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Article

Analysis of water pollution in Chinese port regions to inform green port development

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Abstract: Water transport has emerged as one of the most significant modes of transportation globally, owing to its high carrying capacity, low transport costs, and minimal energy consumption. As a critical hub for land-water transfer, ports experience frequent interactions between ships and land, leading to substantial discharges of domestic sewage and oily wastewater, as well as suspended pollutants from construction activities. Consequently, water pollution in port areas has become increasingly severe. To implement sustainable development strategies and promote green port initiatives, it is essential to research and address water pollution in these areas. This paper first summarizes the sources and impacts of the main water pollutants associated with port construction and operations. It then discusses the spatial and temporal distribution patterns of these pollutants. Finally, based on a literature review, the author highlights the current state of water pollution in port areas, advocates for the introduction of ecological engineering solutions for wastewater treatment, compares the differences in water pollution prevention plans between domestic and international ports, and identifies the shortcomings and gaps in existing research and prevention efforts related to water pollution in port areas.

Keywords: green port; water pollution; space-time distribution characteristics; prevention and control measures

1. Introduction

Water Transport has become one of the most important transport modes in many countries in the world due to its large carrying capacity, low transport cost and low energy consumption, it undertakes the long-distance transportation of oil, coal, ore, machinery and other heavy materials. Statistics from Chongqing Traffic ALMANAC show that since 2010, in the four major modes of transport in Chongqing, the volume of goods turnover by water transport accounts for more than 60% of all goods. As the gathering point and hub of the land-water connection, the port also releases a lot of domestic sewage and oil sewage from the ships and the land, as well as the suspended pollutants produced during the construction period because of the frequent trade exchanges, the problem of water pollution in port area is becoming more and more serious [1]. The statistical data show that: (1) cargo ships are the main source of oil sewage discharged from ships, but the amount of oil sewage discharged from passenger ships and non-transport ships can not be ignored; (2) suspended matter and organic matter in domestic sewage from ships are the main pollutants, which will reduce the transparency of water bodies, affecting respiration and metabolism of aquatic organisms [2]. Based on the statistical analysis of water pollutants produced by ships in the ports of Zhangjiagang and Chongqing respectively, it is found that the annual production of ballast water and oil sewage from ships in Zhangjiagang is 12,000 t and 12,900 t respectively, the average annual production of domestic sewage from ships is 0.26 million tons [3], and the production of pollutants from ships in Chongqing Port from 2014 to 2018 is shown in figure [4], comparing the current situation of receiving 6731 t of ship waste and 3273 t of oily sewage in Chongqing Port in 2014 [5] and the current situation of receiving 6 731 t of ship garbage and 3 115 tons of oily sewage in Chongqing Port in 2016 [6] discover, there are many ship water pollutants in the port area, but most of them cannot be received and processed through formal channels. At the same time, it can be seen from **Figure 1** that the amount of domestic sewage produced by ships is relatively large, and the statistical data show that at present, none of the ports and wharves in the Three Gorges reservoir area have built domestic sewage receiving and treatment facilities, and the social receiving ships do not receive domestic sewage from ships outside the agreement, as a result, domestic sewage from ships is likely to be discharged directly into the water body, seriously endangering the safety of water environment in Port areas. Therefore, in order to implement the strategy of sustainable development of ports, the International Port Community put forward the concept of green port development, which is to maintain a balance between environmental protection and economic development. At present, in terms of green port construction, developed countries such as Europe, the United States and Japan have achieved remarkable results due to their early start. For example, the Long Beach Port of the United States has implemented the “Wharf Storm Rainwater Pollution Prevention Plan”, and the Japanese port has formulated and implemented the “Law on the Prevention of Oil Pollution from Marine Vessels”, Australia’s Sydney Port has implemented the Green Port Guidelines [7], etc. However, the construction of green ports in China is still in its infancy, and there are few relevant research results. It is necessary to summarize and analyze the research status and prevention measures of water pollution in China’s port areas, in order to monitor and simulate the water pollution in the port area and formulate the water pollution in the port area. Prevention and control policies provide theoretical and technical support.

