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Post-dredging effect assessment based on sediment chemical quality in urban rivers of Yangzhou

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Abstract Deteriorating of urban river environment in Yangzhou is gradually serious in recent years. Treatment measures including pollution source control, sewage interception, and sludge dredging have been carried out in recent years, but urban river environment is still poor. In order to ascertain the causes, post-dredging effects were assessed based on sediment chemical quality in urban rivers of Yangzhou. Results indicate that post-dredging effects are not ideal because of backward dredging technique and incomplete pollution control. Eutrophication degree is still relatively high for most of them and pollution degree of nutrients is total phosphorus (TP) > total nitrogen (TN) > organic matter (OM). Although the pollution of heavy metals is not serious, the major pollution factors Cd and Hg should still be monitored intensively in the sludge dredging for the toxic effect of heavy metals.

Keywords Urban river · Post-dredging effect · Pollution evaluation · Nutrient · Heavy metal

Introduction

Urban river environment greatly affects human health because urban district is the most centralized and active region for human beings to produce and live. Urban district of Yangzhou, located at the intersection between Yangtze River and Grand Canal, is an extremely important water source of the South-to-North Water Diversion East Route Project. With the rapid progress of urbanization and industrialization, deteriorating of urban river environment in Yangzhou is gradually serious. It greatly restricts the sustainable development of social economy.

Comprehensive treatment measures, including sediment dredging, sewage intercepting, and garbage management, have been taken to improve urban river environment in recent years. However, urban river environment is still poor according to the 2015 annual environmental quality report of Yangzhou. In order to ascertain the causes, post-dredging effects were assessed based on sediment chemical quality in urban rivers of Yangzhou.

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Materials and methods

Sampling and treatment

Researches indicate that 0~15 cm surface sediment is the main storage site for pollutants including nutrients and heavy metals (Mortimer 1941; Reddy 1983; Yang et al. 2015). Thus, 0~15 cm sediments in 12 urban rivers, which have been dredged in the last 5 years (see Table 1), were sampled along the flow direction to assess the post-dredging effects (see Fig. 1).

Surface sediments were sampled about 1.5~2.0 kg by a long-handle metal shovel during dry season (from December 2015 to April 2016). Then, samples were poured into plastic buckets. After full precipitation,

Table 1 Recent dredging time of the 12 urban rivers (up to June 2016)

No.	River	Abbreviation	Recent dredging time
1	Siwangting River	SWT	2015
2	Xincheng River	XC	2015
3	Niansi River	NS	2012
4	Yangzhuang River	YZ	2012
5	Baodai River	BD	2012
6	Erdao River	ED	2013
7	Hangou River	HG	2014
8	Caohe River	CH	2014
9	City Moat	CM	2013
10	Yudai River	YD	2012
11	Little Qinhuai River	LQH	2011
12	Ancient Canal	AC	1998–2015

Segmental dredging project of Ancient Canal began from 1988 and the entire line was basically completed in 2015

overlying water was excluded and impurities were sieved out as possible. The sieved sediments were put into polyethylene-sealed bags with a corresponding label. Appearance characteristics were recorded including color and smell.

Surface sediments were pretreated before testing. First of all, surface sediments in the polyethylene-sealed bags were poured into wide-mouth glass containers and placed in a cool, ventilated, shady environment to air dry naturally. Secondly, air-drying surface sediments were spread on a hard plastic board and crushed slowly by glass rod. Then, detrital sediments were ground to powders in an agate mortar and impurities were removed further. Next, pass through a 100-mesh nylon sieve and get enough samples by sample quartering method. Finally, samples were poured into jars with a corresponding label and placed in a cool, ventilated, shady environment again.

Testing items and methods

In general, the most concerned pollutants in the surface sediment can be classified into three types including organic matter (OM), nutrient salts (total nitrogen/total phosphorus (TN/TP)), and heavy metals. Twelve items were tested in this investigation including pH, total organic carbon/organic matter (TOC/OM), TN, TP, and eight kinds of heavy metals (Cu/Zn/Pb/Cr/Cd/Hg/Ni/As). The testing items of heavy metal were determined according to the Chinese code "Environmental Quality Standard for Soils" (GB15618-1995).

Each testing item was carried out in accordance with the Chinese current codes shown in Table 2. The data presented here are average values of sampling points to represent average river segment.

Evaluation methods

Evaluation method of nutrients

There is no uniform standard evaluation method of nutrients including OM, TN, and TP in sediment both in China and abroad. According to the existing research results, nutrient pollution of the surface sediments was

Fig. 1 Location of the 12 urban rivers in Yangzhou

Table 2 Testing methods of twelve items

No.	Testing item	Testing method	Testing basis
1	pH	Glass electrode method	NY/T 1377-2007
2	OM/TOC	Potassium bichromate titrimetric method	NY/T 85-1988
3	TN	Semi-micro macro Kjeldahl method	NY/T 53-1987
4	TP	Molybdenum antimony colorimetric method	NY/T 88-1988
5	Cu	Flame atomic absorption spectrophotometry	GB/T1713-8-1997
6	Zn	Flame atomic absorption spectrophotometry	GB/T1713-8-1997
7	Pb	Graphite furnace atomic absorption spectrophotometry	GB/T1714-1-1997
8	Cr	Flame atomic absorption spectrophotometry	HJ 491-2009
9	Cd	Graphite furnace atomic absorption spectrophotometry	GB/T1714-1-1997
10	Hg	Cold atomic absorbent spectrophotometry	GB/T1713-6-1997
11	Ni	Flame atomic absorption spectrophotometry	GB/T1713-9-1997
12	As (metalloid)	Potassium borohydride-silver nitrate spectrophotometry	GB/T1713-5-1997

evaluated comprehensively by single-factor index method (Wang et al. 2011; Kang et al. 2012; Li et al. 2014; Tian and Zhu 2014; Zhou et al. 2015) and classification criterion of soil nutrient in China.

(1) Single-factor index method

$$I_i = C_i \ / \ S_i \tag{1}$$

$$I_c = I_i - 1, \tag{2}$$

in which

I_i is single-factor index of a pollutant;
C_i is measured value of a pollutant in sediment;
S_i is background value of a pollutant;
I_c is superstandard multiple of a pollutant.

Although single-factor index method can reflect superstandard multiple of a pollutant in sediment, it is unable to make a clear judgment to pollution degree for lack of pollution grade classification. Thus, classification criterion of China's soil nutrients was introduced here to make further evaluation on the pollution degree.

