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WATER QUALITY AND SEDIMENT QUALITY OF WATERS NEAR SHANGHAI SEWAGE OUTFALLS

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Abstract: This paper analyzes the water quality and sediment quality near Zhuyuan and Bailonggang sewage outfalls and compared them with those of the large waters of Changjiang estuary. The trophic states in the estuarine waters are evaluated by employing different standards. Serious nitrogen and phosphorus pollutions are found in the waters near the outfalls, which are due to large sewage discharges of Shanghai City. Heavy metals and other pollutants are found at low concentrations and cause no serious water and sediment pollution. In the Changjiang estuary, the concentrations of nitrogen, phosphorus, copper, lead and COD are relatively high and are rising year by year. It is concluded that the sewage discharges from Shanghai provides large quantities of nitrogen and phosphorus but little heavy metals to the estuary. The local waters near the outfalls and large waters of Changjiang estuary are in the state of phosphorus-limited potential eutrophication and slightly-phosphorus-limited potential eutrophication. The risk of eutrophication and red tide may be reduced if municipal sewage of Shanghai is denitrogenated and dephosphorized before discharged.

Key words: Changjiang estuary, Sewage discharge, Water quality, Sediment quality, Eutrophication

1. INTRODUCTION

Shanghai, China's largest metropolitan area with a population of about 14 million, is situated at the mouth of the Yangtze River, and bordered with the East China Sea to the east, Hangzhou Bay to the south, and the provinces of Zhejiang and Jiangsu to the west. The good geographic location and natural conditions have provided the city with superiority in its social and economic center and port city of the country. Since the 1980s, great efforts have been devoted to improve the water environment by the provision of proper sewerage treatment and disposal systems. The First Shanghai Sewerage Project (SSPI) was completed in 1993, by which over a million tonnes of wastewater is collected per day in a centralized sewerage system and disposed to the Changjiang Estuary at Zhuyuan through a submerged outfall after preliminary treatment. The second stage of the project (SSPII) added the second outfall at Bailonggang in 2000 to discharge pre-treated sewage into the more stratified downstream reaches of the Changjiang, near the turbidity maximum zone of the estuary (Fig. 1). At present sewage after preliminary treatment is discharged to the Changjiang Estuary from the Zhuyuan and Bailonggang outfalls, at a flow of 1.45 and 0.79 million m^3/d respectively; the corresponding designed capacities are 3.30 and 1.70 million m^3/d. (Liu et al., 2001).

2. FIELD INVESTIGATION AND ANALYSIS OF WATER QUALITY AND SEDIMENT QUALITY IN THE WATERS NEAR THE SEWAGE OUTFALLS IN THE CHANGJIANG ESTUARY

Water samples from 42 stations and sediment samples from 12 stations around Zhuyuan and Bailonggang sewage outfalls in the Changjiang estuary were taken during 6th to 7th September, 2000. Two water samples were taken from each station at 0.5 m and 5 m below the water surface if the water depth is smaller than 10 m. Where the water depth is larger than 10 m, three water samples at 0.5 m, 5 m and 10 m below the water surface were taken from each station. Sediment samples were taken at 12 stations which were around the Zhuyuan and Bailonggang outfalls. Table 1 shows the locations of 12 sediment-sample stations. Sediment samples were taken from a 2 cm thick bed surface layer. All these sediment-sample stations are also the water-sample stations. The water and sediment qualities at these stations are analyzed in this paper.

