**A study of runoff and water quality changes under the influence of different climate and land use —— Taking the Yongding River Basin as an example**

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**Abstract:** Global warming has caused changes in the spatial and temporal distribution of water resources and affected the water environment. Land use change is mainly influenced by human activities, which is also one of the reasons for the water environment problems have become increasingly serious. The Yongding River basin is important water connotation area and ecological barrier in Beijing-Tianjin-Hebei region in China. The basin has been affected by human activities and climate change, there are problems such as significant reduction in runoff and serious water pollution. To study the effects of climate change and land use on runoff and water quality, this paper simulates runoff and water quality by the Hydrological Simulation Program FORTRAN(HSPF) model, then studied the changes of runoff and water quality under different land use and climate scenarios. The results show that: the HSPF model has good applicability in the Yongding River basin, the Relative Error (Re) of runoff and water quality simulation is within 10%, the Nash Coefficient (NSE) and Correlation Coefficient (R) are above 0.6. The simulation results of different land use scenarios show that the expansion of construction land has a facilitating effect on runoff and also leads to the increase of pollutant concentrations in river; forest and grassland inhibit the generation of runoff, while having a purifying effect on water quality. The simulation results of different climate scenarios show that the rainfall rising has a positive effect on runoff generation and water quality improvement and the temperature rising has a negative effect on runoff generation and water quality improvement. At the same time, the "evaporation paradox" also affects the runoff change. In the integrated scenario, simulation results show that the land use and climate change influence the changes in runoff and water quality, but the influence mechanism is not a simple superposition.

**Keywords:** climate and land use change; runoff and water quality; HSPF model; scenario simulation

# 1 INTRODUCTION

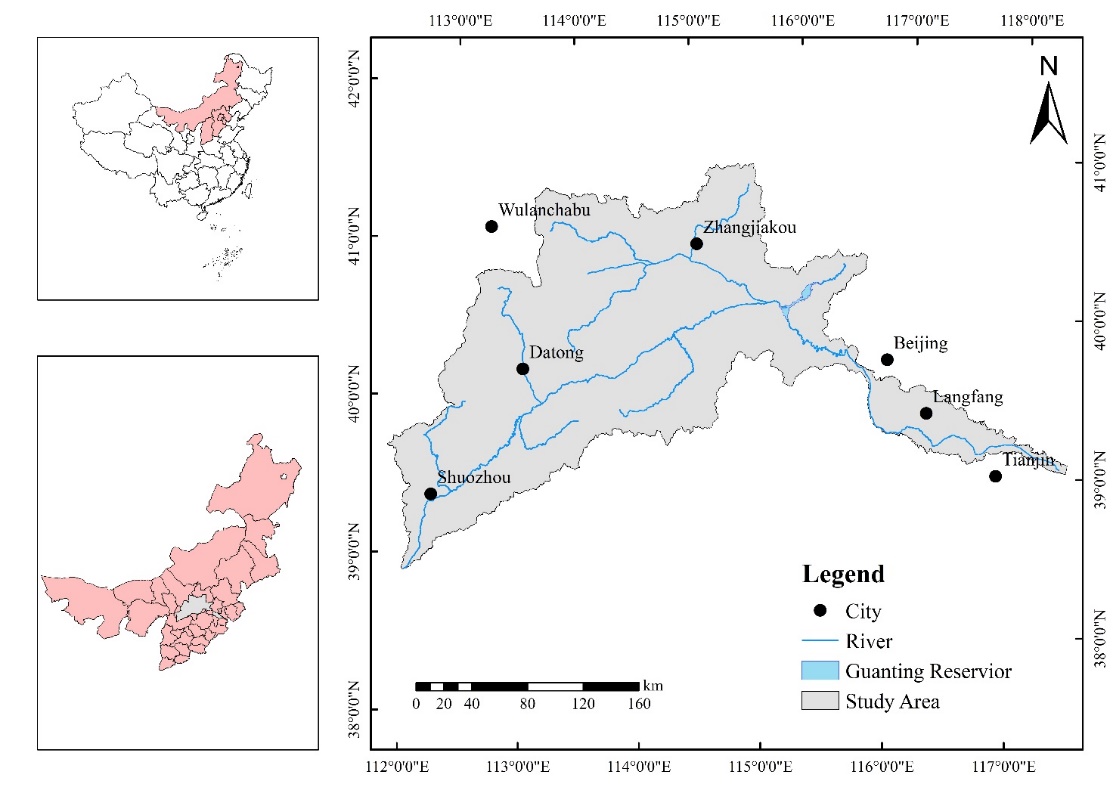
The sixth report of the Intergovernmental Panel on Climate Change (IPCC) indicates that the global average temperature has increased by about 1°C compared to pre-industrial and temperature increases 1.5°C perhaps in the future *(Wang et al., 2022)*. The frequent occurrence of extreme climates such as high temperatures and droughts have caused a spatial and temporal redistribution of water resources as well as a change in the total amount of water resources, while showing obvious geographical characteristics, such as increased rainfall at high latitudes and decreased at low latitudes in the tropics *(Stocker et al., 2015; Hulme et al., 1998; Liu et al., 2020. Mitchell et al.,2013)*. The increase in temperature will also cause an increase in the temperature of river water bodies, which will promote algal blooms and cause ecological degradation; the increase in rainfall will easily induce flooding and a large amount of pollutants will enter water bodies with surface runoff, then cause the degradation of water environment *(Chang et al., 2001; Murdoch et al., 2000)*. Land use change is one of the most direct manifestations of human activities. Existing studies point out that land use change is an important cause of global ecological changes and water environment problems becomes more and more serious *(Shi et al., 2015; Fan and Shibata, 2016)*. The Yongding River basin is important water connotation area and ecological barrier in Beijing-Tianjin-Hebei region. Affected by human activities and climate change *(Hou et al., 2020)*, the runoff in the basin has been sharply reduced and even some of rivers have been dried up *(Li et al., 2021）*. Meanwhile, the water bodies in the basin are seriously polluted and the ecosystem is degraded. On the other hand, the rate of land use change has accelerated since 2015, especially the expansion of construction land, which has crowded out the original distribution of land types*(Cao et al., 2022)*, so further optimization is needed in town planning and land type allocation.

