Investigation on Sediment Treatment in a Heavily-Polluted River, China

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Abstract: Proper treatment of contaminated sediment in heavily-polluted rivers is of importance to water quality improvement, especially in black-odor rivers. In the present study, 86 columnar samples are obtained by drilling with depth of 3~4 m in the Maozhou River, known as black and odorous water body. Firstly, potential ecological risk indexes at different depths in the study area is calculated according to heavy metal concentration. Afterwards, the dredging depths are determined based on vertical pollutant level analysis. Then, a harmless treatment system is established to achieve stabilization and solidification of dredged sediment. The results of this study provide systematic scheme and valuable reference for sediment treatment in black and odorous rivers.

1 INTRODUCTION

Sediment is one of the most important component of an aquatic ecosystem which can provide a production environment for microorganisms and food for fish. It is also the main sink of various extraneous chemicals. As a result, the sediment will be polluted if chemical concentration exceeds a threshold, called contaminated sediment, thus causing permanent hazards to water bodies (Singh, 2005; Kara, 2017). What's worse, accumulated contaminants in sediment could result in secondary pollution because they can be released back to the water body under disturbance of hydrodynamic force or human activities by effect of molecular diffusion, particle resuspension, and bioturbation (Wang, 2016). Therefore, contaminated sediment is often regarded as the secondary pollution source in deteriorating water quality and becomes the focus in water treatment (Kwaterczak, 2009). Among many chemicals in sediment, Heavy metal elements (HME) should be given enough attention. HME are generally defined as metals with relatively high densities, atomic weights, or atomic numbers. HME are accumulated in sediment under effect of adsorption, complexation and precipitation and usually attach to fine-grained components (Lin, 2016). They not only influence aquatic ecosystem but also threaten human health.

Thus, harmless treatment of contaminated sediment is of importance in river projects. A variety of remediation options for polluted sediments is available (Rulkens, 1998; Thomas, 2001; Saponaro, 2003; Rulkens, 2005), mainly including in-suit and ex-suit treatment. It is better to choose ex-suit treatment as the pollutant concentration greater than 2~3 times the local background value (Chen, 2011).

Maozhou River, located in Bao'an District of Shenzhen, Guangdong Province, Southwestern China, which has been experiencing rapid urbanization and industrialization. More and more HME are released to water body and then accumulated in the sediment. As a result, the sediment is characterized as to be black and odorous, which is threatening the living environment. According to studies from year 1996 to 2016 (Jia, 2001; Dai, 2010; Gong, 2016), it can be seen that sediment has been polluted by HME seriously. In order to grasp the situation of sediment pollution, a detailed investigation has been conducted using columnar samples in 2016, especially on vertical pollution of heavy metals in different depths.

Therefore, the objectives of the present study are: (1) to understand the sediment pollution risk; (2) to determine the dredging depths at different observed points; (3) to establish a sediment treatment system

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for solidification and dehydration of dredged sediment.

2 SEDIMENT POLLUTION CONDITIONS

2.1 Study Area

Maozhou River springs from the Yangtai Mountain, running through Dongguan City and Shenzhen City and into the Pearl River Estuary, as shown in Figure 1. There are about forty one rivers in the basin area, including 1 trunk stream, 23 second-order tributaries and 17 third-order tributaries.

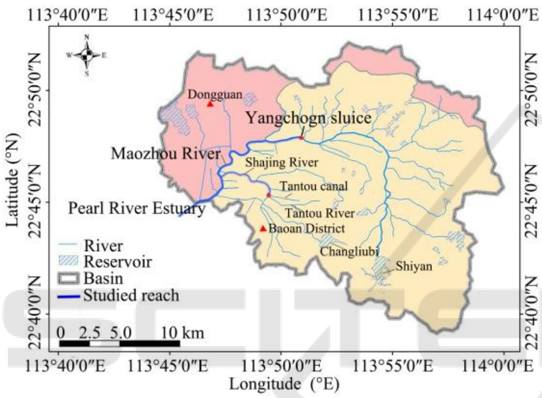

Figure 1. Maozhou River Basin.

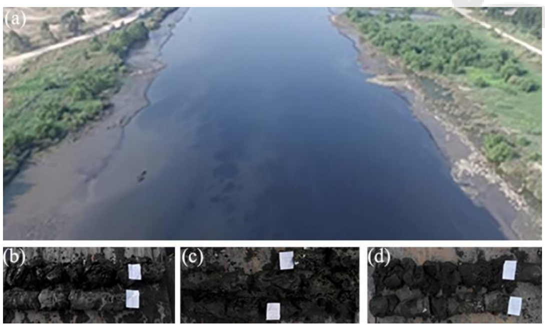

Figure 2. Sediment pollution conditions: (a) black and odorous water body; (b)~(d) black and odorous sediment.

