



## Surface water resources assessment based on water quantity and quality coupling

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### ABSTRACT

The rational surface water resources evaluation and research is a prerequisite for the development, utilization, and protection of water resources. The amount of water resources is an important factor related to the socio-economic development and ecological security of a region. Accordingly, this paper aims to establish a suitable water quality and quantity coupling model based on the current situation of river pollution in the Shenfu section of the Hunhe River basin, with the prediction of surface water resources as the objective function. The research compares the model simulation results with the hydrological data of Fushun No. 2 Station and Cheung Tsing Bridge Station in relevant hydrological data and observes the water quality stations in the basin. Then it sets a conversion coefficient ratio based on common indicators for water quality discrimination and converts the available amount of surface water resources in the study area. The results showed that the error between the simulated and actual measured values of the water station flow and section water level in the study area was 8%, which was within the range specified by the state. Due to water pollution, the amount of locally available water resources were reduced by 16.18% compared to the total amount of surface water resources after conversion. The research results proved that the model constructed in this study had excellent performance in the calculation and evaluation of surface water resources.

*Keywords:* Water quality and quantity coupling; Surface water; Water resources; Hydrodynamic force

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### 1. Introduction

Industrialization and urbanization have led to increasingly intense human activities and an increasing demand for water resources. China is facing a severe water shortage, with a per capita water resource of only 2,200 m<sup>3</sup>. Moreover, water resources distribution is very uneven, making the development of groundwater difficult. In the context of water shortage, only by reasonably evaluating, planning, and managing the limited amount of surface water resources can their maximum social and ecological

value be brought into play. Water quality and quantity are two important attributes for evaluating water resources, and they complement each other. In terms of water quantity, human activities, including farmland irrigation, land development and utilization, and water regulation, mainly lead to water resource shortages; In terms of water quality, the discharge of domestic and industrial water, the continuous growth of population, and weak awareness of ecological environmental protection have caused pollution to the water body and ecological environment [1,2]. Water quality factors were not taken into account in previous water

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resource quantity evaluation simulations. Therefore, adding water quality as a variable to water resource quantity evaluation can more accurately determine the available amount of water resources in a certain region, which is more in line with the requirements of water resource protection and allocation [3]. Due to the continuous development and construction of the Shenfu reach of the Hunshui River basin, the vegetation and land along the reach have been gradually destroyed, and the integrity of the water ecosystem has been constantly destroyed. Therefore, this article selects the Shenfu reach of the Hunshui River basin as the research object, simulates hydrodynamic and quality of the water from a one-dimensional perspective, and couples water quantity models based on this, in order to comprehensively reflect the available amount of surface water resources.

## 2. Related work

Hydrodynamic water quality models offers a trustworthy foundation for predicting the water pollution degree, which has been studied by domestic and foreign scholars. To efficiently utilize water sources in plain areas and scientifically allocate water, Meijun et al. established a river network hydrodynamic model to simulate Haishu Plain's water intake location, water volume, and water transfer impact range. The model results showed a small error, which can provide a scientific basis for water transfer projects and have a certain reference value for the study of water transfer schemes in the Haishu Plain [4]. Peng et al. [5] proposed a bidirectional method for simulating urban water flow based on coupling SWMM and ANUGA models. A hydraulic model based on unstructured triangles was used as a spatial discretization scheme to capture the spatial heterogeneity of urban surfaces. The research results showed that the coupled model can accurately describe surface water logging areas, and urban flood models based on heterogeneous characteristics can be used to determine different types of urban water flow processes. Moghaddam et al. [6] used the Sobol method for sensitivity analysis of hydraulics. The best location in the water network was then selected using sensitivity and cost criteria. The head drive simulation method (HDSM) and various parameters were utilized to assess the impact on the standard deviation (SD) of hydraulic and mass models. The analysis was applied to the combined SD, and the outcomes demonstrated notable shifts in priority for specific selected points as a result of implementing the Sobol method and HDSM. Heidarzadeh et al. [7] used a simple mathematical model to simulate the water quality of the Seymareh reservoir, predicting total solution solids (TDS), biochemical oxygen demand (BOD), and nitrate ( $\text{NO}_3^-$ ) content. Experimental data showed that the average relative errors of TDS, BOD, and  $\text{NO}_3^-$  predicted by this model were 10.8%, 31.5%, and 16.5%, respectively, which was similar to the prediction results of the complex model CE-Qual-W73 model and the actual reservoir sampling data, and the simple mathematical model took less time. Sudhir et al. [8] evaluated northern India groundwater by the WATEQ4F geochemical model. In the component analysis results, PC1 explained 34.066% of the total variance, followed by PC2 with 20.65%, PC3 14.29%, PC4 9.62%, PC5 7.44%, and the cumulative variance was 86.088%.

The  $r_1$  and  $r_2$  indices indicated that the groundwater in the investigated region belonged to  $\text{Na-SO}_4^{2-}$  and deep meteoric infiltration types, which were basically consistent with the groundwater sample dataset, indicating that the model had good applicability in groundwater quality analysis.