This paper firstly summarizes the sources and hazards of major water pollutants during port construction and operation. Then, the spatiotemporal distribution characteristics of these water pollutant emissions are expounded. Finally, on the basis of summarizing and analyzing the existing literature, the paper summarizes the prevention and control measures of water pollution in the port area, proposes the introduction of ecological engineering to deal with the sewage in the port area, and compares the gaps between domestic and foreign ports in formulating water pollution prevention and control plans., pointed out that the existing water pollution research and prevention in the port area lacks a complete and systematic water pollution discharge inventory, the research on the characteristics of water pollutant discharge is not comprehensive, the prevention and control measures are still mostly at the theoretical stage, and the pollutant treatment process is relatively simple.

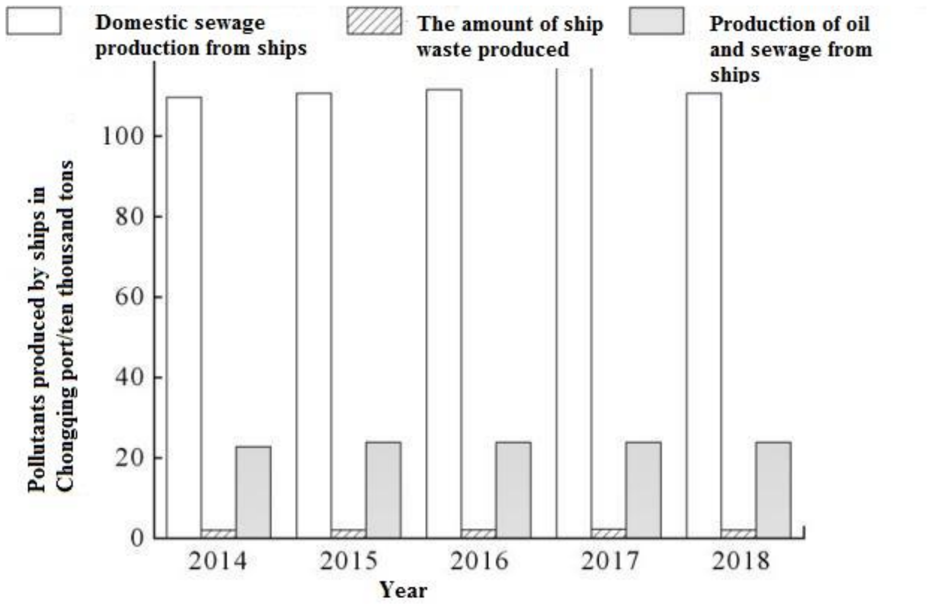

Figure 1. The amount of pollutants produced by ships in Chongqing Port from 2014 to 2018.

2. Main sources and hazards of water pollutants in port area

Before the prevention and control of water pollution in the port area, the main pollutants and their sources and harms should be identified first.

2.1. Main source of water pollutants in port area

At present, the research methods of pollution source analysis in port area include emission inventory method, watershed model method and statistical method. Among them, the most commonly used methods are multivariate statistics method and emission inventory method. Multivariate statistics method uses bottom-up method to determine the main pollutants and then seek the pollution sources, while emission inventory method mainly uses top-down research method to calculate the emissions of each pollution source, which is relatively simple to calculate. Bai et al. [8] summarized the pollution sources of port waters during construction period and operation period based on the emission inventory method. On this basis, this paper summarized the main pollutants corresponding to various pollution sources, as listed in **Table 1**.

Table 1. Port water pollution discharge list.

Project		**Water pollution sources**	**Major water pollutants**
During the construction		Harbor dredging	Suspended solids
		Wharf pile foundation works	Suspended solids
		Discharge of construction machinery	Oil, heavy metal ions, etc.
		Construction personnel domestic sewage	Oil, heavy metal ions, etc.
Operating period	The ship	Container washing waste water	Oil, suspended matter, toxic substance, organic chemical composition
		Ballast water	Gasoline, kerosene, oil, benzene, paraffin, etc.
		Ship's engine room washing sewage	Gasoline, kerosene, oil, benzene, paraffin, etc.

