The characteristics of nutrients and eutrophication in the Pearl River estuary, South China

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Abstract

In the spring of 1998, 24-h time series and synchronization of vertical profiles of NO₃–N, NO₂–N, NH₃–N, PO₄–P, chlorophyll a, suspended substance, salinity, temperature and other chemical parameters were taken at 10 stations in the Pearl River estuary in order to analyze the status and characteristics of nutrients and eutrophication. The results indicated that dissolved inorganic nitrogen (DIN) mainly came from the four river channels in the main estuary, and NO₃–N was the main form of DIN in most area. The concentration of DIN was generally above 0.30 mg l⁻¹ in the estuary, and more than 0.50 mg l⁻¹ in most part. Phosphate from four river channels was not the main sources, but land-based sources from the area near Shenzhen Bay or along the estuary were obvious, and other land-based sources outside the estuary brought by coastal current and flood tide current were also the main contributions. The concentration of phosphate was generally about 0.015 mg l⁻¹ except the area near Shenzhen Bay. The ratio of N:P was generally high, and it was higher in the north than in the south. The highest ratio was higher than 300, and the lowest one was over 30. The concentration of chlorophyll a was about 0.8–7.8 mg m⁻³, and turbidity and phosphate may be the main two limiting factors for algal bloom in the estuary. The concentration of nutrients decreased slightly in the past decade, but still stayed at a high level. The nutrients mainly came from domestic sewage, industrial wastewater, agriculture fertilizer and marine culture in the Pearl River estuary.

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1. Introduction

As we know, human activities are changing land use, habitats, the chemistry of Earth’s atmosphere and water, rate and balance of biogeochemical processes, and diversity of life on the planet (Vitousek et al., 1997). One prominent mode of human disturbance has resulted from activities that mobilize the nutrient elements nitrogen and phosphorus through land clearing, production and applications of fertilizer, discharge of human waste, animal production, as a result of these activities, the mobilization of N and P has accelerated the fluxes of these elements to coastal waters (Cloern, 2001). Coastal eutrophication is a recently recognized phenomenon, and scientific investigation of this human disturbance has progressed for a few decades. The recent research results indicated that the eutrophication had influence on transportation and transformation of contaminants in aquatic environment, which including potential key factors, such as biomass’s dissolving functions, staying period in waters, sediment embedding, and structures of food net (Skei et al., 2000; Gunnarsson et al., 2000). The scientific community has faced a challenge to find innovative ways to synthesize information from multiple sources, and then use syntheses to guide action plan (Cloern, 2001), which should including the development of new tools for building restoration strategies.

The concentrations of DIN and phosphate in the coastal water of China were all-pervading high, as a result, eutrophication was very serious, which was the most outstanding environmental problem (Zhanget al., 1999; Harrison et al., 1990). It was generally regarded that eutrophication had a close relation to the occurrence of harmful red tide in these areas (Tang, 1997; Zou et al., 1983; Yin et al., 2000).

The Pearl River estuary is located in southern China (Fig. 1), and it is the area of Pearl River flowing into the South China Sea. The Pearl River estuary supported

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large population of marine organism and contributed significantly to the fisheries in South China Sea, and it is also the main receiving water of land-based pollutants of South China Sea. In the last decades, massive economic growth and urban development in the region has led to excessive release of waste into the estuarine (Tang, 1997; Wen et al., 1995). The environmental quality of the Pearl River estuary is vital for future sustainable development in the region. Therefore, detailed study is required to understand the environmental change, to find appropriate ways for sensible and responsible development and to maintain a sustainable environment. Nutrients enrichment and eutrophication are also the key environmental problems (Wen, 1991; Qiu, 1992; Tan et al., 1993; Zhang et al., 1999; Yin et al., 2000), which often led to red tide in this area (Ho and Kodgkiss, 1995; Liang and Qian, 1999).

The Pearl River estuary is a complicated system with respect to geography and hydrodynamics. The coastal waters in the estuary are profoundly influenced by three water regimes: the Pearl River discharge, oceanic water from the South China Sea and coastal water from South China Coastal Current (Ying, 1994; Zhao, 1990). There are many different sources of nutrients in the estuary regions, mainly including runoff of river, estuarine land-based discharge, coastal land-based pollutants coming with South China Coastal Current and atmospheric deposition. Therefore, the dynamical variation and biogeochemical processes of nutrients in the estuary are very complicate. In order to find a way to solve the environmental problems of nutrient enrichment and eutrophication, and develop new tools for building eco-restoration strategies in Pearl River estuary, it is very necessary to understand the processes of spatial–temporal variation of nutrients and sources. However there was few reports discussing on the characteristics of spatial–temporal variation of nutrients and sources in this area. People usually analyzed the data obtained from provincial sea area in asynchronous and one time observation (e.g. Wen, 1991; Qiu, 1992; Tan et al., 1993; Yin et al., 2000). There was few report based on a continuous and synchronous observation data in the whole estuary area, this may be because of very difficult field works by using this research method.