Water quality and quantity jointly affect the utilization rate of water resources. Coupling them can optimize the utilization of water resources and solve problems such as water shortage. Domestic and foreign scholars have also conducted a large amount of research on water quality and quantity coupling simulation. Masoumi et al. [9] for the first time introduced a sustainable water quality and quantity management model into the Karkh River Reservoir system in Iran, combining two-dimensional fluid dynamics and water quality simulation models with multi-objective particle swarm optimization to develop a simulation optimization method. The outcomes demonstrated that utilizing ANN in a dynamic form as opposed to CE-QUAL-W2 could substantially impacted the computation time, while also factoring in the precision of the developed simulation optimization model. In addition, the use of sustainability indices significantly reduced the severity and sequence of failure periods in water quality and quantity. Golzari et al. [10] used the Soil and Water Assessment Tool for the water volume and quality of basins in northwestern Iran simulation and determine the impact of dam construction and land use changes on river flow, evapotranspiration, groundwater recharge, and nitrate loading. Dam construction and land use not only significantly reduced the amount of water flowing into the Zarina River, and dried up the lake, but also increased the nitrate load. Hence, it was advised to implement remedial measures within the watershed region to enhance the ecological condition of Urmia Lake. Shihab et al. [11] used factor analysis techniques to study the water quality and quantity changes after influencing Qaber Al Abid Village and Dwezat Village downstream of Mosul City with the Upper Zabu River. To conduct seasonal analysis, two to four factors were derived from the measured water quality parameters and flow data to test the pH value, electrical conductivity, total alkalinity, etc. of the samples. The results showed that pH, electrical conductivity, and  $\text{PO}_4^{3-}$  were the biggest factors leading to changes in water quality at the two locations. Azadi et al. [12] suggested a simulation optimization technique that merged the CE-QUAL-W2 hydrodynamic model with the k-nearest firefly algorithm model. This method was employed to attain the best reservoir flow rate for meeting water quality targets in the face of changing climatic conditions. To evaluate The 36 dry and wet year simulation optimization scenarios under both baseline and climate change scenarios, the assessment was conducted by taking into account three initial water levels (minimum, average, and normal) and three reservoir thresholds. The results showed that this algorithm overcome the computational burden of CE-QUAL-W2, and optimized the total dissolved solids calculation efficiency. It provided a feasible scheme for reservoir operation in combination with water quantity and quality and optimized water supply response methods in different climates.

The research on hydrodynamic and water quality at home and abroad mainly focused on model

solving, practicality, and comprehensiveness. This article will improve the hydrodynamic equations based on the current situation of the selected waters, using implicit difference methods to solve the Saint Venant equations, ensuring the stability of the model, and obtaining more accurate simulation data. In terms of water quality and quantity models, research has focused on improving different algorithms and models to simulate water areas. This article will establish a water quality and quantity coupling model for the selected water areas during the flood season and non-flood season as the research object.

### 3. Water quality and quantity coupling model

#### 3.1. One-dimensional hydrodynamic model

In reality, the depth of a river is smaller than its length and width. Assuming that the distribution of hydrodynamic elements in the water body on the section perpendicular to the river and the surface is balanced, a two-dimensional model can be built on the length and section to analyze the water body [13]. In this paper, the Saint Venant equation is used to simulate the flow state. Before establishing the model, certain idealized assumptions need to be made. First, the flow velocity of the river is uniform, which can be replaced by the average flow velocity; Second, the water pressure is proportional to the water depth, ignoring the flow velocity and acceleration on the river section; Third, the surface of the river is horizontal, ignoring the partial head generated during the flow movement; Last, the riverbed slope is assumed to be zero [14].

Considering that the branching points of the flow segments in the study area may have some interference with the hydrodynamic analysis, this paper improves the Saint Venant equation based on the above assumptions, and the improved equation is as follows:

The flow continuity equation is:

$$\frac{\partial Q}{\partial t} + \frac{\partial A}{\partial t} = 0 \tag{1}$$

The hydrodynamic equation is:

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x} \left( \alpha \frac{Q^2}{A} \right) + gA \left( \frac{\partial z}{\partial x} + S_f \right) = 0 \tag{2}$$

where  $Q$  in Eqs. (1) and (2) refer to the flow through the river section, with the unit of  $m^3/s$ ;  $x$  is the coordinate length with the water flow direction as the coordinate axis, and the unit is  $m$ ;  $t$  is the time allotted for the study, in seconds;  $q$  is the side inflow, in  $m^3/(s \cdot m)$ ;  $z$  is the average of the river digits;  $R$  is the hydraulic radius ( $m$ );  $S_f$  represents the frictional gradient;  $n$  represents the Manning coefficient.

Research suggests that when there is a side inflow flow, the dynamic equation needs to add additional value to the side flow. However, in reality, this impact is relatively small and can be ignored [15]. However, rivers with side inflow flow injection also have branching points, so it is also necessary to meet the connection conditions of the branching points. The branching point equation is as follows:

Mass conservation equation:

$$\sum_{i=1}^n Q_i = \frac{dV}{dt} \tag{3}$$

Momentum conservation equation:

$$z_i + \frac{1}{2g} v^2 = E \tag{4}$$

where  $Q_i$  represents the flow of the  $i$ -th tributary into the river channel, in unit  $m^3/s$ ;  $n$  is the number of tributaries, and  $V$  is the water storage capacity of the junction, expressed in  $m^3$ .  $z_i$  in Eq. (4) represents the river water level;  $E$  is the total energy contained in the studied river water body.

