of water pollution, water shortage in the Huaihe river basin is frequent, and contradiction between water supply and demand is increasingly prominent. By analysis of the long-term observation data, temperature in the Huaihe river basin rise in fluctuation in recent 50 years, annual average surface temperature increased by 0.5 °C, and precipitation shows a fluctuating downward trend contrary to the rising temperature [8-12]. Therefore, study of climate change impact on the water resources in the Huaihe river basin has great theoretical meaning and realistic meaning in understanding and solving the possible causes of water resources management and ecological environment protection which are closely related to the economic and social fields.

In this paper Xinanjiang monthly hydrological model for Huaihe river basin is built based on the

hydro-meteorological data of the major sub-basins of the Huaihe river basin, the model parameters are calibrated and the model is validated. Furthermore, the predicted results of future temperature and precipitation of NCAR global climate model under three typical emission scenarios i.e. RCP2.6, RCP4.5 and RCP8.5 released by the fifth assessment of the IPCC, in combination with the Xinanjiang monthly hydrological model, are adopted to investigate the effects of climate change on water resources in the Huaihe river basin under different RCP emission scenarios.

2 Study Area

The Huaihe River is one of the seven major rivers in the middle-east China, with the Huanghe in the north and Yangtze River in the south. The Huaihe Basin is embraced on three sides by mountains with one side facing the sea. The area of basin is approximately 270,000 km², of which the main Huaihe River system with a catchment area of 190,000 km² and the Yishusi Rivers system with a catchment area of 80,000 km². Apart from mountainous areas in the western, the southern and north-eastern parts of the whole basin, the rest are broad plain areas. Mountainous area accounts for 31.5%, plains and lowlands areas take up 65.1% and water bodies occupy 3.4% (Figure 1).