The current climate status and land use changes in the Yongding River basin have been studied to some extent, but little research has been done on the effects of different land use and climate conditions on runoff and water quality in the basin. Therefore, this paper investigates the effects of different land use and climate conditions on runoff and water quality by using the Hydrological Simulation Program FORTRAN (HSPF) model, which is suitable for larger basin and this model can simulate hydrology and point source/non-point source pollution, especially in the simulation of pollutants *(Hayashi et al.,2004; Mishra et al.,2009; Yan et al.,2014; Lee et al.,2010)*. The HSPF model meets different land use *(Bai et al.,2020; Bello et al.,2019; Liu et al.,2011; Ahn et al.,2016; Luo et al.,2020)* and meteorological conditions *(Gizaw et al.,2017; Yi et al.,2020; Kim et al.,2019; Zhou et al.,2017; Taner et al.,2011)* input with the convenience due to a separate operator interface. In this study, runoff and water quality changes under different Land use and climate scenarios are studied to provide reference for river water resources allocation, water environmental protection and optimal configuration of land use types.

# 2 DATA AND METHODS

## 2.1 Study river description

Yongding River is one of the seven major water systems in the Haihe River Basin, located between 112°-118°and 39°-41°20'N (Fig. 1). The river has a total length of 747 km and the basin area of 47016 km2. It spans five Provinces (Autonomous Regions and Municipalities), including Inner Mongolia, Shanxi, Hebei, Beijing and Tianjin. The main tributaries are Sangan River and Yanghe River, which are called Yongding River after their confluence in Huailai County of Hebei Province, then flows into the Bohai Sea through Beijing and Tianjin. The western and northern parts of the basin are mostly mountainous with undulating terrain and fast flowing water. From the Guanting Reservoir to Sanjiadian is the mountain gorge section, then enters the Beijing-Tianjin Plain with flat terrain. The Yongding River basin has a typical features of temperate continental monsoon climate. The annual distribution of rainfall in the basin is uneven, mostly concentrated in summer, accounting for 64% of the annual rainfall, and evaporation is mainly concentrated in spring and summer, accounting for 75% of the annual evaporation. The average temperature is 7.3℃ with the highest temperature occurring in 1999 (8.78℃) and the lowest temperature in 1957 (5.5℃).



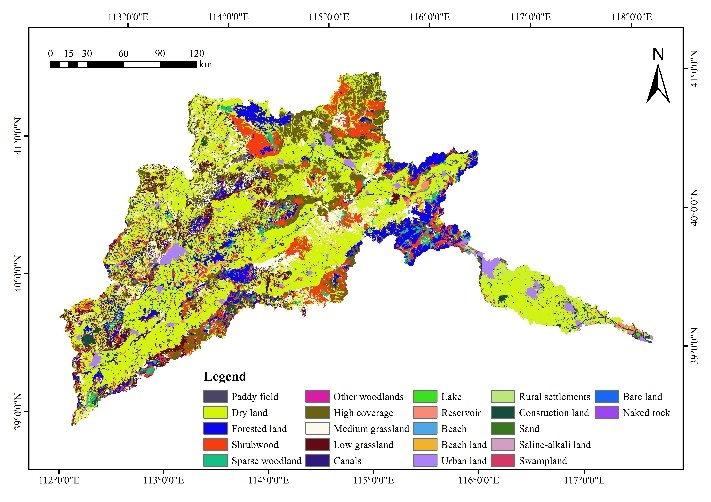
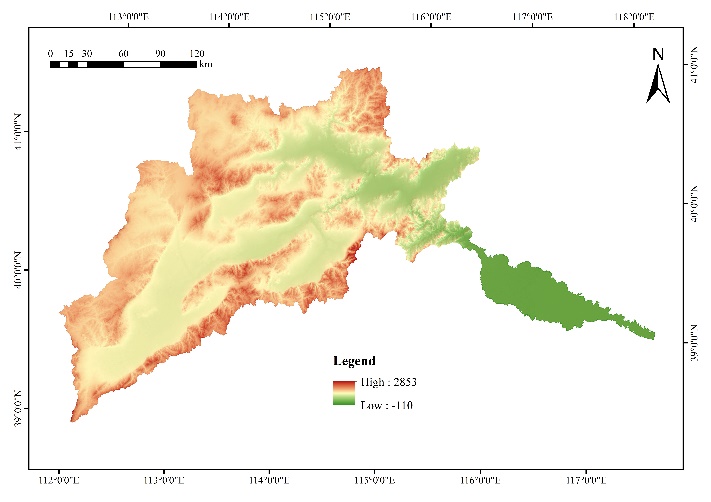
**Fig. 1 The location of Yongding River**

## 2.2 Data Description

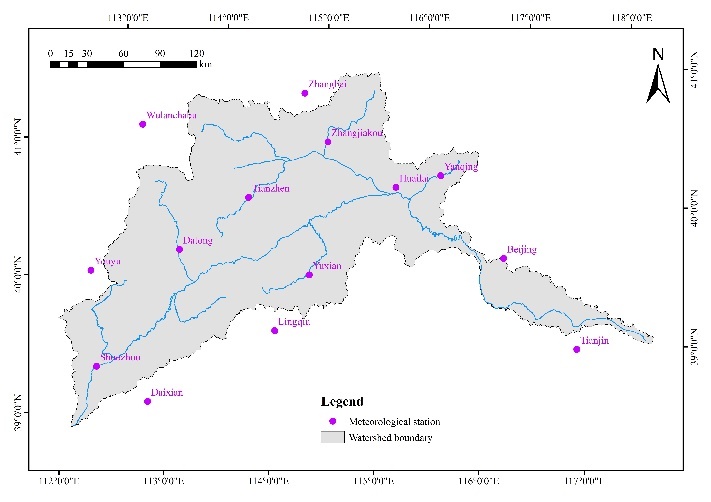
Various types of data are mainly used as input data for the hydrological model, the main contents are shown in Table 1. Among them, the meteorological stations are used as one of the basic data and 14 meteorological stations in the watershed are selected in this study (Table 2), then seven parameters, such as rainfall, evaporation, dew-point temperature, wind speed, relative humidity, hours of sunshine are inputted into the model. The distribution of meteorological stations are shown in Fig. 4. The Digital Elevation Model (DEM) data (Fig. 2) is used to match the distribution of waterways for the delineation of catchment units. In addition, there are land use (Fig. 3), runoff and pollutant discharge data, all of which are used as model input data.