(2) Classification criterion of China's soil nutrients

Based on the authoritative results of the extensive and systematic survey on China's soil nutrients, classification criterion of China's soil nutrients was developed by National Soil Survey Office of China (1998). Fertility status of China's soils could be judged by classification criterion, and then, eutrophication degree of the urban rivers could be evaluated indirectly. Classification criterion of China's soil nutrients is shown in Table 3.

Evaluation method of heavy metals

Harmfulness of heavy metal draws considerable attention because of its long-term cumulative toxic effect. There are many evaluation methods of heavy metal at present. Among them, two frequently adopted methods to evaluate the pollution of heavy metals in China were introduced here.

(1) Geoaccumulation index method (Müller 1969)

$$I_{\text{geo}} = \log_2(C_n \ / \ kB_n), \tag{3}$$

in which

I_{geo} is index of geoaccumulation that reflects the enrichment degree of a heavy metal;
C_n is measured value of heavy metal n in sediment;

Table 3 Classification criterion of China's soil nutrients

Grade	Fertility	OM/%	TN/%	TP/%
1	Rich	>4	>0.20	>0.10
2	Relatively rich	3–4	0.15–0.20	0.08–0.10
3	Moderate	2–3	0.10–0.15	0.06–0.08
4	Relatively poor	1–2	0.075–0.10	0.04–0.06
5	Poor	0.6–1	0.05–0.075	0.02–0.04
6	Very poor	<0.6	<0.05	<0.02

Table 4 Relationship between pollution degree of heavy metal and I_{geo}

I_{geo}	≤0	0–1	1–2	2–3	3–4	4–5	>5
Grade	0	1	2	3	4	5	6
Pollution degree	Free	Slight	Relatively moderate	Moderate	Relatively heavy	Heavy	Serious

B_n is background value of heavy metal n;
k is correction constant of the background value for considering fluctuation of background value caused by diagenesis, and generally takes 1.5.

The relationship between pollution degree of heavy metal and I_{geo} is shown in Table 4.

(2) Potential ecological risk index method (Hakanson 1980)

$$C_f^i = C_0^i / C_n^i \tag{4}$$

$$E_r^i = T_r^i \times C_f^i \tag{5}$$

$$RI = \sum_{i=1}^{n} E_r^i, \tag{6}$$

in which

C_f^i is index of pollution of heavy metal i;
C_0^i is measured value of heavy metal i in sediment;
C_n^i is background value of heavy metal i;
E_r^i is potential ecological risk index of heavy metal i;
T_r^i is toxic response factor of heavy metal i that reflects the level of toxicity and the sensitivity of organisms to the pollution;
RI is comprehensive potential ecological risk index of multiple heavy metals.

Toxic response factors of the eight heavy metals (Hakanson 1980; Xu et al. 2008) are shown in Table 5, and classification criterion of ecological risk degree of heavy metal (Hakanson 1980) is shown in Table 6.

Background values for evaluation

In order to analyze and evaluate pollution status more objectively and realistically, background values of neighboring regions or regions with similar environmental conditions can be adopted when lacking local background values. Consequently, content of nutrients and heavy metals of paddy soil in Tai Lake Basin nearby Yangzhou City (see Fig. 2) was adopted here as the background values for evaluation. These data shown in Table 7 were quoted from authoritative research results of the National Key Technology Research and Development Program of China during the “6th Five-Year Plan” (Co-operative Group 1988). Furthermore, the results above achieved in the initial stage of industrialization of china (early 1990s) and thus could reflect the pollution status of the urban rivers in Yangzhou more accurately.

Results and analysis

Analysis of pH

pH values of surface sediments are shown in Fig. 3. pH values of surface sediments are between 8.230 and 8.322 with the average being 8.262. In accordance with classification criterion of pH value of China’s soils (see Table 8), surface sediments of the urban rivers are alkaline soils. It is principally due to the fact that soils in the north of the China’s Yangtze River (N 33°~N 35°) contain abundant inorganic carbonate and inorganic bicarbonate. They maintain the acid–base balance of surface sediments together with the organic substance (Ueda 1992; Wang et al. 2004; Obear and Soldat 2016; Obear et al. 2016).

Table 5 Toxic response factors of heavy metals

Heavy metal	Cu	Zn	Pb	Cr	Cd	Hg	Ni	As
T_r^i	5	1	5	2	30	40	5	10

Table 6 Classification criterion of ecological risk degree of heavy metal

Ecological risk degree	Slight	Moderate	Strong	Very strong	Extremely strong
E_r^i	<40	40–80	80–160	160–320	≥320
RI	<150	150–300	300–600	≥600	

Analysis of nutrients

Content of nutrients in the surface sediments is shown in Table 9. Content of OM is between 2.425 and 4.582% with the average being 3.142%. TOC is 1.407~2.658% with the average being 1.822%. TN is 0.073~0.386% with the average being 0.235% and TN is 0.038~0.153% with the average being 0.104%. Comparison of the nutrients in the surface sediments of different urban rivers is shown in Fig. 4. It is clear from Fig. 4 that the content of nutrients in the surface sediments of Ancient Canal is maximum, and that of Niansi River, Hangou River, and City Moat is relatively low.

Researches indicate that there is some correlation among the nutrients in soils (House and Denison 2002; Bai et al. 2005; Li et al. 2013). About 92~98% of total nitrogen in soil is organic nitrogen. Most of the organic nitrogen is stored in humus that is the main component of organic matter. Therefore, content of total nitrogen and that of organic matter are closely related. Organic phosphorus accounts for only 10~ 30% of total phosphorus and the most is inorganic phosphorus. There might be some relevance between the content of total phosphorus and that of organic matter. The correlation among the nutrients in the surface sediments of the urban rivers is shown in Fig. 5. It can be seen that the linear correlation between TN, TP, and OM is prominent in the surface sediments in Yangzhou.

Analysis of C/N ratio

Researches reveal that carbon-nitrogen (C/N) ratios of different species are different. C/N ratios of benthos, planktons, and lower aquatic plants without vascular bundle are small and usually less than 10. And that of higher terrestrial plants can reach more than 20 (Giresse et al. 1994; Meyers and Lallier-Vergés 1999). Thus, C/N ratio of sediment can reflect the sources of OM in the sediment to some extent (Krishnamurthy et al. 1986; Dean 1999; Wagner et al. 2000). In general, when the C/N ratio of the sediment is between 4 and 10, a major portion of OM is derived from internal sources including benthos, planktons, and lower aquatic plants. When the C/N ratio is greater than 20, OM mainly comes from external sources for example higher terrestrial plants. When the C/N ratio is between 10 and 20, OM has mixed sources that consist of internal sources and external sources (Ishiwatari and Uzaki 1987; Meyers 1994).