This study uses the implicit difference method to solve the equations formed by the above formulas, and the discrete diagram is shown in Fig. 1:

In Fig. 1  $\Delta_x$  is the spatial step size, and  $\Delta_t$  is the time step size, which is biased towards the time of  $m + 1$ ;  $n$  refers to the quantity of the river node, and  $m$  refers to that of the time step;  $\theta$  is the weight coefficient, with a value between 0–1.

The functional expressions of  $L$ ,  $R$ ,  $U$ , and  $D$  can be obtained from the image:

$$f_L = f_n^{m+\theta} = \theta f_n^{m+1} + (1-\theta) f_n^m \tag{5}$$

$$f_R = f_{n+1}^{m+\theta} = \theta f_{n+1}^{m+1} + (1-\theta) f_{n+1}^m \tag{6}$$

$$f_U = f_{n+0.5}^{m+1} = \frac{(f_n^{m+1} + f_{n+1}^{m+1})}{2} \tag{7}$$

$$f_D = f_{n+0.5}^m = \frac{(f_n^m + f_{n+1}^m)}{2} \tag{8}$$

The point  $M$  in the grid is located in the middle of the spatial step size, so the function value and derivative value obtained from the point  $M$  can be obtained through Eqs. (5)–(8), thereby obtaining the discrete-continuous equation expression:

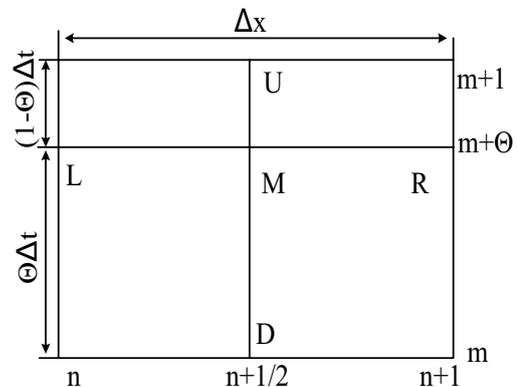


Fig. 1. Schematic diagram of four-point implicit difference separation.

$$\frac{D_n^m - D_{n-1}^m}{\Delta x} + \frac{D_n^{m+1} - D_n^m}{\Delta t} = q \quad (9)$$

The expression of the dynamic equation is shown below:

$$\begin{aligned} & \frac{1}{\Delta t} D_n^{m+1} - \frac{1}{\Delta t} D_n^m + \frac{u_n}{\Delta x} D_n^m - \frac{u_n}{\Delta x} D_{n-1}^m \\ & - \frac{E_x}{\Delta x^2} D_{n+1}^{m+1} + \frac{2E_x}{\Delta x^2} D_n^{m+1} - \frac{E_x}{\Delta x^2} D_{n-1}^{m+1} \\ & + \frac{1}{2} K_D D_{n-1}^m + \frac{1}{2} K_D D_n^{m+1} - \frac{S_d}{h} = 0 \end{aligned} \quad (10)$$

The three-level solution of the river network is used to solve Eqs. (9) and (10), and the equations of river sections, micro sections, and branching points are processed step by step, followed by joint operations. Finally, the water level and flow relationship equations of the head and end sections of the river are obtained as follows:

$$Q_n = \frac{R_{n-1} S_{n-1} - U_{n-1} P_{n-1}}{R_{n-1}} + \frac{U_{n-1}}{R_{n-1}} z_n + \frac{U_{n-1} I_{n-1} - R_{N-1} T_{n-1}}{R_{n-1}} z_1 \quad (11)$$

### 3.2. One-dimensional water quality model for unsteady flow

After pollutants enter the river, the water body will purify the pollutants through physical or chemical processes until the concentration of the pollutants is controlled within the normal range [16]. When constructing a river water quality model, it is necessary to consider the impact of three dimensions of pollutants on water quality. The concentration of pollutants in the section along the water flow direction changes more significantly than the concentration of pollutants in the transverse and longitudinal directions of the section. Therefore, it is only possible to take into account the concentration of pollutants within the section that is aligned with the direction of water flow, that is, a one-dimensional water quality model is constructed [17]. The convection–diffusion equation is shown below:

$$\frac{\partial c}{\partial t} + u \frac{\partial c}{\partial x} = E_x \frac{\partial^2 c}{\partial x^2} - K_c + S \quad (12)$$

where  $c$  is the concentration of the pollutant, in mg/L;  $u$  is the water flow velocity, in m/s;  $E_x$  is the pollutant diffusion coefficient, and  $K_c$  is the comprehensive attenuation coefficient;  $S$  represents the impact of source and sink terms such as tributaries and sewage outlets on the concentration of pollutants.

The main pollutants in the Shenfu section of the Hunhe River basin are chemical oxygen demand (COD) and  $\text{NH}_3\text{-N}$ . Assuming that the river section in the study area is in an aerobic state and that the attenuation of the two pollutants conforms to the first-order reaction kinetics, Eq. (12) can be improved:

$$\begin{cases} \frac{\partial D}{\partial t} + u \frac{\partial^2 D}{\partial x^2} = E_x \frac{\partial^2 D}{\partial x^2} - K_D D + \frac{qD}{A} \\ \frac{\partial N}{\partial t} + u \frac{\partial^2 N}{\partial x^2} = E_x \frac{\partial^2 N}{\partial x^2} - K_N N + \frac{qN}{A} \\ \frac{\partial O}{\partial t} + u \frac{\partial^2 O}{\partial x^2} = E_x \frac{\partial^2 O}{\partial x^2} - K_D D - E_N N + K_O (O_s - O) + \frac{qO}{A} \end{cases} \quad (13)$$

where  $D$ ,  $N$ , and  $O$  in Eq. (13) represent the concentration values of the pollutants COD,  $\text{NH}_3\text{-N}$ , and dissolved oxygen in the river, respectively, in mg/L;  $O_s$  is the concentration of dissolved oxygen at a given temperature, in mg/L;  $K$  is the attenuation coefficient;  $A$  represents the cross-sectional area, in  $\text{m}^2$ .

