The simulation of water quality control of Fengping section in Mangshi River

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Abstract. The assessment of water quality is mainly based on Environmental Quality Standards for Surface Water (GB3838-2002), which divided surface water into five classes (Class I to Class V) according to its purpose for use and protection target. In April 2015, the State Council issued an Action Plan for the Prevention and Control of Water Pollution, which is a law formulated to effectively increase the prevention and control of water pollution and ensure national water safety. In 2016, the Yunnan Provincial People's Government and the Dehong Prefecture People's Government successively proposed work plans for the prevention and control of water pollution, requiring the Fengping Section (State Control) in Mangshi River to reach Class III of surface water by 2020. But the current water quality fluctuates between Class III and V. Based on the current status of water quality and pollution sources, the paper uses HD (hydrodynamic model) and AD (hydrodynamics advection diffusion model) in MIKE 21 FM model to establish the two-dimensional water quality model to simulate the distribution characteristic of different water quality parameters, which are Biochemical Oxygen Demand (BOD5), Total Phosphorus (TP), Ammonium Nitrogen (NH3-N). The conclusion is that reduction targets of BOD5, TP and NH3-N are namely 40%, 30% and 10% to ensure water quality, which guides the formulation of pollutant emission reduction plans more scientifically.

1. Introduction

Water quality, as an important factor in judging the water environment, plays a vital role in social production and people's lives. River water quality is mainly according to Environmental Quality Standards for Surface Water (GB3838-2002). Different standards of water quality serve different purposes, for example, drinking, agricultural irrigation, industry, entertainment and so on. In recent years, with the rapid development of cities in China, the scale of cities has been expanding, and sewage discharges increasingly [1]. But the urban environmental infrastructure, especially in the old urban areas, is difficult to control and interception. A large amount of pollutants enter the river, and the river water is seriously polluted [2]. Campaigns for water environment improvement have begun throughout the country, with section water quality as the basis for assessment. In order to promote the environmental management work efficiently and scientifically, the hydrodynamic models and water quality models are widely applied [3]. MIKE 21 FM model, which could be used in the simulation of water quality in river, lake, estuary and bay, is widely in the water environment management. Wang Z et al. simulated the flow field distribution and water quality diffusion of Jincang Lake by Mike 21[4]; Yang W et al. studied the hydrodynamic and water quality distribution of 5 different connection schemes of the Tangxun Lake...
lake group [5]; Zhang H et al. based on Mike 21 to simulate and compare the improvement of water quality of Chao Lake by the water diversion schemes of "Caizi Lake" and "Bai Dang Lake"[6]. This paper uses HD and AD model in Mike 21 FM to obtain the water quality diffusion and distribution of Mangshi River, and guides the formulation of pollutant reduction plans to reach the water quality target of Fengping section.

2. Materials and methods

2.1. Study area

Mangshi, located in the western part of Yunnan province, is the seat of Dehong Prefecture. The region has a subtropical monsoon climate, where the average annual temperature is 11.9 degrees Celsius. Mangshi River, which is one of the main river in Mangshi, belongs to the first tributary of the left bank of Longjiang River. It originates in the north of Jinzhuping Village, Longling County and finally injects into Longjiang in the west of Nanbang Village. The river is 102.1km long, the basin area is 1830.5km², and the average annual runoff is 2.06 billion m³ [7].

Fengping section, the most important monitoring section of Mangshi River, is located in the downstream of Mukang section (Figure 1). The water quality of Fengping fluctuates between Grade III and V, and the Mukang attains standards of Grade III for 3 years stably. Based on the Monitoring data, the major pollution factors are BOD₅, NH₃-N and TP. Therefore, the key study area in the paper is between Mukang section and Fengping section, where the river passes through the main urban area of Mangshi and there are 6 tributaries are heavily polluted. The distance between the two sections is 14.3 km [8].

The main pollution sources within study area are urban living pollution, rural living pollution, agricultural non-point source pollution, livestock and poultry farming pollution, and aquaculture pollution. According to the water quality monitoring data, the perennial exceeding standards are 3 items: BOD₅, NH₃-N and TP in the project area. Therefore, these 3 items are identified as key research factors.

According to the urban population, rural population, farmland area and farming type, livestock and poultry breeding amount and sediment, the paper bases on Handbook of National Pollution Source Emission Coefficients (2010) to calculate pollution sources in the project area. The main pollution factors BOD₅, NH₃-N and TP have a total of 1006.66 t/a, 307.78 t/a and 103.82 t/a (Table 1.), respectively. After analysis, the main influencing factors of BOD₅ and NH₃-N are urban domestic pollution, and the TP is from rural and agricultural non-point source pollution mainly.