	Machinery maintenance oil sewage	Gasoline, kerosene, oil, benzene, paraffin, etc.
	Chemical sewage from ships	Chloride, cyanide, benzene, toluene, xylene, etc.
	Dangerous goods leakage	Chloride, cyanide, benzene, toluene, xylene, etc.
	Crew sewage	Pathogenic microorganism, organic matter, inorganic salt, etc.
Land	Domestic sewage of land production personnel	Pathogenic microorganism, organic matter, inorganic salt, etc.
	Industrial waste water from land	Heavy metal ions, inorganic salts, etc.
	Storage yard coal rain water, ore rain water	Suspended matter, particulate matter, heavy metal ions, etc.

It should be pointed out that the water pollutants produced during port construction are usually easy to be ignored. And in addition to the oil sewage produced by construction machinery and construction personnel of sewage, construction process and central pool dredging dredging, wharf pile foundation construction process, etc. shall be carried out in the water, makes the river disturbance and the pollution of water body, resulting in a decline in local waters within the scope of construction water transparency, thereby affect port ecological environment [9-11]. According to statistics, when the dredging quantity is 80,000 m^3, the suspended pollutants produced by dredging and mud throwing are 6500 t and 3 500 t respectively [12]. Wang et al. [13], Xu et al. [14] studied the influence of dredged suspended sand on phytoplankton and plants, and found that suspended pollutants would affect the growth of phytoplankton and the development and metamorphosis of some zooplankton. Newcombe [15] and East China Sea Fisheries Research Institute [16] carried out relevant researches on fish, shrimp and crab, which showed that the increase of suspended matter concentration had a serious impact on their ecological environment. When the dredging period is 140 days, more than 10 million fishery resources will be lost even during the semi-avoidance spawning period. Thus, the problem of water pollution in the process of port construction must be taken seriously.

In addition, there are many research results on water pollution generated by ships and land auxiliary facilities during port operation [17–24]. However, the stormwater flow problem generated by land storage yard of bulk cargo terminal is less concerned by scholars [25,26]. The sewage produced by stormwater runoff is related to rainfall, rainfall frequency and bulk cargo turnover. According to statistics, 2017 inland port coal and metal ore throughput for 2 more than 800 t [4], and for more rain like Chongqing port along the Yangtze river port, inevitably will produce large amounts of coal and ore rain, if produce overflow port storage facilities, will lead to the sewage directly discharged into waters, It has had a very serious impact. Taking the rainfall data of Chongqing from 1961 to 1970 as an example [27], if the port is set to collect and process 60 mm daily rainfall, there will be 19 overflows, and the total rainfall without processing is about 219.7 mm, about 6.3%, or 6.3% coal rain water, ore rain water directly into the port area without treatment. However, with the construction of the Three Gorges Dam, the rainfall in Chongqing increased year by year, so the amount of coal rain water and ore rain water discharged into the port area without treatment is still increasing year by year, which must be paid attention to.

2.2. Harm of main water pollutants in port area

There are many kinds of water environmental pollutants in the port area, which have different effects on aquatic organisms and ecological environment of the port area. Therefore, it is necessary to clarify the harm of water pollutants during construction and operation period of the port area, and provide basis for formulating corresponding prevention and control measures.

Although the effects of water pollutants on aquatic organisms in the port area during construction are temporary, irreparable losses will be caused if the construction lasts too long. Domestic and foreign scholars have carried out relevant studies on the impact of port construction period on aquatic organisms, which are summarized in **Table 2** in this paper. It can be seen from **Table 2** that the impacts of construction period on aquatic organisms in the port area are mainly shown in the following three aspects: (1) It affects the survival rate and embryo development rate of aquatic animals; (2) increased mortality of adult aquatic animals; (3) clog the food filtration system and digestive organs of aquatic animals, reduce feeding rate and foraging behavior. In addition, the existing research results show that there has been some progress in the research on the impact of water pollution on aquatic organisms in coastal ports during construction period, but in comparison, there is less research on inland ports. In fact, the unreasonable discharge and control of water pollutants during the construction of inland river ports will directly threaten the safety of drinking water and aquatic products, so attention should be paid to it.

Table 2. The impact of suspended solids on aquatic organisms during the construction period.

