Method Study on Establishing of Ship Sewage Pollutants Discharging Inventory Based on AIS

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Abstract. In order to analyse the ship sewage discharge and pollution characteristics, and put forward the solutions of pollution preventing and control, it is necessary to establish the ship sewage pollutants discharging inventory. Based on the ship AIS data source, the data preparation processes of AIS data cleaning, thinning and screening are established, and the rapid establishing method of discharging inventory is proposed. The concept of ship activity degree is put forward for the first time to characterize the density and residence time of ships in a certain time period and water area. On the basis of the ship sewage production-and-discharge characteristics and the pollution production coefficient, the formula of pollutants discharging inventory based on ship activity is established. Compared with the traditional datum based on the ship entry and exit visa, the proposed calculating method takes full account of the ship's residence time, loading and unloading, mooring and other activities in a certain water area and time period, as well as the pollution discharged by any transit ships. The method has been applied to the downstream sections of the Yangtze River. The ship sewage pollutants discharging inventory is established for the first time, and the change of pollutants discharging intensity along the Yangtze River has been studied by the geo-information system. The method proposed in this paper can be used to provide scientific basis for ship traffic management-and-control in certain sections, setting up discharging control area, layout planning of the public receiving facilities for ship pollutants, and to prevent the pollution of local waters caused by the ship sewage.

1. Introduction

There are three sources of pollutants produced during ship operation. One is pollutants and noise pollution produced by ship power plants during operation and maintenance. The second is sewage pollutants produced by crew and passengers. The third is pollutants produced in the ship operations relating to cargo loading and carrying. The ship pollutants mainly consist of oily bilgewater, oil residue, sewage (black water), grey water, garbage, noxious liquid substance residue, ballast water, etc.

The establishment of pollutants discharging inventory and the study of discharging intensity and temporal-and-spatial variations are the basis for the detailed discharging control management of ship pollutants. The study on ship pollutants discharging inventory is mainly focused on the regional emission inventory of ship exhaust gas, while the studies on the other ship pollutants discharging inventories have been seldom reported. The ship sewage pollutants are discharged on board by most ships. With increasing ship traffic volume, it is necessary to study the pollutants discharging inventory...
of sewage in some water areas, especially in navigable inland waters with relatively small environmental carrying capacity, so as to preventing ship sewage polluting the local waters.

2. Ship Automatic Identification System and Degree of Ship Activity

2.1. Ship Automatic Identification System and Its Application

Under the International Convention for the Safety of Life at Sea (SOLAS), ships greater than or equal to 300 gross tons on ocean routes built on or after 1 July 2002, cargo ships greater than or equal to 500 gross tons on inland river routes, and all passenger ships shall be fitted with Ship Automatic Identification System (AIS) equipment. According to the requirements of ship inspection technical rules in china, all passenger ships, liquid cargo ships, container ships, and other ships over 100 gross tons, shall be fitted with AIS equipment. AIS is composed of shore-based facilities and shipboard equipment. AIS with GPS can provide ship name, call sign, nine-digit code, ship type, captain, ship width and other ship static data, as well as longitude and latitude of ship, ship heading, track, speed, and other ship dynamic data.

With the popularization of shipborne AIS equipment, full coverage of AIS base station and the maturity of data management technology, ship AIS data has entered the big data era[1]. AIS in the scientific researches mainly focuses on ship route optimization, impingement optimization, traffic accident warning, shipping information big data analysis, ship exhaust gas pollutant emission inventory and so on.

At present, there are still some problems in the applications of ship AIS system. For example, the AIS is not turned on normally, the equipment antenna is not connected or there are installation problems, the wrong AIS information setting, the unauthorized modified MMSI of AIS equipment and ship name, poor quality equipment, poor level and ability of crew operating AIS equipment and so on.

A special inspection on the AIS equipment of 150 ships randomly selected was carried out by Shanghai Yangpu Maritime Administration in March 2017[2]. The inspection results show that the normal proportion of sea vessels is 87.76%, and that of inland ships is only 79.21%, as for AIS devices. For the light-tonnage ships navigating in Jiaxing section of the Beijing-Hangzhou Canal, the overall AIS operation rate is only 26.91%[3].

