Estimation and Analysis of Water Environment Capacity: A Case Study of Huaxi Watershed in Guizhou Province

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Abstract. A one-dimensional water quality mathematical model was put forward to calculate the water environmental carrying capacity (WECC) for rivers in Huaxi District. The river system of Huaxi district is divided into four basins. Based on field observation and numerical simulation, the pollutant degradation coefficients and diffusion coefficient for different river districts were determined to explore the WECCs of COD, NH₃-N and TP. It reflects the pollutant carrying capacity of different basins under the hydrological condition of 90% guarantee rate, which plays an important role in pollution control and water environmental protection.

1. Introduction

Water environmental carrying capacity [1-5] is one of the most important contents of water environment assessment, which focuses on the environmental characteristics of water, including water quality conditions and water pollution capacity [6], and it is of great significance for promoting social and economic development, industrial construction, and harmonious coexistence of human health and ecological environment [7].

Huaxi District is located in the watershed of the Yangtze River and the Pearl River, and is a well-known ecological area in Guizhou Province, China. There are 51 rivers of different scales in the area, among which 18 main rivers include Huaxi River, Wenggang River, Marin River, Qingyan River, Xiaoche River, Kailun River and Dumu River, etc.

According to ‘Calculation Rules for Water Pollution Capability’ (GB/T25173-2010), the corresponding formula of one-dimensional river model for pollutants capacity is:

$$M = (C_s - C_i)(Q + Q_p)$$

Where $C_s$ is the pollutant concentration in the initial section (mg/L); $C_i$ is the target concentration of water pollution (mg/L); $Q$ is the inflow of initial section (m³/s); $Q_p$ is waste water discharge (m³/s); $C_x$ is concentration of pollutants (mg/L) after flowing through $X$ distance, which can be obtained by simulation of mathematical model.
2. Mathematical Water Quality Estimation Model
MIKE11 model uses the one-dimensional non-constant flow Saint-Venant equations to describe the flow of river water flow. Continuous equation:
\[
\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = q
\]
Momentum equation:
\[
\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x} \left( \alpha \frac{Q^2}{A} \right) + gA \frac{\partial h}{\partial x} + gQ|Q| = 0
\]
in which \(x\) and \(t\) are the space and time coordinates of the calculation point; \(A\) is the flow cross-sectional area; \(Q\) is overflow discharge; \(h\) is water depth; \(q\) is flow discharge of branch; \(R\) is hydraulic radius, and \(\alpha\) is the momentum correction coefficient; \(G\) is gravity acceleration; \(C\) is Chezy coefficient.

The governing principle of river network water quality model is the one-dimensional convection-diffusion equation, that is:
\[
\frac{\partial AC}{\partial t} + \frac{\partial QC_p}{\partial x} = \frac{\partial}{\partial x} \left( AD \frac{\partial C}{\partial x} \right) = -AKC + C_p q
\]
where \(C_p\) (mg/L) is the concentration of water pollution; \(Q\) (m³/s) is the flow rate; \(A\) (m²) is the flow cross-sectional area; \(D\) (m²/s) is the longitudinal diffusion coefficient; \(C_2\) (mg/L) is the source/sink concentration; \(K\) (1/d) is the attenuation coefficient.

3. Water Quality Prediction Results and Analysis

3.1 Malin River
The water quality target of the Malin River is Class III, and Class II for Wan River. The prediction results of COD, ammonia nitrogen, and total phosphorus in Malin River Basin are shown in Fig.1 to Fig.3, respectively, showing that pollutant in Malin River and Wan River are all lower than the corresponding quality limits, meeting water quality requirements.
3.2 Qingyan River

The prediction results of Qingyan River Basin are shown in Fig.4 to Fig.6. The water quality targets of Zhaosi River and Wenggang River water function zones are Class II, and targets of Qingyan River, Yangmei River, and Laobang River are Class III. It can be known that the indicators in Qingyan River Basin meet the requirements except the COD in Wenggang River.