**Table 1. Data content.**

| Name | Content | Time Series |
| --- | --- | --- |
| Land use | Primary Land use classification | 2018 |
| Meteorological Data | Day-by-day observation data | 2014-2018 |
| Hydrological Data | Runoff observation data | 2014-2018 |
| Pollutant emission Data | Annual Emissions | 2017-2018 |
| Terrain Data | DEM data | — |
| Water system vector image | Main streams and first and second tributaries | — |



|  |  |
| --- | --- |
| **Fig. 2 DEM in Yongding River** | **Fig. 3 Land use in Yongding River** |



**Fig. 4 Meteorology Station in Yongding River**

**Table 2. Meteorology Station Information.**

| ID | Station | Province | Longitude | Latitude | Elevation |
| --- | --- | --- | --- | --- | --- |
| 1 | Datong | Shanxi | 113.33°E | 40.10°N | 1067.2 m |
| 2 | Shuozhou | Shanxi | 112.43°E | 39.30°N | 1114.8 m |
| 3 | Tianzhen | Shanxi | 114.05°E | 40.43°N | 1014.7 m |
| 4 | Youyu | Shanxi | 112.45°E | 40.00°N | 1345.8 m |
| 5 | Daixian | Shanxi | 112.90°E | 39.02°N | 859.7 m |
| 6 | Lingqiu | Shanxi | 114.18°E | 39.45°N | 938.7 m |
| 7 | Wulanchabu | Inner Mongolia | 113.07°E | 41.03°N | 1419.3 m |
| 8 | Zhangjiakou | Hebei | 114.88°E | 40.78°N | 772.8 m |
| 9 | Yuxian | Hebei | 114.57°E | 39.83°N | 909.5 m |
| 10 | Huailai | Hebei | 115.50°E | 40.40°N | 570.9 m |
| 11 | Zhangbei | Hebei | 114.70°E | 41.15°N | 1393.3 m |
| 12 | Yanqing | Beijing | 115.95°E | 40.45°N | 487.9 m |
| 13 | Beijing | Beijing | 116.47°E | 39.80°N | 31.3 m |
| 14 | Tianjin | Tianjin | 117.07°E | 39.08°N | 3.5 m |

## 2.3 Proofreading of simulation results

The Relative Error (Re), Nash-Sutcliffe Efficiency (NSE) and Correlation Coefficient (R) are used to measure the simulation results and the range of values are shown in Table.3. The expressions are shown below：

|  |  |  |
| --- | --- | --- |
|  |  | (1) |
|  |  | (2) |
|  |  | (3) |

where is the observed value, is the simulated value, and are the average values of the observed and simulated values, respectively.

**Table 3. Range of model evaluation indicators.**

| Evaluation Indicators | Good | Better | General | Bad |
| --- | --- | --- | --- | --- |
| Re | <10% | 10%-15% | 15%-25% | >25% |
| NSE | >0.9 | 0.7-0.9 | 0.5-0.7 | <0.5 |
| R | >0.9 | 0.7-0.9 | 0.6-0.7 | <0.6 |

2.2.3 Scenario Setting

In order to study the effects of different land use and climate conditions on runoff and water quality, the study set different land use and climate scenarios are set up on the base on the model that has been established.

(1) Land use scenarios setting

In 2020, the land use types in the Yongding River basin are mainly cropland, grass land and forest land, accounting for 89.25% of the basin area, while the trend of construction land is expanding *(Cao et al., 2022)*. Based on land use status, slope analysis is conducted by using DEM data and the result shows that the slope of the Yongding River basin distributes between 0~35.38°. To facilitate analysis, the slope is graded, every 5° is divided as one level and there are 8 levels in total. Then the slope data were overlaid with the land use data to obtain the distribution of each land use type under each level, as shown in Table 4.

Using the land use in 2018 as the benchmark scenario(L0), integrating with each city's land use master plan, considering the economic development and basic farmland protection in the watershed (by 2025, the basic cropland in the watershed is about 16835 km2), two scenarios are set: (1) Considering the current economic development in the watershed and integrating with the land use plan, land use scenario 1 (L1) is set as: expanding the scope of construction land (mainly urban areas), then converting grassland and forest land below 2° into construction land. (2) Considering the protection of basic farmland in the basin and the improvement of cropland quality, based on the distribution and area of basic farmland in each city, land use scenario 2 (L2) is set: the distribution of basic farmland in the basin remains unchanged and cannot be transferred to other land types, while the conversion area of cropland to forest land, grassland and construction land is reduced. The results of the land use scenarios are shown in Table 5.

**Table 4. Distribution of Land use with slope.**

| Slope level | Slope  (°) | Cropland  (km2) | Forest land  (km2) | Grass land  (km2) | Waters  (km2) | Construction land  (km2) | Unused land  (km2) |
| --- | --- | --- | --- | --- | --- | --- | --- |
| 1 | 0-5 | 19106.8 | 5026.10 | 7662.20 | 754.85 | 3818.04 | 158.51 |
| 2 | 5-10 | 1219.49 | 3598.07 | 3433.58 | 20.74 | 199.99 | 9.92 |
| 3 | 10-15 | 117.48 | 1402.07 | 695.81 | 2.50 | 27.18 | 0.98 |
| 4 | 15-20 | 11.96 | 364.18 | 106.12 | 0.08 | 3.03 | 0.15 |
| 5 | 20-25 | 0.45 | 58.59 | 26.95 | — | — | — |
| 6 | 25-30 | — | 7.72 | 7.57 | — | — | — |
| 7 | 30-35 | — | 0.53 | 0.98 | — | — | — |
| 8 | ≥35 | — | — | 0.076 | — | — | — |

