Study on eutrophication characteristics of rainy and dry season in Shenzhen Bay

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Abstract. Firstly, the eutrophication of five monitoring points in Shenzhen Bay was analyzed by using the nutritional status quality index method, and the eutrophication of the entire Shenzhen Bay was analyzed by the results of the eutrophication model simulation. The results showed that the maximum of the nutritional status quality index (NQI) in the dry season was 22, the minimum was 3; the maximum NQI in the rainy season was 23, the minimum was 4, and when NQI is greater than 3, the water is eutrophication level, so whether it was the dry season or the rainy season, Shenzhen Bay is basically eutrophic, and the eutrophication of the Shenzhen Bay in the rainy season is more serious than that in the dry season. Regardless of the dry season or the rainy season, the NQI of the Shenzhen Bay outer area is basically around 5, while the NQI of the interior area is basically larger than that of the outer area. The degree of eutrophication is more serious than that of the outer area; the maximum NQI is 21 in the high tide during the dry season, and the maximum NQI is 23 in the rainy season; the maximum NQI is 22 in the ebb during the dry season, and the maximum NQI in the rainy season is 22, so the eutrophication of Shenzhen Bay is more serious than the ebb when the high tide.

1. Introduction

With the rapid development of the urban economy, the problem of environmental pollution has become increasingly prominent. In particular, the problem of water pollution has become increasingly prominent. The development of industry and the large discharge of domestic sewage have greatly increased the problem of water pollution. Industrial wastewater contains a large amount of nitrogen and phosphorus pollutants, Nitrogen and phosphorus pollution is the main cause of eutrophication of water. The direct or indirect discharge of a large amount of industrial wastewater into each water is a key factor leading to eutrophication of water. Shenzhen Bay is located at the Pearl River Estuary, between Shenzhen and Hong Kong. It is a semi-closed shallow water bay with a wide interior and a narrow exterior in the middle of the east side of the Lingding Ocean of the Pearl River Estuary. The straight line of the bay is 17.5 km, and the average width is about 7.5 km. The Bay covers an area of about 90.8 km², with an average depth of 2.9 m and the maximum water depth not exceeding 5 m, and the hydrodynamic conditions are poor [1]. The rapid development of Shenzhen and Hong Kong in recent decades has imported a large number of pollutants into Shenzhen Bay, making the water environment problem in Shenzhen Bay increasingly obvious [2]. Especially the eutrophication problem has not been solved. The red tide in Shenzhen Bay has occurred more than 30 times since 1981 [3-6], which greatly affected the development of the Shenzhen Bay ecosystem and further affected the economic development of Shenzhen and Hong Kong. Domestic scholars have also made relevant
research on the eutrophication of Shenzhen Bay[7-9]. However, these studies are only aimed at the
eutrophication of Shenzhen Bay under certain environmental conditions, and this paper will simulate
the changes of various pollution indicators in the dry and rainy seasons of Shenzhen Bay, and analyze
the eutrophication of Shenzhen Bay under different hydrological conditions in dry season and rainy
season.

In order to understand the degree of eutrophication of water, domestic and foreign scholars have
conducted detailed research and proposed some evaluation methods and models[10-13], based on this,
the eutrophication degree of water can be more objectively characterized, and the changing trend of
water quality can be predicted, so as to provide a basis for scientific treatment of water environment
problems. So far, there have been dozens of methods for evaluating eutrophication of water at home
and abroad. The evaluation methods of eutrophication have not been unified internationally. At
present, the methods used by researchers at home and abroad are single factor method and
comprehensive index method[14-15] and the eutrophication fuzzy evaluation model[16]. The
eutrophication problem is formed by the combination of various pollution factors. The single index is
used to evaluate the problem of eutrophication is not comprehensive. Therefore, the comprehensive
index method is the most widely used method today[17].