Figure 1. Location of study area.
Table 1. Pollution sources in the study area.

| serial number | pollution factors                          | pollution(t/a) |
|---------------|-------------------------------------------|----------------|
| 1             | urban living pollution                    | NH$_3$-N 182.69, TP 21.04, BOD$_5$ 533.53 |
| 2             | livestock and poultry farming pollution   | NH$_3$-N 56.78, TP 38.61, BOD$_5$ 127.75 |
| 3             | agricultural non-point source pollution   | NH$_3$-N 43.11, TP 37.79, BOD$_5$ 188.25 |
| 4             | rural living pollution                    | NH$_3$-N 23.26, TP 2.51, BOD$_5$ 65.14 |
| 5             | aquaculture pollution                     | NH$_3$-N 1.96, TP 3.87, BOD$_5$ 91.99 |
|               | **Total**                                 | NH$_3$-N 307.78, TP 103.82, BOD$_5$ 1006.66 |

2.2. model setup

This paper builds a water quality model for Mangshi River. The study area is divided by orthogonal curve grids. The calculated river section is from Mukang to Fengping section with a length of about 15 km and 1220 main grids. Besides, the tributaries of Mukang-Fengping section are generalized into 7 major tributaries, A1—A7 (Figure 2). The input data of the water quality model mainly includes initial data, boundary condition data, and meteorological condition data.

2.2.1. Basic settings. Combining the calculation results of the SWAT model, the model takes 2015 as the current level year, and the model is calibrated. The model simulation start time is January 1, 2015, the calculation cycle is 364 days, and the time step is 30 seconds. The elevation contour map and discrete grid at the bottom of Mangshi River are shown in Figure 2 below.

2.2.2. Inflow boundary. The model's inflow boundary contains inflow data, water temperature data, and a time series of water quality concentrations [9]. Among them, the concentration boundaries of the pollution factors (BOD$_5$, NH$_3$-N, and TP) of the 7 tributaries and upper streams are shown in the figures 3 below.

Figure 2. The elevation contour map and discrete grid.
2.2.3. **Major meteorological driving boundaries.** The MIKE21 AD model generally requires five meteorological elements, namely temperature, rainfall, evaporation, wind speed, and wind direction [10]. The calculation of meteorological factors in this model mainly considers precipitation and evaporation. The 2015 map of precipitation and evaporation in Mangshi River Basin is shown in the figure 4 below.
2.3. Parameter calibration
During the process of organic matter entering the river and flowing with water, it will be degraded by various physical, chemical and biological factors [11]. The degradation rate is affected by various hydrological conditions such as water temperature, sediment and flow velocity. These factors are often generalized into a comprehensive attenuation coefficient K, as a comprehensive reflection of the degree of pollutant degradation. In this paper, the river flow, flow velocity, pollutant concentration, and the empirical K value set are brought into the water quality model, and the Nash efficiency coefficient is used to evaluate the model. After adjusting the value of K, and analysing the degree of fit between the simulation process and the measured values, select the value of K when the fitting condition is better [12]. The calculation formula of the Nash efficiency coefficient is shown as follows and the parameters in the formula is described in Table 2:

\[
E = 1 - \frac{\sum_{t=1}^{T}(Q_0^t - Q_m^t)^2}{\sum_{t=1}^{T}(Q_0^t - \bar{Q}_0)^2}
\]

| No. | Parameters | Description       | No. | Parameters | Description |
|-----|------------|-------------------|-----|------------|-------------|
| 1   | \(Q_0\)    | Observed value    | 3   | \(Q_t\)    | some value at time \(t\) |
| 2   | \(Q_m\)    | Analog value      | 4   | \(\bar{Q}_0\) | Average of observed value|

The model roughness parameters were calibrated in conjunction with the relevant reports of the river section, and Fengping section was selected from January 1, 2015 to December 31, 2015 (BOD\(_5\), TP, and NH\(_3\)-N) Perform calibration and verification as table 3. The specific simulation results and checkpoints are shown in the figures (5 to 7) below. The comprehensive attenuation coefficient K and Nash efficiency coefficient are valued as Table 4.