Eq. (13) is discretized and solved using an implicit difference method. The discretization diagram is shown in Fig. 2:

Fig. 2 is a discrete diagram of implicit difference. The implicit difference discrete method builds a linear equation set to solve the equation [18]. Implicit difference dispersion is performed on the convection diffusion equation:

$$\frac{c_i^{j+1} - c_i^j}{\Delta t} + u_i \frac{c_i^j - c_{i-1}^j}{\Delta x} = E_x \frac{c_{i+1}^{j+1} - 2c_i^{j+1} + c_{i-1}^{j+1}}{(\Delta x)^2} - \frac{1}{2} K (c_i^{j+1} + c_{i-1}^j) + S_i \quad (14)$$

In Formula (14),  $\alpha_i = -\frac{E_x}{(\Delta x)^2}$ ,  $\beta_i = \frac{1}{\Delta t} + 2\frac{E_x}{(\Delta x)^2} + \frac{K}{2}$ ,

$$\gamma_i = -\frac{E_x}{(\Delta x)^2}, \delta_i = c_i^j \left( \frac{1}{\Delta t} - \frac{u_i}{\Delta x} \right) + c_{i-1}^j \left( \frac{u_i}{\Delta x} - \frac{K}{2} \right) + S_i.$$

Eq. (14) is constrained with boundary conditions:

When  $i = 1$ ,

$$\beta_1 c_1^{j+1} + \gamma_1 c_2^{j+1} = \delta_1 - \alpha_1 c_0^{j+1} \quad (15)$$

When  $i = n$ ,

$$\alpha_n c_{n-1}^{j+1} + \beta_n c_n^{j+1} = \delta_n \quad (16)$$

By discretizing a one-dimensional water quality model, a discrete matrix equation can be obtained, and each equation can form a complete solution matrix to obtain the concentration of pollutants at each cross-section.

### 3.3. Water quality and quantity coupling model

The hydrodynamic model provides the required hydraulic parameters for the water quality model. The coupling of the water quality and quantity coupling model with the same time step jointly evaluates water resources [19].

The goal of the water quality and water quantity coupling model built in this study is to obtain a model with

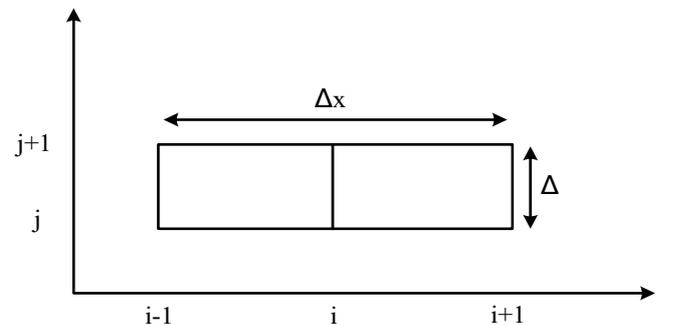


Fig. 2. Schematic diagram of implicit differential separation.

greater improvement in river water quality and smaller water demand. The objective function is shown below:

$$\min G = \min \sum_{i,j} \theta_i \left| \frac{c_{i,j}}{c_j^0} - 1 \right| \tag{17}$$

where  $G$  is the square sum of deviations from the water quality target, and  $\theta_i$  is  $i$ -th water quality weight;  $c_{i,j}$  is the concentration value of the  $j$ -th parameter at time  $i$ , and  $c_j^0$  is  $j$ -th water quality standard concentration, both in units of mg/L.

$$W = \min \{W_1 W_2 \dots W_n\} \tag{18}$$

where  $W$  is the minimum recharge water required for the river channel, in  $m^3$ ;  $W_i$  is the amount of water required for the river channel under the  $i$ -th regulation scheme.

You also need to add constraints to the model, where the water balance equation is:

$$\sum Q_{in} = \sum Q_{out} + \Delta Q_m - \Delta Q_{out} \tag{19}$$

where  $Q_{in}$  is the flow at the river starting section,  $Q_{out}$  is the flow at the river end section,  $\Delta Q_m$  is the flow at the river side, and  $\Delta Q_{out}$  is the water outflow at the river side, all in units of  $m^3/s$ .

The water level constraint expression is shown:

$$h \leq h_1 \leq \bar{h} \tag{20}$$

where  $h$  represents the lowest allowable water level of the river section, and  $h_1$  represents the normal water level;  $\bar{h}$  is the highest water level in meters.