The research object		Effects on the body	The study area	Reference
Invertebrates	Zooplankton	Excess suspended matter can clog the zooplankton's food-filtering systems and digestive organs	-	Perricord [28]
	Shrimp and crab	The survival rate of litopenaeus vannamei was affected when the concentration of suspended matter was more than 10mg/L and the duration was more than 12 h. If the duration is longer than 48 h, all larvae may die	Zhanjiang Port Area, China	Li et al. [29]
	Benthic animals	The high concentration of suspended matter has strong chronic lethal effect	China's Liaoning Province	Ma et al. [30]
		The suspended matter rich in nutrients and small particle size will bring great pressure to the survival of polyps after short-term exposure.	Australia	Weber et al. [31]
		The increase of suspended matter concentration greatly reduced the feeding rate of bivalve after oviposition, but had relatively little effect on the feeding rate before oviposition	East coast of North Island, New Zealand	Hewitt et al. [32]
		The dredging and excavation in the port area changed the sediment environment and had a great influence on benthic organisms	Qingdao Port Area, China	Sun et al. [33]
Fish	Roe, larva	High concentration of suspended matter can reduce the survival rate of eggs and larvae, affect embryo development, and even affect the full exchange of dissolved oxygen and carbon dioxide between larvae and water flow	East coast of USA, UK	Auld et al. [34]; Greig et al. [35]
	Salmon	Suspended solids can greatly reduce the fertilization success rate of eggs, cause physical damage to gills, and cause a significant reduction in the foraging behavior of salmon	Canada	Lake et al. [36]; Martha et al. [37]; Galbraith et al. [38]
	Sweet fish	Suspended solids significantly increased cortisol levels in the	Japan	Satoshi et al. [39]

	fish		
Cynoglossus semilaevis	With the increase of suspended solids concentration, the larvae and embryos of Cynoglossus semilaevis will be semi-lethal	China's Shandong Province	Zhou et al. [40]
Lutianus sebae	When the suspended substance concentration was 1105.096 mg/L, it was semi-lethal for 8 days. When the concentration reaches 2560 mg/L, the mortality rate is up to 70%	China Zhanjiang	Lin et al. [41]

During the operation period, the water pollutants carelessly flowing into the water will cause extremely severe harm to water quality. Wang et al. [42] believe that the harm is mainly reflected in the following three aspects: (1) The organic matter contained in sewage in the decomposition, will consume a lot of dissolved oxygen in the water, so that most aquatic organisms due to hypoxia and asphyxia death; (2) Inorganic nutrient salts in sewage are the main factors causing eutrophication of water areas, especially when the content of N and P is too high, it will cause the proliferation of toxic and harmful algae, causing serious damage to the aquatic ecosystem; (3) there are a lot of pathogenic microorganisms in sewage, which is a potential source of infectious diseases. Through the research and analysis of existing literature, this paper believes that in addition to the above hazards, the following considerations should also be taken into account: (1) The harm of accidental discharge of ship washing water to various organisms in the water body. According to statistics, about 6 million to 8 million tons of toxic and harmful ship washing water was generated in the trunk line of the Yangtze River in 2016 [43], which will cause serious water pollution. (2) Dust and air pollutants after rains dissolved into water bodies to aquatic organisms as well as the harm caused by the human, An et al. [44] with the weather bureau and the ministry of environmental protection from 2014 to 2016, 6 kinds of air pollutant concentration data analysis of the atmospheric pollutants concentration before and after the rain, in Beijing-Tianjin-Hebei, Yangtze river delta and the pearl river delta region, After rainfall, its concentration decreases by 43%~60%. It can be seen that the precipitation of dust and air pollutants can not be ignored.

3. Discharge characteristics of water pollutants in port area

There are many kinds of water pollutants in the port area, which show the characteristics of spatio-temporal differentiation under the influence of geographical, climate and other environmental factors and human activities. To clarify the spatio-temporal discharge characteristics of water pollutants in the port area is the premise of evaluating and improving the water quality of the port area.

3.1. Time distribution feature

According to the amount of rainfall and the level of water level, the port area can be divided into wet season, normal season and dry season, and the emission and concentration of pollutants in different periods are different. Based on literature analysis and summary [45–48], this paper obtained the monthly changes of COD_{Mn} and NH_3-N, the main super standard indicators of Cuntan port in 2016,2018 and 2019 (the research data came from the monitoring data of the national surface water environmental quality monitoring network [48]), as shown in **Figure 2**.