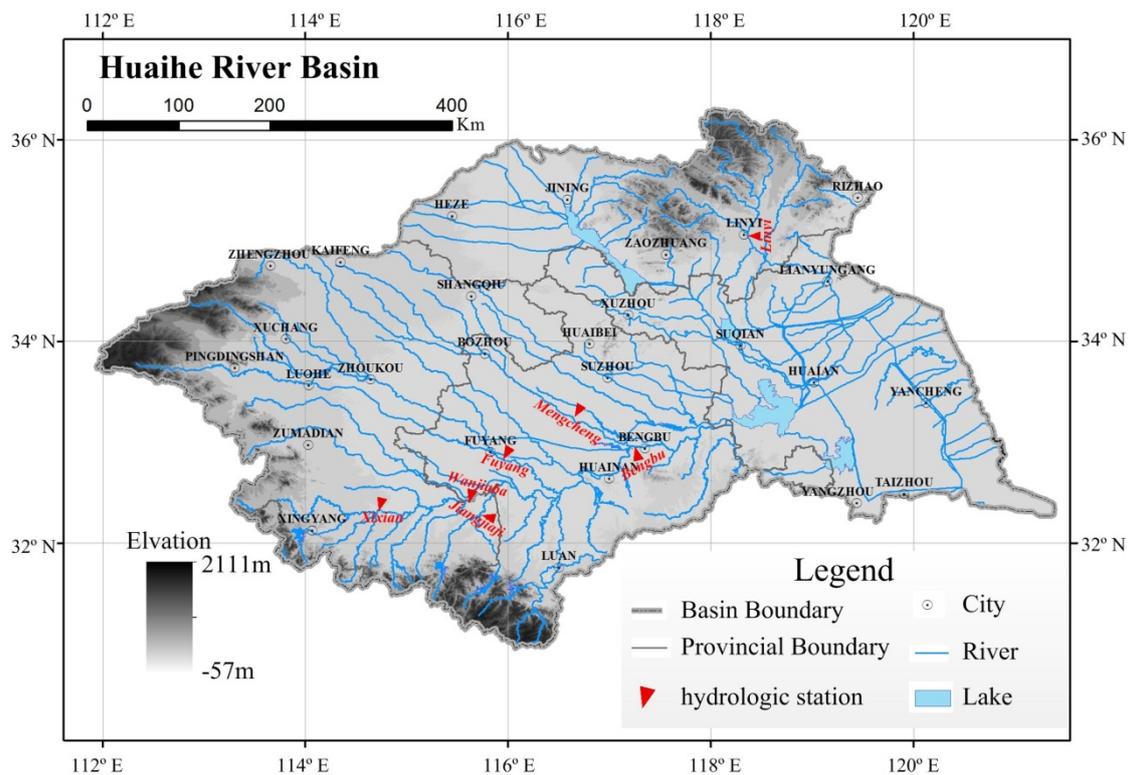


Figure 1 Main drainage system and location map of Huaihe Basin

The Huaihe River is located at China's transition terrain of northern climate and southern climate. The north of the Huaihe and the Northern Jiangsu Irrigation Canal is warm semi-humid monsoon climate zone and the south is sub-tropic humid monsoon zone. From south to north the climate in the HRB transitioned from the north of warm semi-humid climate zone to the south of sub-tropic humid zone. The activities of warm and cold air masses are intensive, and precipitation varies greatly. The average annual precipitation of HRB is 883mm, of which the average annual precipitation in the subbasin of the Huaihe river mainstream is 910mm, and the average annual precipitation in the Yishusi sub basin is 836mm [10].

Spatially, the precipitation decrease from south to north. The precipitation in mountains area is greater than that in plain area and precipitation of areas along the sea is greater than that of inland area. There are three areas with high precipitation, the first one is located in Funiu mountainous area with an annual average precipitation of

more than 1000mm, the second is located in Dabie mountainous area with an annual average precipitation of more than 1400mm and the third is in area near to the sea with an annual average precipitation of more than 1000mm. The zhongmou along the Yellow River is low-precipitation area with an annual average precipitation of less than 650mm.

The intra-annual distribution of precipitation is greatly uneven, and 50%~ 80% precipitation is concentrated in the rainy season (June-September), of which, precipitation of July approximately account for 24% of the annual amount. Then inter-annual variation is also great. The maximum annual precipitation is 2~4 times than the minimum annual precipitation. Comparing precipitation in rainy year to that in drought year, in mountainous area the ratio reaches to 3~4 and in plain area it can reach to 4~5. Therefore it is a typical disaster-intensive area. The average annual runoff of HRB is 230mm, of which the average annual precipitation in the subbasin of the Huaihe river mainstream is 238mm, and the average annual

precipitation in the Yishusi sub basin is 215mm. The average annual precipitation in the upper part of the Pihe River reaches to the highest 1054mm, and that in northern plain of the Henan province along the Yellow River and west of the Nansihu Lake reaches to the lowest 50~100mm. The intra-annual distribution of runoff shows similarities with intra-annual distribution of precipitation, with 50%~88% concentrated in the rainy season (June-September). Inter-annual variation of runoff is greater than that of precipitation, and ratio of the maximum annual precipitation to the minimum annual precipitation reaches to 5~30.

3 METHODOLOGY

3.1 Climate model and climate scenarios

In 2010, the National Center for Atmospheric Research (NCAR) released the fourth edition of the Common Climate System Model (CCSM4.0) [11-12]. It consists of 5 models: atmosphere, ocean, land surface, sea ice and coupler, which can support multiple resolutions and combine different modules by the open source model to meet the needs of different studies. In this study, the medium-resolution version was adopted. The horizontal resolution of the Community Atmosphere Model version4 (CAM4) and the Community Land Model version 4(CLM4) that adopt the Finite Volume Element driving force is about 1.9° (lat) \times 2.5° (lon) in the horizontal position, while CAM4 was divided into 26 layers and CLM4 is 15 layers in the vertical position. The horizontal resolution of the Slab Ocean Model (SOM) with mixed-layer model is about 1° (lat) \times 1° (lon), and the Community Ice Code version 4(CICE4) has the same resolution as SOM. The Land surface model is Community Land Model (CLM3.5) [11-12].

In order to predict the future climate change, firstly, the driving factors of climate change i.e. socio-economic development, population growth rate, environmental conditions and equity principles is simulated to calculate the future scenarios of greenhouse gas and sulfide aerosol emission. Secondly, the atmospheric concentration is calculated, and then the corresponding solar radiation is obtained. Finally, the data mentioned above are input to the climate models to simulate corresponding climatic changes. Therefore, each climate model considers the future climate simulation under different scenarios. To predict future global and regional climate change, the IPCC's Fifth Assessment Report in 2013 presented four representative climate scenario assumptions. They are respectively RCP2.6、RCP4.5、RCP6.0、RCP8.5 according to the concentration of RCP(Representative Concentration Pathway), the numbers in which represent the radiative forcing in year 2100 relative to year 1750. Considering the most probable social development of the Huaihe River Basin,

the following three scenarios are selected for future climate change analysis: (1) RCP8.5: high emission scenario, without any mission reduction measures; (2) RCP 4.5: medium emission scenario, maybe closer to the future; (3)RCP2.6: low emission scenario, in the future humanity will take mission reduction measures to make radiation force reach its peak in the 21st Century and then decline.

