MIKE11 Model in Water Quality Research of Songhua River in Jiamusi City

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Abstract. The monitoring data of chemical oxygen demand and NH3-N in the upper and lower sections of Jiamusi City in Songhua River were analyzed, and the law of water quality change in Songhua River in Jiamusi City was explored. Based on the simulation results of MIKE11 model for the water from the interval, the minimum ecological safety distance of the upper and lower reaches of Songhua River in Jiamusi city is predicted. Between the rainy season and the standard water period, the Jiamusi section meets the minimum ecological safety distance between Tangyuan County and there is no minimum safety distance during the dry season. The MIKE11 model has good adaptability to the diffusion simulation of pollutants in the upper and lower reaches of the Songhua River in Jiamusi and can be used as an evaluation basis for analyzing the impact of the water quality of the sewage outlet of the river.

1. Introduction

The water quality model is a mathematical equation that simulates the temporal and spatial migration and transformation of pollutants in the water. It can predict the trend of water quality changes [1]. Among them, one-dimensional water quality model has been widely used in the study of small rivers [2]. In the one-dimensional river water quality model, the MIKE11 model has useful functions to simulate river flow, water level, water quality [3]. MIKE11AD calculates the hydrodynamic conditions based on the HD module calculation. It is also widely used in some large-scale projects in China, such as the treatment of the Suzhou River in Shanghai and the evaluation of urban sewage in Chongqing [4]. The convection-diffusion equation is used to calculate the concentration of pollutants in the reach, and the physical and chemical index data of the section are analyzed to obtain the self-purification effect of the contaminants [5]. The self-purification ability of the water body can eliminate the contaminants discharged into it, but this ability is limited. After the contaminants are released into the upstream water body, if the pollution concentration of the cross-section is too large or is also close to the downstream pollutant discharge cross-section, the water quality cannot achieve the self-purification effect [6], which will affect the water quality of the downstream city[7]. The towns and some high-pollution enterprises in Jiamusi City are distributed along the Songhua River, and the drinking water sources in rural areas are severely affected by sewage and sewage from livestock and poultry farming. The water quality of the Songhua River is susceptible to pollution. To protect and monitor water quality, the ecological safety distance between cities and towns should be calculated to reduce the impact of pollution on the water quality of the Songhua River. This research is based on the...
MIKE11 model construction system to investigate and analyze the distribution of built-up areas and pollution source concentration areas in Jiamusi City. Based on the hydrological and hydrodynamic characteristics of the Songhua River, the model is used to calculate and determine the minimum ecological safety distance between the upstream and downstream of Jiamusi City to provide a theoretical basis for urban construction and deployment, environmental protection planning and water pollution control.

2. Materials and methods

2.1. Overview of the study area

The Jiamusi section of the Songhua River is divided into two monitoring sections: Jiamusi upper and Jiamusi lower sections. According to their water area functions, the "Surface Water Environmental Quality Standards" (GB3838-2002) Class III water body standardis implemented. Each section is monitored for eight periods each year[4]. There are 25 monitoring items in each segment [5]. According to the information provided by the environmental monitoring department, the main pollution problem of the Jiamusi section of the Songhua River is organic pollution. The top three pollution indicators are total nitrogen (TN), chemical oxygen demand (COD), and ammonia nitrogen (NH3-N). The TN index of the Jiamusi River section is basically of category IV-V and has been in a state of exceeding the standard. The impact of TN on ecological safety distance has not been considered. In this study, COD and NH3-N are selected as the primary accounting indicators. The year is divided into a high water period (May to September), a flat-water period (April, October to November), and a dry season (December, 1 to 3 Months). Three water periods, using the water quality standards of three types of water bodies (COD: 20mg/L; NH3-N: 1mg/L) as the calculation threshold of the water environment safety distance, comprehensively considering the pollution discharge of the cities and towns along the Songhua River With the sewage treatment capacity, the gap between the water quality of various counties and districts in different water periods reaching the Class III water quality standard is calculated as the water ecological safety distance[6].