Based on the continuous and synchronous observation data in 1998 and historical data, the objectives of the present study were (1) to assess the status of nutrients enrichment and eutrophication, (2) to study the processes of spatial–temporal of nutrients variation, and (3) to find the main sources of nutrients. The results will help to understand the problems of nutrients enrichment and eutrophication, to find suitable treatment techniques for polluted materials and propose measure for strategic ecological restoration in the Pearl River delta region in the new century.

2. Methodology

2.1. Study area

The Pearl River is the second largest river in China and it is the 13th largest river in the world by discharge volume. The yearly average river discharge is 10 524 m³ s⁻¹, with 80% occurring in the wet season (Zhao, 1990). It stretches for 2214 km and 452 000 km², and flows into the Pearl River estuary though eight majors channels into South China Sea, four (Humen, Jiaomen, Hongqimen and Hengmen) of which enter the Lingdingyang, a main subestuary of Pearl River estuary (Fig. 1). The Pearl River estuary is located in a subtropical area, with annual rainfall from 1600 to 2300 mm. The main Pearl River estuary (also called Lingdingyang) is a N–S bell-shape area with a N–S distance about 49 km and E–W width varying from 4 to 48 km. The estuarine region in this study (i.e. Lingdingyang) covers an area of 2100 km². The average tidal range is 1–2 m, and tidal current is 1.0–2.0 ms⁻¹. The water depth of Lingdingyang varies from 5 m to more than 20 m. In the wet seasons the river effluents cover the entire region with a salinity of <20–25 at the surface, while in dry seasons seawater may occupy the whole estuary with salt wedge entering the mouth (Ying, 1994). The interaction between fresh water and marine water is very strong. The main wind directions in the area are from south-east and south, particularly in the summer. The delta region of Pearl River is one of the most densely populated areas in China with several economic and industrial centers, like Guangzhou, Hong Kong, Shenzhen, Zhuhai and Macau around the Lingdingyang. In the past two decades, the Pearl River estuary has received a high loading of anthropogenic nutrients from increased activities in agriculture, sewage and marine fish farming due to the population increase and economic development in southern China and Pearl River delta.

2.2. Field sampling

In the present study, 10 anchor stations (Fig. 1) were distributed in main Pearl River estuary for synchronous sampling in the spring of 1998. A time series of temperature, salinity, pH, NH₃–N, NO₂–N, NO₃–N, PO₄–P, SiO₄–Si, DO, chlorophyll a and suspended substance (SS) samples were taken for eight times in a tidal period (about 24 h, the time interval of sampling was 3 h) at surface layer (1 m under water surface), middle layer (middle of water depth) and bottom layer (1 m above sea bottom). Water samples were collection by 5 l Niskien bottles attached to a nylon cable at various depths. After collection, the water samples were filtered immediately trough pre-cleaned 0.45 μm pore-size cellulose filters for
nutrients. The samples were preserved deep frozen in dark before analysis.

2.3. Analysis methods

Samples analyses were undertaken either on broad or later in laboratory depending on the field work condition and the necessity of samples, with a brief summary: (1) Temperature, salinity and depth were measured in situ by CTD, DO was also measured situ by YSI. (2) \( \text{NH}_3-N, \text{NO}_3-N, \text{NO}_2-N, \text{PO}_4-P \) and \( \text{SiO}_4-Si \) were determined by colorimetric methods with the precision reported by elsewhere (Zhang et al., 1997). (3) Chlorophyll \( a \) analysis was measured on particles trapped by Whatman GF/F filters with fluorescence method, the precision was estimated to c. 5–10% (Parsons et al., 1984). (4) Other parameters were measured by the methods according to the specification of oceanographic survey (SOA, 1991). All apparatus and laboratory ware for sample collection and analyses were carefully pre-cleaned before use and care was taken in both field observations and laboratory analyses to avoid contamination. High quality reagents were selected and reagents were purified to reduce blank if necessary.