As can be seen from **Figure 2**, the monthly variation regularity of COD_{Mn} concentration is obvious, showing that the concentration is higher from July to September and lower from December to March of the next year. The main reason is that oxidants are used in the determination of COD_{Mn} concentration, and the oxidized substances in water are detected as COD_{Mn}. However, there is a lot of rainfall from May to September, and a lot of reducing substances flow into the port area. The concentration of COD_{Mn} was high, and the dry season was from December to March of the next year, with less rainfall and lower concentration of COD_{Mn}.

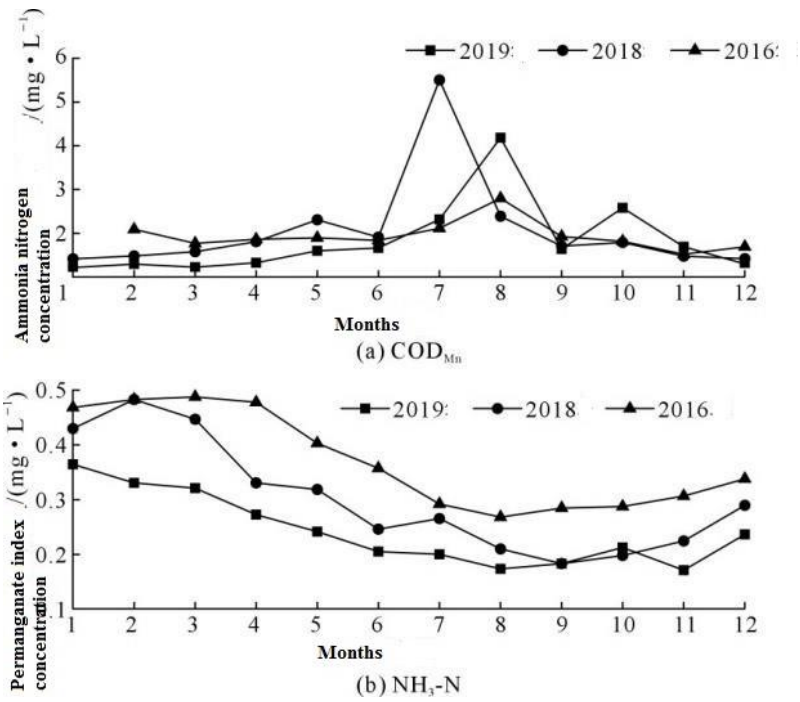

Figure 2. Monthly changes of COD_{Mn} and NH_3-N concentrations in Cuntan Port in 2016, 2018 and 2019.

The monthly variation of NH_3-N concentration in Cuntan Harbor was different in recent 3 years, which showed that the concentration was higher from January to March and lower from July to September. The reason is that NH_3-N concentration is relatively low due to dilute release of NH3-N due to increased rainfall in wet season. Nh_3-N concentration is relatively high in dry season due to less precipitation. In April, October and November, the relative concentration of NH_3-N is higher than that in wet season and lower than that in dry season. Considering the increasing effect of port ships on pollutant concentration in the port area and the diluting effect of precipitation on pollutant concentration, the comprehensive impact of ships arriving at the port and precipitation in each period was analyzed, and the average water freight volume and average rainfall of Chongqing in wet season, normal season and dry season in 2018 were obtained, as listed in **Table 3**. Among them, the number of average freight volume of water transport represents the frequency of ships to the port. In this paper, the dimensionless treatment is carried out, and the ratio of the two factors, γ, is taken as the comprehensive influence coefficient. The calculation results are listed in **Table 4**. It can be seen that when the two influencing factors are considered comprehensively, the temporal distribution of NH_3-N emission is still in the order of dry season > normal season > wet season, which is consistent with the above analysis results. As can be seen from **Figure 2**, the concentration of NH_3-N and other water pollutants shows a downward trend on the whole, indicating that water quality is getting better year by year.

Table 3. Chongqing's average freight volume of water transport and average rainfall in wet season， normal flow period and dry season in 2018.

Period	**Average water freight volume/10,000 tons**	**Average rainfall/mm**
The plentiful	1637.0	718.4
Level period	1884.7	271.8
The mutagenicity	1405.3	195.5

Note: Data are from Ministry of Transport, PRC and China Statistical Yearbook.