### 3.4. Calculation method of water resource availability based on water quality conversion

The water resources obtained by conventional methods include a combination of water quantities of different water quality categories, which can be divided into five categories according to the surface water use. Generally speaking, Class II and Class III water are suitable for human consumption; Class IV water is used as industrial water; Class V water can be used for agricultural irrigation. The standards for various types of water quality specified in the Environmental Quality Standard for Surface Water (GB3838-2002) are as follows [20]:

The environmental quality standards for surface water include a variety of chemical substances such as COD,  $NH_3-N$ ,  $BOD_5$ , etc. In this study, other indicators are ignored using the actual situation, and surface water use levels are classified based on the content of COD,  $NH_3-N$ . The classification results are shown in Fig. 3. Maintaining a dynamic balance in the available amount of water resources, increasing the amount of Class I, II, and III water resources available for human consumption, and reducing the amount of Class IV and V water resources can improve water resource management. Therefore, the proportion also needs to be comprehensively considered when assessing water resources. The specific water quality conversion calculation

method is designed as follows: First, the amount of surface water resources are calculated; Second, the distribution of available water quality categories and water quality categories is calculated; Third, the amount of available water resources is calculated based on the proportional conversion method. In the third step of conversion, the conversion coefficient needs to be reasonably set based on commonly used indicators for water quality discrimination. The conversion coefficients for the five types of water resources  $k_1, k_2, k_3, k_4, k_5$  are set as follows based on their water quality content with a ratio of 1:2:4:6:9. Class I, II, and III water resources available for human consumption are set as standard groups with a coefficient of 1. Class IV and V water resources used in industry and agriculture are dynamically adjusted based on total balance. The coefficient table is as follows:

Table 1 is a conversion table that converts all water qualities into the same water quality. According to the standard, Class III water can be consumed by humans, so in this study, Class I, II, III, IV, and V water resources are converted into Class III water at a ratio of 6:6:6:4:3.

## 4. Evaluation of surface water resources

### 4.1. Study area

The area studied in this study is the Shenfu River section of the Hunhe River basin, with an annual average

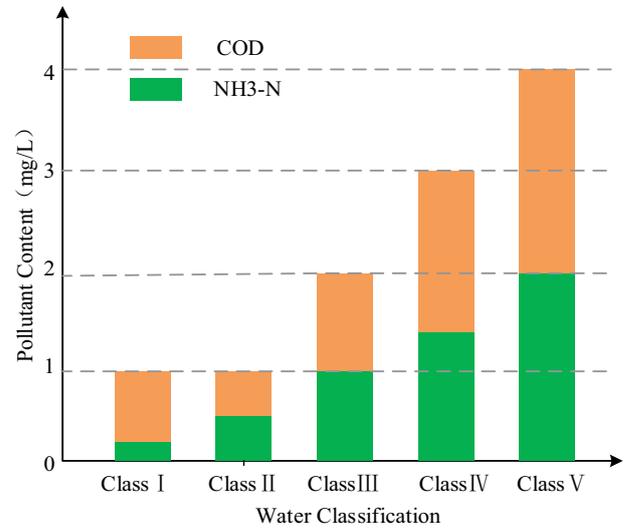


Fig. 3. Standard limits of surface water environmental quality impact factors.

Table 1 Conversion factors for conversion of various types of water into different types of water

Conversion factor	$k_1$	$k_2$	$k_3$	$k_4$	$k_5$
Class I water conversion	1	1/2	1/4	1/6	1/9
Class II water conversion	1	1	1/2	1/3	2/9
Class III water conversion	1	1	1	2/3	1/2
Class IV water conversion	6	3	3/2	1	2/3
Class V water conversion	9	9/2	9/4	3/2	1

precipitation of about 720 mm, and most of the precipitation is concentrated in summer, generally speaking, in a state of water resource shortage. The ice cover period in Liaoning Province lasts for four months. During this period, the number of microorganisms and the concentration of pollutants in the rivers will have certain changes. According to the statistical data in 2016, the total amount of industrial sewage and domestic sewage from the Shenfu reach of the Hun River was 12.6543 million tons. Most of these sewage was directly discharged into the Hun River, placing a great burden on the river's self purification. The sewage from the tributaries mainly came from the drainage flowing through urban and rural areas.

Fig. 4 shows the change of COD concentration of pollutants in Shenfu River's mainstream section from 2014 to 2016. The change of pollutant concentration in the five selected sections was basically consistent in each month, with the concentration of pollutants rising first and then falling. The peak concentration period was mainly concentrated in January to March, with the highest concentration being Gaoyang Rubber Dam, with the COD concentration reaching 42.32 mg/L. The pollutant concentration from May to September was significantly lower than that in other months, due to the flood season from May to September each year, and the lowest COD concentration was Gaoyang Rubber Dam, as low as 21.56 mg/L. According to the water quality classification standards, the section water quality in the flood season was mainly detected as Class III and Class IV, distributed in May to August; During non-flood season, its water quality exceeded the Class IV standard, and even in the Class V standard, it was at a poor level, reaching Class V, mainly from September to April of the next year.