Due to the urbanization and industrialization in recent decades, Maozhou River has been disturbed by human activities significantly. As a result, increasing domestic, municipal and industrial wastewater have been discharged into rivers which have caused black and odorous sediment as well as water body, as shown in Figure 2.

2.2 Sample Collection

During the summer months of July and August in 2016, 86 borehole columnar samples were collected with depth of 3~4 m in Maozhou River (reach A and C) and Shajing River (reach B), as shown in Figure 3. Each point was located by GPS precisely. Each borehole columnar sample was divided into four layers, marked as I (0~1 m), II (1~2 m), III (2~3 m), IV (>3 m) and layer I represents the surface. Each layer was divided into two parts on average. Then, the HME of Cu, Zn, Cr, Cd, Pb and Ni were tested by plasma direct reading spectroscopy. Therefore, for a certain HME, there were eight values for each points.

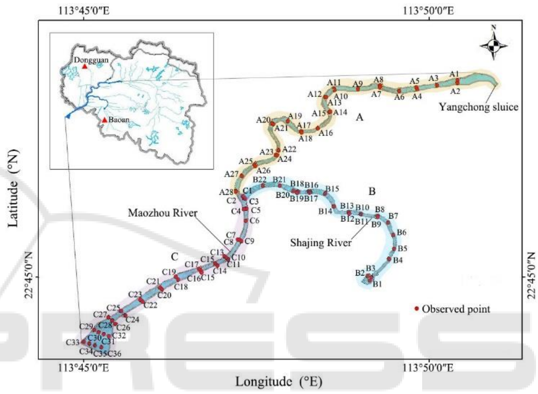

Figure 3. Distribution of observed sections and points.

3 SEDIMENT POLLUTION RISK LEVEL

3.1 Analysis Method

The potential ecological risk index (RI) is applied to evaluate pollution risk level of HME. It was proposed by Hakanson in 1980, which taken into account the effects of pollutant concentration and toxicity on the environment, and can comprehensively reflect the impact of heavy metals on the ecological environment (Hakanson, 1980; Xu, 2008). RI can be calculated as follows:

$$RI = \sum_{i=1}^{n} E_{\mathrm{r,i}} \tag{1}$$

$$E_{\mathrm{r,i}} = T_{\mathrm{r,i}} \times P_{\mathrm{i}} \tag{2}$$

$$P_{\mathrm{i}} = \frac{C_{\mathrm{i}}}{C_0} \tag{3}$$

Where *RI* is the potential ecological risk index; $E_{r,i}$ is the potential ecological risk coefficient of a certain heavy metal element; P_i is pollution index of a certain heavy metal element; $T_{r,i}$ is biotoxicity weighting coefficient of a certain heavy metal element, according to Table 1; C_i is the measured concentration of pollutants of a certain heavy metal element; C_0 is the soil background values of Shenzhen City, according to Table 2.

Once the *RI* is calculated, pollution risk level can be determined according to Table 3.

Table 1. Biotoxicity of heavy metals.

Element species	Cu	Zn	Cr	Ni	Pb	Cd
Biotoxicity	5	1	2	5	5	30

Table 2. Background values of heavy metals.

Element species	Cu	Zn	Cr	Ni	Pb	Cd
Background values (mg/kg)	11.10	78.70	30.97	17.80	40.90	0.09

Table 3. Potential ecological risk coefficient and comprehensive potential ecological risk index.

Er,i	RI	Pollution risk level
<40	<150	Light ecological risk
40~80	150~300	Medium ecological risk
80~160	300~600	Strong ecological risk
160~320	⩾600	Very strong ecological risk
⩾320	⩾600	Extremely strong ecological risk

3.2 Pollution Risk Analysis

According to the HME content, the sediment pollution risk level at different observed points with various depths are determined by potential ecological risk index (*RI*).

Generally, along with the increase of depth from riverbed surface, the *RI* decreases gradually for all reaches. That is, the surface layer (layer I) is the most polluted.