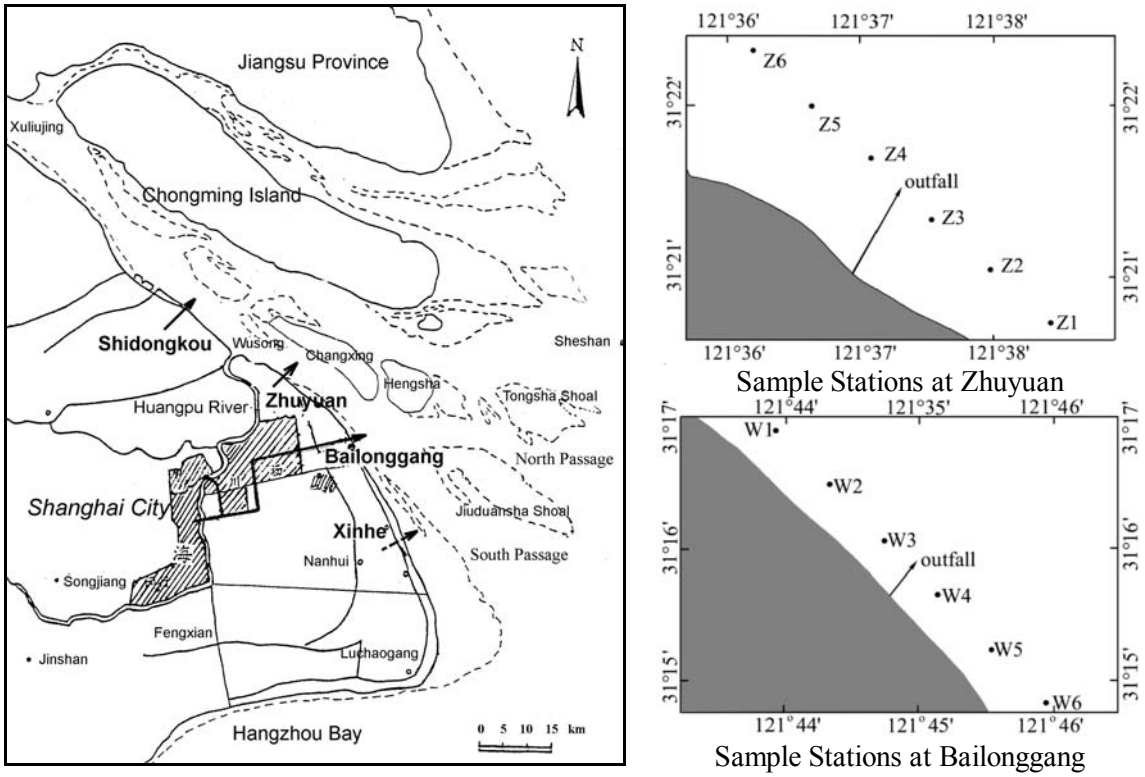

Fig. 1 Map of the Changjiang Estuary showing the location of the sewage outfalls

Table 1 Longitudes and latitudes of sample stations in the waters near Zhuyuan and Bailonggang outfalls

Zhuyuan	Longitudes	Latitudes	Bailong gang	Longitudes	Latitudes
Z1	121° 38′ 25.6″	31° 20′ 44.3″	W1	121° 38′ 25.6″	31° 16′ 54.3″
Z2	121° 37′ 58.6″	31° 21′ 02.4″	W2	121° 38′ 25.6″	31° 16′ 29.3″
Z3	121° 37′ 31.7″	31° 21′ 20.6″	W3	121° 38′ 25.6″	31° 16′ 04.2″
Z4	121° 37′ 04.9″	31° 21′ 41.0″	W4	121° 38′ 25.6″	31° 15′ 39.3″
Z5	121° 36′ 38.3″	31° 21′ 59.8″	W5	121° 38′ 25.6″	31° 15′ 14.1″
Z6	121° 36′ 11.8″	31° 22′ 18.6″	W6	121° 38′ 25.6″	31° 14′ 49.0″

2.1 WATER QUALITY AROUND THE ZHUYUAN AND BAILONGGANG OUTFALLS

For convenience of discussion we use the following abbreviations in the paper: GB3838－2002 for the *Environmental Quality Standard for Surface Water of China* (GB3838－2002); GB3097－1997 for the *Sea Water Quality Standard of China* (GB3097－1997); NOAA for the National Oceanographic and Atmospheric Administration of USA; TRSBI for the *Technical Rules of the Second Baseline Investigation on Chinese Ocean Pollution*; ER-L and ER-L for the values of Effects Range-Low and Effects Range-Median for the concentrations of pollutants in sediment in the guidelines of NOAA; DO for the dissolved Oxygen; and DIN for the dissolved inorganic nitrogen.

Table 2 shows the ranges and average values of water quality indexes of the water samples obtained during flood and ebb tides in each station. The Changjiang estuary, where the fresh water mixes with the seawater, has natures of both the surface waters and sea waters. So the Environmental Quality Standard for Surface Water (GB3838－2002) and the Sea Water Quality Standard (GB3097－1997) of China were employed to evaluate the water quality (Table 3).