2.2. Construction of hydrodynamic and water quality models

2.2.1. Model principle. Hydrodynamic Module (HD).The MIKE11 hydrodynamic module (HD) is a conservation equation of matter and momentum based on vertical integration, that is, one-dimensional unsteady flow Saint-Venant equations. as follows:

\[
\begin{align*}
\frac{\partial Q}{\partial t} + \frac{\partial A}{\partial x} = 0 \\
\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x} \left( \frac{\alpha Q^2}{A} \right) + g \cdot A \cdot \frac{\partial h}{\partial x} + \frac{g}{C^2 A} \frac{Q |Q|}{R} = 0
\end{align*}
\]

Note: \(x\) and \(t\) are the coordinates of the calculation point space and time, \(A\) is the cross-sectional area of the water, \(Q\) is the overflow, \(h\) is the water level, \(q\) is the lateral inflow, \(C\) is Xie Cai coefficient, \(R\) is the hydraulic radius, \(\alpha\) is the momentum correction coefficient, and \(g\) is the acceleration of gravity.

Convection diffusion module (AD). MIKE11AD is a model that simulates the transport process of soluble and suspended substances in water. The basic equation of the one-dimensional river water quality and the empirical formula of the convection-diffusion coefficient is as follows:

\[
\frac{\partial C}{\partial t} + u \frac{\partial C}{\partial x} = \frac{\partial}{\partial x} \left( E_x \frac{\partial C}{\partial x} \right) - K
\]

\(E_x = aV^b\)

Note: \(C\) is the simulated substance concentration; \(u\) is the average flow velocity of the river; \(E_x\) is the convection diffusion coefficient; \(K\) is the first-order attenuation coefficient of the simulated substance; \(x\) is the space coordinate; \(t\) is the time coordinate. \(V\) is the flow rate, from the hydrodynamic calculation results; \(a\) and \(b\) are the parameters set by the user.
2.2.2. Model building. Generalization of river areas. The study area is the Jiamusi section of the Songhua River, and it is determined that the study section starts in Tangyuan County and ends in Huachuan County. Because, since the shape of the actual river channel is mostly irregular and the calculation of water conservancy factors is complicated, a specific regional generalization of the river channel is required. Collect the data of the simulated distance $x$ of the river reach and the height $z$ of the river bed, edit it into a text file according to a specific format, import it into MIKE11, that is, generate a profile file, which is used for model construction.

Boundary conditions. In the model, the discharge of Tangyuan, Jiamusi, and Huachuan flowing into the Songhua River is used as the point source boundary. The sewage discharge and pollutant discharge of each town are obtained according to statistical data. The sewage discharge in different water periods is unusual. During the water-rich period, there is more rainfall and a lot of non-point source pollution (livestock and poultry farming, pesticides, fertilizers, domestic wastewater, and garbage, etc.) enter the river network with the rain current and enter the Songhua River, and the discharge of sewage exceeds that of other water periods; the rainfall in the average water period is relatively small, and the discharge of sewage is second; the dry water period (i.e. the ice period), the release of sewage is lower. Water period. The concentration of COD in sewage discharge is 397mg/L, and the concentration of NH$_3$-N is 29mg/L. In Table 1 for the abundant water period was standard water period, low water period, and sewage discharge flow of each town.

Calibration of the hydrodynamic model. In this study, manual calibration is mainly used to adjust the roughness coefficient of the river channel. The model was calibrated and tested using the measured water level and flow data throughout 2018. After calibration, the roughness coefficient of the Songhua River Jiamusi section is set to 0.028. The simulation results after calibration are shown in Figure 1.

| Tab 1. Model boundary settings As Sewage Discharge Flows For Three Water Seasons Per Boundary (m$^3$/s) |
|---------------------------------------------------------------|-----------------|-----------------|-----------------|
| River code | River mileage | Boundary type | Boundary data type | Boundary code |
| Songhua River | 0 | Point source boundary | flow | Tangyuan County |
| | 36940 | | | Jiamusi downtown |
| | 73990 | | | Huachuan County |
| | 12 | 9 | 6 |
| | 19 | 16 | 11 |
| | 11 | 8 | 6 |

Determining the water quality model. As the core model of the water quality simulation, MIKE11AD can accurately predict the change of pollutant concentration over time. For the case of long-distance transmission of river pollutants, the calculation result of the model is not sensitive to the value of the diffusion coefficient. After sensitivity analysis, the value of the diffusion coefficient is not significantly different from the model result, so the overall diffusion coefficient value is set to 20m/s, that is, $a = 20$ and $b = 0$ in formula (4). The attenuation coefficients in different periods are based on the monitoring data of Jiamusi lower section water quality. The attenuation coefficients of the two physical and chemical indicators in different periods are in Tab 2.