2.2. Degree of Ship Activity

The amount of sewage produced by ships in certain water area is closely related to the time during which the ships are operating in that water area. In this study, "Degree of Ship Activity" (DSA) is proposed to characterize the density and residence time of ships in a certain time period and water area. DSA is used to quickly extract the valid fields of AIS massive archived data, providing effective data for follow-up analysis and research.

DSA refers to the hourly residence time of the number of active ships in a certain period of time and in a certain water area, in hour per day or hour per year. Based on the broadcast time field of AIS source data message, no matter how many messages are broadcast by the ship in one hour, it is calculated as the activity degree of one hour.

Another concept associated with DSA is the Number of Active Ship (NAS), referring to total quantity of active ships (in navigating, berthing, operating or other states) in a certain water area in a certain time, in ship per day, ship per month, ship per year. The NAS statistics is based on the number of MMSI fields in the AIS source data message. DSA can be understood as the product of NAS and the residence time (in hour).

3. Establishing method based on AIS

3.1. Summary of main methods for estimating ship Pollutants

At present, the methods of calculating the emission of the ship exhaust gas are more mature, including the trade method based on cargo turnover and cargo type, the fuel oil method based on fuel
consumption statistics and emission factors, the statistical method based on the ship entry and exit data and engine power, the dynamic method based on the ship dynamic operation conditions and the engine emission factor under different working conditions[4]. Among them, the core of dynamic method is to obtain high resolution ship power information and determine engine load and working condition by means of real-time monitoring of ship operation. In turn, an emission inventory is established by using different emission factors for ship engine running conditions. The dynamic method depends on the acquisition of real-time ship dynamic information and is mainly calculated by means of AIS data source. At present, there are many researches on establishing ship exhaust gas pollutant emission inventory based on AIS data source, such as Baltic Sea waters[5], Australian waters[6], Arctic waters [7], China sea waters[8], Changjiang Estuary[9], Pearl River Delta region[10], etc.

The ship water pollutants are usually calculated based on the ships’ port entry-and-exit data, throughput and other statistical data as well as the pollution production coefficient. The transit ship traffic, ship navigating time, berthing time and other important parameters are difficult to get from the ships’ port entry-and-exit data, so the empirical formula methods cannot completely meet the demand of calculating the large range of ship water pollutant production in a basin. They are more suitable for the calculation of the capacity requirements for the onshore reception capacities of ship's pollutants from ships arriving at port. The calculation method based on AIS data source can solve the above problems through statistical analysis of DSA in the area. At present, there have not been reported on the application and research of AIS in the rapid calculation of ship sewage pollutants discharging inventory.

3.2. Datum preparation and calculation formula
The fast estimation method proposed in this study is based on AIS source data to calculate the statistics of ship activity, combined with the ship static database and discharging coefficient to calculate the pollutant production and discharging. The key link of the calculation is the determination of the parameters in the formula for calculating the production and discharging of ship sewage, datum preparation and the analysis of the calculation results. The flow chart is shown in Figure 1.

3.2.1. Data preparation.
The data preparation includes the cleaning, thinning and regional screening of the obtained AIS original archived datum for the DSA classified statistical analysis and the ship sewage pollutants production and discharging calculation.
The data cleaning is aimed to deleting the invalid data, irrelevant data, redundant data and irrelevant fields from the AIS data messages so as to reduce the amount of datum and improve computational efficiency, which can reduce the processing capacity by more than 80% for the follow-up work.

The data thinning is mainly aimed at the broadcast time of AIS messages to calculate DSA and the original single-ship broadcast time intervals of seconds to hours are thinned to 1 message per hour. The AIS data after cleaning and thinning can reduce the processing capacity by more than 95% for the follow-up work.

Regional screening is that the DSA data after cleaning and screening, further according to the actual requirements of the water zone, are screened and allocated to each water area. In calculation, the longitude and latitude coordinates of each AIS message are compared with the range of each water area, and incorporated into the DSA data pool for each water area.