2. Materials, analysis and evaluation methods

2.1. Shenzhen Bay monitoring and analysis

In this paper, the water quality eutrophication characteristics of Shenzhen Bay are characterized by the
seven water quality monitoring data of the Ocean Bureau in March, May, August, October of 2017
and March, June and September of 2018. The monitoring point map is shown in Figure 1. Among
them, GD082, ZQ019, and GD083 are in the inner bay, and GD084 and GD085 are in the outer bay,
and these points are on the Shenzhen side. and using this monitoring data to validate and calibrate the
Shenzhen Bay eutrophication model. The main analytical indicators are inorganic nitrogen (DIN),
active phosphate (DIP), chemical oxygen demand (COD_mn) and chlorophyll-a (Chl.a).

![Figure 1. Distribution map of Shenzhen Bay conventional monitoring site (Shenzhen Ocean Bureau).](image-url)
2.2. Eutrophication evaluation method

In this paper, the nutritional status quality index method [18-19] is used to comprehensively consider four water quality indicators: DIN, DIP, COD$_{Mn}$, and Chl.a. Calculate the corresponding NQI, the specific calculation formula is as follows:

$$NQI = \frac{COD}{COD_S} + \frac{DIN}{DIN_S} + \frac{DIP}{DIP_S} + \frac{Chl.a}{Chl.a_S}$$

Where: the numerator is the monitored value, and the denominator is the standard value. According to Sea Water Quality Standard (GB3097-1997), the standard values of DIN, DIP, COD$_{Mn}$, and Chl.a are determined as COD$_S$ = 4.000 mg·L$^{-1}$, DIN$_S$ = 0.600 mg·L$^{-1}$, DIP$_S$ = 0.045 mg·L$^{-1}$, and Chl.a$_S$ = 5.000 mg·m$^{-3}$. When NQI > 3 is the eutrophication level, NQI < 2 is the oligotrophic level, and NQI is between 2 and 3 as the moderate eutrophication level [20].

3. Results and discussion

3.1. Monitoring data results and discussion

Using the monitoring data to calculate the NQI of the Shenzhen Bay, the results are shown in Figure 2. The NQI of each monitoring point in Shenzhen Bay exceeded 3 in each period, indicating that the water is eutrophication level. At the same time, it can be seen that Shenzhen Bay from the outer bay to the inner bay showed the tendency of eutrophication has aggravated gradually. The average value of the NQI of GD082 is 21.1. The average value of the NQI of ZQ019 is 15.4. The average value of the NQI of GD083 is 8.2. The average value of the NQI of GD084 is 6.0. The average value of the NQI of GD085 is 5.3.

![Figure 2. NQI of each monitoring period in each monitoring points in Shenzhen Bay.](image)

In order to further understand what kind of nutrients has a greater impact on eutrophication, the degree of eutrophication of individual nutrients is evaluated. The evaluation criteria are shown in Table 1 [21]. The nutrient status of the water was evaluated by DIN, DIP, Chl.a and COD$_{Mn}$, and the statistics showed the proportion of oligotrophic, moderate eutrophication and eutrophication. The statistical results are shown in Table 2. Evaluation of nutrition status by DIN as the criterion, the proportions of water showing oligotrophic, moderate eutrophication and eutrophication were 2.86%, 2.86% and 94.28%. The nutrition status was evaluated by DIP as the criterion, the proportions of water showing oligotrophic, moderate eutrophication and eutrophication were 0%, 8.57% and 91.43%. The nutrition status was evaluated by Chl.a as the criterion, and the proportions of water showing oligotrophic, moderate eutrophication and eutrophication were 16.67%, 20% and 63.33%. The nutrient
status was evaluated by COD\textsubscript{Mn} as the criterion. The proportions of water showing oligotrophic, moderate eutrophication and eutrophication were 65.71\%, 5.71\% and 28.58\%. It can be seen that if DIN and DIP are used as the evaluation criterion, Shenzhen Bay is basically at the level of eutrophication. If Chl.a is used as the evaluation criterion, most areas of Shenzhen Bay are at eutrophication level. COD\textsubscript{Mn} is the evaluation criterion, and most areas of Shenzhen Bay are at the level of eutrophication.