Table 4. Dimensionless processing results.

Period	***α*/%**	***β*/%**	***γ***
The plentiful	33	61	0.54
Level period	38	23	1.65
The mutagenicity	29	16	1.81

Note: α represents the proportion of NH_3-N emissions after ships arrived at the port in each period, β represents the dilution degree of NH_3-N by rain water in each period, and γ represents the comprehensive influence coefficient of NH_3-N concentration in each period.

3.2. Spatial distribution characteristics

The spatial characteristics of water pollutant discharge in port area are mainly shown as different pollutant discharge concentrations of port water on different rivers and different pollutant discharge concentrations of port water along the main stream. For ports on rivers of different grades, the lower the river grade is, the higher the concentration of pollutants in port water is, and the more exceeds the standard is relatively. For ports along the main stream of the Yangtze River, as shown in **Figure 3**, pollutant emission concentrations from ports in the middle reaches of the Yangtze River are higher than those from ports in the lower reaches of the Yangtze River. The reason may be that the trade of ports in the middle and lower reaches is more frequent than that in the upper reaches, which leads to more pollutant discharge and higher emission concentration of land and arriving ships in the port area.

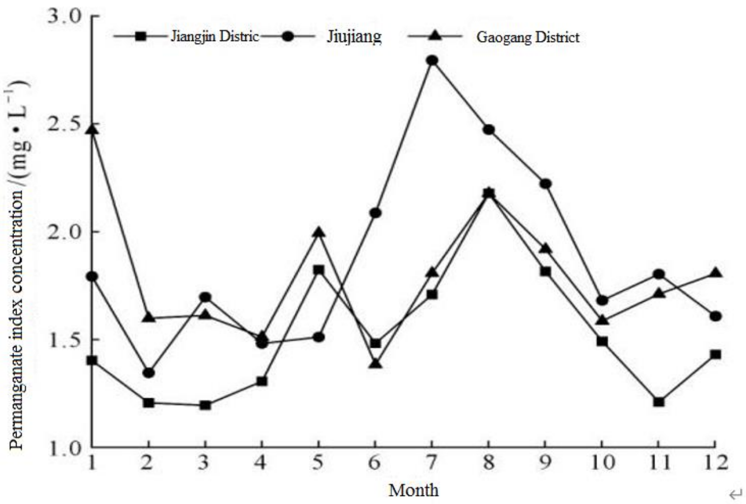

Figure 3. Changes in monthly COD_{Mn} concentration of ports along the main stream of the Changjiang River in 2019.

4. Water pollution prevention and control measures and planning analysis in port area

Green port construction must be formulated and implemented a series of water pollution prevention and control measures, this paper analyzed the port wastewater collection processing present situation, and then through the bow everearth, [7,8, 49], such as the analysis of the research results, summarized four kinds of port sewage control measures, and suggest using ecological engineering to deal with port area sewage, The gap between domestic and foreign ports in formulating water pollution prevention and control plan is compared, which can provide reference for domestic port water pollution research and prevention.

4.1. Current situation of water pollution control in domestic port area

As MARPOL73/78 marpol I the prevent oil pollution rules and bylaws IV the prevention of sewage pollution rules and bylaws V the prevention of waste pollution rules gradually come into effect as well as the law on the prevention and control of water pollution and the prevention and control of pollution by vessels in inland water environment management regulations enacted, port area water environment should be improved in theory, But at present, the prevention and control of water pollution in domestic port area still faces big problems.

Xu et al. [50] investigated the status quo of sewage collection and treatment of ports and docks in Jiangsu Province and found that the sewage receiving and treatment facilities of bulk cargo terminals were not perfect, and the proportion and number of berths without facilities were large. In contrast, hazardous chemicals wharf on the whole sewage receiving and treatment facilities are more perfect. The prevention and control of water pollution in coastal wharves is good. At the same time, the sewage receiving and treatment situation of wharves along the river is better than that of inland ports, and the receiving and treatment situation of berths of inland ports is relatively poor, and most berths have imperfect facilities and no facilities. Yang et al. [51], Li et al. [52] also drew a similar conclusion that the construction of ship sewage receiving and treatment facilities in the port area was insufficient and the utilization rate was generally low. In addition, due to the low value of domestic sewage recycling and relatively high cost of recycling and treatment, many ports do not build domestic sewage receiving and treatment facilities, but rely on social ships for receiving and treatment, resulting in difficulties in the discharge of domestic sewage from ships other than the agreement units [53]. At the same time, the operating efficiency of domestic ports is low, which increases the difficulty of equipping domestic sewage treatment equipment.