3.2.2. Production and discharging calculation formulas.
The degree of ship activity(DSA) in different waters is obtained based on the ship AIS data source, on which the number of ships and residence time of ships in a certain water area are estimated accordingly. Thus the ship sewage production T is obtained. See (1).

\[ T_{\text{sewage}} = \frac{NAS \cdot r \cdot q_s}{24 \cdot k} \]

That is

\[ T_{\text{sewage}} = \frac{\text{DSA} \cdot r \cdot q_s}{24 \cdot k} \]  

Where \( T_{\text{sewage}} \) is the sewage production in tons per day; \( NAS \) is the number of active ships in ships per day; \( DSA \) is the degree of ship activity in a single day in h/d; \( r \) is the average number of persons of a single ship crew; \( t \) is the average time of a single ship in a certain water area in a single day, in h; \( q_s \) is pollution production coefficient of sewage, in t/person·day; \( k \) is the shipborne AIS operation rate, in %.

The production and discharging of ship sewage pollutants are calculated by means of sewage production T, the concentration of pollutants in the raw sewage and the effluent concentration of the sewage treatment device. See (2).

\[ P = T_{\text{sewage}} \cdot C \cdot 10^{-6} \]

Where \( P \) is production or discharging of pollutants in ship sewage in t/d; \( C \) is the concentration of pollutants in the raw sewage or treated effluent, in mg/L.

4. Calculation of ship sewage pollutants discharging inventory in the Yangtze River downstream

4.1. Datum preparation
In this study, the AIS archived data of ships from Nanjing to the estuary of the Yangtze River between November 2016 and November 2017 are obtained. The data from April to November 2017 after cleaning and thinning are used as the calculation base of ship activity degree, and the dates with incomplete messages are eliminated. The density of ship activities of one day in the Yangtze River downstream is shown as figure 2.

Figure 2. The density of ship activities (on 23 November 2017)
According to the DSA density distribution, most of the areas with concentrated ship activities are in the river sections with more ports and wharves. The areas with DSA over 600,000 hours on that day are concentrated in the river sections of Shanghai, Nantong-Zhangjiagang, Zhenjiang-Jiangyin and near Nanjing. The areas with DSA between 300,000 and 450,000 hours on the day are concentrated in the sections of Shanghai-Taicang, Zhenjiang-Nanjing. DSAs of other water areas are mostly less than 150,000 hours.

In view of the fact that the Yangtze River is a linear, long and narrow water area on a large scale, the dividing method according to the river sections is more advantageous to analyze the change of pollutant discharging along the river compared with the two-dimensional planar grid. In this study, the lower Yangtze River from Nanjing to the estuary is divided into 41 sections at the same distance of 10km. The ship activity in each section is calculated to study the discharging of ship sewage pollutants in each river section. The DSAs in the water areas of the lower Yangtze River are shown in Figure 3.

![Figure 3. DSA distribution in 41 sections of the lower Yangtze River (in 2017)](image)

The DSA in river sections of the lower Yangtze River is calculated to be 37.56 million hours per year, and the average DSA of each river section is about 0.92 million hours per year.

### 4.2. Production and discharging calculation

After DSAs in 41 river sections are calculated, the annual production of ship sewage and pollutant discharging are calculated according to the formulas for each river section.

#### 4.2.1. Sewage productions

The annual productions of ship sewage are shown in Figure 4. According to the results of the calculation, the distribution of ship sewage productions in the lower Yangtze River is basically the same as that of DSAs. There are 20 river sections with the productions of ship sewage over 100,000 tons per year, accounting for 50% of the total length of the river section. There are 10 sections with the productions of ship sewage over 150,000 tons per year, accounting for nearly 25% of the total length of the section.