The three climate model scenarios above provide monthly rainfall and temperature raster data with spatial resolution of 50km*50km, however the Xinanjiang monthly hydrological model uses sub-basins as calculation units. In order to match the input of the climate model and the hydrological model, the effective grid points in different sub basins covered by climate model were determined by using spatially analysis with aid of the geographic information tool (ARCGIS 10.1), and the precipitation and temperature in each sub-basin were calculated by arithmetical average method to feed Xinanjiang monthly hydrological model.

3.2 Monthly Xinanjiang Hydrological Model

Numerous studies [13-19] indicate that most studies on the impact of climatic changes on hydrology and water resources are mainly conducted on a monthly or seasonal scale. Furthermore the monthly model or even the seasonal model performs better than daily/hourly model in terms of simulating large-scale regional runoff [13-19]. In addition, the high-precision meteorological elements (temperature, precipitation, etc.) exported by climate models are mostly on monthly scales. Therefore, monthly hydrological model is an important method to study the impact of climate change on regional water resources.

The Xinanjiang model is a kind of hydrological model which is widely used in humid and semi-humid areas in China. The Huaihe river basin is located in the humid and semi humid zone, which meets the requirements of the Xinanjiang model. It is appropriate to choose Xinanjiang model as a hydrological model. Originally the Xinanjiang model was applied to the continuous hydrological process simulation at hourly/daily scale. According to the characteristics of monthly runoff generation and confluence, Liu et al. [20] has developed a monthly hydrological model of Xin'an River for large-scale hydrological model and water resources evaluation (Figure 2).The sensitive parameters in the model mainly include: (1) Evaporation parameter K: is the ratio of potential evapotranspiration to pan evaporation if pan evaporation measurements are used as reference. (2) Runoff parameter Wm: is the areal mean tension water capacity. (3) Runoff separation parameter Sm: the areal mean of the free water capacity of the surface soil layer, represents the maximum possible deficit of free water storage. (4) Confluence parameter Cg: Groundwater regression coefficient.