In the present study, average sediment pollution level corresponding to value of *RI* at different layers for each reach are given, as shown in Figure 4. The *RI* in layers I~III of reach B and C are greater than 300. That is, the pollution risk level has exceeded 'very strong'; it evenly reaches 'extremely strong' for reach B in layer I and II. For reach A, *RI* in layer I approaches to 300, thus the pollution risk level is 'medium'; *RI* in layers II and III are all less than 150, of which the pollution risk levels are 'light'. Lastly, for reach A, B and C, *RI* in layer IV are all less than 150, of which the pollution risk levels appear to be 'light'.

Therefore, it is appropriate to dredge the contaminated sediment for high pollution risk level. Specifically, taking observed points (A10, B10 and C10) for example, if the pollution risk level is 'light', sediment will not be dredged; otherwise, sediment will be dredged, as shown in Figure 5.

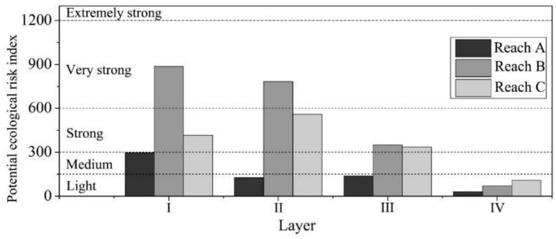

Figure 4. Potential ecological risk index at different layers for each reach.

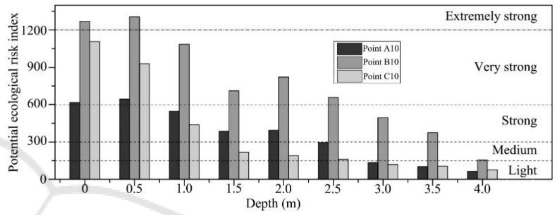

Figure 5. Potential ecological risk indexes for observed points A, B and C at different depths.

4 SEDIMENT DREDGING AND TREATMENT

4.1 Dredged Depths Analysis in Study Area

According to the pollution risk level of observed points at different layers, the dredged depths can be determined. For each columnar sample has been divided into eight sub-samples with depth of 0.5 m, it can be need to distinguish the polluted and unpolluted sediment by physical methods such as colour and plasticity. Generally, sediment in vertical direction can be divided into pollution area, transition area and clear area. In the pollution area, the colour of the sediment is black to dark black, which is slurry or flowing plastic and smells bad. In the transition area, the colour is mostly grey-black and soft-plastic, of which the density is greater than the polluted area. In the clear area, the colour of the sediment keeps the normal colour similar to the unpolluted local soil, which is generally odourless and has the maximum density.

Accounting for the above principles, the minimum and maximum dredging depths in reach A are 1.05 m 3.31 m, respectively; the values for reach

B are 1.20 m and 3.43 m, respectively; the values for reach C are 1.65 m and 3.65 m, respectively.

Afterwards, the dredging depths in the study area can be determined by reverse distance interpolation method, as shown in Figure 6. The dredging depths range from 1 m to 4 m in the study area. The total amount of dredging is above two million cubic metres.

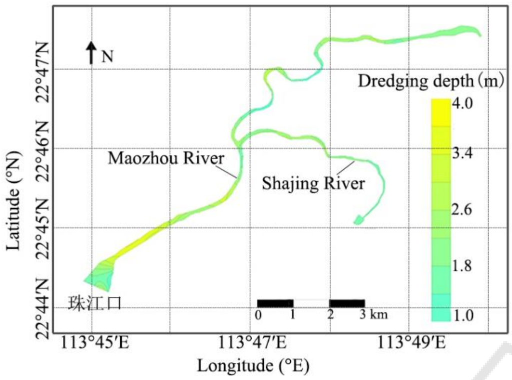

Figure 6. Dredging depth in study area.

4.2 Dredging Method

Therefore, in order to improve the situation of black and odor water in Maozhou River, it is necessary to scavenge the contaminated sediment known as 'authigenic pollution treatment'. However, the sediment can also secondary pollution under violent disturbance. Accordingly, in order to avoid secondary pollution as much as possible, selection of silt dredging method is also critical.

Common equipment for sediment dredging include cutter suction dredger, rake suction dredger, grab dredger, water excavator, stirring suction pump and suction pump, each of which has its advantages and disadvantages, as shown in Table 4. Therefore, the cutter suction dredger has been chosen for lowest ecological impact and highest dredging efficiency, what's more, it is convenient for underwater transportation.

Table 4. Sediment dredging equipment.

	Cutter suction dredger	Rake suction dredger	Grab dredger	Water excavator	Stirring suction pump	Suction pump
DE	●	◎	○	○	◎	○
CE	●	●	○	○	◎	○
MC	●	●	○	○	●	●
EI	○	○	●	●	◎	◎

Note: ●, ◎ and ○ represent high, medium and low, respectively.