Besides, in view of the fact that the urban district is the most centralized and active region for human beings to produce and live, input of nutrients caused by human activities should be considered. Input of exogenous nitrogen caused by human activities can significantly reduce the ratio of C/N and make it difficult to determine the sources of OM. Thus, it is necessary to combine the practical investigation of the urban rivers for making a comprehensive judgment to the sources of OM.

Fig. 2 Geographical position relationship between Yangzhou City and Tai Lake Basin

Table 7 Background values for evaluation

Items	OM	TN	TP	Cu	Zn	Pb	Cr	Cd	Hg	Ni	As
Background values	2.680	0.141	0.053	22.78	73.02	20.39	65.72	0.116	0.163	29.12	8.80

C/N ratios of the surface sediments of the urban rivers are shown in Fig. 6. C/N ratios of the surface sediments of Niansi River, Hangou River, and City Moat are between 10 and 20. Those of the other urban rivers are between 5 and 10. According to the practical investigation of the urban rivers in Yangzhou, principal internal sources of OM are benthos, zooplankton, and algae (see Figs. 7 and 8). There are three chief approaches to the exogenous input of OM. First, Yangzhou belongs to transitional zones between the subtropical monsoon humid climate and temperate monsoon climate. It has a long rainy season with abundant sunshine and rainfall. The foliage or debris of the higher terrestrial plants around the urban rivers can be washed into the rivers by the runoff or rainwater during rainy season (see Figs. 7 and 8). Second, combined sewer system, in which only one single sewer is provided for both rainwater and sewage, is used in the urban district of Yangzhou. The sewer system is old with inadequate drainage capacity. It results in that the overflow pollutants of the sewer system flow into the urban rivers with the stormwater runoff during the rainy season (see Fig. 9). Third, except for Niansi River, Hangou River, and City Moat, pollution sources control and sewage interception of the urban rivers are not thorough, and the domestic sewage of sewage outfall is still discharged into the rivers directly (see Fig. 10). Accordingly, it can be judged that OM of the urban rivers in Yangzhou has mixed sources. OM of Niansi River, Hangou River, and City Moat is mainly from the higher terrestrial plants. Besides the higher terrestrial plants, the main external sources of OM of the other urban rivers also include large amounts of exogenous nitrogen input in the domestic sewage and the overflow pollutants of the sewer system.

Analysis of heavy metals

Content of heavy metals in the surface sediments is shown in Table 10, It can be seen that there are differences in the content of various heavy metals in the sediments of the urban rivers in Yangzhou. Content of Cu is between 13.20 and 72.40 mg/kg with the average being 29.07 mg/kg; Zn is 20.30~135.30 mg/kg with the average being 64.40 mg/kg; Pb is 14.23~118.40 mg/kg with the average being 38.87 mg/kg; Cr is 11.57~85.50 mg/kg with the average being 37.85 mg/kg; Cr is 0.065~0.460 mg/kg with the average being 0.277 mg/kg; Hg is 0.028~0.338 mg/kg with the average being 0.195 mg/kg; Ni is 8.90~29.10 mg/kg with the average being 24.15 mg/kg; As is 5.20~15.30 mg/kg with the average being 11.12 mg/kg.

Comparison of the heavy metals in the surface sediments of different urban rivers is shown in Fig. 11. It is clear from Fig. 11 that the content of heavy metals in the surface sediments of Ancient Canal is maximum, and

Fig. 3 pH value of the surface sediments

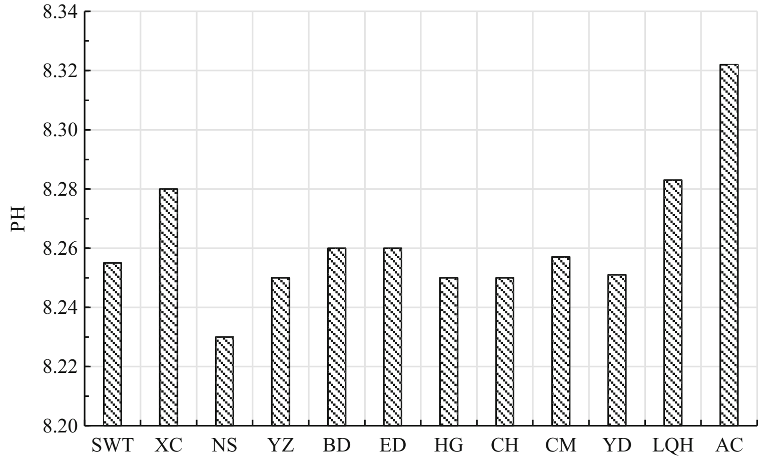

Table 8 Classification criterion of pH value of China's soils

pH	<4.5	4.5~5.5	5.5~6.5	6.5~7.5	7.5~8.5	8.5~9.5	>9.5
Grade	Extremely strong acid	Strong acid	Acid	Neutral	Alkaline	Strong alkaline	Extremely strong alkaline

Table 9 Content of nutrients in the surface sediments

River	Content of nutrients/%			
	OM	TOC	TN	TP
SWT	2.868	1.664	0.204	0.092
XC	3.475	2.016	0.240	0.120
NS	2.848	1.652	0.125	0.053
YZ	3.274	1.899	0.265	0.135
BD	3.323	1.927	0.356	0.140
ED	3.056	1.773	0.325	0.120
HG	2.634	1.528	0.127	0.053
CH	2.706	1.570	0.208	0.112
CM	2.425	1.407	0.073	0.038
YD	2.680	1.555	0.178	0.088
LQH	3.830	2.222	0.336	0.147
AC	4.582	2.658	0.386	0.153

that of Niansi River and City Moat is relatively low. It is similar to the results of the analysis of nutrients. Generally speaking, the organic matter itself does not contain heavy metals. Thus, the increase of OM cannot increase the input of heavy metals. However, OM can be involved in the complexation and chelation of heavy metals to affect the migration and transformation of heavy metals, and then affect the accumulation of heavy metals further (Reuter and Perdue 1977; Adamu et al. 1989; Lin and Chen 1998; Ottosen and Villumsen 2006; Barakat et al. 2012). The correlation between the content of heavy metals and that of OM in the surface sediments of the urban rivers is shown in Fig. 12. It can be seen that the linear correlation between Cu, Pb, Cr. and OM is prominent. A certain correlation exists between Zn, As, Cd, Hg, and OM but not significant. And there is no correlation between Ni and OM. The correlation between various heavy metals and OM has remarkable difference. It is due to the complex relationship between OM and the accumulation of heavy metals which is not only related to the content and properties of OM and heavy metals but also affected by many other factors such as soil type, soil utilization pattern, soil biological activity, community composition, and ecosystem type (Bååth and Tunlid 1998; M. Šmejkalová et al. 2003; Kandpal et al. 2005; Lorenz et al. 2006; Pollard and Yuan 2006; Feketeová et al. 2015).