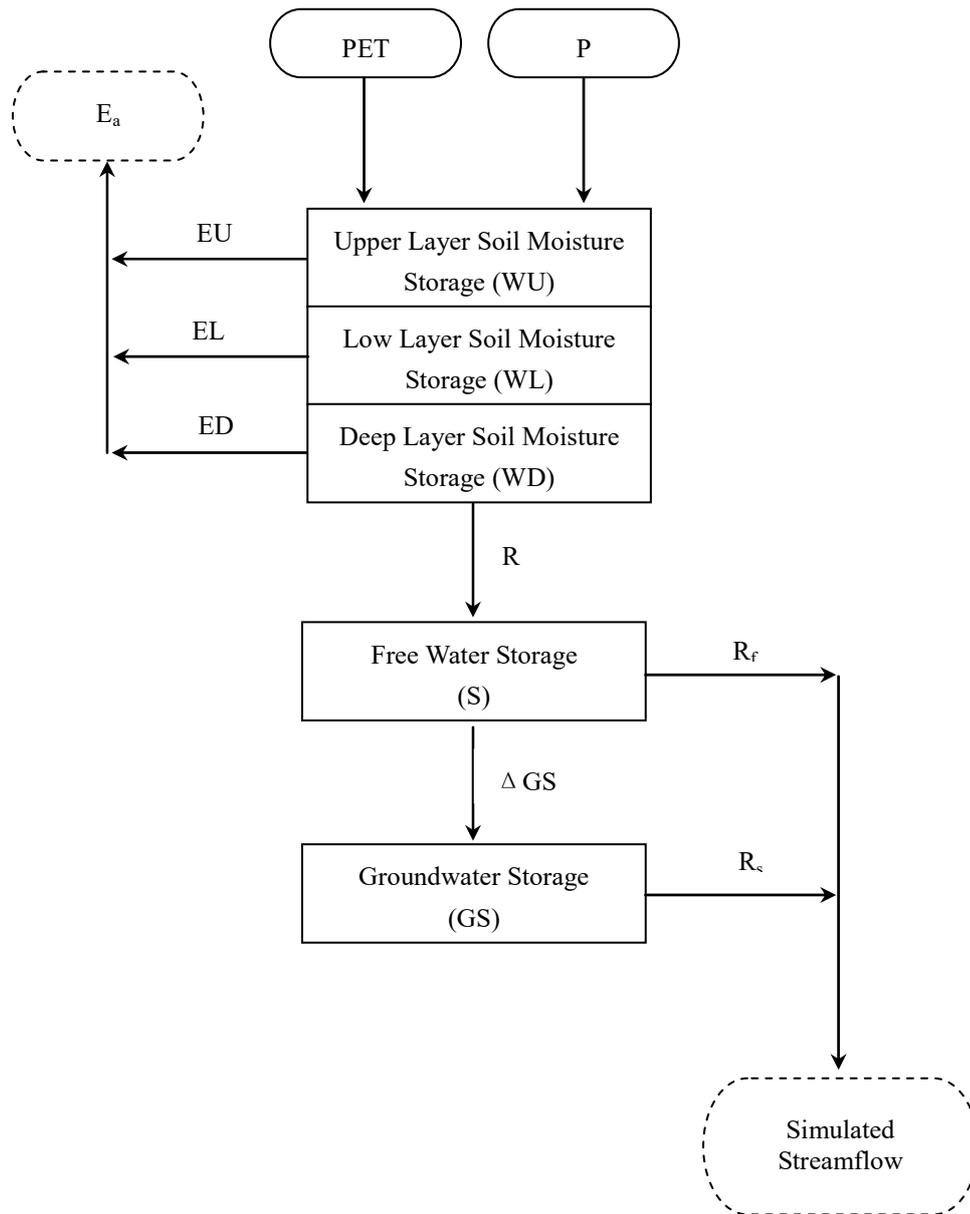


Figure 2 Schematic representation of the Xinanjiang monthly hydrological Model

Evapotranspiration is a key component in hydrological simulation. However, there are no available predicted evapotranspiration data in the future. Therefore, it is necessary to establish an evaporation capacity calculation method based on available climatic factors (temperature, humidity, radiation and wind speed) predicted by climate model. The NCAR climatic model is capable of generating climatic factors i.e temperature,

humidity, radiation and wind speed). Therefore, it is an effective way to establish the evapotranspiration capacity calculation model based on all or part of these factors. In this paper, the statistical relationship between monthly evaporation and monthly mean temperature in the Huaihe River Basin was established to predict ET in the future 100 years in conjunction with temperature generated by climate model (Figure 3).

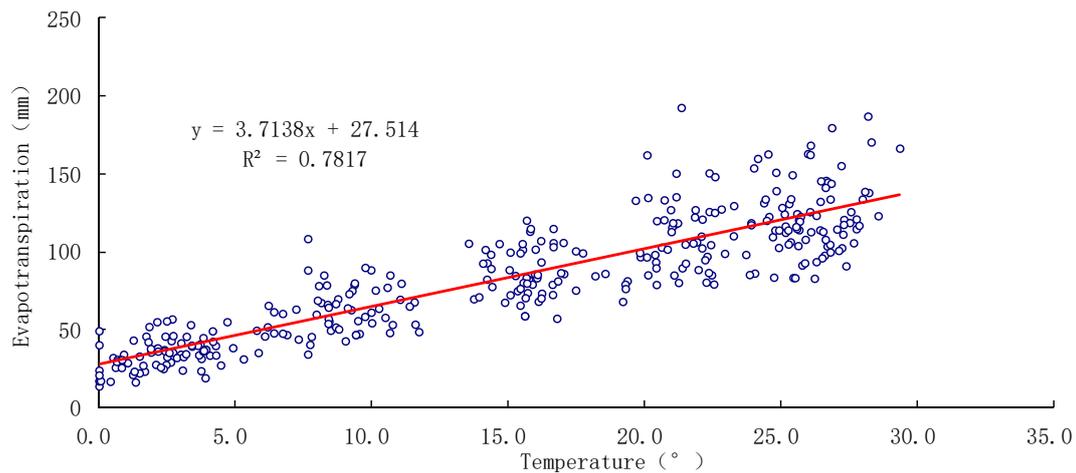


Figure 3 Relationship of monthly evaporation monthly mean temperature in Huaihe River Basin

Annual temperature in the Huaihe River basin shows rising characteristics under different emission scenarios, but the rising amplitude in different years in the future is different under different emission scenarios, especially in the RCP 8.5 emission scenario (Table 1).