4.2. Water quality and quantity coupling model verification

Setting a reasonable water quality and quantity coupling model can reflect the available amount of surface water resources in the region. When performing the water quantity simulation calculation, the time step was selected as 30 s, and the simulation results were saved every other day. Fig. 4 shows the results of calibration and verification of the water volume at Fushun No. 2 Station:

Fig. 5 shows the calibration and verification images of the cross-sectional flow at Fushun No. 2 Station. The model simulation and calibration images had the same change trend, but there were certain errors. When the flow rate was

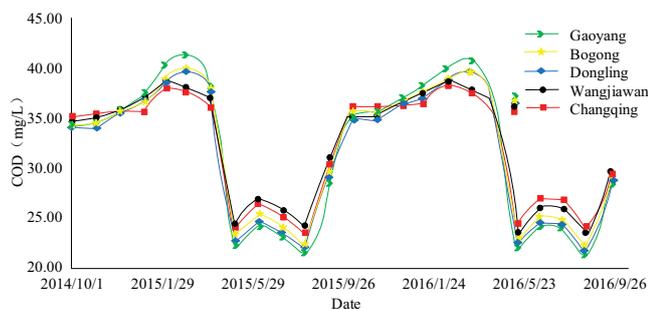


Fig. 4. Change of chemical oxygen demand concentration in Shenfu River's mainstream.

small, the error was relatively large, but overall, the flow rate simulated by the model can reflect the actual river flow rate:

The section water level at Fushun Station is shown in Fig. 6. In March 2015, the section water level at the station dropped sharply. Based on the information in Fig. 5, this was the flood discharge stage of the river section. The water level value obtained by coupling the water quality and quantity model was in good agreement with the actual

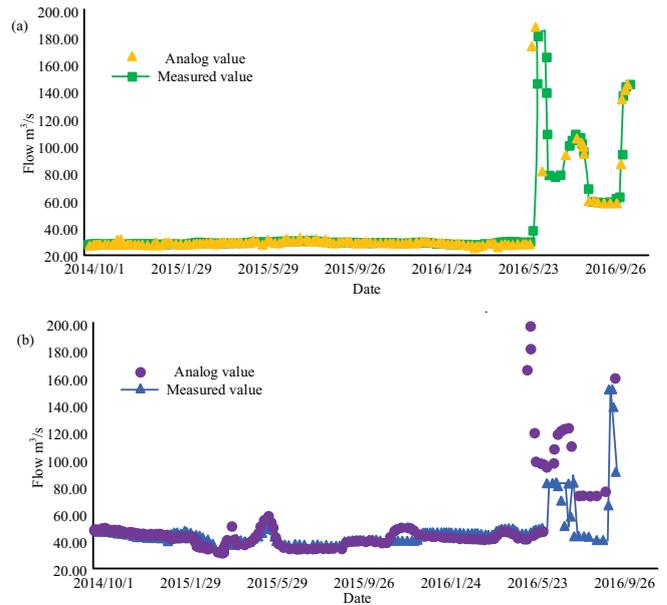


Fig. 5. Flow calibration and verification image of the section of Fushun second station.

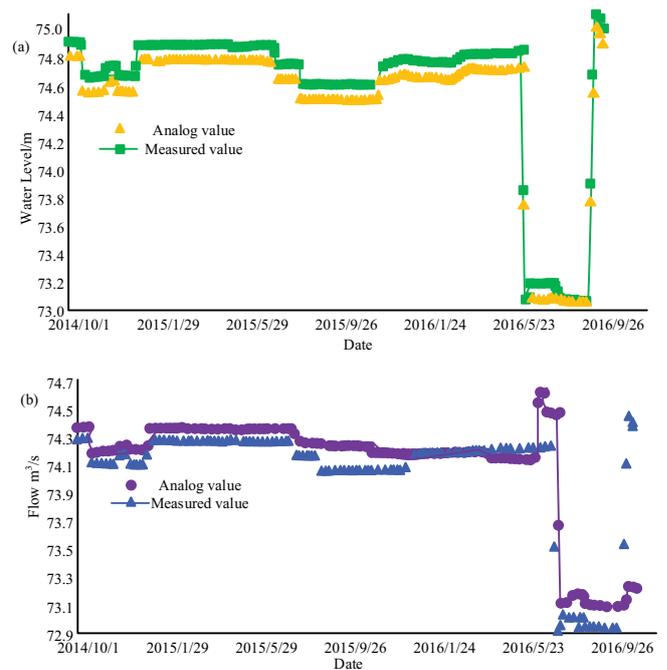


Fig. 6. Water level calibration and verification image of Fushun No. 2 station section.

situation. According to the provisions of the “Specifications for Hydrological Information and Prediction”, the simulated value and the actual value of the section water level were below 10 cm. The relative error in Fig. 6 meets the requirements of the specification, so it can be used as a theoretical model for evaluating and predicting section water levels. The error between the simulated value and the actual value may be due to data errors caused by operational issues during the measurement process. According to its water level and flow, the total amount of water resources in the basin at a certain time period can be comprehensively obtained, and the hydrodynamic force of the flow section can be simulated.

Next, the water quality calculation of the model was conducted, with five sections as the detection objects, and the time step was selected as 30 s. The data was saved every

30 d. Fig. 6 is the validation diagram of COD calibration for the section of Changqing Bridge.

In Fig. 7 the trend of the data coupled by the model is basically consistent with the actual data, with an error of around 8%, meeting the requirements of the “Hydrological Information Forecast Specification”. According to analysis, the error mainly came from the fuzzy positioning of sewage outlets and the highly restrictive one-dimensional model that ignored the complex components of the ecosystem.

