Spatiotemporal Changes of Nutrients and Eutrophication in a Semi-Enclosed Bay, Southeast China

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Abstract: According to the data of water quality monitoring in Xiamen Bay in May and October 2010, we analysed the spatiotemporal variation trend of nutrients and eutrophication, discussed the main potential sources. The results show that Western Sea, Jiulong River Estuary and Tongan Bay were the high value areas for chemical oxygen demand (COD), dissolved inorganic nitrogen (DIN) and active phosphate (PO_4-P). The eutrophication level decreased from Western Sea and Jiulong Estuary to Southeast Sea and Dadeng Sea. The eutrophication in May was lower than that in October. The proportion of ammonia nitrogen was higher in Western Sea and Tongan Bay, while in the Jiulong Estuary, Southeast Sea and Dadeng Seas, the proportion of nitrate nitrogen was higher. Poor hydrodynamic forces, land-based pollution and short-term strong rainfall might contribute to eutrophication. Correlation analysis showed that the main sources of pollution were land-based sources. The origins of COD, NO_2-N and NH_3-N were similar. Changes in DO might be related to the N/P ratio. The research results could provide technical support for marine environmental protection in Xiamen Bay.

1 INTRODUCTION

Eutrophication is caused by structural changes and functional degradation of the original ecosystem due to the increase of nutrients in the ocean (Capriulo et al., 2002). With the development of economy and population increase in coastal areas, more and more industrial wastewater and domestic sewage are discharged into coastal waters, resulting in the increase of nutrient content and eutrophication, which can induce red tide and other ecological disasters (Zhang et al., 2007;Zhang et al., 2009), causing disastrous consequences for coastal marine ecosystems. To grasp the content, distribution of nutrients and eutrophication in coastal waters is very important for marine environment protection.

In the 1980s, Chinese scholars have begun to study the problem of eutrophication in the gulf (Zou et al., 1983). The eutrophication research has focused on eutrophication assessment and trends (Guo et al., 1998; Lin and Zhang, 2008; Yuan et al., 2016). However, few studies analyzed the causes of eutrophication from the perspective o the relationship between water quality parameters.

Xiamen Bay (XMB) is a semi-enclosed bay located in Southeast China. With the rapid economic development around Xiamen Bay, a large number of nutrients discharge from the sewage outfall and rivers into the sea. Aquaculture in XMB also produces some nutrients. Many sources of pollution, high-nutrient water bodies, and poor water exchange conditions make eutrophication of XMB very serious (Lin and Zhang, 2008), which can adversely affect marine ecosystem. Therefore, it is very important to control the water pollution and protect the environment of XMB. Based on the water monitoring data of XMB in May and October 2010 (the latest and comprehensive data we can obtain), this study discussed the spatiotemporal trend and cause of nutrients and eutrophication in order to provide technical support for the ecological protection and restoration in XMB.

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2 MATERIALS AND METHODS

2.1 Study Area

XMB, which is a semi-enclosed bay located in Southeast China, includes Tongan Bay, Dadeng Sea, Southeast Sea, Jiulong Estuary and Western Sea (Figure 1). Around XMB, there are some cities such as Xiamen and Longhai. Developed industries and agriculture were along the coastal areas. A large amount of industrial and agricultural wastewaters are received by the sea. After land-based pollutants entered the sea, XMB faces severe environmental crisis. Due to the closed nature and the poor hydrodynamic conditions, land-based pollution had a great impact on the environmental quality and ecosystem of the XMB.

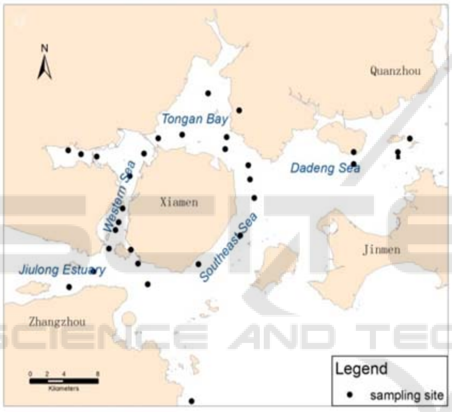

Figure 1: The map of study area with sampling sites.