Evaluation and discussion

Pollution evaluation of nutrients

Evaluation results of single-factor index method are shown in Table 11. Content of OM in eight urban rivers

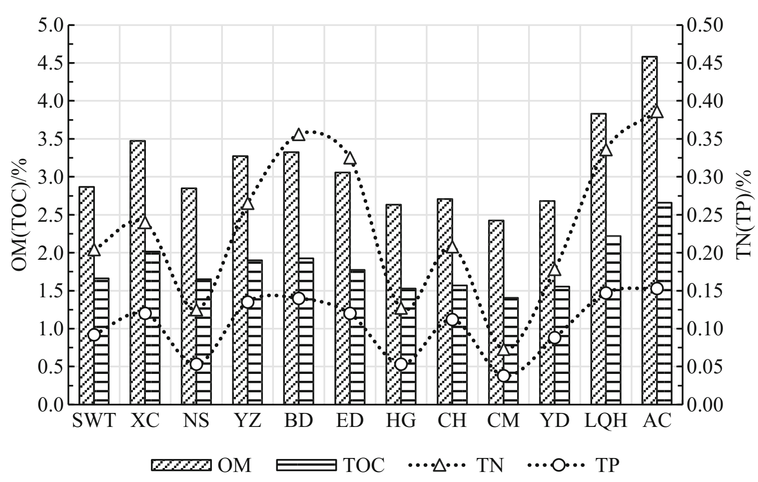

Fig. 4 Comparison of the nutrients in the surface sediments

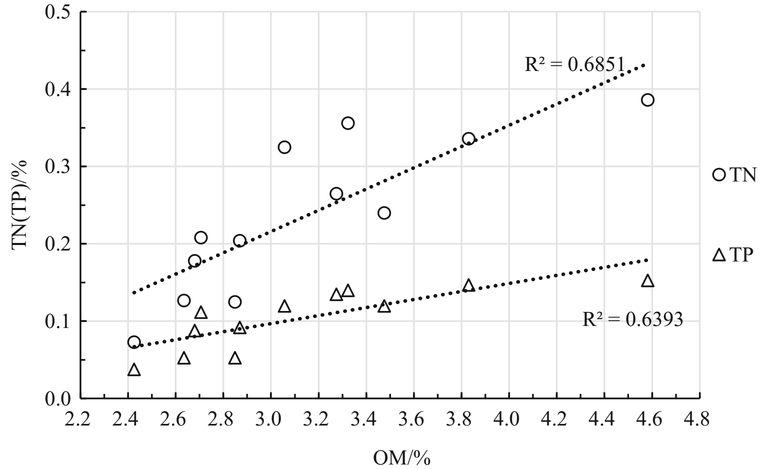

Fig. 5 Correlation among the nutrients in the surface sediments

exceeds the standard, accounting for about 67% of the total survey with the maximum being 0.7 times and an average 0.2 times of the background value. Content of TN in nine rivers exceeds the standard, accounting for about 75% of the total survey with the maximum being 1.7 times and an average 0.7 times of the background value. Content of TP in nine rivers exceeds the standard, accounting for about 75% of the total survey with the maximum being 1.9 times and an average 1.0 times of the background value. It suggests that pollution degree of nutrients in the surface sediments of urban rivers in Yangzhou is TP > TN > OM.

Comparison of superstandard multiple of the nutrients in the surface sediments of different urban rivers is shown in Fig. 13. It is clear from Fig. 13 that nutrients in the surface sediments of Hangou River and City Moat did not exceeded the standard. Only content of OM is slightly exceeded for Niansi River. Nutrients in the remaining rivers exceed standard in varying degrees and Ancient Canal is the most serious among them.

Nutrients in the surface sediments are graded according to classification criterion of China's soil nutrients (see Table 12). Nutrients in the surface sediments of Niansi River, Hangou River, and City Moat are the moderate level or below. Those of the other rivers can achieve the relatively rich level. Especially in Ancient Canal, the nutrients are all high to the rich level.

OM in the sediments is the main oxygen-consuming pollutant which causes the phenomenon of hypoxia, black color, and offensive odor in water (Pereira et al. 2002; Bergondo et al. 2005). Thus, content of OM can reflect the degree of organic pollution. Content of nitrogen and phosphorus is one of the important indicators to determine the release degree of nitrogen and phosphorus

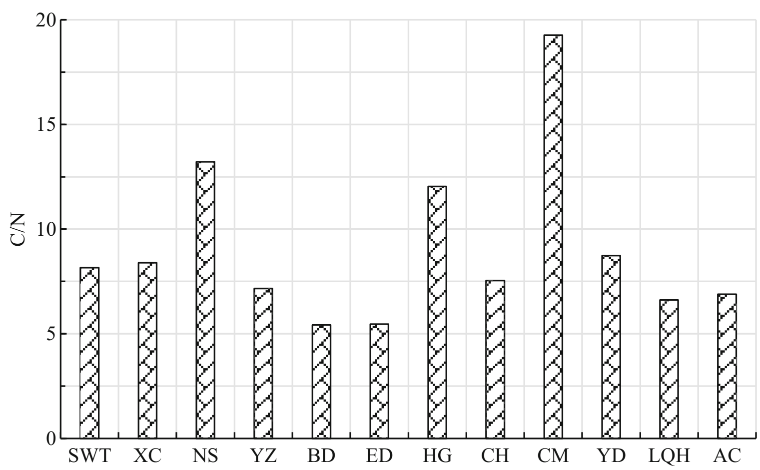

Fig. 6 C/N ratios of the surface sediments

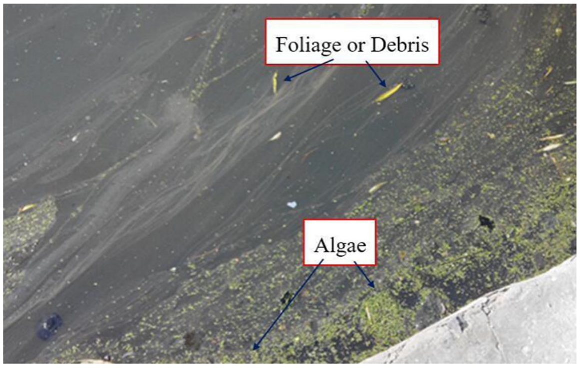

Fig. 7 Algae floating on the rivers

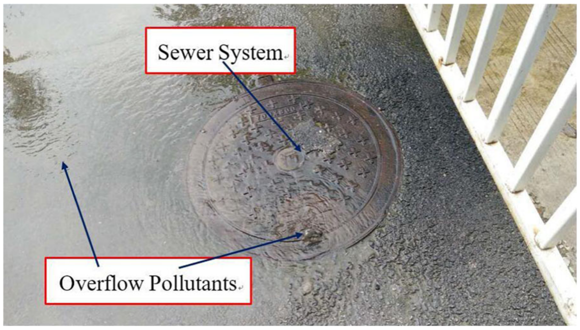

Fig. 9 Urban runoff pollution

from sediment to overlying water (Marsden 1989; Nowlin et al. 2005). The results of the two evaluation methods above are basically consistent. They indicate that there is no trend of eutrophication in Niansi River, Hangou River, and City Moat, and the eutrophication degree of the other urban rivers is relatively high.