Then, the error between the coupling data and the actual data is calculated and analyzed, and the relative error is used to compare the flow rate, and the absolute error is used to compare the water level. The monthly average flow and water level values of Fushun No. 2 Station section and Changqing Bridge section are compared, and Table 2 shows the result:

Table 2  
Comparison of flow accuracy between Fushun second station section and Changqing bridge section

Month	Fushun second station section			Changqing bridge section		
	Analog value (m <sup>3</sup> /s)	Measured value (m <sup>3</sup> /s)	Relative error (%)	Analog value (m <sup>3</sup> /s)	Measured value (m <sup>3</sup> /s)	Relative error (%)
1	3.45	3.02	1.42	3.53	3.02	1.44
2	4.22	3.99	0.58	4.78	5.61	-0.42
3	28.36	27.85	0.18	24.35	26.44	-0.24
4	53.48	51.03	0.47	53.52	50.45	0.53
5	114.36	118.05	-0.31	119.25	115.34	0.62
6	49.32	49.98	-0.13	35.34	43.58	-0.48
7	81.76	85.09	-0.39	72.34	80.34	-0.37
8	50.78	49.33	0.29	64.21	58.52	0.71
9	16.25	17.35	-0.63	30.25	25.12	0.55
10	5.59	5.32	0.50	12.45	8.65	0.50
11	5.32	6.48	-0.31	7.25	8.31	-0.35
12	4.02	5.01	-0.25	3.22	4.54	-0.40

Table 3  
Comparison of water level accuracy between Fushun second station section and Changqing bridge section

Month	Fushun second station section			Changqing bridge section		
	Analog value (m)	Measured value (m)	Absolute error (m)	Analog value (m)	Measured value (m)	Absolute error (m)
1	74.63	74.66	-0.03	37.53	37.52	0.02
2	77.34	77.35	-0.01	37.69	37.67	0.02
3	74.74	74.81	-0.07	37.25	37.27	-0.02
4	75.44	75.50	-0.06	37.04	37.18	-0.06
5	75.33	75.38	-0.05	37.53	37.50	0.03
6	75.06	75.07	-0.01	37.38	37.35	0.03
7	75.51	75.50	0.01	37.49	37.49	0.00
8	75.47	75.49	-0.01	37.04	37.05	-0.01
9	75.82	75.33	0.10	35.87	35.86	0.02
10	75.44	75.49	-0.05	36.29	36.27	0.02
11	75.42	75.48	-0.06	36.29	36.27	0.02
12	75.42	75.48	-0.06	36.30	36.28	0.02

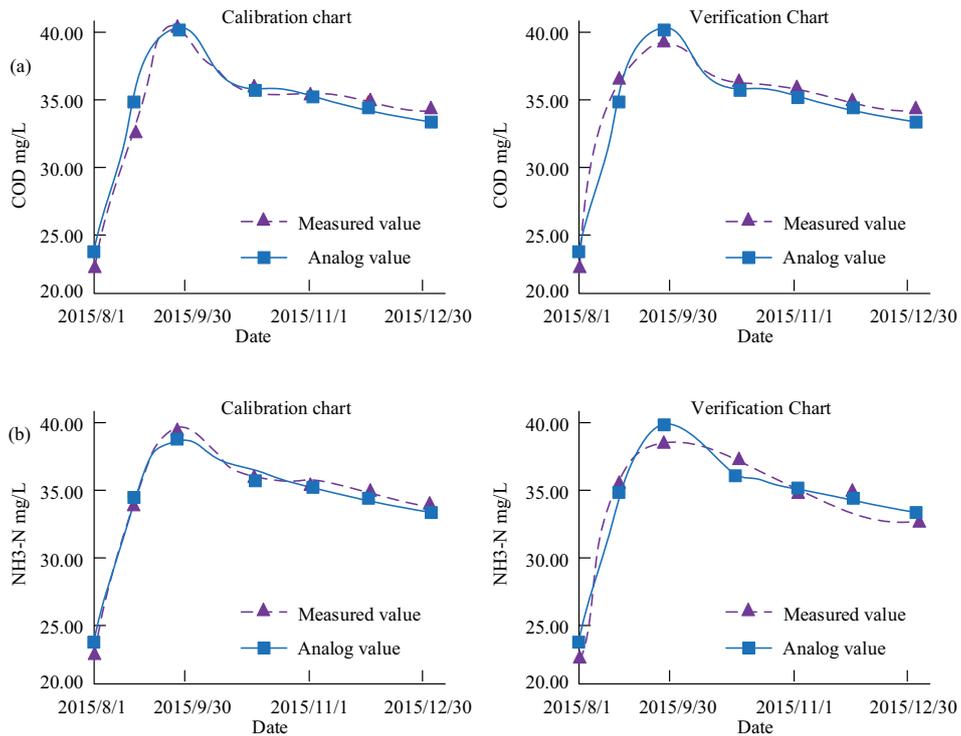


Fig. 7. Verification diagram for chemical oxygen demand and NH<sub>3</sub>-N calibration of Changqing bridge section.

In Tables 2 and 3, the maximum relative error of the sectional flow accuracy of Fushun No. 2 Station is 1.42%, and the minimum relative error is 0.13%; The maximum relative error of the section of Changqing Bridge is 1.44%, and the minimum relative error is 0.24%. In the comparison of water level accuracy, the maximum absolute error of Fushun No. 2 Station is 0.10 m, and the minimum absolute error is 0.01 m; The maximum absolute error of the cross section of Changqing Bridge is 0.06 m, and the minimum absolute error is 0.00 m.