Table 2 Water quality index of the waters Near Zhuyuan and Bailonggang outfalls

Index		Flood tide		Ebb tide	
		Zhuyuan	Bailonggang	Zhuyuan	Bailonggang
pH	range	7.95 - 8.24	8.09 - 8.23	8.08 - 8.22	8.05 - 8.21
	Average value	8.10	8.18	8.16	8.14
DO (mg/L)	range	5.26 - 7.16	6.55 - 7.90	6.75 - 8.52	6.16 - 7.18
	Average value	6.39	6.99	7.46	6.77
COD_{Mn} (mg/L)	range	0.59 - 1.26	0.88 - 1.16	0.80 - 1.08	0.88 - 1.36
	Average value	0.94	1.02	0.93	1.12
COD_{Cr} (mg/L)	range	6.61 - 15.7	5.26 - 11.30	2.54 - 9.94	1.96 - 33.40
	Average value	10.84	7.68	5.14	8.04
BOD_5 (mg/L)	range	1.87 - 2.15	1.14 - 2.18	0.69 - 2.30	0.61 - 1.72
	Average value	2.02	1.71	1.21	1.09
PO_4-P (mg/L)	range	0.0272-0.0583	0.0283-0.0653	0.0044-0.0764	0.0336-0.0592
	Average value	0.0449	0.0425	0.0484	0.0478
DIN (mg/L)	range	2.25 - 3.43	1.56 - 2.50	2.01 - 2.52	2.30 - 3.12
	Average value	2.83	2.06	2.30	2.67
Hg (μg/L)	range	* - 0.540	0.001 - 0.104	0.001 - 0.023	0.009 - 0.520
	Average value	0.068	0.021	0.021	0.081
Cu (μg/L)	range	3.45 - 11.85	2.48 - 15.37	2.61 - 5.42	3.20 - 14.22
	Average value	7.36	7.81	3.60	7.18
Cd (μg/L)	range	0.03 - 0.38	* - 0.049	0.042 - 0.081	* - 0.092
	Average value	0.082	0.026	0.058	0.027

Note: * means no-observed

The measured water quality indexes (Table 2) are compared with GB3838－2002 and GB3097－1997 are as following: (1) The values of pH, COD_{Mn} and Cd are all in the range of Class I of GB3838－2002 and Class One of GB3097－1997; The measured concentrations of COD_{Cr} are lower than Class I of GB3838－2002 excepts that of one water sample at Bailonggang is as high as 33.40 mg/L; (2) The average values of DO and Hg are in the range of Class II of GB3838－2002 and Class One of GB3097－1997, and those of BOD_5 and Cu are in the range of Class I and Class Two. The variation of the concentration of Hg is relatively high which ranges from "no-observed" to 0.540 μg/L. Most of the concentrations in

surface water are much higher than those in bottom layer, of which the maximum value exceeds the standards of Class III of GB3838－2002 and Class Four of GB3097－1997; (3) The average concentrations of PO_4-P near two outfalls during ebb and flood tides are around the value of Class Four of GB3097－1997. The concentrations of the dissolved inorganic nitrogen (DIN) far exceed the standard of Class Four of GB3097－1997, the values range from 3 to 6 times of the standard. It indicates that phosphorus and nitrogen are main pollutants in the waters near two outfalls.