2.2 Water Quality Monitoring

In order to explore the spatiotemporal variation of water quality in XMB, a survey of seawater quality at 30 stations was carried out in May and October 2010 (Figure 1). The monitoring was based on some survey criteria (State Oceanic Administration, 1998). The water quality parameters surveyed included salinity, dissolved oxygen (DO), COD, nitrate nitrogen (NO_3-N), nitrite nitrogen (NO_2-N), ammonia (NH_3-N), total nitrogen (TN), PO_4-P and total phosphate (TP) (Table 1). The average and median value of Salinity, COD, NH_3-N, DIN, PO_4-P and TP in October were higher than that in May. The average and median value of DO, NO_2-N in October were lower than that in May. The average value of NH_3-N in October was higher than that in May, while the median value in October was lower than that in May.

Table 1: Statistical descriptives of water quality parameters.

Indicators	Average±SD		Median	
	May	October	May	October
Salinity	25.53±4.84	25.91±7.95	26.24	27.91
DO	7.99±1.29	6.04±0.59	7.88	6.02
COD	1.03±1.97	1.30±1.22	0.88	0.92
NO_3-N	0.05±0.05	0.67±0.41	0.04	0.51
NO_2-N	0.71±0.37	0.12±0.10	0.55	0.10
NH_3-N	0.19±0.24	0.24±0.34	0.17	0.12
DIN	0.95±0.49	1.03±0.60	0.94	0.97
TN	1.12±0.65	1.25±0.74	1.03	1.07
PO_4-P	0.04±0.03	0.06±0.03	0.03	0.06
TP	0.06±0.04	0.10±0.04	0.05	0.09

DIN is the sum of NO_3-N, NO_2-N and NH_3-N

2.3 Comprehensive Evaluation Method for Eutrophication

Evaluation methods of seawater eutrophication include single factor evaluation method, comprehensive evaluation method and fuzzy mathematics evaluation method. Since eutrophication is a complex process and the cause of eutrophication is multidimensional, it is impossible to comprehensively evaluate eutrophication with a single factor. Therefore, the comprehensive index method has been widely applied (Zou et al., 1983; Guo et al., 1998; Lin and Zhang, 2008). In this study, comprehensive evaluation method for eutrophication was also used for XMB waters eutrophication evaluation. The formula was as follows:

$$E = \frac{COD \times DIN \times PO_4P}{4500} \times 10^6 \quad (1)$$

Where E is eutrophication level; The COD, DIN and PO_4-P represent the concentration of COD, DIN and PO_4-P (mg / L); The DIN concentration equals the sum of NO_3-N, NO_2-N and NH_3-N concentrations; When tE > 1, the water is considered as eutrophic.

3 RESULT AND DISCUSSION

3.1 Spatiotemporal Changes of Nutrients

Since DIN and PO_4-P are the main factors causing eutrophication (1, 4) and COD contributes greatly to eutrophication (Cai, 1998), we mainly analyzed the spatiotemporal changes of COD, DIN and PO_4-P in XMB.

The spatial characteristics of COD, DIN and PO_4-P were different. In both sampling periods, the high value areas of COD were mainly distributed at the waters of the Western Sea. While those of DIN were at the Western Sea and at the Jiulong River Estuary. The high value areas of PO_4-P in May were mainly found at the Western Sea and the Tongan Bay, while in October were found at the Western Sea and at the Jiulong Estuary (Figure 2).

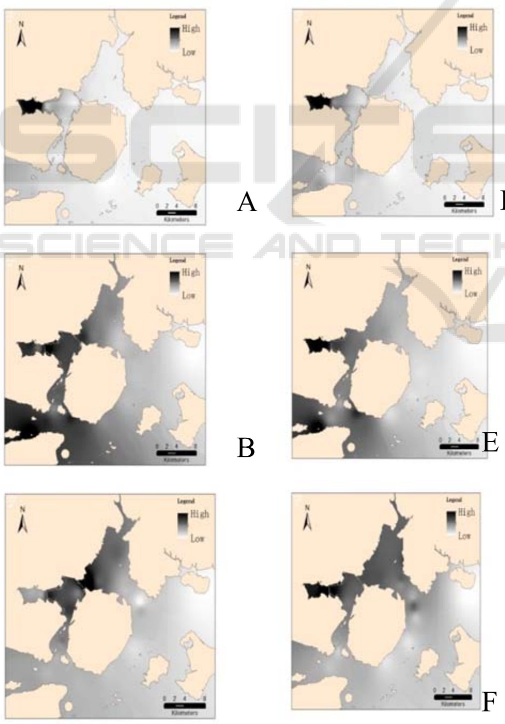

Figure 2: The spatiotemporal distribution of COD, DIN and PO4-P; A, B, C and D, E, F represent COD, DIN, PO4-P for May and October 2010, respectively.

The average of COD, DIN and PO_4-P concentration in October was higher than that in May (Table 1), which might be related to high intensity rainfall in October (Figure 2) (Xiamen Statistics Office, 2011).