Pollution evaluation of heavy metals

Geoaccumulation index (I_{geo}) of heavy metals in surface sediments is shown in Table 13. I_{geo} of Cu is between −1.4 and 1.1 with the average being −0.2; Zn is −2.4~0.3 with the average being −0.8; Pb is −1.1~2.0 with the average being 0.3; Cr is −3.1~−0.2 with the average being −1.4; Cd is −1.4~1.4 with the average being 0.7; Hg is −3.1~0.5 with the average being −0.3; Ni is −2.3~−0.6 with the average being −0.9; As is −1.3~0.2 with the average being −0.2. According to the average of I_{geo}, the enrichment degree of different heavy metals in the surface sediments of the urban rivers in Yangzhou is Cd(0.7) > Pb(0.3) > Cu(−0.2) ≈ As(−0.2) > Hg(−0.3) > Zn(−0.8) > Ni(−0.9) > Cr(−1.4).

Evaluation results of geoaccumulation index method are shown in Table 14. It can be seen that pollution of heavy metals is not detected in Niansi River, City Moat, and Yudai River. Only slight pollution of Cd is detected in Baodai River, Hangou River, and Caohe River. Although more than one kind of heavy metal pollution can be detected in the remaining six rivers, no pollution degree is more than relatively moderate level. Pollution of heavy metals in Ancient Canal is relatively serious among the rivers investigated, and pollution of six heavy metals is found there. Among the eight heavy metals tested, Cd is the major pollution factor, and the pollution of Ni and Cr is not detected in all the urban rivers investigated.

Calculations of potential ecological risk index method are shown in Table 15. E_r of Cu is between 3 and 16 with the average being 6; Zn is 0~2 with the average being 1; Pb is 3~29 with the average being 10; Cr is 0~3 with the average being 1; Cd is 17~119 with the average being 72; Hg is 7~83 with the average being 48; Ni is 0~5 with the average being 4; As is 6~17 with the average being 13. According to the average of E_r, the potential ecological risk of different heavy metals in the surface sediments is Cd(72) > Hg(48) > As(13) > Pb(10) > Cu(6) > Ni(4) > Cr(1) ≈ Zn(1). According

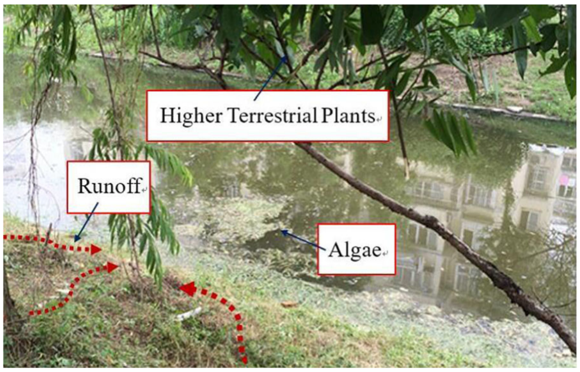

Fig. 8 Higher terrestrial plants around the rivers

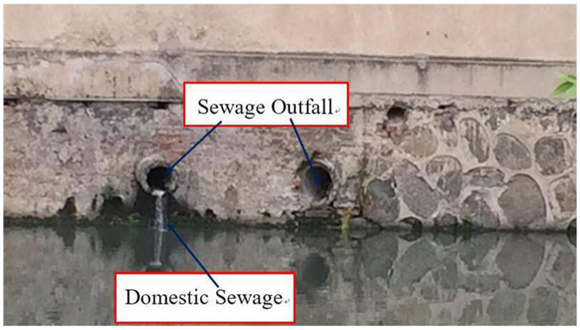

Fig. 10 Sewage outfall along the rivers

Table 10 Content of heavy metals in the surface sediments

River	Heavy metal/(mg/kg)							
	Cu	Zn	Pb	Cr	Cd	Hg	Ni	As
SWT	23.40	65.80	31.50	34.23	0.350	0.198	26.40	10.10
XC	25.40	70.80	36.80	32.50	0.360	0.225	27.10	11.50
NS	16.20	30.10	16.20	27.80	0.102	0.041	11.80	7.30
YZ	35.20	76.30	48.60	40.20	0.270	0.242	29.10	13.20
BD	20.20	32.50	18.40	32.10	0.200	0.158	25.30	11.90
ED	28.60	69.20	40.10	48.80	0.350	0.216	27.90	12.10
HG	26.40	66.90	30.12	32.47	0.345	0.206	27.40	11.20
CH	25.40	64.70	29.89	30.26	0.272	0.211	25.90	10.98
CM	13.20	20.30	14.23	11.57	0.065	0.028	8.90	5.20
YD	25.80	65.70	30.00	31.35	0.158	0.169	26.60	11.06
LQH	36.60	75.20	52.15	47.38	0.392	0.311	25.20	13.60
AC	72.40	135.30	118.40	85.50	0.460	0.338	28.20	15.30

to the value of RI, the comprehensive potential ecological risk of the eight heavy metals to the urban rivers of Yangzhou is AC(274) > LQH(221) > XC(183) > ED(181) > HG(172) > YZ(171) > SWT(170) > CH(154) > BD(119) > YD(114) > NS(56) > CM(38).

Evaluation results of potential ecological risk index method are shown in Table 16. It can be seen that pollution degree of heavy metals is slight ecological risk in Niansi River, Baodai River, City Moat, and Yudai River, and that in the others is moderate ecological risk. Among them, potential ecological risk of heavy metals in Ancient Canal is relatively large, and pollution degree of Cd and Hg achieves the strong ecological risk level.

