Calculation of Pollutant Carrying Capacity in Shaanxi Section of Weihe River in China

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Abstract. At present, in the calculation of water pollution carrying capacity, only the guarantee rate of the driest month is 90% to calculate it. The water pollution carrying capacity of the water function area is relatively small, so it is more stricter to control the total amount of pollutants on this basis, and the actual water pollution carrying capacity is not fully utilized, which will form a significant constraint on the social and economic development. Moreover, it is inconvenient to assess the actual water environment management by using the annual pollution capacity obtained by this method. Therefore, this paper takes Shaanxi section of Weihe River in China as an example to calculate the pollutant carrying capacity under different guarantee rates, taking COD and NH3-N as the representatives of organic pollutants, and taking the national standard pollutant carrying capacity calculation model as a means to reflect the river's pollutant carrying capacity under different guarantee rates, so as to provide reference for the comprehensive treatment of water environment in Weihe River basin.

Keywords: Pollution carrying capacity, water function area, standard model.

1. Introduction

The first paragraph after a heading is not indented (Bodytext style). Water is an indispensable natural resource for human survival and social development, a lifeline for economic development and social progress, and an important material basis for sustainable development. In the last century, human society has not only made great material wealth, but also paid a heavy environmental price. China's water pollution has become no less serious than flood, drought and even more serious disasters. Rational use of environmental resources, control and reduction of environmental pollution has become one of the main issues that should be considered in the economic development of all countries. Rapid and effective control of water pollution is of great significance to protect the quality of water resources and support the sustainable development of social economy with the sustainable development and utilization of water resources. In 2009, China proposed to implement a more stringent water resources management
system focusing on the allocation, conservation and protection of water resources. One of the three "red lines" is to "clarify the red line of water function area to limit the amount of sewage into the river" and strictly control the total amount of sewage into the river. With the increase of population and the development of economy, the living environment of human beings is increasingly damaged, especially the water environment, which attracts more and more attention.

The Weihe River Basin is an important industrial and agricultural research and production base in Shaanxi Province with a large population. However, the water quality of the main and tributaries of the Weihe River is deteriorating day by day, which seriously affects the production and living water of urban residents. In order to ensure the quality of water entering the Yellow River, starting from the environmental protection objectives and management needs, it is of great significance to analyze and predict the water pollution capacity of each river in the Weihe River Basin and the control of pollutants entering the river [1]. Therefore, the study on the calculation of water environmental pollution carrying capacity and the control of pollutants into the river in the Weihe River basin can provide the basis for the comprehensive management of the Weihe River Basin, provide limited water resources for Guanzhong region, alleviate the current situation of water resources shortage, and promote economic development.

The concept of water pollution capacity is mostly put forward in the way of water quality management and water environmental carrying capacity. The concept of total maximum daily loads (TMDL) and total maximum annual loads (TMYL) were first proposed by the US Environmental Protection Agency in 1972. Pollution load can be expressed as mass per unit time, toxicity and other indicators suitable for determination [2]. The overall goal of TMDL plan is to identify specific pollution areas and land use conditions, and to propose control measures for the concentration and quantity of point source and non-point source pollutants in these specific areas, so as to guide the whole basin to implement the best watershed management plan [3]. TMDL program is widely implemented in the United States, and has achieved remarkable results in the integrated control of point source and non-point source [4]. On December 8, 1983, the United States formally legislated to implement the emission control route based on water quality restriction.

The calculation method of water pollution carrying capacity or water environmental capacity is an important part of water pollution carrying capacity research, which directly affects the accuracy of calculation results. However, due to the vast area of China and the obvious difference of water characteristics, it is more difficult to study the calculation method of water pollution capacity. The main research methods of water pollution capacity calculation are analytical method [5], model trial and error method [6], system analysis method [7] and probability dilution model method [8]. It is an important subject to establish a theoretical system that can be used to calculate the water environmental capacity of different water bodies, so as to promote the deepening of water resources protection.