Figure 3. Prediction results of total phosphorus in Malin River

Figure 4. Prediction results of COD in Qingyan River Basin

Figure 5. Prediction results of ammonia nitrogen in Qingyan River Basin
3.3 Huaxi River

The predicted results in Huaxi River Basin are shown in Fig. 7 ~ Fig. 9. It can be known that the three indexes in the Huaxi River Basin all meet the quality target requirements.

Figure 6. Prediction result of total phosphorus in Qingyan River

Figure 7. Prediction results of COD in Nanming River (Huaxi River, Xiaoche River)

Figure 8. Prediction results of ammonia nitrogen in Nanming River (Huaxi River, Xiaoche River)

Figure 9. Prediction results of total phosphorus in Nanming River (Huaxi River, Xiaoche River)
4. Results and analysis of pollutant capacity

In this paper, a new method of oil containment in polar oil spill environment is proposed. In the later stage, it can be used in combination with the high-efficiency oil spill recovery device in polar ice water environment to realize the high-efficiency oil spill recovery in ice water oil mixed environment. At the same time, there may be a certain amount of garbage at the oil spill accident site, which will have a certain impact on the oil containment effect of the oil boom.

In the later stage, the structure and function of the oil boom should be optimized and improved, so that the oil boom can eliminate the impact of the site garbage on the oil containment work, and improve the oil containment method to achieve the optimal oil containment effect.

The calculation results of pollution capacity of Malin River Basin are shown in Table 1, showing that there is a certain amount of pollution capacity in Malin River Basin at present.

| River      | The driest monthly water volume P=90% (×10^4 m^3) | COD (t/a) | NH₃-N (t/a) | TP (t/a) |
|------------|-----------------------------------------------|-----------|------------|----------|
| Malin River| 100.3                                          | 72.208    | 10.963     | 1.757    |
| Wan River  | 30.8                                           | 3.701     | 1.310      | 0.140    |

The calculation results of pollutant carrying capacity of Qingyan River Basin are shown in Table 2. At present, the COD in the water body of Wenggang River exceeds the standard, with capacity of 0. The calculation results show that Qingyan River Basin has a certain pollutant holding capacity except for the COD of Wenggang River.

| River      | The driest monthly water volume P=90% (×10^4 m^3) | COD (t/a) | NH₃-N (t/a) | TP (t/a) |
|------------|-----------------------------------------------|-----------|------------|----------|
| Qingyan River | 83.0                                          | 59.765    | 8.407      | 1.394    |
| Wenggang River    | 28.5                                          | 0.000     | 1.448      | 0.098    |
| Zhaosi River     | 39.5                                          | 6.323     | 1.540      | 0.245    |
| Laobang River   | 56.4                                          | 38.335    | 5.935      | 0.979    |
| Yangmei River | 18.4                                          | 12.965    | 1.862      | 0.324    |

The calculation results of pollutant carrying capacity of the Huaxi River Basin are shown in Table 3, showing that there is a certain capacity of Huaxi River Basin at present.

| River      | The driest monthly water volume P=90% (×10^4 m^3) | COD (t/a) | NH₃-N (t/a) | TP (t/a) |
|------------|-----------------------------------------------|-----------|------------|----------|
| Huaxi River | 99.9                                          | 95.876    | 10.853     | 2.027    |
| Chetian   | 52.0                                          | 29.105    | 5.819      | 1.061    |
| Xiaohuang | 49.0                                          | 27.439    | 5.486      | 1.000    |

5. Results and analysis of pollutant capacity Conclusion

In this paper, a planar one-dimensional water quality mathematical model was used to simulate WEC of four major basins in Huaxi district. The three indexes of COD, NH₃-N and TP were selected for WEC evaluation by the mathematical model. Combined with the field data, the water pollution capacity was calculated under the hydrological condition of 90% guarantee rate. The results show that the concentrations of COD, NH₃-N and TP in the Malin river basin, Huaxi river basin and Changhe river basin were all lower than the corresponding water quality standard concentration limits, meeting
the water quality objectives. In Qingyan river basin, COD in Wenggang river exceeded the standard to some extent. Based on the water quality model, the study of the migration and diffusion of biogenic substances in the water area has the advantages of high efficiency, economy and convenience, which can provide insight for the protection of water resources and the optimal allocation of water resources.

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