Table 3 shows the Proportion of various nutrient factors in the Shenzhen Bay during the rainy and dry seasons showing oligotrophic, medium nutrition and eutrophication. The nutrition status of the bay was evaluated with DIN as the criterion. The proportions of oligotrophic, medium nutrition and eutrophication in the bay during the dry season were 6.67\%, 0, and 93.33\%. The proportions of oligotrophic, medium nutrition and eutrophication in the bay during the rainy season were 0, 5\%, and 95\%. DIP was used as the standard to evaluate the nutrition status of the bay. The proportions of oligotrophic, medium nutrition and eutrophication in the bay during the dry season were 0, 13\%, and 87\%, respectively. The proportions of oligotrophic, medium nutrition and eutrophication during the rainy season were 0, 0, and 100\%, respectively. Using Chl.a as a standard to evaluate the nutritional status, the proportions of oligotrophic, medium nutrition and eutrophication in the bay during the dry season were 26.67\%, 13.33\%, and 60\%, and the proportions of oligotrophic, medium nutrition and eutrophication in the bay during the rainy season were 20\%, 25\%, and 55\%, respectively. COD\textsubscript{Mn} was used as the standard to evaluate the nutrition status. The proportions of oligotrophic, medium nutrition and eutrophication in the bay during the dry season were 66.67\%, 6.66\%, and 26.67\%, and the proportions of oligotrophic, medium nutrition and eutrophication in the bay during the rainy season were 65\%, 5\%, and 30\%, respectively. It can be seen from the table that if DIN and DIP are used as the evaluation criterion, The Shenzhen Bay area is basically eutrophic. If Chl.a is used as the evaluation criterion, eutrophication in most areas of Shenzhen Bay. If COD\textsubscript{Mn} is used as evaluation criterion, oligotrophication in most areas of Shenzhen Bay. Regardless of the dry season or rainy season, the eutrophication of Shenzhen Bay is basically the same.

| Table 1. Evaluation criteria for single indicator eutrophication level. |
|---|---|---|---|
| Trophic level | DIN/(mg·L⁻¹) | DIP/(mg·L⁻¹) | Chl.a/(μg·L⁻¹) | COD\textsubscript{Mn}/(mg·L⁻¹) |
| Oligotrophic | 0.2 | 0.015 | 1 | 2 |
| Moderate eutrophication | 0.3 | 0.03 | 3 | 3 |
| Eutrophication | 0.4 | 0.045 | 5 | 4 |

| Table 2. Proportion of various nutrient factors in Shenzhen Bay showing oligotrophic, moderate eutrophication and eutrophication. (Unit: %) |
|---|---|---|---|---|
| Trophic level | DIN | DIP | Chl.a | COD\textsubscript{Mn} |
| Oligotrophic | 2.86 | 0 | 16.67 | 65.71 |
| Moderate eutrophication | 2.86 | 8.57 | 20 | 5.71 |
| Eutrophication | 94.28 | 91.43 | 63.33 | 28.58 |

| Table 3. Proportion of various nutrient factors in the Shenzhen Bay during the rainy and dry seasons showing oligotrophic, medium nutrition and eutrophication.(Unit: %) |
|---|---|---|---|---|---|---|
| Trophic level | Dry season DIN | DIP | Chl.a | COD\textsubscript{Mn} | Rainy season DIN | DIP | Chl.a | COD\textsubscript{Mn} |
| Oligotrophic | 6.67 | 0 | 26.67 | 66.67 | 0 | 0 | 20 | 65 |
| Moderate eutrophication | 0 | 13 | 13.33 | 6.66 | 5 | 0 | 25 | 5 |
| Eutrophication | 93.33 | 87 | 60 | 26.67 | 95 | 100 | 55 | 30 |
Contrast found that the eutrophication of water is mainly caused by nitrogen and phosphorus nutrients, followed by Chl.a, COD$_{Mn}$ has little effect.