**Table 5. Land use scenarios setting.**

| Type | L0  (km2) | L1  (km2) | L2  (km2) |
| --- | --- | --- | --- |
| Cropland | 20842.19 | 20842.19 | 20712.94 |
| Forest land | 10663.23 | 10438.68 | 10690.26 |
| Grass land | 12355.80 | 12177.28 | 12428.86 |
| Waters | 893.30 | 893.30 | 893.3 |
| Construction Land | 4109.20 | 4512.27 | 4123.78 |
| Unused land | 178.66 | 178.66 | 178.66 |

(2) Climate change scenario setting

As of the mid-21st century, the range of temperature change in North China is 1.6-3.42°C and the range of rainfall change is -29.7%~18.5% *(Tang et al., 2009)*. Rainfall in the Yongding River basin shows a decreasing trend from 1957 to 2018 with a decrease rate of -2.88 mm/10a*（Yang et al., 2022）*. From 1958 to 2018, the temperature in the basin shows an increasing trend with an increase rate of 0.29 °C/10a. At the same time, evaporation shows a decreasing trend with a decrease rate of -48.88 mm/10a and shows the "evaporation paradox"*（Li et al., 2021）*.Based on the above climatic background, the climate assessment tool CAT (Climate Assessment Tool) in HSPF model is used and combine the multi-year evolution of rainfall and temperature in the Yongding River basin, using the climate status in 2018 as the benchmark scenario(C0), climate scenario 1 (C1) is set as: rainfall increased/decreased by 10% from benchmark scenario (P+10%, P -10%, respectively); climate scenario 2 (C2) is set as: the temperature increases by 1°C and 2°C (T+1°C and T+2°C, respectively) from benchmark scenario. The climate scenarios are shown in Table 6.

**Table 6. Climate scenario setting.**

| Scenario | Sub-scenario | Average rainfall | Average temperature |
| --- | --- | --- | --- |
| C0 | P  T | 422.77mm | 8.87℃ |
| C1 | P+10% | 465.05 mm | 8.87℃ |
| P-10% | 380.49 mm | 8.87℃ |
| C2 | T+1℃ | 422.77mm | 9.87℃ |
| T+2℃ | 422.77mm | 10.87℃ |

(3) Integrated land use and climate change impact scenario setting

In order to analyze the runoff and water quality response under the integrated impact of land use and climate change, the simulation results of 2018 land use and 2014-2018 meteorological conditions are used as the base scenario(S0), then land use scenarios (L1, L2) and climate scenarios (C1, C2) are intersected with each other, so eight scenarios are designed. As shown in Table 7.

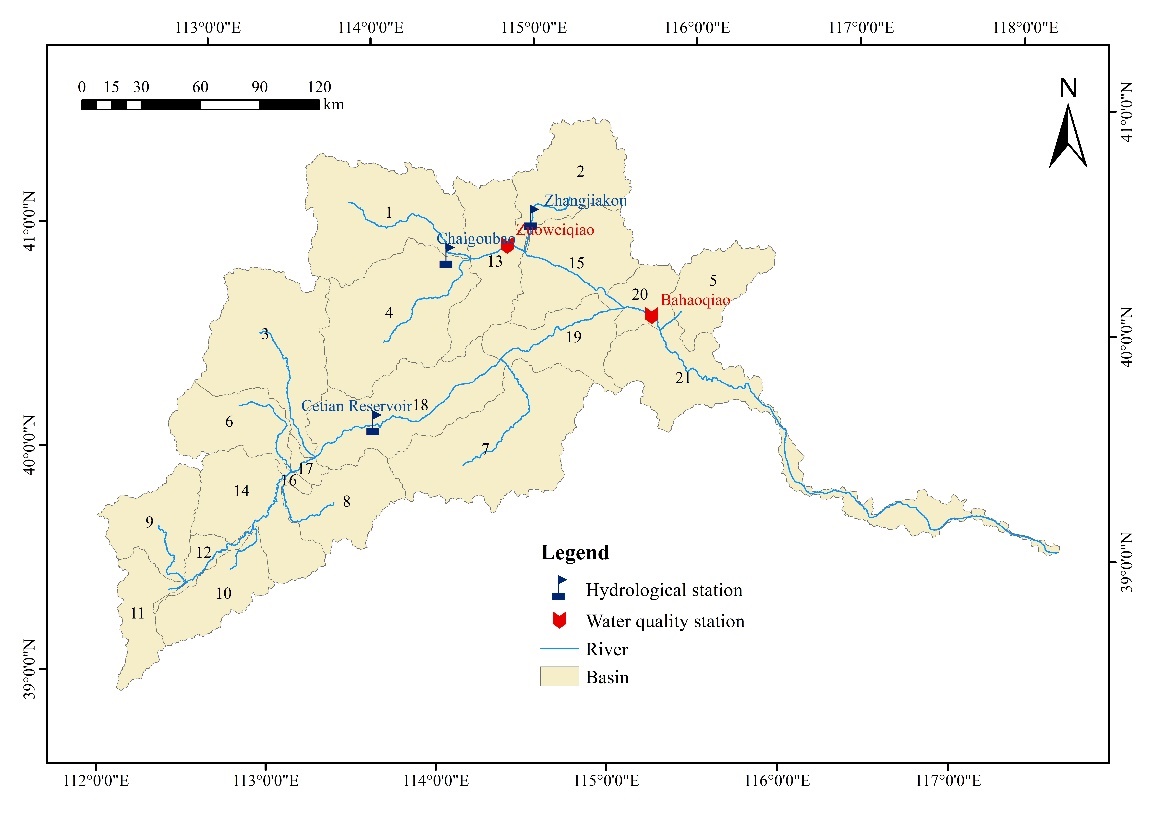
**Table 7. Integrated scenario setting.**

| Land use Scenario | Climate Scenario | Integrated Scenario | Rainfall/Temperature Change |
| --- | --- | --- | --- |
| L0 | C0 | S0 | P  T |
| L1 | C1 | S1 | P+10% |
| S2 | P-10% |
| C2 | S3 | T+1℃ |
| S4 | T+2℃ |
| L2 | C1 | S5 | P+10% |
| S6 | P-10% |
| C2 | S7 | T+1℃ |
| S8 | T+2℃ |