Both Cd and Hg are the major pollution factors here. It is slightly different from the results of geoaccumulation index method which only considers Cd as the major pollution factor. It is mainly due to that geoaccumulation index method only evaluates the pollution characteristics of single heavy metal and focuses on the enrichment of heavy metal. Potential ecological risk index method not only considers the content of heavy metal but also introduces toxic response factor

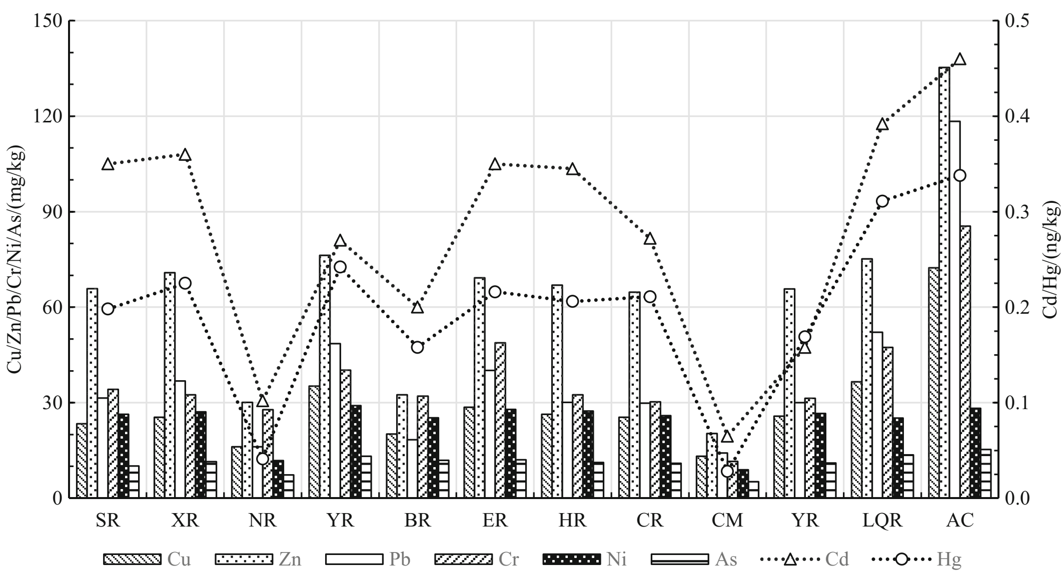

Fig. 11 Comparison of heavy metals in the surface sediments

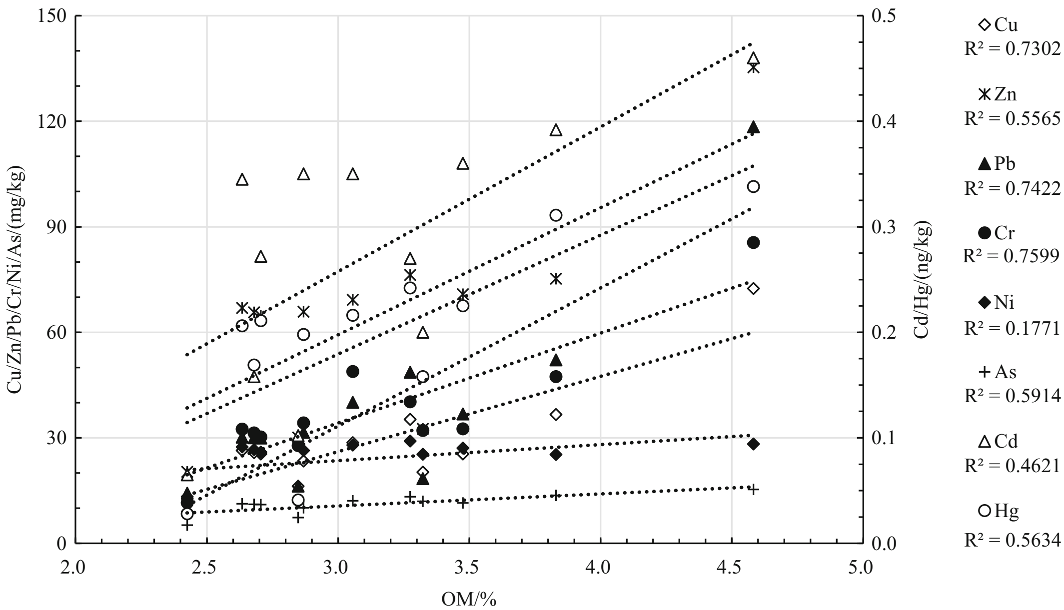

Fig. 12 Correlation between heavy metals and OM

of heavy metal, which associates the ecological effect and environmental effect with toxicity to evaluate potential ecological risk of heavy metal. Potential ecological risk of Hg is large for its high toxic response factor (see Table 5). Besides, potential ecological risk index method also takes the combined effect of multiple heavy metals into account, and thus, the evaluation results are more objective and comprehensive.

Table 11 Superstandard multiple of nutrients in the surface sediments

River	OM		TN		TP	
	I_i	I_c	I_i	I_c	I_i	I_c
SWT	1.1	0.1	1.4	0.4	1.7	0.7
XC	1.3	0.3	1.7	0.7	2.3	1.3
NS	1.1	0.1	0.9	−0.1	1.0	0.0
YZ	1.2	0.2	1.9	0.9	2.5	1.5
BD	1.2	0.2	2.5	1.5	2.6	1.6
ED	1.1	0.1	2.3	1.3	2.3	1.3
HG	1.0	0.0	0.9	−0.1	1.0	0.0
CH	1.0	0.0	1.5	0.5	2.1	1.1
CM	0.9	−0.1	0.5	−0.5	0.7	−0.3
YD	1.0	0.0	1.3	0.3	1.7	0.7
LQH	1.4	0.4	2.4	1.4	2.8	1.8
AC	1.7	0.7	2.7	1.7	2.9	1.9

Overall, pollution of heavy metals in the surface sediments of the urban rivers in Yangzhou is not serious. Much of that is because the tertiary industry is predominant in the urban district of Yangzhou, especially the tourism, catering, and entertainment industry which are the three major economic pillars of Yangzhou. What is more, there is no large-scale mining areas or heavy metal enterprises in the urban district.

Evaluation of post-dredging effects

Based on the pollution analysis and evaluation above, although the 12 urban rivers investigated have been dredged in recent 5 years, post-dredging effects of most urban rivers are not very ideal except Niansi River, Hangou River, and City Moat. The remaining nine rivers have different degrees of eutrophication, and it can be intuitively felt from the practical investigation. Sampling photos of the surface sediments (take Xincheng River for example) are shown in Fig. 14. It is clear as can be seen that the surface sediments are black. Besides, the turbid water was observed and offensive odor was smelt during the sampling process.