3. Results and discussion

3.1. Variation characteristics of dissolved inorganic nitrogen

Fig. 2(a) shows the concentration variation of DIN from north to south. It can be seen that in spite of flood tide or ebb tide, the concentration of DIN in north sea area was generally higher than that in the south part, the situation was more evident in the course of ebb tide. The results indicated that DIN mainly came from the runoff of Pearl River. The concentration of DIN was general over 0.30 mg\text{L}^{-1}. In most area, the concentration was over 0.50 mg\text{L}^{-1}. The highest concentration was more than 1.6 mg\text{L}^{-1}, which was just as the same as that in Baixada Santista estuarine system of Brazil (Braga et al., 2000), but lower than in Girode estuary of France (Irigoien and Castel, 1997). It can also be seen that the concentrations of DIN in ebb tide and flood tide were very different, the variation range of concentration can reach up to two times in some area. So in those estuarine areas affected by tide seriously, the analysis results from one time sampling was always short of representative.
Fig. 2(b) and (c) show the variation of DIN concentrations in vertical direction in ebb tide and flood tide respectively. The results indicated that both in the north area and south area of the estuary, the variation was not apparent in vertical direction, while the concentration in surface layer was higher than that in bottom layer in the middle area. The reason is that the middle area is influenced by the invasion of the briny wedge, the fresh-waters of runoff mainly centralize on the surface, and the seawaters distribute in the bottom (Ying, 1994). While the water system in south and north area is well mixing in vertical direction. This also indicated that the runoff of Pearl River was chief source of the DIN from another point of views.

Fig. 2(d) and (e) indicate the form variation of DIN in ebb tide and flood tide respectively. It can be seen that NO$_3$–N was the main form in most sea area except station 6 both in ebb tide and flood tide, and the concentration of NO$_3$–N was generally over 60% of DIN, it was even over 90% in some stations. The second one was NH$_3$–N, and the third one was NO$_2$–N (below 10%). However, in the area near station 6, NH$_3$–N was the main form of DIN, and NO$_3$–N was the next one. This indicated that this area was mainly influenced by the domestic wastewater (Wen, 1991). It may be related to the influence of domestic wastewater in Shenzhen (including the submarine wastewater discharge project in the west of Shenzhen) and Hong Kong near this area (Wen et al., 1995).

3.2. Variation characteristics of phosphate

The spatial–temporal variation patterns of phosphate in the flood and ebb tide are shown in Fig. 3(a). The results indicated that the phosphate concentration in the seawater near the area of Shenzhen Bay was the highest, which was over 0.030 mg l$^{-1}$, this implicated that land-based pollutants near Shenzhen Bay contributed to phosphate greatly. Phosphate concentration in the other area was 0.010–0.015 mg l$^{-1}$ in ebb tide, 0.007–0.017 mg l$^{-1}$ in flood tide. The concentration of phosphate was general higher than that in Baixada Santista estuarine system of Brazil (Braga et al., 2000) and Girole estuary in France (Iriogoin and Castel, 1997). What should be emphasized was that concentration of phosphate in south seaward area was higher obviously than north riverward area in flood tide, while the difference of concentration in north part and south part was not obvious in ebb tide (except the middle area near Shenzhen Bay). This result implicated that the contribution of land-based phosphate along Pearl River estuary was great, and also the phosphate discharged from the area outside the Lingdingyang. It can also be seen that the variation of phosphate concentration in ebb tide and flood tide was obvious, but the range of variation was smaller than that of DIN, this maybe relate to decentralization of sources of phosphate.

Fig. 3(b) and (c) show the variation of phosphate concentrations in vertical direction in ebb tide and flood tide respectively. The results indicated that vertical variation of phosphate concentration was not obvious. This proved further that contribution of phosphate from river runoff was not large to the sea area of Pearl River estuary.
3.3. Variation characteristics of N/P ratio

In sea area of eutrophication, N and P are often supplied plentifully. N:P ratio was often regarded as dominant factor, and when it was about 16 in outer sea, and 5–15 in coastal area, phytoplankton could attain growth climax (Ho and Kodgkiss, 1995). N:P ratios in ebb tide and flood tide in each stations are shown in Fig. 3(d). The results indicated that N:P ratio was all higher than 100 in north sea area, the highest was over 300; about 40–100 in middle sea area; and 30–40 in south sea area. It can be concluded that DIN in the Pearl River estuary was surplus comparatively, and phosphate may be the limiting factor. Such similar conclusion can be seen in other research results in the Pearl River estuary (Zhang et al., 1999; Yin et al., 2000).

3.4. Variation characteristics of chlorophyll a

The spatial–temporal variation patterns of chlorophyll a in the flood and ebb tide are shown in Fig. 4(a). It can be seen that phosphate concentration in the estuary was 0.8–5.6 mg m$^{-3}$ in ebb tide, and 0.8–7.8 mg m$^{-3}$ in flood tide. Nutrients in north part of the estuary were rich, but the concentration of chlorophyll a was low. This was because of radiation reduced by SS (Fig. 4(b)) limiting photosynthesis (Zhang et al., 1999). There were two relatively high concentration of chlorophyll a in the estuary, one was near Shenzhen Bay, and the other was in the southwest part of Hong Kong. As the main channels for flood tide current (from east side and west side of Lautau Island respectively) (Ying, 1994), the concentrations of SS in the two areas were relatively low, which was useful for the photosynthesis of phytoplankton. In fact, the two sites were the main areas where red tide occurred (Liang and Qian, 1999).