4.2. Measures for preventing and controlling water pollution in port areas

(1) Dusty rainwater and washing water. Bulk terminal due to rainfall and irrigation water, can be in bulk yard near mining collect sewage ditches and adjusting tank, by using features, its density is greater than the water make heavy particles sedimentation in the ditch, achieve the goal of initial clearance, flocculating agent is added in the regulating tank, then use its adsorption, make small particles suspended matter condenses into larger particles, And gradually formed floccules, which rapidly precipitated at the bottom under the action of gravity, thus removing most suspended matter in water [8].

(2) Container flushing water. The waste water produced by container flushing can be set up in the vicinity of the container yard with ditches and regulating ponds. The first step is to preliminarily precipitate the waste water and then add chemical reagents to effectively remove the pollutants. Containers loaded with toxic substances should be cleaned before being washed, and sewage containing toxic and harmful substances should be received and treated by relevant units. The yard of dangerous goods container should be separated from the yard of ordinary container, and an independent drainage ditch should be set around the yard. The flushing water in the accident state should be collected and disposed through the drainage ditch [8].

(3) Domestic sewage. After the domestic sewage is treated by the sewage treatment plant, part of it is recycled, and the rest is purified by setting appropriate sewage outlet and using the dilution and diffusion capacity of the water body itself. In order to achieve recycling or discharge after reaching the standard, domestic sewage treatment facilities can be installed on the ship, or domestic sewage can be collected and stored in water storage tanks on the ship, and then discharged to the sewage treatment plant or sewage receiving and treatment ship at the port [7].

(4) Oil and sewage in port area. On the one hand, the prevention and control measures on ships can be improved, such as the installation of oil-water separator devices, the use of “upper device method” and “crude oil washing water method” for tankers, new ships can be built special ballast water tank; On the other hand, port prevention and control capacity can be improved by setting up a special ship sewage receiving and processing ship in the port to directly treat the received sewage on the ship, or setting up a sewage treatment plant on the shore to receive the oil sewage from the ship and send it to the sewage treatment plant for centralized treatment [7].

The measures for the rehabilitation of oil and sewage in the accident port area are: (1) after the closure of the oil boom with oil, felt oil absorption, and then manpower to reduce oil pollution; (2) the use of some chemical reagents to decompose the oil into fine particles, accelerate its decomposition, diffusion and degradation; (3) the biochemical decomposition of microorganisms is used to decompose complex oil organics into simple substances, so as to transform toxic substances into non-toxic ones, so that port waters can achieve the purpose of self-purification [49].

In addition, with the increasingly mature development of ecological engineering, this paper believes that ecological engineering should be introduced to treat sewage in the port area, and make full use of its advantages such as low construction cost, convenient maintenance, low energy consumption, high sewage treatment efficiency and comprehensive utilization of sewage. For example, Dong et al. [54] used ecological engineering to treat petrochemical wastewater, and the removal rate reached 72% and created huge economic benefits. Qiu et al. [55] carried out in-depth treatment of sewage by constructing the Ecological project of Fengyanlian three-stage series purification pond, and the results showed that the removal rates of N and P were both higher than 60%.

4.3. Comparative analysis of water pollution control plan in port area

Green port construction started earlier abroad, part of the port has formulated a series of relatively mature prevention measures and planning, and ports to the implementation of environmental protection has accumulated certain experience, this article will this paper summarizes the water pollution prevention plan for major foreign ports as follows, thought that the domestic ports provide reference and reference for the establishment of relevant planning.

(1) The Port of Oakland in the United States formulated the Storm Water Plan to prevent and control storm water during the construction and operation period, so as to reduce runoff pollutants; As the second busiest port in the United States, the Port of Long Beach has launched a "green Port policy", which includes nearly 40 projects in seven aspects, including water quality and sustainable development.