# 3 RESULTS

## 3.1 Model calibration and validation

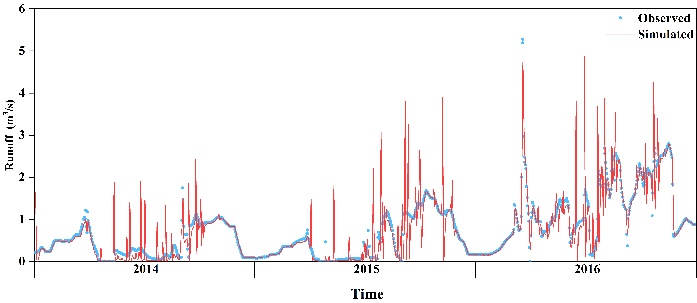
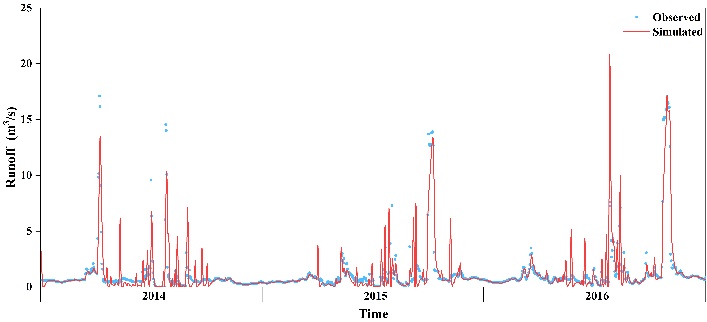
According to the distribution of basin topography and river network, Yongding River basin is divided into 21 sub-basins with the help of "Automatic Watershed Delineation" function in the HSPF model.The results are shown in Fig. 5. Meanwhile, the distribution of hydrological stations and water quality stations used for runoff and water quality calibration and verification are also shown in Fig. 5.The runoff simulation result of Yongding River basin are shown in Fig. 6 and Fig. 7 and the simulation result of the water quality are shown in Fig. 8 and Fig. 9. The simulation effect is shown in Table 8.



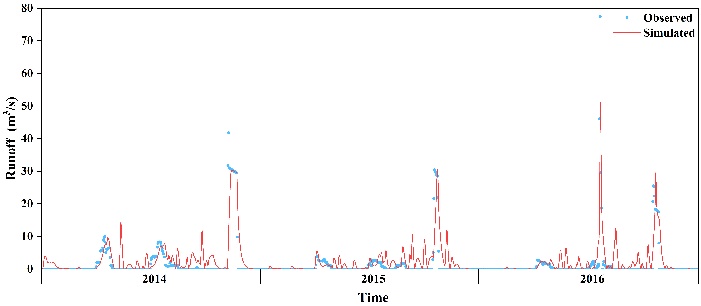
**Fig. 5 Results of sub-basins delineation**

The Relative Error (Re) is below 10%, the Nash-Sutcliffe Efficiency (NSE) is between 0.6 and 0.9, the Correlation Coefficient (R) is between 0.7 and 0.9 in both the calibration and validation, which achieve better results. Among them, the simulation results of the calibration of Zhangjiakou station and the validation of Cetian Reservoir station are better with the Relative Error (Re) of -1.07% and 0.25%, the Nash-Sutcliffe Efficiency (NSE) of 0.85 and 0.76, the Correlation Coefficient (R) of 0.93 and 0.88, respectively.

Bahaoqiao shows that the simulation of COD is better in the calibration and the validation with the Relative Error (Re) are between -1.23% and -1.80%, the Nash-Sutcliffe Efficiency (NSE) are between 0.68 and 0.59, the Correlation Coefficient (R) are between 0.89 and 0.82, respectively. The water quality simulation results of the Zuoweiqiao are similar to the Bahaoqiao and the simulation of COD is better. The Relative Error (Re) during the validation of NH4-N is larger (25.75%); But the simulation of TP is not as good as the Bahaoqiao, the Relative Error (Re) during the calibration and validation are between -10.86% and 15.99%, respectively; the Nash-Sutcliffe Efficiency (NSE) are between 0.81 and 0.76; the Correlation Coefficient (R) are between 0.81 and 0.63, respectively.

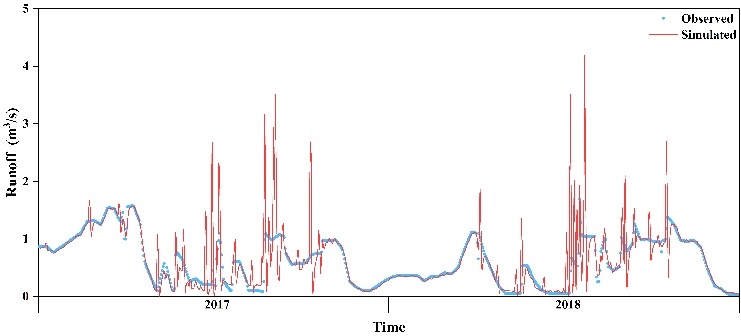
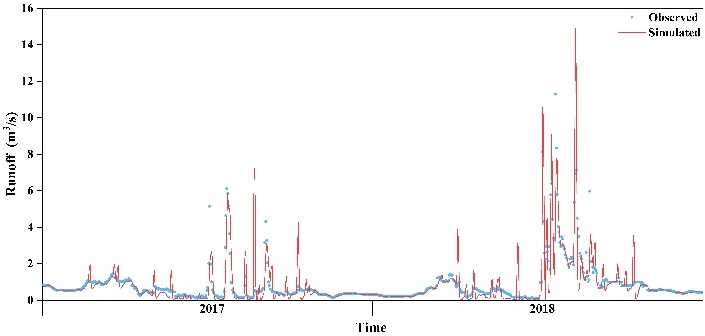