3.5. Input amounts of DIN and phosphate from the runoff of four river channels

The runoff of the main Pearl River estuary mainly comes from four river channels: Humen, Jiaomen, Hongqimen and Hengmen. According to the results of monitoring and analysis in 1996 (Li, 2000), Table 1 shows the specific input amounts of DIN and phosphate from the four river channels. Thus it can be seen that...
DIN and phosphate transported by the runoff of Pearl River mainly came from Humen. The amount of DIN from runoff was very large, while the mount of phosphate was small comparatively.

3.6. Sources for nutrients

The nutrients in the Pearl River estuary mainly came from domestic sewage, industrial wastewater, agriculture fertilizer and marine culture. The Pearl River delta is densely populated with a population density of more than $1.0 \times 10^9$ km$^{-2}$, there are a lot of small towns locating around the big or middle cities, and all kinds of industries as well. In the delta (not including Hong Kong and Macau), domestic sewage amounted to more than $6.0 \times 10^8$ m$^3$/a and, industrial wastewater was about $9.0 \times 10^8$ m$^3$/a. More than 70% of domestic wastewater in the Pearl River delta was not treated, and discharged into river or coastal waters directly (Wen et al., 1999). The industrial wastewater discharged from Macau amounted to $0.45 \times 10^8$ m$^3$ per year and domestic sewage was about $0.46 \times 10^8$ m$^3$ per year (Wen et al., 1999). All the wastewater was been discharged directly into the Pearl River estuary from more than 10 discharge openings without any disposal. In Hong Kong, there was about $7.8 \times 10^8$ m$^3$ of wastewater per year (Wen et al., 1999). Of the total volume, 10% was treated by biochemical treatment method, 40% was disposed incompletely, and the remaining 50% was discharged without any treatment, of which, 80% was domestic sewage, and was discharged into coastal water directly.

In the middle and low reaches of Pear River, fertilizer was widely used in agriculture, and this was also a main source of nutrients for the estuary. This kind of non-point pollution of surface water was also one of the main sources of nutrients in other countries (Carpenter et al., 1998). There was a lot marine culture in the Pearl River estuary. The surplus feedstuff and the excretion of fish also contributed much to nutrients (Holby, 1993).

3.7. Yearly variation trend of nutrients

Based on data from governmental gazette, unpublished survey results and published literatures (e.g. Wen et al., 1995; Li and Chen, 1998; Zhang et al., 1999; Li, 2000; Lin and Han, 2001), Fig. 5(a) and (b) show the yearly variation trend of DIN and phosphate in the estuary in the recent decade. It can be seen that both DIN and phosphate had a decreasing trend, although there was some fluctuating, and decreasing trend of phosphate was more obvious. However, the concentrations of nutrients still stayed at a high level.

4. Summary

In the past two decades, the Pearl River estuary has received a high loading of nutrients. The results in this study indicated that DIN in the Pearl River estuary was mainly from the runoff of four river channels, at the same time the land-based pollutants near Shenzhen Bay also contributed to it markedly. The concentration of DIN exhibited a tendency of reducing from north to south, and the variation was great during one tidal period. The main form of DIN in most sea area was NO$^3$–N, but was NH$_3$–N in the area near Shenzhen Bay. The concentration of DIN in the Pearl River estuary was generally over 0.30 mg l$^{-1}$, while it was over 0.50 mg l$^{-1}$ in most area.

The contribution of phosphate from runoff was not evident, but land-based sources from the area near Shenzhen Bay or along the estuary were obvious, and other land-based sources outside the estuary brought by coast current and flood tide current were also the main contributions. The concentration of phosphate varied less evidently in one tidal period. The concentration of phosphate was about 0.015 mg l$^{-1}$ in most sea area except the area near Shenzhen Bay, where it exceeded 0.030 mg l$^{-1}$.
The N:P ratios in this estuary was comparatively high, and it was higher in north area than in south area. Its highest value was over 300, and the lowest value was over 30. The concentration of chlorophyll a was about 0.8–7.8 mg m\(^{-3}\). Turbidity and phosphate may be the main two limiting factors for algal bloom in the estuary.

The concentrations of DIN and phosphate have a decreasing trend in the recent decade, although there was some fluctuating. The decreasing trend of phosphate was more obvious. However, the concentrations of nutrients still stayed at a high level.

The nutrients mainly came from domestic sewage industrial wastewater, agriculture fertilizer and marine culture in the Pearl River estuary.

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References