4 Results and discussion

4.1 Analysis of climate model output

(1) Temperature change

Table 1 Variation of aSnnual temperature from Year 2020 to 2100 in Huaihe basin Unit (°C)

Scenario	2000-2020	2020-2050	2050-2100
RCP8.5	13.5	14.5	15.9
RCP4.5	13.5	14.4	15.6
RCP2.6	13.7	14.1	14.6

Under the RCP 8.5 scenario, the annual mean temperature in the Huaihe River Basin shows an obvious upward trend in the next 100 years, and the upward trend of temperature in most of the time reaches a significant degree of change. The average annual temperature from 2080 to 2100 is 16.98 C, which is 3.5 °C higher than that of 13.54 °C from 2001 to 2020. The increase rate is 0.35 °C every10 years.

Under the RCP 4.5 scenario, the annual mean temperature in the Huaihe River Basin increases at a rate of 0.2 °C every 10 years in the next 100 years. The annual temperature rise rate is lower than that of RCP8.5.

In the RCP 2.6 scenario, the annual mean temperature

in the Huaihe River Basin increases slightly in the next 100 years. Compared with the RCP 8.5 and RCP 4.5 scenarios, the temperature tendency rate in the RCP 2.6 scenario is obviously smaller, far less than the corresponding increase in the RCP 8.5 and RCP 4.5 scenarios. The rate of increase is 0.1 °C every 10 years.

(2)Precipitation change

Under the RCP 8.5 (high emission) scenario, the predicted annual precipitation is 1105mm in 2001-2060 and it has no obvious increasing or decreasing trend. The average annual precipitation predicted by the model is 1290mm from 2060-2100, which is about 20% higher than that in 2001-2060 (Figure 4).

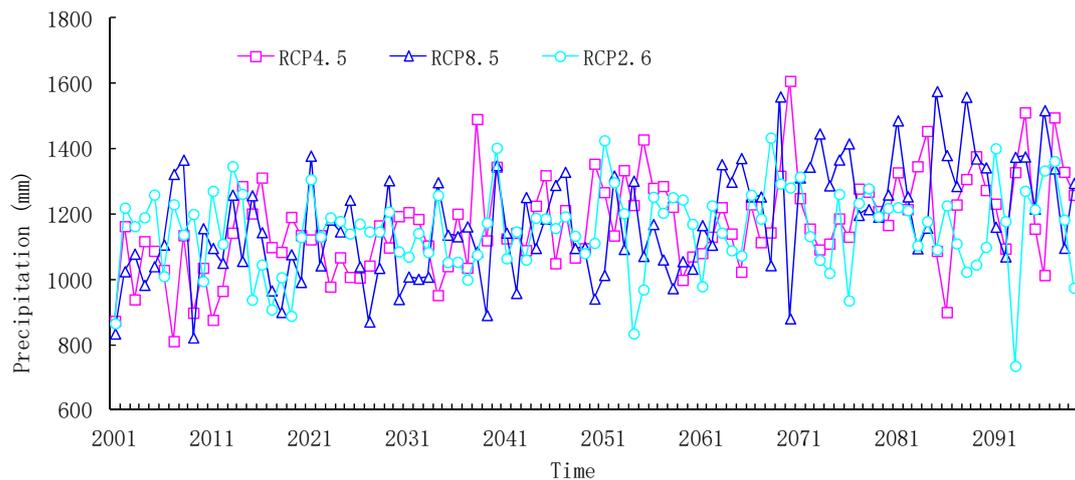


Figure 4 Prediction of precipitation in Huaihe basin from 2000 to 2100 under different scenarios

Under the RCP4.5 scenarios (medium emissions), precipitation of Huaihe River basin shows increased trend of fluctuation in the next 100 years, the increase degree of precipitation are less than the estimated precipitation under the RCP8.5 scenario. Precipitation in 2001-2013 is relatively low, and however precipitation in 2036-2055 is relatively high.

Under the RCP2.6 scenarios (low emissions), precipitation of Huaihe River basin shows no obvious increased or decreased trend in the next 100 years.

4.2 Model calibration and validation

The Xinanjiang monthly hydrological model was applied to simulate the monthly runoff for the period of 1980-2000 for model calibration and for the period of

2001-2010 for validation at seven hydrological stations of the mainstream and major tributaries. The model input data includes measured precipitation and temperature data of the 78 stations on a monthly basis, and model output is monthly average discharge.