|  |  |
| --- | --- |
| (a) Chaigoubao | (b)Zhangjiakou |

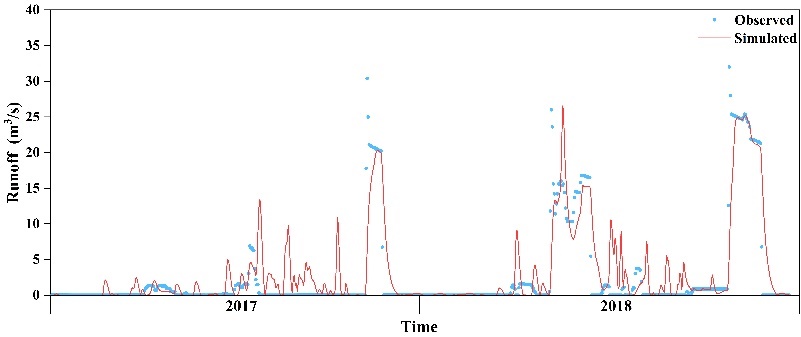


(c) Cetian Reservoir

**Fig. 6 Calibration period Runoff Simulation Results.**



|  |  |
| --- | --- |
| (a) Chaigoubao | (b)Zhangjiakou |



(c) Cetian Reservoir

**Fig. 7 Validation period runoff simulation results.**

|  |  |
| --- | --- |
|  |  |
|  | |
| **Fig. 8 Water quality simulation results of Bahaoqiao** | |
|  |  |
|  | |
| **Fig. 9 Water quality simulation results of Zuoweiqiao** | |

**Table 8. Simulation effect.**

| Station | Classification | Calibration | | | Validation | | |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Re | NSE | R | Re | NSE | R |
| Chaigoubao | Runoff | -1.65% | 0.67 | 0.82 | -1.81% | 0.63 | 0.79 |
| Zhangjiakou | Runoff | -1.07% | 0.85 | 0.93 | -5.14% | 0.68 | 0.75 |
| Cetian Reservoir | Runoff | 4.42% | 0.63 | 0.81 | 0.25% | 0.76 | 0.88 |
| Bahaoqiao | COD | -1.23% | 0.68 | 0.89 | -1.80% | 0.59 | 0.82 |
| NH4-N | -4.81% | 0.60 | 0.79 | -21% | 0.67 | 0.84 |
| TP | -4.63% | 0.68 | 0.88 | -6.34% | 0.57 | 0.76 |
| Zuoweiqiao | COD | -1.12% | 0.66 | 0.92 | -6.54% | 0.53 | 0.88 |
| NH4-N | -18.36% | 0.88 | 0.94 | 25.75% | 0.68 | 0.70 |
| TP | -10.86% | 0.59 | 0.81 | 15.99% | 0.76 | 0.63 |

## 3.2 Analysis of simulation results of different land use scenarios

According to the two land use scenarios, the average runoff from 2014 to 2018, the change of water quality in from 2017 to 2018 are simulated. The above simulation results are compared and analyzed with the results of the baseline scenario simulation. As can be seen from Table 9, compare with L0, the average runoff of L1 and L2 both increase with 0.79 m3/s and 0.78 m3/s, respectively. The rate of change of runoff is 7.52 % and 7.47 %, respectively. Comparing the changes of average runoff in L1 and L2, it is found that the average runoff of L2 is smaller than that of L1, but the difference is not significant (0.01 m3/s). Analyzing the changes of Land use in the two scenarios, it is found that the increase of construction land is beneficial to runoff generation, while the increase of forest land and grassland can intercept rainfall, reduce evaporation, so that the runoff decreases. So there is a phenomenon that the runoff of L1 and L2 increase, but the runoff of L2 scenario is smaller than L1.

The concentrations of various pollutants increase in both scenarios and the NH4-N concentration increases most significantly. Compared with L0, the COD concentrations in L1 and L2 increase by 6.52 mg/L and 6.25 mg/L, with a change rate of 35.00 % and 33.52 %, respectively; the NH4-N concentrations increase by 0.23 mg/L and 0.22 mg/L with a change rate of 78.53 % and 76.94 %, respectively; the TP concentrations increase by 0.061 mg/L and 0.059 mg/L with the change rate are 35.26 % and 33.82 %, respectively. Comparing the L1 and L2 scenarios, it is found that the average concentrations of the three pollutants in the L1 are greater than L2 (0.280 mg/L, 0.004 mg/L, and 0.003 mg/L for COD, NH4-N, and TP, respectively), this situation is mainly due to the increase of forest land and grassland in the L2 scenario, which plays a certain purifying effect on the river.

**Table 9. Land use scenarios runoff and water quality changes.**

| Scenario | Runoff | | COD | | NH4-N | | TP | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Annual average（m3/s） | Rate of change  (%) | Annual average  (mg/L) | Rate of change  (%) | Annual average  (mg/L) | Rate of change  （%） | Annual average  (mg/L) | Annual average  (%) |
| L0 | 10.43 | — | 18.6348 | — | 0.2879 | — | 0.1730 | — |
| L1 | 11.22 | 7.52 | 25.1575 | 35.00 | 0.5140 | 78.53 | 0.2340 | 35.26 |
| L2 | 11.21 | 7.47 | 24.8808 | 33.52 | 0.5094 | 76.94 | 0.2315 | 33.82 |

## 3.3 Analysis of simulation results of different climate change scenarios

According to the two climate scenarios, the average runoff from 2014 to 2018, the changes of water quality in from 2017 to 2018 are simulated. The above simulation results are compared and analyzed with the results of the baseline scenario simulation. As can be seen from Table 10, the runoff increases by 7.52 m3/s compares with the C0 scenario and the change rate is 72.08 %, the runoff increases significantly in the case of a 10% increase in rainfall (C1, P+10%). The runoff decreases by 7.23 m3/s compares with the C0 scenario and the change rate is -69.71 % in the case of a 10% decrease in rainfall (C1, P-10%). The runoff increases by 0.05 m3/s compares with the C0 scenario and the change rate is 0.41% in the case of a 1°C increase in temperature(C2, T+1℃). And the runoff decreases by 0.31 m3/s compares with the C0 scenarioand the change rate is -2.98% in the case of a 2°C increase in temperature(C2, T+2℃).For the water quality simulation, the concentrations of COD, NH4-N and TP decrease 9.03 mg/L, 0.09 mg/L, and 0.05 mg/L in the 10% increase in rainfall (P+10%) sub-scenario, respectively. The change rate is -94.00 %, -47.45 %, and -133.04 %, respectively. In the remaining three sub-scenarios, the concentrations of the three pollutants increase compare with the C0 scenario.