Table 3 Values of classes for the standards of surface waters and sea waters

Classes for GB3838－2002 and GB3097－1997		Class I Class One	Class II Class Two	Class III Class Three	Class IV Class Four	Class V
pH	GB3838－2002	6 – 9				
	GB3097－1997	7.8 – 8.5		6.8 – 8.8		
DO > (mg/L)	GB3838－2002	7.5	6	5	3	2
	GB3097－1997	6	5	4	3	
COD_{Mn} ≤ (mg/L)	GB3838－2002	2	4	6	10	15
	GB3097－1997					
COD_{Cr} ≤ (mg/L)	GB3838－2002	15	15	20	30	40
	GB3097－1997	2	3	4	5	
BOD_5 ≤ (mg/L)	GB3838－2002	3	3	4	6	10
	GB3097－1997	1	3	4	5	
PO_4-P ≤ (mg/L)	GB3838－2002					
	GB3097－1997	0.015	0.030	0.030	0.045	
DIN ≤ (mg/L)	GB3838－2002					
	GB3097－1997	0.2	0.3	0.4	0.5	
Hg ≤ (μg/L)	GB3838－2002	0.05	0.05	0.1	1	1
	GB3097－1997	0.05	0.2	0.2	0.5	
Cu ≤ (μg/L)	GB3838－2002	10	1000	1000	1000	1000
	GB3097－1997	5	10	50	50	
Cd ≤ (μg/L)	GB3838－2002	1	5	5	5	10
	GB3097－1997	1	5	10	10	

By the comparisons hereinabove, it can be concluded that the waters near Zhuyuan and Bailonggang outfalls are seriously polluted. The main pollutants are DIN and PO_4-P. Regional heavy Hg pollution appears randomly, and the water pollutions caused by other pollutants are relatively minor.

2.2 SEDIMENT QUALITIES NEAR ZHUYUAN AND BAILONGGANG OUTFALLS

The sediment quality guidelines for waters by the National Oceanographic and Atmospheric Administration (NOAA) of USA (Long and Morgan, 1990) are employed to evaluate degree of sediment contamination by the heavy metals and arsenic, and the standards of specific pollutants in sediment of the *Technical Rules of the Second Baseline Investigation on Chinese Ocean Pollution* (TRSBI) are used to evaluate the sediment contamination by the concentrations of organic material, oil and total phosphorus (TP) (Xu et al. 2000). The values of Effects Range-Low (ER-L)/Effects Range-Median (ER-M) for the concentrations of As, Cu and Cd in sediment are 8.2/70, 34/270 and 1.2/9.6 mg/kg in the guidelines of NOAA. ER-L values indicate the concentrations below which adverse effects to the benthic organisms rarely occur and ER-M values represent the concentrations above which effects frequently

occur. The concentrations of organic material, oil and TP in the standards of TRSBI are 3.0%, 500 mg/kg and 600 mg/kg.

Table 4 Pollutant concentrations in the sediment of Zhuyuan and Bailonggang waters

Station	As (mg/kg)	Cu (mg/kg)	Cd (mg/kg)	Organicmaterial (%)	Oil (mg/kg)	TP (mg/kg)
z1	9.31	18.7	0.040	0.94	76.3	493.09
z2	8.95	18.0	0.031	0.86	52.2	507.37
z3	18.70	22.3	0.086	1.10	60.9	737.17
z4	9.39	23.7	0.119	0.82	61.8	684.85
z5	18.00	37.8	0.181	1.07	99.8	710.3
z6	14.10	25.9	0.167	0.79	96.3	635.67
w1	14.80	28.4	0.172	1.24	101.1	605.1
w2	13.70	17.3	0.083	0.47	89.6	639.5
w3	13.20	28.0	0.090	0.66	62.5	637.88
w4	9.78	30.1	0.109	0.77	64.1	688.72
w5	7.75	25.8	0.156	0.70	70.5	815.97
w6	13.10	12.4	0.103	0.57	106.3	670.43
Average	12.57	24.0	0.111	0.83	78.5	652.17

Table 4 shows the pollutant concentrations in the sediment samples at 12 stations near the outfalls (Monitoring Center of East Sea, 2000; Li, 2001). The concentrations of As in all sediment samples are higher than ER-L value of NOAA guidelines except one sample, but they are much lower than ER-M value. The concentrations of Cu in all sediment samples are much lower than ER-L value except one sample is slightly higher than ER-L. All concentrations of Cd are much lower than the ER-L value. The contents of organic material in all of the sediment samples are lower than the standards of TRSBI, those in Zhuyuan are higher than in Bailonggang. The oil contents in all of the samples are much lower than the value of the standards of TRSBI. The average TP content is higher than the value of the standards of TRSBI. Two samples have the TP contents lower than the value of the standards while the others exceed the standards. The sediment samples in Bailonggang are more polluted by TP than in Zhuyuan.