The reasons for the poor post-dredging effects are as follows. First, pollution source control and sewage interception of the eutrophic urban rivers are not thorough. Second, overflow pollutants can be washed into the rivers during rainy season because of the inefficient

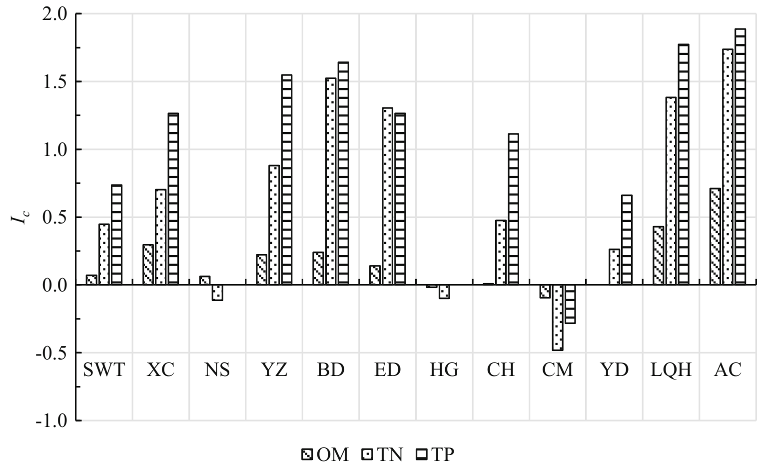

Fig. 13 Comparison of I_c of the nutrients in the surface sediments

sewer system. The reasons above have been mentioned in the chapter of the source analysis of organic matter. Besides, another very important reason is that dredging technique carried out in most of urban rivers in Yangzhou is too backward. The traditional hydraulic cutter-suction dredger (see Fig. 15) was used in the sludge dredging of the urban rivers in Yangzhou for lack of ecological dredging equipment suitable for small rivers in China. This type of dredger is usually simply assembled by wooden boat, spud system, and hydraulic dredging pump.

The spud system and manual measurement are used to planar location and depth control of dredging, respectively (see Figs. 15 and 16). Over-excavation and under-excavation of the polluted sediments are inevitable in operation of the dredger for its low dredging precision. Both of them lead to the rapid deterioration of water eco-environment again. Over-excavation destroys the ecological soil layer in the river bed which plays a significant role in the self-repairing of river ecosystem. And under-excavation causes the taintless sediments to turn into the pollutants again because of the activation effect of uncleaned activated sludge.

Hydraulic dredging pump is prone to cause the disturbance, suspension, and diffusion of polluted sediments for lack of precautions when working (see Fig. 16). Suspension colloids caused by the disturbance suspend in the overlying water for a long time, and then, the pollutants in the sediments can release into the overlying water again. Remarkably, although the pollution of heavy metals in the surface sediments of urban rivers in Yangzhou is not serious, heavy metals are

Table 12 Classification of nutrients in the surface sediments

River	OM	TN	TP
SWT	Moderate	Rich	Relatively rich
XC	Relatively rich	Rich	Rich
NS	Moderate	Moderate	Relatively poor
YZ	Relatively rich	Rich	Rich
BD	Relatively rich	Rich	Rich
ED	Relatively rich	Rich	Rich
HG	Moderate	Moderate	Relatively poor
CH	Moderate	Rich	Rich
CM	Moderate	Poor	Poor
YD	Moderate	Relatively rich	Relatively rich
LQH	Relatively rich	Rich	Rich
AC	Rich	Rich	Rich

Table 13 I_{geo} of heavy metals in surface sediments

River	I_{geo}							
	Cu	Zn	Pb	Cr	Cd	Hg	Ni	As
SWT	−0.5	−0.7	0.0	−1.5	1.0	−0.3	−0.7	−0.4
XC	−0.4	−0.6	0.3	−1.6	1.0	−0.1	−0.7	−0.2
NS	−1.1	−1.9	−0.9	−1.8	−0.8	−2.6	−1.9	−0.9
YZ	0.0	−0.5	0.7	−1.3	0.6	0.0	−0.6	0.0
BD	−0.8	−1.8	−0.7	−1.6	0.2	−0.6	−0.8	−0.1
ED	−0.3	−0.7	0.4	−1.0	1.0	−0.2	−0.6	−0.1
HG	−0.4	−0.7	0.0	−1.6	1.0	−0.2	−0.7	−0.2
CH	−0.4	−0.8	0.0	−1.7	0.6	−0.2	−0.8	−0.3
CM	−1.4	−2.4	−1.1	−3.1	−1.4	−3.1	−2.3	−1.3
YD	−0.4	−0.7	0.0	−1.7	−0.1	−0.5	−0.7	−0.3
LQH	0.1	−0.5	0.8	−1.1	1.2	0.3	−0.8	0.0
AC	1.1	0.3	2.0	−0.2	1.4	0.5	−0.6	0.2

Table 14 Evaluation results of geoaccumulation index method

River	Pollution degree							
	Cu	Zn	Pb	Cr	Cd	Hg	Ni	As
SWT	Free	Free	Slight	Free	Relatively moderate	Free	Free	Free
XC	Free	Free	Slight	Free	Relatively moderate	Free	Free	Free
NS	Free	Free	Free	Free	Free	Free	Free	Free
YZ	Slight	Free	Slight	Free	Slight	Free	Free	Free
BD	Free	Free	Free	Free	Slight	Free	Free	Free
ED	Free	Free	Slight	Free	Relatively moderate	Free	Free	Free
HG	Free	Free	Free	Free	Slight	Free	Free	Free
CH	Free	Free	Free	Free	Slight	Free	Free	Free
CM	Free	Free	Free	Free	Free	Free	Free	Free
YD	Free	Free	Free	Free	Free	Free	Free	Free
LQH	Slight	Free	Slight	Free	Relatively moderate	Slight	Free	Slight
AC	Relatively moderate	Slight	Relatively moderate	Free	Relatively moderate	Slight	Free	Slight

pollutants of potential ecological risk and toxic effect (Baby et al. 2010). Heavy metals released from the sediments can be converted into more toxic organometallics, which may result in the chronic toxicosis of organisms by the bioaccumulation and biomagnification of the food chains (Bryan and Langston 1992; Janssen et al. 1993; Raskin et al. 1994; Vandecasteele et al. 2004). All of them lead to water quality deterioration and secondary pollution. More seriously, suspension-polluted colloids can migrate with the flowing water together to pollute the downstream river further. This phenomenon was reflected in this investigation. As the main river for flood discharge and water drainage in the urban district of Yangzhou, Ancient Canal is flowed into by most of urban rivers. The emission or migration of pollutants from upstream rivers has resulted in the treatment of Ancient Canal to be almost in vain. Ancient Canal is the most polluted river in either nutrients or heavy metals based on the evaluation results.

