Study on the Influence of COIM model on the Water Environment of inland River ship pollution discharge

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Abstract. In order to calculate and analyze the ship sewage river water environment, the influence of internal selection of rivers into the lake taihu main Chengdong port as the research object, based on the speed of flow, ship, ship engine power data such as a ship sewage and oil wastewater is put forward and the calculation method of and on the basis of zero dimensional water quality model, using the method of simulation optimization control goal against the push model (COIM method), the water environmental carrying capacity and the associated model of ship emissions of pollutants. The maximum bearing capacity of the Chendong port water body to the ship is deduced by using the correlation model, and the method to improve the bearing capacity of the water body is proposed according to the COIM model. The results show that the number of ships can be accommodated in Chendong Port is more than three times that of the existing ships, and the organic oxygen consumption (COD), nitrogen (N) and phosphorus (P) in the ship sewage have no significant influence on the water environment of Chendong Port.

Keywords: Water environment; The ship; Model; The bearing capacity

1. Introduction
Ship waste water pollution mainly refers to the effect of waste water discharged by ships during navigation, berthing at ports, loading and unloading of goods on the surrounding water bodies [1]. The water environment of navigable waters will be damaged when the total pollution of ships and other pollutants exceeds the water environmental capacity (water environmental carrying capacity). The research of runoff environmental carrying capacity for many years starts from the concept and connotation discussion, and gradually turns to the construction of quantitative analysis method and predictive evaluation model.

Baijie et al.[2] established a water environment carrying capacity evaluation index system and standard with 16 indexes in Baiyangdian Basin. Liu Xiaodong et al. [3, 4] estimated the pollution of inland river vessels in the Taihu Basin and predicted the improvement effect of petroleum water quality after implementing pollution control with the segmented mixed water quality model. Sun Jiajia et al. [5] established the simulation model by using the system dynamics method, and designed five schemes of status continuation, economic development, resource conservation, environmental protection and comprehensive development, and applied the affinity value method to optimize the scheme.
Based on the results of the prototype water transfer test of the river network in the research area, constructed the model of water quantity and quality and the calculation model of the river network's pollutant carrying capacity, calculated the pollutant carrying capacity of the river network, and put forward various measures to improve the water environment from three aspects: water resource, water body's pollutant carrying capacity and economic and social aspects.

At present, the water environment improvement in Taihu Basin mainly includes pollution containment, pollution interception, water diversion, dredging, fishing back to lake and lakeside improvement, etc., but the research on pollution control by ships is still rare. This paper adopted the model based on simulation and optimization of the control goal of backstepping method and to improve the zero dimensional water quality model was established, the water environment bearing capacity calculation method that is associated with vessel pollution calculation, calculation of ship pollution and analysis with the relationship between the bearing capacity of water environment, aims to provide a scientific reference for taihu lake ecosystem management and effective method.

2. Research scope and methods

2.1. Research Scope
In this paper, Chendong Port (Level 4 channel), which has the highest navigable class and the largest navigable volume, is taken as the research scope. According to the investigation, there is basically no heavy pollution industrial enterprises in chendong Port basin, and the living area involves 1 township (Dingshu Town) and 1 sub-district (Xinzhuang sub-district). The total farmland area is 2744 mu, mainly for rice, vegetables and other crops. It has basically realized the return of fishing wet, there is no aquaculture farmers. There are two piers and gas stations in the basin. The land use status of Chendong Port is shown in Figure 1.

![Fig1 Land use status map of ChenDong port](image)

2.2. Calculation of water environmental carrying capacity
The following two aspects should be controlled for the benign ecological circulation of river water resources: (1) Total quantity control: the total quantity of discharge of sewage or pollutants shall not exceed a certain limit; (2) Concentration control: The pollutant concentration of the water body shall not exceed the water quality standard of the water body's water function area. Taking the control target as the constraint to reverse push the carrying capacity of water environment, it is therefore called "control target reverse push model" method, abbreviated as COIM model [7]. The calculation idea of water environmental carrying capacity constructed by COIM can be summarized in Figure 2.
2.2.1. Zero dimensional water quality model. The zero-dimensional model is widely used in water quality models of lakes and reservoirs, and the space described is similar to a fully reactive mixing vessel in an ideal state [8] Chendong Port is 2.28 kilometers long with an annual runoff of 15.44×10^8 m^3. The average river bottom width is 40-50m, the average river surface width is 70-80m, and the river width is less than 100m. Therefore, the zero-dimensional water quality model is chosen to calculate the water environmental capacity of Chendong Port. The zero-dimensional water quality model constructed by COIM model can be expressed as:

\[ Q_M C_M = W_{wd} + Q_1 C_0 \]  