![Figure 4. Annual productions of ship sewage (t/a)](image)
4.2.2. Pollutants production and discharging

Empirical value of the concentration of raw sewage adopts the concentration of pollutants in the influent of sewage treatment device onboard cruises navigating in Alaska waters[11]. Sewage treatment device installations on board adopt different discharging indicators and limits (see table 1), according to the date when they were installed on board. So the concentration levels of pollutants in the treated effluent vary considerably. In the fast calculation method of this study, the discharging limit values of Five-day Biochemical Oxygen Demand, Chemical oxygen demand, Suspended substance indicators according to the requirement of IMO MEPC 227 (64) are taken as the pollutant concentration values of treated effluent. At present, except for a small number of large passenger ships equipped with additional treatment units for nitrogen and phosphorus navigating in the Baltic Sea, none of the other ships' sewage treatment devices have nitrogen and phosphorus treatment capacity. So, indicators for total nitrogen, ammonia nitrogen, total phosphorus are determined by the effluent concentration of nitrogen and phosphorus co-treated by the treatment devices according to IMO MEPC 227 (64) requirements. The concentrations of pollutants in the raw sewage and the effluent from treatment devices are shown in Table 1.

| No. | Pollutant                          | Raw water concentration | Effluent concentration treated |
|-----|------------------------------------|-------------------------|--------------------------------|
| 1   | Five-day Biochemical Oxygen Demand (BOD₅) | 526                     | 25                             | - |
| 2   | Chemical Oxygen Demand (COD)        | 1140                    | 125                            | - |
| 3   | Suspended Substance (SS)            | 545                     | 35                             | - |
| 4   | Total Nitrogen (TN)                | 111                     | -                              | 35.82 |
| 5   | Ammonia Nitrogen (NH₃-N)            | 78.6                    | -                              | 36.6 |
| 6   | Total Phosphorus (TP)              | 18.1                    | -                              | 5.05 |

According to the above concentrations of raw sewage and effluent from the treatment device as well as the total amount of sewage, the discharging inventory of ship sewage pollutants in the lower Yangtze River is shown in Table 2. And the distribution in each river section is shown in Figures 5-10.

| Pollutant | COD | BOD₅ | SS | TN | NH₃-N | TP |
|-----------|-----|------|----|----|-------|----|
| Production (t/a) | 4995.34 | 2304.87 | 2388.12 | 486.39 | 344.42 | 79.31 |
| Discharging (t/a) | 547.73 | 109.55 | 153.37 | 156.96 | 160.38 | 22.13 |

From the results of six pollutants in the ship sewage, it can be seen that the discharging law of each pollutant in each river section is basically the same as that of DSA and the discharging of sewage in river sections. The water areas with relatively large discharging intensity are mainly concentrated in river sections of Shanghai, Nantong-Zhangjiagang and Zhenjiang-Jiangyin. It is necessary to take measures to reduce the concentrated discharging of ships' pollutants by limiting the traffic of ships entering these waters, prohibiting discharging and building the public receiving facilities for the ship's pollutants.
5. Conclusions and prospects

This paper proposes a rapid method to establish pollutants discharging inventory of ship sewage based on AIS data source. The method has the following advantages: (1) Full considerations given to the residence time and activities of the ships in a certain water area in a certain time period, not only to the ships with loading and unloading operations in a certain water area, but also to the discharging of the transiting ships; (2) Able to estimate rapidly based on the limited pollution production coefficient and to put forward the basis of management and control of ship traffic in the river sections in the view of polluting prevention; (3) The calculated discharging intensity can be used in the layout planning of pollutant discharging control area and ship pollutant public reception facilities.

At present, the AIS data source is still difficult to match between the dynamic and static data, the ship database is incomplete, and there are some problems in AIS equipment use. It is necessary to develop further researches and establish the standard flow chart of sewage pollutant discharging inventories based on AIS step by step. In order to ensure that the calculation results are more reasonable, it is recommended: (1) The measurement work for ship sewage pollutant production and discharging coefficients, effluent concentration of sewage treatment devices should be developed by typical river section so as to propose graded recommendation range of parameters such as ship type, tonnage, crew number; (2) The range of calculation should be extended to all kinds of pollutants produced by ships, and the comprehensive evaluations of pollutant discharging intensity in the waters of the river sections should be carried out; (3) The dynamic evaluation platform of ship pollution productions and discharging should be established based on AIS and GIS, and drinking water source protection areas, reception facilities, port waterway anchorages and other basic information should be included.
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