Table 15 E_r and RI of heavy metals in surface sediments

River	E_r								RI
	Cu	Zn	Pb	Cr	Cd	Hg	Ni	As	
SWT	5	1	8	1	91	49	5	11	170
XC	6	1	9	1	93	55	5	13	183
NS	4	0	4	1	26	10	2	8	56
YZ	8	1	12	1	70	59	5	15	171
BD	4	0	5	1	52	39	4	14	119
ED	6	1	10	1	91	53	5	14	181
HG	6	1	7	1	89	51	5	13	172
CH	6	1	7	1	70	52	4	12	154
CM	3	0	3	0	17	7	2	6	38
YD	6	1	7	1	41	41	5	13	114
LQH	8	1	13	1	101	76	4	15	221
AC	16	2	29	3	119	83	5	17	274

Aiming at the subsistent problem, some suggestions for the optimization of the treatment technology and the improvement of the treatment scheme of urban rivers in the future are put forward as follows.

Treatment pattern that combines pollution source control, sewage interception, and ecological restoration can be adopted in the comprehensive improvement of the urban rivers in Yangzhou. It is essential to get rid of the external pollution sources thoroughly first, especially sewage outfall along the rivers. Besides, it is necessary to promote the construction of separate sewer system and the remake of combined sewer system to avoid the overflow pollutants from the sewer system. After intercepting the exogenous pollution, the endogenous pollution of polluted sediments should be removed precisely by advanced ecological dredger with adequate precautions for the disturbance, suspension, and diffusion. The ecological dredger should be suitable to the complex conditions of the urban rivers in China and can be improved on the basis of the traditional dredger if possible. More importantly, appropriate ecological restoration technology should be applied to promote the

Table 16 Evaluation results of potential ecological risk index method

River	Pollution degree by E_r								Pollution degree by RI
	Cu	Zn	Pb	Cr	Cd	Hg	Ni	As	
SWT	Slight	Slight	Slight	Slight	Strong	Moderate	Slight	Slight	Moderate
XC	Slight	Slight	Slight	Slight	Strong	Moderate	Slight	Slight	Moderate
NS	Slight	Slight	Slight	Slight	Slight	Slight	Slight	Slight	Slight
YZ	Slight	Slight	Slight	Slight	Moderate	Moderate	Slight	Slight	Moderate
BD	Slight	Slight	Slight	Slight	Moderate	Slight	Slight	Slight	Slight
ED	Slight	Slight	Slight	Slight	Strong	Moderate	Slight	Slight	Moderate
HG	Slight	Slight	Slight	Slight	Strong	Moderate	Slight	Slight	Moderate
CH	Slight	Slight	Slight	Slight	Moderate	Moderate	Slight	Slight	Moderate
CM	Slight	Slight	Slight	Slight	Slight	Slight	Slight	Slight	Slight
YD	Slight	Slight	Slight	Slight	Moderate	Moderate	Slight	Slight	Slight
LQH	Slight	Slight	Slight	Slight	Strong	Moderate	Slight	Slight	Moderate
AC	Slight	Slight	Slight	Slight	Strong	Strong	Slight	Slight	Moderate

Fig. 14 Sampling photos of the surface sediments (take Xincheng River for example)

recovery of self-repairing ability and maintain a good water eco-environment. The last but not the least, the comprehensive improvement of the urban rivers in Yangzhou should be conducted on the basis of overall planning. The relationship between the upstream and downstream of the urban rivers should be taken into account in the design of the treatment scheme to make the dredging effects better.

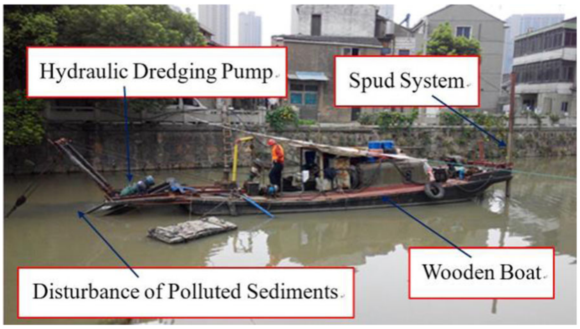

Fig. 15 Traditional hydraulic cutter-suction dredger

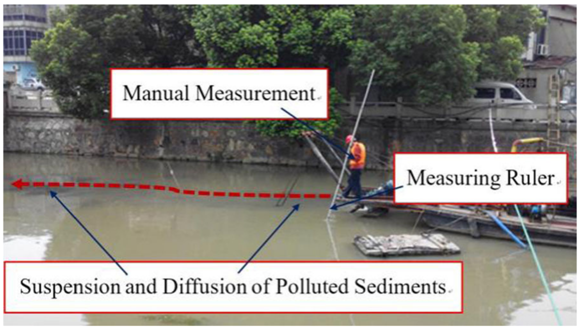

Fig. 16 Suspension and diffusion of polluted sediments

Conclusions

The main conclusions drawn from this study are summarized as follows.

(1) Surface sediments of the urban rivers in Yangzhou are alkaline soils. Thus, appropriate treatment technology should be in accordance with the neutral or alkaline environment.
(2) Post-dredging effects of most urban rivers in Yangzhou are still poor because of backward dredging technique and incomplete pollution control. Eutrophication degree is still relatively high for most of them and pollution degree of nutrients is TP > TN > OM.
(3) OM in the surface sediments of the urban rivers in Yangzhou has mixed sources. The main external sources are the debris of higher terrestrial plants, overflow pollutants, and domestic sewage.
(4) Pollution of heavy metals in the surface sediments is not serious for the reason that the tertiary industry is predominant, and no large-scale mining areas or heavy metal enterprises are located in the urban district of Yangzhou. However, release of heavy metal should still be paid attention to in the sludge dredging for its potential ecological risk and toxic effect. In particular, the major pollution factors Cd and Hg should be monitored intensively.
(5) Treatment pattern that combines pollution source control, sewage interception, and ecological restoration can be adopted in the comprehensive improvement of the urban rivers in Yangzhou. Besides, relationship between the upstream and downstream of the urban rivers should also be taken into account in the design of the treatment scheme to make the post-dredging effects better.
(6) Results presented here is not only helpful to promote the treatment effects of the urban rivers in Yangzhou but also suitable for many other cities with similar circumstances in the world, especially cities in the Yangtze River Delta region of China.

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