By these comparisons, it can be concluded that heavy metals, arsenic, organic material and oil in the sediment near the waters of Zhuyuan and Bailonggang outfalls have minor adverse effects to the benthic organisms. The TP contents are relatively high which are due to the municipal sewage discharges from Shanghai.

2.3 COMPARISONS OF WATER QUALITY AND SEDIMENT QUALITY AROUND OUTFALLS WITH THE WHOLE CHANGJIANG ESTUARY

During May and August each year from 1999 to 2001, the Environmental Monitoring Networks for the East China Sea Fishery monitored the water quality and sediment quality at the fixed stations in the Changjiang Estuary ranging 121°00′E – 123°00′E and 30°00′N – 31°30′N (Shen and Yuan, 2002) (Fig. 2), which we call the whole Changjiang estuary in this paper. Table 4 shows the average pollutant concentrations and compared with those near Zhuyuan and Bailonggang outfalls. The major pollutants are also nitrogen and phosphorus in the whole Changjiang estuary. The concentrations of DIN meet or exceed the standard of Class Four of GB3097 – 1997 in which the concentration in 1999 was triple and double of those of successive two years. The concentrations of PO_4-P are in the range of values of Class Three to Four of GB3097–1997, which change a little in three years. The values of COD were increasing from the value of Class Two in 1999 and 2000 to Class Three in 2001. The waters was also severely polluted by copper, the concentrations of Cu were in the range of Class Three to over Class Four of GB3097–1997 and were increasing during the three years. The

concentrations of zinc and cadmium and were relatively small which meet the standards of Class One or Two of GB3097－1997. The concentrations of lead increased from the value of Class Two in 1999 to Class Four in 2000 and 2001. In a word, the whole Changjiang estuary are polluted mainly by nitrogen, phosphorus, copper, lead and COD and the pollution increases year by year.

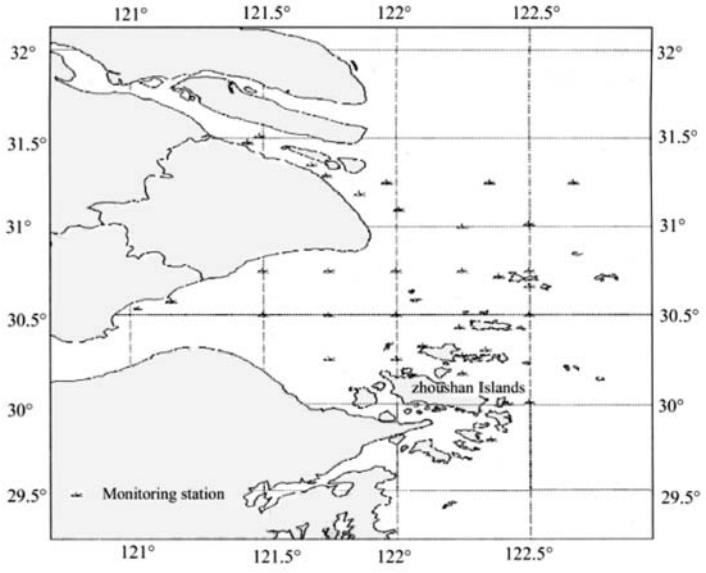

Fig. 2 Area of large waters of Changjiang estuary

Table 5 Pollutant concentrations in the whole Changjiang Estuary and their comparison with those around outfall waters

Year and Place	DIN (mg/L)	PO_4-P (mg/L)	COD (mg/L)	Cu (mg/L)	Zn (mg/L)	Pb (mg/L)	Cd (μg/L)
1999 – large	1.34	0.036	2.60	0.029	0.015	0.003	0.04
2000 – large	0.42	0.025	2.94	0.056	0.029	0.018	2.47
2001 – large	0.59	0.030	3.26	0.040	0.040	0.021	2.40
2000 – Zhuyuan	2.59	0.047	7.99	0.0055			0.070
2000 – Bailonggang	2.37	0.045	7.86	0.0075			0.027

Comparing the pollutant concentrations in waters near Zhuyuan and Bailonggang outfalls with those in the Changjiang estuary, we find the concentrations of DIN and COD much higher near the outfalls than those in the whole estuary. The concentration of PO_4-P was higher and the concentrations of copper and cadmium were much lower near the outfalls. It can be concluded that the municipal sewage discharges contribute a large quantities of nitrogen and phosphorus to the waters of Changjiang estuary. The sewage discharge has minor effect to the heavy metals pollution in the waters.