Nash-Sutcliffe efficiency coefficient and relative error of runoff depth was selected to evaluate model performance. Model parameters and model error indexes were shown in Table 2. Simulated and observed runoff hydrographs of two representative major hydrological stations for the calibration periods are presented in Figures 5 and Figure 6. The figures show that the model perform satisfactorily well in the Huaihe River Basin. Therefore, the model, in combination with future climate scenarios generated by climate model, is well suitable for assessing climate change impact on water resources.

Table 2 Major model parameters for sub basins in the Huaihe River Basin

Subbasin	K	Wm	Sm	Cg	Efficiency coefficient	Relative Error
Xixian	0.6	150	20	0.55	0.8	3.05%
Wangjiab	0.7	140	20	0.6	0.82	6.50%
Jiangjiji	0.75	140	20	0.4	0.78	-1.11%
Fuyang	1.15	110	20	0.65	0.75	12%
Mengcheng	0.64	160	30	0.4	0.72	14%
Bengbu	1.05	140	15	0.6	0.828	-4.80%
Linyi	1.05	120	20	0.66	0.78	1.11%

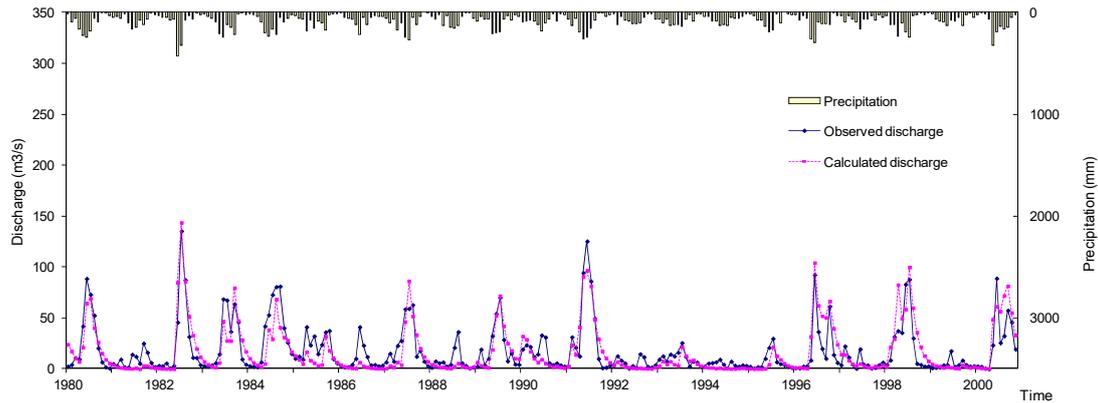


Figure 5 Comparison of monthly observed and simulated runoff for the calibration period at Bengbu hydrological stations

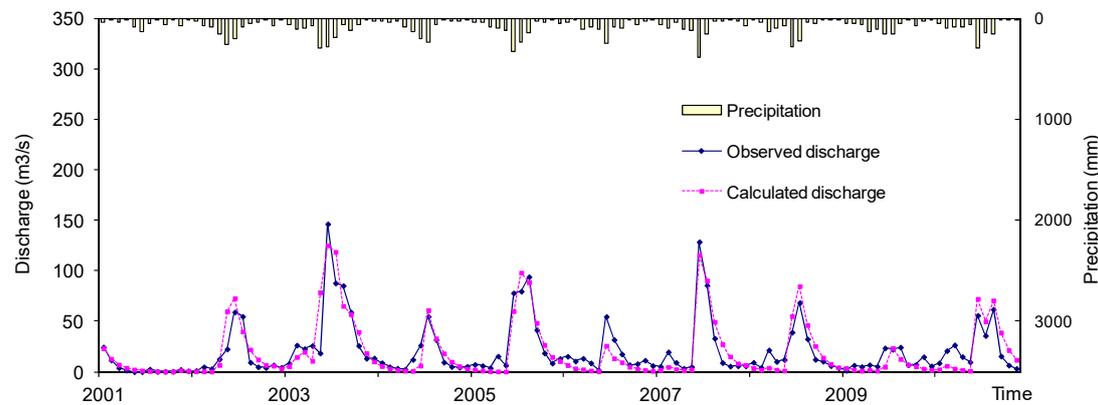


Figure 6 Comparison of monthly observed and simulated runoff for the validation period at Bengbu hydrological stations