(1)

\[ W_{wd} = Q_w \mu C_d + Q_w (1 - \mu) C_w \]  

(2)

Type: Q_M—Target sectional runoff, m^3; C_M—Target cross section concentration, mg/m^3; W_{wd}—Total amount of pollutants from land into the region, t; Q_1—The flow from the upper reaches of the river, m^3; C_0—Original value of water environment, mg/m^3; Q_w—Total sewage discharge, m^3; C_w—Comprehensive concentration of a pollutant before land sewage treatment, mg/m^3; C_d—The concentration of a pollutant after sewage treatment, mg/m^3; \mu—Sewage treatment rate

2.2.2. Model reconstruction. In the watercourse, the vessels pass through the waters have a fast flow speed, so they have a certain self-purification ability, and the vessels are also an important source of pollution. Therefore, two factors, pollution amount of ship and self-purification capacity of water body, were introduced to improve the model. Add the reconstruction model of ship pollution W_{C0} and comprehensive attenuation coefficient K:

\[ Q_M C_M = (W_{wd} + Q_1 C_0 + W_{C0})(1 - K) \]  

(3)

Type: CM—Target cross section concentration, mg/m^3; W_{wd}—Total amount of pollutants from land into the region, t; W_{C0}—Discharge of pollutants from ships, t; K—Comprehensive attenuation coefficient.

2.3. The correlation model of ship pollution amount and water environment carrying capacity

According to equation (3), the amount of sewage discharged by ships in the deformed water environment is:

\[ W_C = \frac{Q_M C_M}{(1 - K)} - W_{wd} - Q_1 C_0 \]  

(4)

The total pollutant control equation is

\[ W_{C0} \leq W_C \]  

(5)
It can be seen from formula (5) that when the pollutant quality of ships is lower than the target control value of pollutants in river course control section, it indicates that ships still have room to discharge pollutants. When the total amount of pollutants from vessels is greater than the target control value of pollutants from river channel controlled sections, it indicates that the pollution of vessels in the river channel has exceeded the planned target value, and the self-purification ability of the water body can no longer eliminate the impact of pollution from vessels.

2.4. The solution of eigenvalues

(1) Acquisition of ship flow

This vessel flow statistics is based on the statistical data collection method of VITS system. VITS system is an intelligent operation and maintenance platform for monitoring and early warning, on-site supervision and accident investigation of inland river vessels implemented by Jiangsu Bureau of Comprehensive Administrative Law enforcement supervision of Transport. The annual ship flow statistics in 2019 are shown in Figure 3.

![Ship traffic](image)

**Fig 3** Flow of vessels in Chendong Port in 2019

(2) Calculation formula of pollutant discharge from ships

The production of oily sewage from ships and domestic sewage from ships shall be calculated in accordance with The Guidelines for Compilation of Construction Schemes for Receiving, Transferring and Disposing Of Pollutants from Ports and Ships [9]

\[ W_{Ci} = \sum t \times q_l \times (GT \times r) \]  

Type: \( W_{Ci} \) — Emissions of pollutants from ships, \( t = 0,1,2,3; t \) -- Storage time of pollutants for a single vessel, h. According to the ratio of the length of the river to the sailing speed of the ship on the river, 0.29h is calculated; \( q_i \) -- Quantity of pollutant generation system from ships, t/h; \( GT \) -- Gross tonnage per ship; \( r \) - Number of crew members per ship, per unit. In accordance with Decision on amending the minimum safety manning rule (ministry of transport, PRC order no. 43 of 2018)[10] and other factors such as on-site investigation and continuous sailing duration, the number of crew on a single ship \( r \) is calculated by 2 persons.

(3) Total amount of pollutants in upstream and land (\( W_{Wd} \))

The general water quality of the tributaries of Chendong Port is good, and some branches (Yangwei River) are seriously polluted. However, the main branches into the estuaries have been equipped with
intercepting pump stations to avoid the impact on the water quality of Chendong Port. Therefore, only the discharge of pollutants in land is considered in the calculation of this paper.