From the above analysis, it can be seen that both of the rainfall and temperature change will affect runoff and water quality. Changes in rainfall mainly affect the amount of water in the river, more rainfall means more water in the river and vice versa. For pollutants have discharged directly into the river, the increase in water dilutes the pollutant content in the river. The change of temperature affects the evaporation, higher temperature and consequently higher evaporation, the decrease of surface water flow into the river. The changes of temperature affect the content of dissolved oxygen in the water, the higher temperature leads to a decrease in dissolved oxygen and a subsequent increases COD, then a large amount of nitrogen and phosphorus is released from the sediment.

**Table 10. Climate scenarios runoff and water quality changes.**

| Scenario |  | Runoff | | COD | | NH4-N | | TP | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Annual average（m3/s） | Rate of change  (%) | Annual average (mg/L) | Rate of change  (%) | Annual average（mg/L） | Rate of change  (%) | Annual average (mg/L) | Rate of change  (%) |
| C0 | P | 10.43 | — | 18.6348 | — | 0.2879 | — | 0.1730 | — |
| T |
| C1 | P+10% | 17.95 | 72.08 | 9.60 | -94.00 | 0.19 | -47.45 | 0.12 | -133.04 |
| P-10% | 3.16 | -69.71 | 22.07 | 15.57 | 0.31 | 9.50 | 0.22 | 21.84 |
| C2 | T+1℃ | 10.48 | 0.41 | 22.40 | 16.85 | 0.33 | 14.89 | 0.27 | 36.85 |
| T+2℃ | 10.12 | -2.98 | 22.73 | 18.03 | 0.33 | 15.31 | 0.27 | 37.32 |

## 3.4 Changes in runoff and water quality under the combined effects of land use and climate change

The changes in runoff and water quality under the combined effects of land use and climate change are shown in Table11. S1 and S5 scenarios show the most significant increase in runoff with average runoff increasing by 32.90 m3/s and 17.07 m3/s, compared with the S0 scenario, respectively. And the change rate of 315.37 % and 163.59 %, respectively. The runoff in S2 and S8 scenarios is decreased 1.55 m3/s compared with the S0 scenario and the change rate is 14.88 %. It can be seen that both land use scenarios (L1 and L2) experience significant increase in runoff under the condition of increased rainfall, but the increase in forest land and grassland of L2, the increase in water harvesting capacity make the increase in S5 runoff less than S1. The decrease in runoff in S2 is mainly influenced by the decrease in rainfall and the effect of land use change on runoff is weaker than rainfall in this scenario. On the other hand, S8 is affected by the increase in temperature and evaporation, couples with the fact that L2 has a smaller effect on the increase in runoff than L1, so the runoff appears to decrease. In the remaining four scenarios (S3, S4, S6 and S7), the runoff is all increased compare with S0, but the increase in runoff in S6 and S7 is more obvious than that in S3 and S4. The decrease in rainfall and increase in temperature in these four scenarios are no longer the main determinants of runoff changes, the combined effects of land use and climate change are more significant, the impact mechanisms are more complex. In the two land use scenarios, the increase in runoff is influenced by the expansion of construction land, but the increase in temperature in the S3 and S4 scenarios is also influencing the runoff generation. In the S6 and S7 scenarios, the changes in climatic conditions are the decrease in rainfall (P-10%) and the increase in temperature (T+1°C), respectively. The different changes in meteorological conditions combine with the changes in land use lead to the different increases in runoff.

In terms of water quality changes, the concentration change of COD, NH4-N and TP in the same trend. The concentration increase simultaneously in the S2, S3, S4 and S7 scenarios with the most significant increase in TP concentration, which increase by 46.59%, 40.35%, 48.50% and 45.95%, respectively compare to the S0 scenario.

In addition to the influence of land use changes, climate change is also an important influence on the increase in TP concentration. In the S2 scenario, the TP concentration in the water body increase due to the decrease of rainfall and runoff. In the S3, S4 and S7 scenarios, although the runoff increase compare with S0, the increase of temperature lead to the release of large amount of phosphorus from the bottom sediment and the TP concentration increased. In the remaining scenarios, the concentrations of the three pollutants decreased simultaneously with the most significant decrease in COD concentration, which are -69.26%, -55.79%, -59.08% and -57.20% respectively. This phenomenon is significantly influenced by the climate; the most obvious changes in COD concentration in S1 and S5 scenarios are mainly influenced by the dilution of COD in the river due to the increase of rainfall.

**Table11. Integrated scenario runoff and water quality changes.**

| Scenario | Runoff | | COD | | NH4-N | | TP | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Annual average（m3/s） | Rate of change  (%) | Annual average (mg/L) | Rate of change  (%) | Annual average (mg/L) | Rate of change  (%) | Annual average (mg/L) | Rate of change  (%) |
| S0 | 10.43 | — | 18.6348 | — | 0.2879 | — | 0.1730 | — |
| S1 | 43.34 | 315.37 | 5.7288 | -69.26 | 0.1082 | -62.42 | 0.1087 | -37.17 |
| S2 | 8.88 | -14.88 | 23.3549 | 25.33 | 0.3710 | 28.86 | 0.2536 | 46.59 |
| S3 | 11.28 | 8.15 | 20.8960 | 12.13 | 0.3340 | 16.01 | 0.2428 | 40.35 |
| S4 | 11.12 | 6.62 | 22.7325 | 21.99 | 0.3771 | 30.98 | 0.2569 | 48.50 |
| S5 | 27.50 | 163.59 | 8.2393 | -55.79 | 0.1503 | -47.79 | 0.1201 | -30.58 |
| S6 | 15.86 | 52.03 | 7.6249 | -59.08 | 0.1365 | -52.59 | 0.1294 | -25.20 |
| S7 | 16.70 | 60.05 | 23.2341 | 24.68 | 0.3693 | 28.27 | 0.2525 | 45.95 |
| S8 | 8.88 | -14.88 | 7.9764 | -57.20 | 0.1598 | -44.49 | 0.1401 | -19.02 |