| Tab 2. Attenuation coefficients of COD and ammonia nitrogen in different periods (unit: h$^{-1}$) |
|---------------------------------------------------------------|-----------------|-----------------|
| period | Attenuation coefficient (unit: h$^{-1}$) | Diffusion coefficient (unit: m$^2$/s) |
| | COD | NH$_3$-N | |
| Flood season | 0.0080 | 0.0070 | |
| Flatwater period | 0.0050 | 0.0030 | 20 |
| Dry season | 0.0015 | 0.0012 | |
3. Results and discussion

3.1. Calculation of minimum ecological safety distance between Tangyuan County and Jiamusi

The calculation section starts in Tangyuan County and ends in Jiamusi urban area. The river channel is basically located in Tangyuan County. The average distance along the river between Tangyuan County and Jiamusi city is 35km. After the model calibration is completed, the model is calculated according to the calibrated water quality parameters. By comprehensively comparing the values of the intersection points of the curves and the marking lines at different periods of the two physical and chemical properties, NH3-N has no safe distance in the interval during the dry season. Tab. 3 lists the minimum ecological safety distances corresponding to the COD and NH3-N indicators in the three water periods (in Fig 1 and Fig 2).

3.2. Calculation of the minimum ecological safety distance between Jiamusi and Huachuan County

The calculation section starts from the urban area of Jiamusi and finally to Huachuan County. The river channel is basically located in the downtown area of Jiamusi. The average distance along the river between the downtown area of Jiamusi and Huachuan County is 40km. After the model calibration is completed, the model is calculated according to the calibrated water quality parameters. By comprehensively comparing the values of the intersection points of the curve and the marking line in different periods of physical and chemical properties, there is no minimum safety distance between the two indicators in the interval during the dry season. The results are shown in Figures 4 and 5 below. Table 3 lists the minimum ecological safety distances corresponding to the COD and NH3-N indicators in the three water periods (in Fig 3 and Fig 4).

Table 3. Calculated results of minimum ecological security in different water periods of each town (unit: km)

| Section                  | Average of the places | COD degradation distance | NH3-N degradation distance |
|--------------------------|-----------------------|--------------------------|---------------------------|
|                          |                       | Dry season  | Flat water period | Flood season  | Dry season  | Flat water period | Flood season  |
| Tangyuan County-Jiamusi City | 35                    | 33.2        | 21.3            | 11.4          | 37.2        | 25.5            | 13.2          |
| Jiamusi City-Huachuan County | 40                    | -           | 26.6            | 14.5          | -           | 34.7            | 18.9          |
3.3. Analysis and discussion

Analyzing the calculation results of the water quality model, the COD and NH$_3$-N of the upper and lower reaches of the Songhua River Jiamusi urban area can pass the self-purification in the average distance between the two places to meet the three types of water quality standards in the average period. However, during the dry season, the pollutants above the Huachuan area, especially the pollutants discharged from the Jiamusi downtown area, cannot be degraded within the distance from the Jiamusi urban area to the downstream Huachuan County to meet the three types of water quality standards. The ecological safety distance is also affected by the seasons. The temperature of the water body in different water periods is altered, resulting in the actual water environment capacity of the water body and the overall attenuation coefficient of pollutants being different, and the two are positively correlated. And in the three water periods, the dry season has the most massive pollution and the most extensive safety distance, the rainy season has the lightest infection, and the smallest safety distance (in Fig 5 and Fig 6).

4. Conclusions

In this study, the MIKE11 hydrodynamic module was used to simulate the one-dimensional model of the Jiamusi section of the mainstream of the Songhua River. The simulated river flow and the measured value process line fit well. The results show that as long as the hydrological and topographic data are sufficient, using MIKE11 software to establish the hydrodynamic model of Songhua River Basin has good simulation effect. The results are consistent with the theory, indicating that the MIKE11 software can be used to predict the dissolved oxygen content of the Songhua River watershed.
and simulate the migration, diffusion and attenuation of pollutants in the water. Based on the in-depth investigation of the pollution sources and water environment in Jiamusi's counties and cities, it can more realistically reflect the primary pollutant diffusion in the river reach, master the pollutant discharge laws, establish a technical system of minimum ecological safety distance between counties and districts, and guarantee the urban water environment is safe. The minimum environmental safety distance between cities and towns is determined.

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