(4) Calculation of control section runoff

After the sewage is discharged to the water body, the water quantity and quality will change. In this paper, a calculation model is established based on the principle of water mass balance:

\[ Q_M = Q_0 + Q_C - \epsilon (Q_0 + Q_C) \]  \hspace{1cm} (7)

Type: \(Q_0\)—Water volume in the study area, m\(^3\); \(Q_C\)—The total amount of ship sewage discharged, m\(^3\); \(\epsilon\)—Coefficient of total water consumption

(5) Determination of water environmental pollutant factors

According to the water pollution index evaluation method and the comprehensive eutrophication index method, the current situation of water quality and main pollutants of Taihu Lake were evaluated and analyzed [11], the main pollutants of Taihu Lake were organic oxygen consumption (COD), nitrogen (N) and phosphorus (P). Therefore, COD, NH\(_3\)-N, TP and TN were selected as the main research factors when calculating the carrying capacity of water environment in this paper.

(6) Determination of comprehensive attenuation coefficient \(K\) of pollutants

After entering the water body, pollutants are transported by advection, longitudinal dispersion and transverse mixing, so that the concentration of pollutants in the water gradually decreases [12]. The comprehensive attenuation coefficient \(K\) of pollutants can reflect the dilution and degradation process of pollutants, and the attenuation coefficient is determined according to the research results of Feng Shuai et al [13], specifically: \(K_{\text{COD}}=0.1732\), \(K_{\text{NH}_3\text{-N}}=0.1347\), \(K_{\text{TN}}=0.1328\), and \(K_{\text{TP}}=0.1219\).

3. Application

Taking Chendong Port, one of the main rivers into Taihu Lake, as an example, this paper studies the water environmental carrying capacity and analyzes the influence of the ship sewage discharge on the water environmental carrying capacity by establishing the correlation model between the water environmental carrying capacity and the ship sewage discharge capacity.

(1) Calculation of domestic sewage of ships

According to Requirements on the Receiving Capacity of pollutants from Ports, Docks, Loading and unloading Stations and Ship Repair and Dismantling Units [14], the daily production of sewage from ships taken from unit crew is calculated as 0.03 tons/day, that is, 0.00125 tons/hour. In this paper, the discharge concentration of pollutants from ships of less than 400 tons was determined by combining the value range given in Research Status and Development Trend of Domestic Sewage Treatment Technology for Ships [15] and the actual situation of inland rivers in Jiangsu province. The values were COD500mg/L, NH\(_3\)-N25mg/L, TP5mg/L and TN30mg/L. The concentration of pollutants discharged from ships with a gross tonnage of 400 tons or more is COD125mg/L, NH\(_3\)-N25mg/L, TP5mg/L and TN30mg/L according to Standard for Control of Marine Water Pollutants discharge (GB 3552-2018)[16].

The discharge of domestic sewage from ships in Chendong Port in one year is shown in Table 1.

(2) Calculation of oily sewage from ships

For inland river areas, according to the Technical Rules for Statutory Inspection of Inland River Ship of the Ministry of Transport [17] the hourly output \(q\) of oil wastewater from ships per unit gross ton can be calculated by the following formula.

\[ q = \frac{2 \times (0.6P + 35)}{1000 \times 24 \times GT} \]  \hspace{1cm} (8)

Type: \(P\)—total power of main and auxiliary diesel engines, unit kw; \(GT\)—gross tonnage of ship, gross tonnage per unit, obtained according to ship directory.

The engine power of main engine of inland river ships can be directly obtained and used one by one based on Jiangsu Province Shipping List and Jiangsu Province Ship Operation Certificate Information. Based on the questionnaire results of the subject Study on Air Pollution Emission Inventory

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of Ships in Jiangsu Section of Beijing-Hangzhou Canal [18], the auxiliary engine of inland river ships was determined, and the average value was finally calculated by 12.48kW. The COD concentration of Marine oil sewage is calculated according to 400mg/L. The discharge of oil and sewage from ships in Chendong Port in one year is shown in Table 1.

(3) Total pollutants from ships
According to sections (1) and (2), the discharge of sewage and pollutants from ships in Chendong Port in one year is shown in Table 1.