At present, in the calculation of water pollution carrying capacity, Generally, the amount of pollutants that the water body can hold under certain hydrological conditions is used as the pollutant carrying capacity. In recent 10 years, the average flow (water volume) of the driest month or the average flow (water volume) of the driest month with 90% guarantee rate is often used as the design hydrological conditions for the calculation of pollutant carrying capacity. Similarly, 7Q10 (average value of the driest flow for 7 consecutive days with 90% guarantee rate) is also often used as the design hydrological conditions. That is to say, using the national standard model to calculate the pollutant carrying capacity has some limitations, because the national standard model adopts certain hydrological conditions (the hydrological conditions in the driest month of the year). The national standard model only calculates the pollutant carrying capacity under the condition of 90% guarantee rate, but the guarantee rate of water utilization, water quality requirements and water resources protection in different periods is different. It is necessary to calculate the pollutant carrying capacity under different guarantee rates.

Therefore, this paper mainly studies the Shaanxi reach of the Weihe River, collects various data, carries out the investigation of sewage outlets into the river and water quality monitoring, according to the water function zoning and water quality protection objectives of the Weihe River, formulates the calculation and design scheme of the dynamic water pollution capacity, and studies the pollution
capacity of each secondary water function area of the Weihe River. Due to the influence of various factors, especially the influence of hydrological design conditions on the pollutant carrying capacity of water functional areas, the allowable pollutant carrying capacity under different guarantee rates is calculated to provide technical support for the red line management of limited pollutant carrying capacity and water quality supervision and management of water functional areas.

2. Study area

Guanzhong area in the Weihe River Basin is located in the middle of Shaanxi Province in China. Xi'an, Baoji, Xianyang, Weinan and other large and medium-sized cities are located in the area. It is the political, economic, cultural, financial and information center of Shaanxi Province. However, the water environment of Weihe River is seriously overladen due to the dual pressure of population growth, economic development, water consumption and sewage discharge, ecological environment deterioration and pollution aggravation.

According to the method provided by the Ministry of water resources of the Yellow River Basin "technical outline of national water function zoning" and the water environment function zoning of the Yellow River Basin formulated by the environmental protection department, the water function zoning of Shaanxi section of the main stream of the Weihe River can be obtained according to the water quality standard of surface water environment quality standard (GB3838-2002) for five types of water environment function zones, as shown in table 1.

| Code | Function area name                              | The initial section | The end section | River length (km) | Water Quality Target Grade |
|------|------------------------------------------------|--------------------|----------------|------------------|---------------------------|
| 11   | Baoji City Landscape Area                      | Linjia cuan         | Wolongsi       | 20               | III                       |
| 12   | Baoji City Pollution Control Zone              | Wolongsi           | GuoZhen        | 12               | IV                        |
| 13   | Baoji City Transition Area                     | GuoZhen            | Caijiao        | 22               | IV                        |
| 14   | Baomei Industrial and Agricultural Water Zone  | Caijiao            | Tangyuruweikou | 44               | III                       |
| 15   | Yangling Agriculture and Landscape Water Area | Tangyuruweikou     | Qishuihekou    | 16               | III                       |
| 16   | Xianyang Industrial Water Zone                 | Qishuihekou        | Xianyang Road Bridge | 63           | IV                        |
| 17   | Xianyang City Landscape Water Area             | Xianyang Road Bridge | Xianyang Railway Bridge | 3.8   | IV                        |
| 18   | Xianyang Sewage Control Area                   | Xianyang Railway Bridge | Fengherukou  | 5.4               | IV                        |
| 19   | Xianyang- Xi'an Transition Zone                | Fengherukou        | 210 National Highway | 19           | IV                        |
| 20   | Lintong Agricultural Water Area                | 210 National Highway | Lingherukou   | 56.4             | IV                        |
| 21   | Weinan Agricultural Water Area                 | Lingherukou        | Wangjiachengzi | 96.8             | IV                        |
| 22   | Huayin Yellow River buffer zone                | Wangjiachengzi     | Ruhuangkou     | 29.7             | IV                        |

3. Study area

3.1. Generalization of pollution sources

Generally speaking, for the same water function area, the pollutant discharge outlets are irregularly distributed in different sections of the river, and the pollutant concentration at the lower boundary of the water function area is the superposition of the pollutant concentration contributed by all the outlets to the water body of the river. When calculating the pollutant carrying capacity of the reach in the
functional area, the point source and non-point source discharged into the reach should be investigated and counted according to their actual discharge amount and discharge location. However, in the analysis of pollutant carrying capacity, the distribution of sewage outlets in the functional area is generally generalized.