4.3 Assessment of climate change impact on water resources

Variation of annual mean runoff depth over the future 100 years was shown in Figure 7. The figure demonstrate that:

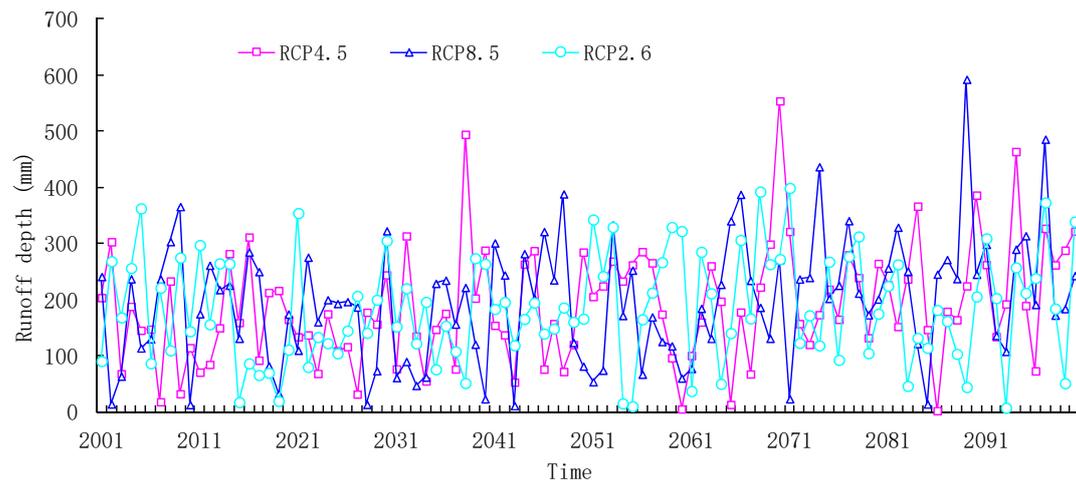


Figure 7 Prediction of runoff depth in Huaihe river basin from 2000 to 2100 under different scenarios

(1) Under the RCP 8.5 scenario, the annual runoff depth of the Huaihe River basin in the next 100 years predicted by the climate model showed no obvious increasing trend, and the annual runoff depth increased trend could not reach the degree of significant change in most periods. The average annual runoff from 2080 to 2100 was 250mm, which increased by 72mm compared

with that was 178mm from 2001 to 2020. The increase rate is 7mm/10 years.

(2) Under the RCP 4.5 scenario, the annual runoff depth of the Huaihe River basin in the next 100 years predicted by the climate model showed no obvious increasing trend, and the annual runoff depth increased trend did not reach a significant degree in most periods. The average annual runoff from 2080 to 2100 was

230mm, which increased by 70mm compared with that 160mm from 2001 to 2020. The increase rate is 11mm /10 years.

(3) Under the RCP 2.6 scenario, the annual runoff depth of the Huaihe River basin in the next 100 years predicted by the climate model showed no obvious increasing trend, and the annual runoff depth increased trend could not reach the degree of significant change in most periods. The average annual runoff from 2080 to 2100 was 183mm, which increased by 16mm compared with that was 167mm from 2001 to 2020. The increase rate is 2mm /10 years, which is far from its corresponding changes in RCP8.5 and RCP4.5 scenarios.

5 Conclusions

Based on the long term hydro-meteorological data in the main districts of the Huaihe River Basin, the impact of climate change on water resources in the Huaihe River Basin was investigated by using monthly hydrological model in conjunction with output products of NCAR climate model. The results showed that:

(1) The NCAR-CCSM4 climate model predicted that precipitation of RCP8.5 and RCP4.5 scenarios in the basin showed a fluctuating upward trend, while the precipitation of RCP2.6 scenario showed no significant upward or downward trend. The predicted temperature in the 3 scenarios showed an upward trend. The rise rates of temperature under RCP8.5, RCP4.5 and RCP2.6 scenarios are 0.35, 0.2, 0.1 C /10, respectively.

(2) The annual runoff of the Huaihe River Basin showed no significant increasing trend from 2001 to 2100. The increasing rates of RCP 8.5, RCP 4.5 and RCP 2.6 were 7 mm/10 years, 11 mm/10 years and 2 mm/10 years, respectively.

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