3.2 Spatiotemporal Changes of Eutrophication

The spatial trends of eutrophication in May and October 2010 were similar. The high value areas of eutrophication were mainly distributed at the Western Sea and at the Jiulong Estuary. Furthermore, the eutrophication at the Southeast and Dadeng Sea was low (Figure 3). The average and median values of eutrophication index in May were lower than those in October (Table 2).

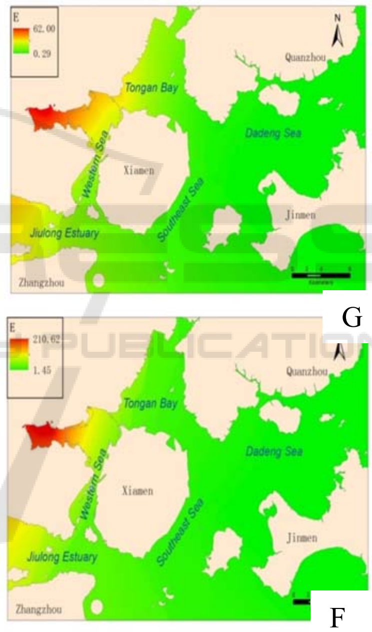

Figure 3: The spatiotemporal distribution of eutrophication.(G and H represent eutrophication for May and October 2010, respectively.)

Table 2: Statistical descriptives of eutrophication index.

tatistics	May	October
Minimum	0.09	0.82
Maximum	87.66	380.14
Average	15.07	38.48
Median	7.28	13.41
Standard Deviation	22.12	83.40

3.3 Nutrient Structure Analysis

In May and October 2010, the spatial distribution of inorganic nitrogen composition at the Xiamen Bay was basically identical. At the Western Sea and Tongan Bay, the proportion of ammonia nitrogen was higher, while at the Jiulong Estuary, Southeast and Dadeng Seas, the proportion of nitrate nitrogen was higher (Figure 4).

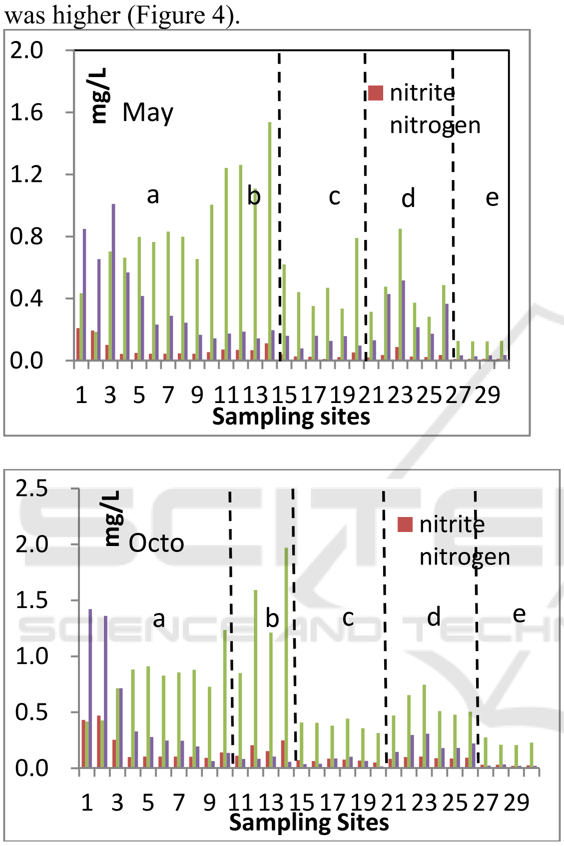

Figure 4: The composition of inorganic nitrogen at Xiamen Bay (A, b, c, d and e represent Western Sea, Jiulong Estuary, Southeast Sea, Tongan Bay and Dadeng Sea, respectively.)

The average of nitrate nitrogen concentration in October was higher than that in May. However, the nitrite nitrogen concentration in October was lower than that in May. The average of ammonia concentration in October is slightly higher than that in May, but the median value is lower than that in May (Table 1).

The conversion process of inorganic nitrogen in water is as follows:

$$NH_3 \Leftrightarrow NH_4OH \Leftrightarrow NO_2 - N \Leftrightarrow NO_3 - N \qquad (2)$$

The DIN in water should be dominated by NO_3-N when the thermodynamic equilibrium is sufficient under the condition of sufficient oxygen (Lin and Zhang, 2008). The proportion of ammonia nitrogen and nitrite nitrogen in Western Sea and Tongan Bay was high, indicating that the water had not reached thermodynamic equilibrium, which might be related to human activities. The Western Sea and Tongan Bay were within the bay, owned insufficient hydrodynamic force and greatly affected by land-based pollution (Pan et al., 2011). Higher nitrous oxide concentration in October suggests that the seawater in October did not reach the thermodynamic equilibrium, which may be related to the rapid increase of pollutants caused by short-term strong rainfall (Figure 5).