DE is dredging efficiency; CE is conveying efficiency; MC is moisture content; EI is ecological impact.

4.3 Sediment Treatment System

Faced with a huge amount of dredged sediment, it is beneficial to adopting ecological treatment method, realizing resource reuse. The key problem is how to deal with pollutants in sediment properly.

Except for heavy metals, polluted sediments very often comprise a mixture of strongly different pollutants such as organic pollutants and PAHs. A comprehensive system is needed for treatment of multi-pollutant sediment. In the present study, a treatment system is established to achieve harmlessness, stabilization and solidification of dredged sediment, as shown in Figure 7. This system mainly consists of five subsystems: ①Classification decrement system; ② Concentration system; ③ Mixing system; ④ Homogenization conditioning system; ⑤Solidification system.

(1) Classification-decrement system

Dredged sediment with a large number of water bodies can be classified into gravel, waste and slush for the purpose of decrement. The gravel is reused by cleaning and the waste is treated by harmless landfill. The slush goes into the next subsystem.

(2) Concentration system

Moisture content of slush is reduced significantly after concentration system, which will be classified into mud and residual water. Residual water can also be classified in standard water and mud through water treatment. Standard water is discharged into river and mud returns to concentration system.

(3) Mixing system

The characteristic of mud mixed fully with solidification, flocculant and chelator will be changed, which makes the mud easy to be stabilized and solidified.

(4) Homogenization conditioning system

After treatment of mixing system, mud flow into the next system by self. Thus, active ingredients in the added materials can be released speedy. Further, mud is concentrated along with residual water.

(5) Solidification system

Concentrated mud will be made into mud cake after solidification system using plate and frame filter press. Mud cake is harmless to environment, of which moisture content is less than 40%, and then can be put in stackyard for reuse. Besides, the residual water is transported back to concentration system for next circulation.

Mud cake appears to be a good eco-building materials, which is used to make ceramic ecological permeable brick in the present study, as shown in Figure 8. Ceramic ecological permeable bricks have many advantages, such as high strength, strong water permeability, good skid and wear resistance, low cost and so on. They have been widely used as revetment material and permeable paving material in Maozhou River projects.

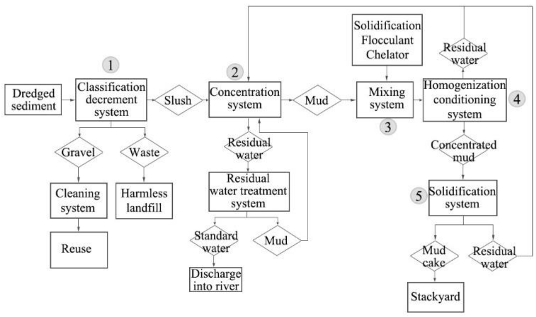

Figure 7. Sediment treatment system.

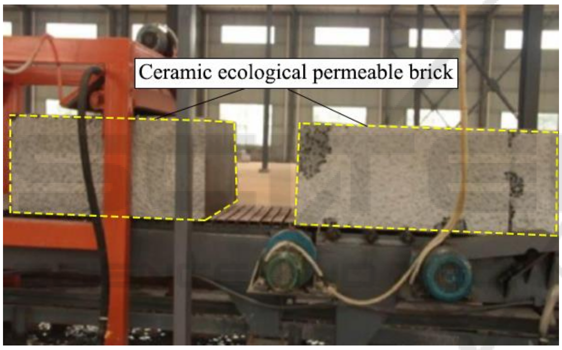

Figure 8. Ceramic ecological permeable brick.

5 CONCLUSION

In the present study, the dredging depths in Maozhou River are determined based on analysis of sediment pollution risk level at different depths of 86 observed points. What's more, a sediment treatment system is established to stabilize and solidify the dredged slush. From the previous discussion, the following important conclusions can be drawn.

Sediment in the surface layer is suffering strong ecological risk even very strong ecological risk, which is necessarily to be dredged. Sediment with depth greater than 3 m appears to be light ecological risk.

Based on the principal that it needs to be dredged as sediment pollution level greater than 'light', dredging depth ranges from 1 m to 4 m in the study area.

Answering for lowest ecological impact and highest dredging efficiency, the cutter suction dredger is used to dredge the polluted sediment.

The sediment treatment system mainly consists of five subsystems, which can be applied to stabilize and solidify contaminated sediment. Afterwards, mud cakes can be used to make ecological permeable materials.

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