3.2. Pollutant carrying capacity calculation model
In this paper, a one-dimensional model is adopted, which is suitable for small and medium sized river sections \( Q \leq 150 \text{m}^3/\text{s} \) where pollutants are uniformly mixed on the cross section

a) The pollutant concentration of the river section is calculated according to formula (1):

\[
C_x = C_0 \exp(-kx/u)
\]

Where:
- \( C \) - pollutant concentration, unit: mg / L;
- \( C_0 \) - pollutant concentration of discharged wastewater, unit: mg/L;
- \( k \) - comprehensive attenuation coefficient of pollutants, unit: negative first power second (1/s).
- \( Q_p \) - discharge flow of wastewater, unit: m³/s;
- \( Q \) - inflow of initial section, unit: m³/s.
- \( C_x \) - pollutant concentration after passing through \( X \) distance, unit: mg/L;
- \( x \) - the longitudinal distance along the river, in meters (m);
- \( u \) - the average velocity of the channel section under the design discharge, in m/s;

b) The corresponding water pollution capacity is calculated according to formula (2):

\[
M = (C_s - C_x)(Q + Q_p)
\]

The meaning of the sign is the same as before.

3.3. Determination of parameters
1. Determination of flow rate
Based on the measured flow and velocity data of each hydrological station, the relationship curve between flow and velocity is established to analyze and calculate the velocity corresponding to the design flow with 90%, 75% and 50% guarantee rate.

According to the existing data and other references, the relationship between flow rate (\( Q \)) and flow rate (\( u \)) is as follows:

- Linjiacun: \( u = 0.163Q^{0.5349} \) \((0<Q<50)\) (3)
- Xianyang: \( u = 0.1736Q^{0.3328} \) \((0<Q<2000)\) (4)
- Huaxian: \( u = 0.0664Q^{0.4695} \) \((0<Q<2000)\) (5)

The flow rate can be calculated from the known design flow rate through such correlation. For other sections, the design flow velocity can be estimated according to the flow velocity relationship in the nearby area. Based on this, the flow velocity corresponding to the design flow of each section under different design hydrological conditions can be calculated. See table 2 below.
Table 2. Design velocity of each section in the driest month. Unit: m/s

| Section name      | 90%  | 75%  | 50%  |
|-------------------|------|------|------|
| Linjiacon         | 0.077| 0.14 | 0.32 |
| Wolongsi          | 0.127| 0.21 | 0.38 |
| GuoZhen           | 0.229| 0.36 | 0.54 |
| Caijiapo          | 0.237| 0.37 | 0.56 |
| Taungyuruweikou   | 0.275| 0.43 | 0.62 |
| Qishuihekou       | 0.341| 0.53 | 0.74 |
| Xianyang Road Bridge | 0.31 | 0.41 | 0.5  |
| Xianyang Railway Bridge | 0.31 | 0.41 | 0.5  |
| Fengherukou       | 0.31 | 0.41 | 0.5  |
| 210National Highway | 0.35 | 0.47 | 0.56 |
| Lingherukou       | 0.35 | 0.47 | 0.57 |
| Huaxian           | 0.18 | 0.28 | 0.36 |

2. Determination of initial section pollutant concentration $C_0$

In order to reflect that "the pollution in the upstream does not affect the downstream", the water quality target of the water function area in the upstream calculation section is selected for the initial section pollutant concentration $C_0$, which can not only strengthen the protection of water resources in the upstream section with better water quality, but also be fair to the downstream section, and easy to be accepted by each calculation section or water function area.

3. Determination of target concentration $C_S$ of water quality

The water quality target value is based on the requirements of the overall planning of the Yellow River Basin, referring to various standards and regulations, as well as the characteristics of water pollution in the Yellow River Basin, using CODcr and ammonia nitrogen as pollutant control parameters. CODcr and ammonia nitrogen standards are in accordance with the environmental quality standard for surface water (GB3838-2002), and the standard values are shown in Table 3.

Table 3. Limits of environmental quality standards for surface water. Unit: mg/L

| Items        | Classification |
|--------------|----------------|
|              | I   | II  | III | IV  | V   |
| COD          | ≤15 | ≤15 | ≤20 | ≤30 | ≤40 |
| NH$_3$-N     | ≤0.15 | ≤0.5 | ≤1.0 | ≤1.5 | ≤2.0 |

4. Determination of degradation coefficient $K$

The pollutant degradation coefficient reflects the degradation rate of pollutants in water, and is a key parameter in the calculation of pollutant carrying capacity. Whether the parameters can be accurately determined directly affects the calculation results of pollutant carrying capacity. Considering the above methods, the $K$ value of COD and NH$_3$-N in the main stream of Weihe River is 0.43/d and 0.30/d respectively [1].