3.2. Model analysis and discussion

The ECOLab module of MIKE was used to simulate the eutrophication of Shenzhen Bay. The simulated pollutants were COD$_{Mn}$, Chl.a, DIN and DIP. The dry season and the rainy season are simulated for three months, and the simulation time is from January 1 to March 31, 2018 and July 1 to September 31, respectively. The predicted results of the model are shown in Figure 3 and Figure 4.

Figure 3 shows the concentration distribution of COD$_{Mn}$, DIN, DIP and Chl.a in the dry season of Shenzhen Bay. It can be seen from the figure that the pollution in Shenzhen Bay in the dry season is basically accumulated in the inner bay, especially near the Shenzhen river estuary. Due to the weak hydrodynamics, the accumulation of pollutants is relatively serious. The pollution at the estuary is more prominent. A part of the pollutants, especially DIP, is concentrated near the Dasha River, with the highest concentration near the Dasha River. The Pearl River estuary also contributes to the pollution of Shenzhen Bay, especially the contribution of DIN and DIP. It can be seen from the figure that the DIN and DIP in Shenzhen Bay in the dry season basically exceed the water quality standard of Shenzhen Bay (DIN≥0.4mg.L$^{-1}$, DIP≥0.03mg.L$^{-1}$), which shows the nitrogen and phosphorus pollution in Shenzhen Bay is relatively serious during the dry season, while nitrogen and phosphorus pollution is the main cause of eutrophication of water. It can be seen that the eutrophication of Shenzhen Bay in the dry season is also serious.

**Figure 3.** Distribution of COD$_{Mn}$, DIN, DIP and Chl.a concentration in the dry season of Shenzhen Bay.
Figure 4 shows the concentration distribution of COD$_{\text{Mn}}$, DIN, DIP and Chl.a in the rainy season of Shenzhen Bay. It can be seen from the figure that the pollution of Shenzhen Bay in the rainy season is basically concentrated in the inner bay, especially near the Shenzhen river estuary. Due to weak hydrodynamics, the concentration of pollutants is relatively serious. The pollution at the estuary is more prominent. A part of the pollutants, especially DIP, is concentrated near the Dasha River, with the highest concentration near the Dasha River. The Pearl River Estuary also contributes to the pollution of Shenzhen Bay, especially the contribution of DIN and DIP. It can also be seen from the figure that the DIN and DIP in Shenzhen Bay in the rainy season basically exceed the water quality standard of Shenzhen Bay (DIN$\geq$0.4mg.L$^{-1}$, DIP$\geq$0.03mg.L$^{-1}$), which shows the nitrogen and phosphorus pollution in Shenzhen Bay is relatively serious during the rainy season, while nitrogen and phosphorus pollution is the main cause of eutrophication of water. It can be seen that the eutrophication of Shenzhen Bay in the rainy season is also serious. Compared with the dry season, the concentrations of DIP and Chl.a in the Shenzhen Bay during the rainy season are basically higher than those in the dry season.

The NQI calculated from the simulation results is shown in Figure 5 and Figure 6. Figure 5(a) is the NQI of the highest pollutant concentration at the ebb of Shenzhen Bay in the rainy season. It can be seen from the figure that the NQI of the Shenzhen Bay during the ebb in the rainy season is greater than 3, according to the NQI evaluation criterion, more than 3 are eutrophication areas, so eutrophication occurs in almost all areas. Figure 5(b) is the NQI of the highest pollutant concentration at the high tide of the Shenzhen Bay in the rainy season. It can be seen from the figure that the NQI of the Shenzhen Bay during the high tide in the rainy season is greater than 3, according to the NQI index.
evaluation criterion, more than 3 are eutrophication areas, so eutrophication occurs in almost all areas. Compared with the eutrophication of ebb and high tide, the maximum NQI at high tide is 23, while the maximum NQI at ebb is 22, so the eutrophication degree of Shenzhen Bay is obviously worse than that at ebb during the high tide in the rainy season.