Table 1. Pollutant emissions from ships in Chendong Port

| Pollutant discharge source | Total sewage production (t) | Pollution factor emission (kg) |
|---------------------------|-----------------------------|-------------------------------|
|                           |                             | COD  | NH₃-N | TP | TN |
| domestic sewage           | 29.463                      | 14.732 | 0.200 | 0.040 | 0.240 |
| oily water                | 13.20                       | 5.28  | /     | /   | /   |
| total                     | 42.663                      | 20.12 | 0.200 | 0.040 | 0.240 |

(4) Total amount of land pollutants discharged into river channels
According to Comprehensive Improvement Plan of Water Environment in Chendong Port of Yixing City (compiled by Yixing Municipal People's Government, 2018) and field verification, the main pollution sources and pollution loads in the land area of Chendong Port are summarized and shown in Table 2.

Table 2. List of pollutants entering the river in the land area of Chendong Port

| The name of the river | Pollutant | Domestic pollution (t) | Agricultural pollution (t) |
|-----------------------|-----------|------------------------|---------------------------|
| Chengdong port        | COD       | 6.31                   | 2.06                      |
|                       | NH₃-N     | 0.88                   | 0.41                      |
|                       | TP        | 0.08                   | 0.41                      |
|                       | TN        | 1.14                   | 4.12                      |

(5) Calculation results of water environmental carrying capacity of Chendong Port
According to the correlation model of vessel pollution amount and water environment carrying capacity in Section 1.3, the water environment carrying capacity of Chendong Port is calculated by taking into account the total pollutants from vessels, total pollutants from land into rivers and water quality control objectives in National Master Plan for Taihu Lake Treatment, as shown in Table 3.
Table 3. The calculation results of the water environment of Chendong Port on the carrying capacity of ships

| Water environment capacity | Flow of ships in 2019 (ship) | Inverting COD emissions from ships under COD Control target (5mg/L) Wc0 (kg) | Inverting NH3-N emissions from ships under NH3-N Control target (1.0mg/L)Wc1(kg) | Inverting TP emissions from ships under TP Control target (0.12mg/L) Wc2(kg) | Inverting TN emissions from ships under TN Control target (3.2mg/L) Wc3(kg) | Inverse annual ship flow under control objectives (ship) |
|---------------------------|-----------------------------|-------------------------------------------------|---------------------------------|---------------------------------|---------------------------------|-----------------------------|
| Marine Sewage Discharge   | 42.663                      | 4074.8                                          | 12357.6                         | 2741.32                         | 976.17                          | 9976.33                      | 151391                      |

(6) Analysis of calculation results

It can be seen from the calculation results in Table 3 that the number of vessels carried by the water environment of Chendong Port (the annual vessel flow under the control target) is more than three times of the current annual vessel flow of Chendong Port, and the water environment carrying capacity of COD, NH3-N, TP and TN is far more than the current vessel discharge. This indicates that vessel pollution has little influence on the water environmental bearing capacity of Chendong Port under the current vessel flow.

4. Conclusions

(1) COIM method is a kind of systematic analysis method in the calculation method of water environment carrying capacity. Taking the index of water resources carrying capacity as the constraint equation, the maximum value of water resources system supporting can be derived back. It is a relatively scientific quantitative description model method at present and can be applied to pollution control of ships in inland river channels after testing.

(2) The control objectives of COD, NH3-N, TP and TN were selected, and the water environmental carrying capacity of Chendong Port was calculated by using the improved model to obtain that the number of ships that could be contained in the channel was more than three times that of the existing ships, and the water environmental carrying capacity of the four types of impact factors was also much higher than the current discharge of ships. This shows that ship pollution has little influence on the water environment of Chendong Port under the condition of steady annual ship flow.

(3) According to the COIM build water quality model of river water environmental capacity can be drawn from the main approaches are: ① to strengthen the construction of sewage treatment facilities, reduce the land area and upstream pollution emission source intensity, improve the system of tradable permits construction; ② to improve the local sewage plant sewage treatment technology and accelerate the construction of water reuse engineering, improve the efficiency of wastewater treatment in the region, improve the threshold into the river upstream inflow; ③ timely increase degradation by dilution to reduce water pollutant concentration.

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