(2) Japanese ports have formulated relatively complete plans and measures for water pollution prevention and control in port areas, including a list of environmental protection facilities such as water exchange facilities for purifying polluted water, pollution prevention buffer zone, environmental pollution prevention facilities, waste water receiving facilities and waste oil treatment facilities.

(3) The Gippsland Port of Australia formulated and implemented the Safety and Environment Management Plan, which stipulated the specific time, place and method for dredging in the port area; The Port of Fremantle operates a comprehensive Marine Quality Monitoring programme, which monitors water quality every two weeks to assess potential factors associated with environmental pollution in the port.

(4) British ports must provide detailed environmental protection and emergency plan to the Port Administration every year, and need to formulate specific prevention and control objectives, measures and implementation methods, and clarify corresponding responsibilities and supervision measures.

(5) The Port of Vancouver in Canada has developed the Stormwater Pollution Prevention Plan and the Port Information Guide to deal with stormwater related pollution and various pollutants discharged by ships; And the Port of Toronto has

developed and implemented the Harbor Cleanup Plan, which will remove 6. More than 80,000 tons of pollutants.

In contrast, only Tianjin Port, Shanghai Port, Dalian Port, Shenzhen Yantian port and other coastal ports in China have put forward some specific plans for the construction of green ports. For example, Tianjin Port has implemented the “Clear water Project” to effectively treat domestic and production sewage and oily sewage from ships [56]. Shanghai Port has established a central monitoring station and a ship waste receiving and treatment system, effectively protecting the water environment of the port area [57]. Dalian Port has established the “three vertical and three horizontal” emergency water emergency system to prevent the water from entering the sea to the maximum extent [58]. Shenzhen Yantian Port carries out “sea-rail combined transportation” and clean production operations to reduce the impact of ships calling at the port on the environment [59]. But these plans are not perfect and rough, such as the lack of green concept in planning and design; The construction period is still “pollution before treatment”, lacking a complete demonstration report on the impact of the construction period on aquatic organisms; The monitoring data of the port area during the operation period are not open, and a complete environmental supervision and management system cannot be formed, which needs further improvement and modification. However, there are relatively few plans for inland river ports, but as can be seen from the analysis in Section 1.1, water pollution in inland river ports cannot be ignored. Therefore, it is necessary to start from the aspects of port design and construction, port area operation, ship monitoring, water quality monitoring, etc., to establish a complete pollutant control and management plan for different forms of pollution and their causes, and form a relatively complete green port evaluation system.

5. Existing problems and suggestions

To sum up, scholars at home and abroad have carried out a certain amount of research on water pollution in the port area, mainly focusing on the main sources and hazards of water pollution in the port area, the spatial and temporal distribution characteristics of pollutant discharge, and the prevention and control measures and planning of water pollution in the port area. However, there are still some deficiencies in the research and prevention of water pollution in port areas in China.

(1) For the establishment of water pollution discharge inventory, Li et al. [60] developed a watershed non-point source water pollution discharge inventory estimation system, but there are still few systematic studies on the establishment of port water pollution discharge inventory, lacking a complete and systematic port water pollution discharge inventory.

(2) At present, researches on the discharge characteristics of water pollutants in the port area mainly focus on ships arriving at the port, while the research results on the discharge characteristics of water pollutants produced by port machinery and collecting and distributing vehicles are limited, which requires further research and discussion.

(3) The water pollution prevention and control measures in some port areas are only in the theoretical stage. The sewage treatment facilities are outdated, the process

is single, the treatment efficiency is not high, and the seriousness of the water pollution problem is not fully understood, the prevention and control planning are not perfect, and the implementation of some ideas is lagging behind.

In view of the above problems, we should first establish a complete system of water pollution discharge inventory of port area; Then, the study on the discharge characteristics of water pollutants from port machinery and collecting and distributing vehicles is carried out. Some foreign emission prediction models are used to study the temporal distribution characteristics of water pollutant discharge. Meanwhile, the spatial characteristics of different pollution sources are studied. Finally, from the beginning of port planning and construction, the water pollution prevention and control measures in the port area should be concretized to specific water pollution sources, new equipment and new technology should be developed to treat sewage in the port area to improve efficiency, and domestic sewage receiving facilities and municipal pipe network construction should be improved.

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