4. Calculation of pollutant carrying capacity

4.1. Calculation steps of pollutant carrying capacity

According to the division of surface water functional areas and water quality target values in Shaanxi section of the main stream of the Weihe River, combined with the discharge data of the Weihe River drainage outlet provided by Shaanxi Provincial Bureau of hydrology and water resources in 2016, and the hydrological data from 1961 to 2017, the pollutant carrying capacity of COD and NH$_3$-N under various hydrological conditions in this subject is calculated.
In this project, the national standard model (one-dimensional model) is used to calculate
Step 1: calculate the pollutant concentration $C_X$ of the first water function area according to formula (1);
Step 2: calculate the pollutant carrying capacity $M_1$ of the first water function area according to equation (2);
Step 3: repeat steps 1 and 2 to calculate and sum the pollutant carrying capacity of all sections, that is, the pollutant carrying capacity of Shaanxi section of Weihe River.

4.2. Calculation results of pollutant carrying capacity
According to the calculated design flow rate and design flow rate in the driest month, as well as other parameters determined, the above steps are used to calculate the COD and NH$_3$-N River sewage capacity in the driest month. The results are shown in Table 4.

| Function area name                        | 90%   | 75%   | 50%   |
|------------------------------------------|-------|-------|-------|
|                                          | COD   | NH$_3$-N | COD   | NH$_3$-N | COD   | NH$_3$-N |
| Baoji City Landscape Area                | 155.29 | 5.73     | 154.94 | 5.57      | 226.78 | 8.02     |
| Baoji City Pollution Control Zone        | 858.52 | 39.18    | 1634.25 | 76.22     | 3262.88 | 155.05   |
| Baoji City Transition Area               | 241.21 | 15.14    | 337.1  | 21.3      | 477.7  | 30.31    |
| Baomei Industrial and Agricultural Water Zone | -464.2 | -19.74   | -1278.16 | -58.7    | -2914.19 | -138.28 |
| Yangling Agriculture and Landscape Water Area | 314.66 | 26.27    | 430.65  | 36.5      | 570.74  | 48.78    |
| Xianyang Industrial Water Zone           | 3092.19 | 138.31   | 5830.83 | 265.7     | 9754.64 | 451.56   |
| Xianyang City Landscape Water Area       | 104.36 | 9.76     | 162.4  | 15.21     | 234.9  | 22.03    |
| Xianyang Sewage Control Area             | 278.57 | 13.61    | 420.25  | 20.53     | 599.23  | 29.27    |
| Xianyang- Xi'an Transition Zone          | 1507.25 | 53.37    | 1913.47 | 67.5      | 2443.87 | 86.04    |
| Lintong Agricultural Water Area          | 3440.45 | 127.14   | 5602.41 | 204.11    | 7976.24 | 288.49   |
| Weinan Agricultural Water Area           | 542.88 | 45.18    | 980.34  | 82.09     | 1432.53 | 120.32   |
| Huayin Yellow River buffer zone          | 2192.13 | 78.97    | 3641.09 | 129.14    | 5008.57 | 176.4    |
| Sum                                      | 12263.32 | 532.93   | 19829.57 | 865.18   | 29073.89 | 1278     |

5. Conclusions
With the increase of population and economic development, the human living environment is being destroyed day by day, especially the water environment destruction has attracted the world's attention. Theoretical research on pollution capacity has become one of the current research hotspots. This paper is based on one of the three red lines in the water resource management system proposed by China in 2009—"Clarify the red line of the water function zone to restrict pollution, and strictly control the total amount of pollution into the river", combined with the water quality management goals of each water function zone, and calculated the pollutant carrying capacity (that is, water environmental capacity) of the key water functional areas of the main stream. It can be seen from the results that certain measures should be taken to effectively control the severely polluted functional areas of the Shaanxi section of the Weihe River to prevent further deterioration of water quality in order to alleviate the shortage of water resources.

The pollutant carrying capacity of the water area is the basis of total pollution control, and its quantitative evaluation has important practical significance for the effective protection of water resources. Formulating scientific improvement strategies based on pollutant carrying capacity is forward-looking and maneuverable. It can not only improve the water environment, but also save manpower, material and financial resources, and achieve harmony between man and nature and sustainable social and economic development.
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