Figure 6(a) is the NQI of the highest pollutant concentration at the ebb of Shenzhen Bay in the dry season. It can be seen from the figure that the NQI of the Shenzhen Bay during the ebb in the dry season is greater than 3, according to the NQI evaluation criterion, more than 3 are eutrophication areas, so all areas are at the eutrophication level. Figure 6(b) is the NQI of the highest pollutant concentration at the high tide of Shenzhen Bay in the dry season. It can be seen from the figure that the NQI of the Shenzhen Bay during the high tide in the dry season is greater than 3, according to the NQI evaluation criterion, more than 3 are eutrophication areas, so there are eutrophication problems in all areas. Compared with the eutrophication of ebb and high tide, the maximum NQI at the ebb is 21, while the maximum NQI at the high tide is 22, so the eutrophication degree of Shenzhen Bay is obviously worse than that at ebb during the high tide in the dry season.

Figure 5. Eutrophication map of the highest concentration of pollutants in the rainy season of Shenzhen Bay.

Figure 6. Eutrophication map of the highest concentration of pollutants in the dry season of Shenzhen Bay.
4. Conclusions
Using the monitoring data and mathematical model, the eutrophication characteristics of Shenzhen Bay were analyzed by using the nutritional status quality index method. The analysis results are as follows:

(1) Using the single indicator to analyze the eutrophication of the Shenzhen Bay, the proportion of eutrophication with DIN as indicator is 94.28%, and the proportion of eutrophication with DIP as indicator is 91.43%. It is the main factor for the eutrophication of the Shenzhen Bay. Therefore, controlling the emission of nitrogen and phosphorus nutrients from the pollution sources in the Bay is the key to alleviating the problem of eutrophication in the Shenzhen Bay. The main sources of nitrogen and phosphorus nutrients are domestic sewage and agricultural sewage. Therefore, the supervision and management of domestic sewage and agricultural sewage should be strengthened to control nitrogen and phosphorus pollution.

(2) Regardless of whether it is dry season or rainy season, the inner Bay pollution is more serious than the outer bay of the Shenzhen Bay. Shenzhen River and Dasha River contribute a lot to the pollution of Shenzhen Bay. The contribution of DIP in Dasha River is prominent. DIN and DIP has exceeded the water quality standards of Shenzhen Bay. The concentration of DIP and Chl.a in Shenzhen Bay during the rainy season was higher than that in the dry season.

(3) Regardless of whether it is in the dry season or the rainy season, the eutrophication status of all areas of Shenzhen Bay and the eutrophication of the Shenzhen Bay in the rainy season is worse than in the dry season. Therefore, it is necessary to strengthen the control of pollution sources entering the bay during the rainy season.

(4) The maximum NQI of the Shenzhen Bay during the high tide in the dry season is 22, the maximum NQI of the rainy season is 23; the maximum NQI of the Shenzhen Bay during the ebb in the dry season is 21, and the maximum NQI of the rainy season is 22. It can be seen that in the dry season or the rainy season, the eutrophication of the Shenzhen Bay during the high tide is greater than that at the ebb.

(5) The eutrophication degree of the inner bay of the Shenzhen Bay is more serious than that of the outer bay. Regardless of the dry season or the rainy season, the NQI of the outer bay is basically around 5, while the NQI of the inner bay is basically larger than the outer bay. This is because the tributaries of the Shenzhen bay are basically in the inner bay. However, the hydrodynamic conditions of the Inner Bay are poor, and the ability of pollutants to diffuse is weak, resulting in a large amount of pollutants hoarding in the bay. Therefore, the governance of the tributaries of the Shenzhen Bay can not be ignored.

(6) The problem of eutrophication in Shenzhen Bay has been particularly prominent in recent years, and Shenzhen Bay is an important ecological wetland system, which is a friendship ties between Shenzhen and Hong Kong. Therefore, it is particularly important to control the pollution problem in Shenzhen Bay.

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