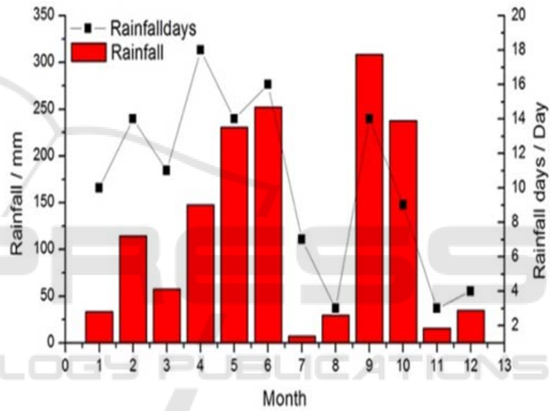

Figure 5: The rainfall and rainfall days at Xiamen in 2010.

3.4 Correlation between Water Quality Indicators

In both sampling periods, COD and DIN were negatively correlated with salinity (Table 3), which indicated that the main sources were land-based source. COD was positively correlated with NO_2-N and NH_3-N, indicating that their origin were similar, which was consistent with the previous analysis (Pan et al., 2011; Chen and Chau, 2016; Olyaie et al., 2015).

Table 3: Correlation analysis of water quality parameters.

Month	Parameters	*S*	DO	COD	PO_4-P	NO_2-N	NO_3-N	NH_3-N	DIN
May	*S*			-0.664		-0.889	-0.664	-0.530	-0.855
	DO				-0.562				
	COD					0.898		0.570	
	PO_4-P							0.628	0.600
	NO_2-N							0.716	0.661
	NO_3-N								0.824
	NH_3-N								0.623
	DIN								
October	*S*			-0.723	-0.512	-0.797	-0.464	-0.621	-0.808
	DO						-0.687		
	COD				0.634	0.970		0.926	0.774
	PO_4-P					0.687		0.770	0.625
	NO_2-N							0.884	0.877
	NO_3-N								0.686
	NH_3-N								0.667
	DIN								

In both sampling periods, the relationship between oxygen and nutrients was different: DO was negatively correlated with PO_4-P in May 2010, while negatively correlated with NO_3-N in October 2010. The above relationship might be related to the N/P ratio (atomic ratio between TN and TP): the average N/P ratio in May was 20.77, which was higher than Redfield ratio (the N/P ratio is about 16:1). The increase of phosphorus could promote the growth of phytoplankton and consuming oxygen in water. The average N/P ratio in October was 13.51, which was lower than the Redfield ratio. The increase in nitrogen could promote the growth of phytoplankton and consuming oxygen in the water (Redfield et al., 1963).

4 CONCLUSIONS

The spatiotemporal characteristics of COD, DIN and PO_4-P were different. In May and October 2010, COD decreased from Western to Southeast Sea, while DIN decreased from Western Sea and Jiulong River Estuary to Southeast Sea. The high value areas of PO_4-P in May were mainly distributed at the Western Sea and Tongan Bay, while in October were mainly distributed at the Western Sea and Jiulong Estuary. The average of COD, DIN and PO_4-P concentration in October was higher than that in May. The spatial trends of eutrophication in May and October 2010 were similar. The eutrophication level in May and October 2010 decreased from Western Sea and Jiulong Estuary to Southeast and Dadeng Sea. The eutrophication in May was lower than that in October.

In May and October 2010, the proportion of ammonia nitrogen was higher at the Western Sea and Tongan Bay, while at the Jiulong Estuary, Southeast and Dadeng Sea, the proportion of nitrate nitrogen was higher. Poor hydrodynamic force, land-based pollution and short-term strong rainfall might contribute to eutrophication.

Correlation analysis showed that the main sources of pollution were land-based sources. The origins of COD, NO_2-N and NH_3-N were similar. Changes in DO might be related to the N/P ratio.

In order to better understand the spatiotemporal changes of nutrients and eutrophication in XMB, a better sampling strategy is necessary. Numerical models can be used to determine if monitoring stations should be added for more targeted investigation. Furthermore, it might be necessary to increase the time frequency of sampling in different seasons

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