Table 6 shows the concentrations of heavy metals in the sediment in the whole Changjiang estuary and their comparison with those around the outfalls. All of the concentrations are lower than the ER-L values of NOAA, which presents that the sediment quality is relatively good. The concentrations of copper and cadmium in the sediment around the outfalls are lower than those in the sediment of the whole estuary, which also proves that the sewage discharges had not caused severe heavy metals pollution.

Table 6 Pollutant concentrations in the sediment of the whole Changjiang Estuary and their comparison with those around the outfalls

	Cu(mg/kg)	Zn(mg/kg)	Pb(mg/kg)	Cd(mg/kg)
1999 – large	34.2	6.4	7.50	1.190
2000 – large	35.7	9.6	6.50	0.895
2001 – large	33.9	8.0	6.75	0.860
2000 – Zhuyuan	24.4			0.104
2000 – Bailonggang	23.7			0.137

3. EUTROPHICATION IN THE CHANGJIANG ESTUARY

3.1 EVALUATION STANDARDS FOR TROPHIC STATE IN COASTAL WATERS

No evaluation standards for trophic state have been accepted worldwide. Many studies believe that the concentrations of nitrogen, phosphorus and COD have close relation with the degree of eutrophication in waters (Liu, 2003). In this paper, the following three methods are used for the eutrophication evaluation.

(1) Zou et al. (1983) put forward an equation that suits for coastal waters in China for the eutrophication judgment as following,

$$E = \frac{COD(\mathrm{mg/l}) \times C_{\mathrm{DIN}}(\mathrm{mg/l}) \times C_{\mathrm{PO_4-P}}(\mathrm{mg/l})}{4500} \times 10^6 \geq 1 \qquad (1)$$

in which COD is the values of COD, C_{DIN} and $C_{PO4\text{-}P}$ is the concentrations of DIN and PO_4-P in waters. When E≥1, the waters is in the state of eutrophication.

(2) The molar ratio of N and P in natural seawater is 16:1, which call for Redfield ratio. When N/P > 30, the environment is in the state of phosphorus-limited; when N/P < 8, it is in the state of nitrogen-limited. Based on this ratio, Guo et al. (1998) put forward a concept of potential eutrophication according to the fact that eutrophication of coastal waters in China is usually nutrient-limited. The classification standard for trophic states is shown as Table 7.

Table 7 Classification standard for trophic state

Class	Trophic State	DIN(mg/L)	PO_4-P(mg/L)	N/P
I	Oligotrophic	< 0.2	< 0.03	8 – 30
II	Mesotrophic	0.2 – 0.3	0.03 – 0.045	8 – 30
III	Eutrophic	> 0.3	> 0.045	8 – 30
IV_P	Phosphorus-Limited Mesotrophic	0.2 – 0.3	/	> 30
V_P	Slightly-Phosphorus-Limited potential Eutrophic	> 0.3	/	30 – 60
VI_P	Phosphorus Limited-Potential Eutrophic	> 0.3	/	> 60
IV_N	Nitrogen Limited Mesotrophic	/	0.03 – 0.045	< 8
V_N	Slightly-Nitrogen-Limited potential Eutrophic	/	> 0.045	4 – 8
VI_N	Nitrogen Limited-Potential Eutrophic	/	> 0.045	< 4

(3) Based on the studies on eutrophication (Tian and Deng, 1998; Fang and Mu, 2001; Tan, 2000; Nakamurat, 1989), the waters are believed in the state of eutrophication when the concentrations of DIN, PO_4-P and COD are higher than 0.3 mg/L, 0.045 mg/L and 3 mg/L respectively.

3.2 TROPHIC STATE IN WATERS OF CHANGJIANG ESTUARY

Based on the statistics, more than 40% events of red tide in the East China Sea occurred in the Changjiang estuary. Totally 83 events of red tide were observed from 1970 to 2001 (Ye et al. 2002).

The trophic state in the waters around Zhuyuan and Bailonggang outfalls is evaluated by three standards described above as Table 8. In the table, the trophic state in the large waters of Changjiang estuary is also compared.