According to the above data, the relative error of flow was below 3%, the absolute error of water level was about 5 cm, and the concentration error of COD and NH<sub>3</sub>-N was also kept below 8%. Therefore, the accuracy of the model proposed in this paper can be verified.

#### 4.3. Available amount of surface water resources converted by water quality

Referring to the surface water quality assessment of Hunhe River, 42 water quality assessment and monitoring stations were selected. Among them, 10 were mainstream monitoring stations, with a total length of 94.5 km in the assessed river section. The distribution map is shown in Fig. 8. The water quality assessment was as follows: The water quality belonged to three mainstream monitoring points of Class V; The water quality belonged to Class IV at two main stream monitoring points; The water quality belonged to Class III and 4 monitoring points; The water quality belonged to Class II and one monitoring point; No water quality belonged to Class I.

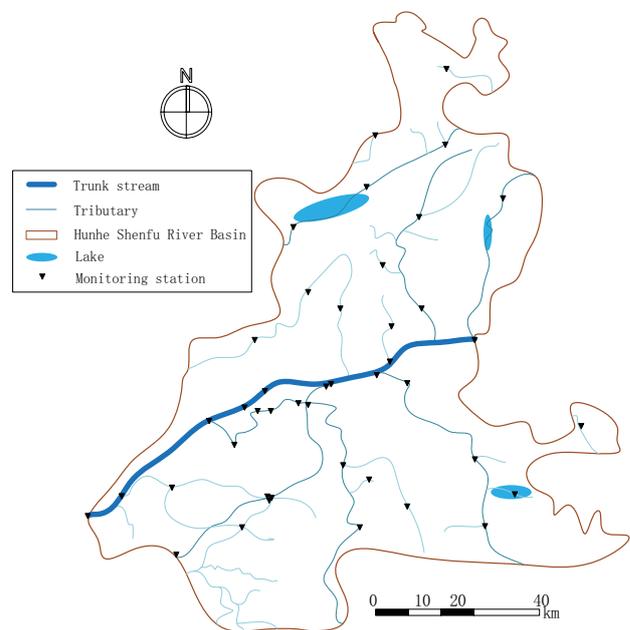


Fig. 8. Water quality monitoring stations in Shenfu River section distribution.

The amount of surface water resources in the current year can be determined based on the pollutant concentrations, water levels, and cross-sectional flows of water resources in the different time periods mentioned above. However, the Fushun River section was polluted by industrial wastewater

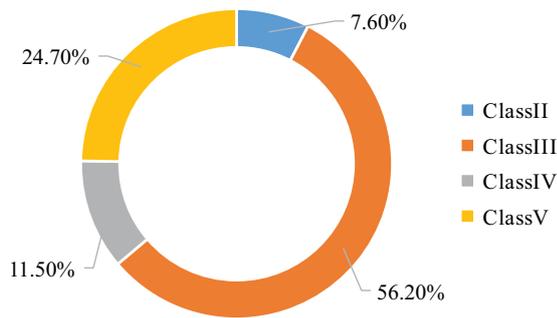


Fig. 9. Surface water resources by water quality.

and residential drainage. Due to the impact of climate, flood discharge, residential water consumption, and industrial drainage, the water quality varied at different times of the year. Through model coupling, the surface water resources classified by different water quality in the study area from October 2014 to September 2016 are obtained as follows:

Fig. 9 shows the quality of surface water resources in the Shenfu section of the Hunhe River during the past 2 y. Class III water in the study area had the largest amount, followed by Class V water. The total amount of local surface water resources was 1,672.545 million cubic meters, which was converted based on the quality of Class III water. The selection of conversion factors is shown in Table 1. The amount of local available water resources was 1,401.87482 million cubic meters, a decrease of 16.18% compared to the total amount of surface water resources, indicating the seriousness of local water pollution.

## 5. Conclusion

The climate in the northern region is arid and precipitation is scarce. The process of urbanization has led to a sharp increase in water consumption for residents, industry, and agriculture, resulting in extreme scarcity of water resources. At the same time, wastewater generated by many residents and factories enters rivers, which has a serious impact on river water quality. Studying the available amount of surface water resources is related to regional water use and scheduling planning. In view of this, this paper constructs a water quality and water quantity coupling model to simulate and calculate the amount of surface water resources in the study area, and ultimately convert it into a usable amount. During the model validation process, the average relative error at the Fushun Second Station section and the Changqing Bridge section was below 3%, the average absolute error was around 5 cm, and the average relative error of the COD and  $\text{NH}_3\text{-N}$  concentrations at the Changqing Bridge section was also kept below 8%. The results showed that the converted utilization amount of surface water resources decreased by 16.18% compared to the total amount of surface water, and the relative error between the simulation results and the actual situation was within the allowable range. This indicated that the model was more accurate in simulating the hydrodynamic, water quantity, and water quality changed in the Shenfu section of the Hunhe River, which can provide a certain reference

for future research on surface water resources. Due to horizontal constraints, there were still some shortcomings in this article, such as a lack of more detailed and comprehensive data, and a long time for monitoring the water quality of the river basin under study, ignoring the impact of many tributaries, resulting in error instability. In the future study, it is necessary to strengthen the collection of river basin data and calibrate and verify the coupling degree of the model to the surface water resources in other years and regions.

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