Based on the research of other scholars in this field on Jing River, Wei River, the Yellow River, Han River [12], Taihu [13] and other rivers and lakes, it is concluded that K\(_{BOD5}\) ranges from 0.009-0.47d\(^{-1}\), K\(_{NH4-N}\) ranges from 0.105-0.35 d\(^{-1}\), and K\(_{TP}\) ranges from 0.056 to 0.573 d\(^{-1}\). And the value of E are all close to 1. Therefore, our model is determined to be reasonable. The time series curve of the comparison between the water quality simulation value and the observation value indicates that this hydrodynamic
water quality model can better reproduce the concentration trends of BOD$_5$, TP and NH$_3$-N in the Mukang-Fengping section. Therefore, the parameters verified by this water quality model can basically represent the migration, diffusion and degradation characteristics of the water quality of this river section, which is suitable for further analysis and research on the water quality of Mangshi River.

Table 3. Observed value of input model.

| Time       | BOD$_5$(mg/L) | NH$_3$-N(mg/L) | TP(mg/L) |
|------------|---------------|----------------|----------|
|            | Observed      | standard       | Observed | standard | Observed | standard |
| 2015/1/5   | 4.60          | 4              | 0.314    | 1        | 0.14     | 0.2      |
| ...        | ...           | 4              | ...      | 1        | ...      | 0.2      |
| 2015/3/2   | 4.98          | 4              | 0.189    | 1        | 0.18     | 0.2      |
| ...        | ...           | 4              | ...      | 1        | ...      | 0.2      |
| 2015/5/5   | 4.96          | 4              | 0.204    | 1        | 0.19     | 0.2      |
| ...        | ...           | 4              | ...      | 1        | ...      | 0.2      |
| 2015/7/2   | 4.65          | 4              | 0.21     | 1        | 0.13     | 0.2      |
| ...        | ...           | 4              | ...      | 1        | ...      | 0.2      |
| 2015/9/1   | 4.88          | 4              | 0.506    | 1        | 0.17     | 0.2      |
| ...        | ...           | 4              | ...      | 1        | ...      | 0.2      |
| 2015/11/5  | 4.58          | 4              | 0.142    | 1        | 0.15     | 0.2      |
| ...        | ...           | 4              | ...      | 1        | ...      | 0.2      |

Table 4. The value of K and E to the major pollutants.

|       | BOD$_5$ | NH$_3$-N | TP     |
|-------|---------|----------|--------|
| E     | 0.831   | 0.792    | 0.884  |
| K(d$^{-1}$) | 0.099   | 0.110    | 0.080  |

Figure 5. The comparison of simulation and observation value—BOD$_5$. 
3. Result and analysis

3.1. Simulation result

The current water quality of the Fengping section shows that the BOD5 and TP pollution factors have exceeded the standard throughout the year. Among them, the BOD5 indicator has the highest risk, followed by TP, and the pollutants entering the river need to be reduced to ensure Fengping section to pass the assessment.

Combining the calculation results of the pollutants in 2020 by SWAT model, the paper takes the model parameters that have been determined to simulate and calculate the pollutants reduction plans.
When the guarantee rate to reach the goal exceeds 90%, it is considered that the required water quality goals can be achieved. Meantime, the target reduction rate is determined, and the corresponding reduction amount can be calculated.

The simulation results show that when BOD$_5$, NH$_3$-N, and TP are reduced by 40%, 10%, and 30%, respectively, it is basically guaranteed that the Fengping National Control Section will reach the water quality target by the end of 2020 (figure 8 to 10).

![Figure 8. The simulation results of 40% BOD$_5$ reduction.](image)

![Figure 9. The simulation results of 10% NH$_3$-N reduction.](image)
3.2. Planning measures and target reachability analysis

According to the pollution characteristics of the study area, the key projects are proposed, such as urban domestic pollution control engineering, rural domestic sewage treatment, river improvement and riverside wetland construction. And the scale of the projects is determined according to the reduction target efficiently. The specific measures are as follows:

- **Urban domestic pollution control engineering**: sewage network improvement, upgrading of sewage plant, and Improvement of urban domestic garbage collection system.
- **Rural pollution control**: sewage and garbage disposal, Livestock and poultry pollution control.
- **River improvement**: Sediment dredging and fishpond management.
- **Riverside wetland construction**: construction of estuary wetlands and buffer zones.

Combining experience with relevant calculation manuals, benefits of similar projects on pollutant reduction as follows:

- **Urban domestic pollution control engineering**: according to urban sewage collection rate, sewage plant effluent concentration, and Garbage collection rate, Calculate the reduced amount of sewage and garbage, and then the amount of pollution contained based on Handbook of National Pollution Source Emission Coefficients (2010).
- **Rural pollution control**: Calculation method is similar to the town.
- **River improvement**: According to literature research [14], the crude endogenous release of river sediment is estimated to be 65 mg / (m².d) of BOD₅, 8.256 mg / (m².d) of NH₃-N, and 15 mg / (m².d) of TP.
- **Riverside wetland construction**: Aquatic plant per hectare can reduce BOD₅, NH₃-N and TP as 5.8t/a, 0.25t/a and 0.03t/a [15].