Table 8 Evaluation of trophic state in the waters near Zhuyuan and Bailonggang outfalls

	Zhuyuan		Bailonggang		Large waters of Changjiang estuary
	Ebb tide	Flood tide	Ebb tide	Flood tide	
COD_{Cr} (mg/L)	10.84	5.14	7.68	8.04	2.94
PO_4-P (mg/L)	0.0449	0.0484	0.0425	0.0478	0.025
DIN (mg/L)	2.83	2.30	2.06	2.67	0.42
N/P	137.9	104.0	106.0	122.2	36.8
E*	306.1	127.2	149.4	228.0	6.9
Eutrophic Class**	VIP	VIP	VIP	VIP	VP
Single Item***	eutrophication	eutrophication	eutrophication	eutrophication	eutrophication

* Calculated by equation 1, the waters is in the state of eutrophication when E > 1;

** Evaluated by the classification standard for trophic states (Guo et al. 1998);

*** in the state of eutrophication when the concentrations of DIN, PO_4-P and COD are higher than 0.3 mg/L, 0.045 mg/L and 3 mg/L

Shown as Table 8, not only the waters around Zhuyuan and Bailonggang outfalls are in the state of eutrophication, but also the whole Changjiang estuary. Detail descriptions as following: (1) Calculated by equation 1, the E values in the waters around the outfalls reach as high as 127 to 306. The waters are in the state of severe eutrophication due to the sewage discharge from Shanghai. The E value in the whole Changjiang estuary is 6.9, which means the waters are also in the state of eutrophication; (2) Evaluated by the classification standard for trophic states by Guo et al. (1998), the trophic classes of waters around two outfalls is VI_P, ie. phosphorus limited-potential eutrophic state. The trophic class of the whole estuary is V_P, ie. slightly-phosphorus-limited potential eutrophic state; (3) The concentrations of DIN in the waters around two outfalls are much higher than 0.3 mg/L. The concentrations of PO_4-P are around the value of 0.045 mg/L. The COD values are much higher than 3 mg/L. It indicates that not only the waters are in the serious eutrophic state, but also the waters are severely polluted by nitrogen. The concentration of DIN in the whole Changjiang estuary is a little higher than the standard value, but other two values are lower than the standard. The whole estuary are in the state of eutrophication but not seriously.

4. CONCLUSION

The qualities of water and sediment around the Zhuyuan and Bailonggang outfalls are compared with GB3838－2002/ GB3097－1997 and NOAA guidelines, and those of the whole Changjiang estuary as well. The sample stations are within 3 km long upstream and downstream of the outfalls. The values of the whole Changjiang estuary are referred to the average water and sediment qualities of the 30 000 km^2 water area of the estuary. The level of eutrophication in the waters around the two outfalls and the whole Changjiang estuary were evaluated by different standards. The following conclusions are obtained: (1) Affected by the municipal sewage discharged from Shanghai City, the waters near the two outfall are seriously polluted by DIN and PO_4-P; (2) The concentrations of heavy metals, arsenic, oil and organic material in sediment near two outfalls are relatively low and pose no obvious adverse effects to the benthic organisms. The concentration of TP is very high; (3) The concentrations of nitrogen, phosphorus, copper, lead and COD in the whole Changjiang estuary are relatively

high and show a tendency to increase with time. The waters have been seriously polluted. Comparing the water quality and sediment quality in the waters near outfalls with those in the whole estuary, we find that the concentrations of nitrogen, phosphorus and COD much higher than those in whole estuary, whereas, the concentrations of heavy metals lower than those in the whole estuary. The municipal sewage discharges provide large quantities of nitrogen and phosphorus, but little heavy metals to the estuary; (4) The waters near the outfalls are in the severe eutrophic state, which classified as phosphorus limited-potential eutrophic state. The whole Changjiang estuary is also in the state of eutrophication, which classified as slightly-phosphorus-limited potential eutrophic state; (5) The waters of Changjiang estuary have the enough nutrients load, appropriate meteorological and hydrological condition for red tide. It is suggested that the risk of eutrophication and red tide may be reduced if municipal sewage of Shanghai is denitrogenated and dephosphorized before discharged.

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