# 4 DISCUSSION

In this paper, runoff and water quality of the Yongding River basin are simulated based on the HSPF model, the simulation results generally met the accuracy requirements. In the process of building the model, it is also found that the meteorological indicators required by the model don’t exactly match with China's climate monitoring indicators, so new indicators had to be converted based on the measured meteorological data. On the other hand, using linear interpolation method is adopted to refine the daily-scale measured meteorological data into hourly scales, such as wind speed and dew point temperature, but this method ignored the actual evolution scenarios. Therefore, localized improvements of the model can be considered in the future to better suit the study of the water ecology of basins in China.

In this paper, to study the impact of land use change on the hydrological cycle under the influence of human activities *(Vitousek et al., 1997)*, different land use type change scenarios are set up in the HSPF model to simulate the changes in runoff and water quality. The results show that both land use change patterns lead to an increase of about 7.5% in runoff and an increase in pollutant concentrations in river. The reasons for the above phenomenon are that both cropland and construction land are "source" landscapes, cropland is significantly affected by human activities, Activities such as cultivation and fertilization affect the nitrogen and phosphorus content of the soil, which are washed into river with rainfall*(Chiang et al., 2012; Hashemi et al., 2016)*; the expansion of construction land expansion increases the area of impervious plots and the natural infiltration of surface runoff is weakened, resulting in more runoff and more pollutants entering river with rainfall *(Lin et al.,2008)*. Therefore, the larger the area of crop land and construction land, the more runoff will generate and the more pollutants will enter the river. On the other hand, forest land is a "sink" landscape, which can reduce pollutants into water bodies through retention and absorption, and has a certain purifying effect on water quality *(Ren et al., 2003; Sliva et al., 2001)*. In view of this, without changing the Land use type, optimization of Land use class distribution should be considered to minimize the negative impact and increase the positive impact.

At present, there is still a small amount of crop land in the Yongding River basin in the range of 15-25°, but there is no crop land above >25°. According to the <Technical Regulations of Land use Status Survey>, soil erosion is more serious in the slope of 15-25° and crop cultivation is prohibited in >25°. Therefore, the area of forest land can be expanded in the range of 15-25°, such as setting up open woodland on the sunny slope of 15-20° and shrubland on the shady slope, and setting up forest land on both the shady and sunny slopes of 20-25°, etc. The development of land with slopes above 25° is prohibited, in order to the vegetation is allowed to recover naturally.

As mentioned earlier, changes in rainfall and temperature affect the spatial and temporal distribution of water resources, and also have an impact on the river water environment. In order to study the possible effects of climate change in the Yongding River basin, different types of climate scenarios are set up in HSPF to simulate the changes of runoff and water quality according to the actual climate evolution trend. The results of the two types of climate scenarios show that the conditions of reduced rainfall cause a significant reduction in runoff and adversely affect the use of water resources in the basin. The Yongding River basin has implemented Yellow River diversion efforts to improve the significant decrease in runoff in recent years *(Li et al., 2021)*, the water shortage has improved, in which reservoirs（such as the Cetian reservoir, etc.）in the basin plays an important role, while influencing the evolution of runoff in its natural state.

In this study, when conducting a study on the effect of climate change on runoff based on simulation results, it is found that the river section in which the Cetian reservoir is not significantly affected by the increase in temperature and did not exactly follow the pattern of decreasing runoff with increasing temperature. The effect of climate on water quality is more complex. This study find that the decrease in rainfall and the increase in temperature cause an increase in pollutant concentrations. On the one hand due to the decrease in rainfall affect runoff production; on the other hand due to the increase in temperature lead to an increase in oxygen consumption in the river, a decrease in dissolved oxygen, an increase in COD content in the ricer, the release of large amounts of ammonia and phosphorus from the sediment. The Yongding River basin is currently experiencing a phenomenon of "decreasing rainfall and increasing temperature", the continuous increase in temperature also leads to an increase in extreme weather events such as droughts and high temperatures *(Hulme et al., 1998; Liu et al., 2020)*. Therefore, in addition to the ecological replenishment efforts implemented in the basin, climate prediction and extreme climate event prevention should be strengthened in the future.

# 5 CONCLUSIONS

HSPF model simulation results show that: The fitting accuracy of the observed and simulated values basically meet the model requirements, indicating that the HSPF model can be applied to the Yongding River basin and then used to study the changes of runoff and water quality under the influence of land use and climate. In the two types of land scenarios, the runoff increase of about 7 % and the concentrations of COD, NH4-N and TP increased by 30~80% compare with L0, respectively. It indicates that the expansion of construction land has a facilitating effect on runoff, while construction land leads to the increase of pollutant concentrations in river, forest land and grassland have a purifying effect on water quality and inhibit the production of runoff. In the two climate scenarios, the changes in runoff are ±70% and the concentrations of COD, NH4-N and TP also show significant changes compare to C0, therefore the increase of rainfall has a positive effect on runoff generation and water quality improvement. The change in runoff is 0.41 % and -2.98 % for the two temperature sub-cases; the concentration of COD, NH4-N and TP change by 10~40%. These results indicate that the increase in temperature has a negative effect on runoff and water quality conditions. At the same time, there is an "evaporation paradox" in the basin, which affects the runoff changes to some extent, so that the runoff still increases under the condition of 1°C increase in temperature. Under the combined influence of land use and climate change, the increase in rainfall leads to an increase in runoff compare to S0. The concentrations of COD, NH4-N and TP decrease compare to S0, respectively. Indicating that the increase in rainfall still has a positive effect on runoff and water quality improvement; in the other scenarios, the changes in runoff and water quality are the result of the combined effects of land use and climate change, rather than the superposition of the two.

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