Estimate the contribution to pollution reduction based on the scale of each measure, at the same time, demonstrate target reachability (Table 5).
Table 5. Target reachability analysis.

| serial number | planning project                              | pollutant reduction(t/a) |
|---------------|----------------------------------------------|--------------------------|
|               |                                              | BOD$_5$ | NH$_3$-N | TP    |
| 1             | urban domestic pollution control engineering | 240.9   | 16.61    | 18.08 |
| 2             | rural pollution control                      | 53.57   | 9.47     | 9.45  |
| 3             | river improvement                            | 56.46   | 3.56     | 3.43  |
| 4             | riverside wetland construction               | 72.72   | 6.72     | 0.55  |
|               | total                                        | 423.46  | 36.36    | 31.52 |

Reduction targets

4. Conclusions and recommendations

Conclusions would be drawn as follows:

- The Mike21 FM model can be used to demonstrate that water quality achieves goals, quantify pollutant reduction goals and guide pollution reduction measures more specifically.
- The Comprehensive Attenuation Coefficients of BOD$_5$, NH$_3$-N and TP between Mukang and Fengping section in Mangshi River are 0.099d$^{-1}$, 0.110d$^{-1}$ and 0.080d$^{-1}$, respectively, which are in line with the research rules in related fields.
- The risks of meeting the water quality standards in Fengping section are BOD$_5$ > TP > NH$_3$-N. Reductions are 402.66t/a, 31.15t/a and 30.78t/a.
- By quantifying reduction benefits of the pollution control measures, demonstrate target reachability better.
- For other similar rivers and lakes, when the goal of water quality needs to be demonstrated, the methods and processes in the paper can be referenced.

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References

[1] Zhang J 2015 The problems and countermeasures in the comprehensive management of rivers Water conservancy of Shanxi 195 115-116
[2] Zhao Y and Yao R H 2015 Discussion on the practice and thinking of Black and Stink Water treatment in China Environmental Protection 43 27-9
[3] Hull V, Parrella L and Falcucci M 2008 Modelling dissolved oxygen dynamics in coastal lagoons Ecol. Model. 211 468-80
[4] Wang Z, Liu L and Song L L 2008 Application of MIKE21 in ecological design of artificial lake Hydropower Energy Science 26 124-7
[5] Yang W, Zhang L P and Li Z L 2018 Research on the River-Lake Connectivity of Urban Lakes based on water environment improvement Acta Geographica Sinica 73 115-28
[6] Zhang H, Dai X J and Dai T 2016 Application of MIKE21 FM in the project planning that absorb Changjiang river to supply Chao river Hydropower Energy Science 9 103-6
[7] Zhang J and Yin Y L 2018 Pollution analysis and treatment countermeasures of Mukang-Fengping section of Mangshi River Environmental Science Guide 37 20-3
[8] Zhang Z Q 2007 Water Quality Evaluation and Pollution Control of Mangshi River Environmental Science and Resource Utilization 3 96-9
[9] Paliwal R and Patra R R 2011 Applicability of MIKE 21 to assess temporal and spatial variation
in water quality of an estuary under the impact of effluent from an industrial estate Water Sci. Techn. 63 1932-43

[10] Jiang T, Zhong M, Cao Y J, Zou L J, Lin B and Zhu A P 2016 Simulation of water quality under different reservoir regulation scenarios in the Tidal River Water Resour. Manage. 30 3593-607

[11] Zhu C J, Liang Q, Yan F and Hao W 2013 Reduction of Waste water in erhai lake based on MIKE21 hydrodynamic and water quality model The Scientific World Journal 5 958506

[12] Li H L, Zhu X H, Bao B H and Han B C 2008 Discussion on Determination of Comprehensive Attenuation Coefficient of River Water Quality Model Environmental Pollution and Prevention 30 1-7

[13] Feng S, Li X Y and Deng J C 2017 Measurement of Comprehensive Attenuation Coefficients of Pollutants in River Networks in the Upper Plains of the Taihu Basin J. Environ. Sci. 37 878-87

[14] Wang R, Zuo J E and Zhang Y 2018 Study on influencing factors of Nitrogen and Phosphorus release in the Sediment of Liangshui River Guangdong Chemical Industry 45 1-3

[15] Ma Y H, Shi Y F and Liu H 2013 Operation benefit analysis of Yaonigou Constructed Wetland Project in Fuxian Lake Environmental Science Guide 32 3-45