The Release Characteristics of Nutrients from Contaminated Sediment and Guiding for Dredging Depth

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Abstract: Dredging is an efficient method for removing contaminated sediment, and the release characteristics of pollutants are important parameters for dredging engineering design. In this paper, the release characteristics of nutrients from contaminated sediment were examined. The dredging depth was determined by the adsorption-desorption equilibrium method. In the sedimentation experiment, the suspended sediment needed 72 h to stabilize, and the deeper sediments showed less effective sedimentation，the diaphanetity for 0~20 cm sediment is 16 cm. In the releasing test, the characteristics of NH_4-N, shown as “L”, was different from P, which had an extreme concentration. The maximum releasing concentration for P is the layer of 20~40 cm sediment, and that for NH_4-N is 0~20 cm. The corresponding equilibrium concentration is 0.1 and 0.16 mg/L for P in the static and dynamic station, respectively, and that for NH_4-N is 2.0 and 3.2 mg/L. On the basis of the vertical release equilibrium profile and sedimentation test, the dredging depth in this study was recommended to be 80 ± 5 cm.

1 INTRODUCTION

Contaminated sediment occurs frequently because of urbanization and industrialization without effective protection (Polrot et al., 2021; Wang et al., 2018) Contaminated sediments enrich contaminants to higher concentration than the background value such as nutrients, heavy metals, pesticides, fertilizers, microplastics, and other persistent organic pollutants, which have severe effect on the water system(Wang et al., 2020; Zhou et al., 2021). The water quality degradation and ecological destruction are the direct consequence. Among these, eutrophication resulting from the surplus of nutrients (nitrogen and phosphorus) is one of the problems.

Because of safety concerns and less effect in harnessing, degradation of water quality and eutrophication of fresh water lakes have caught global attention. Generally, the excess input of nutrients, nitrogen and phosphorus, are regarded as the main reason (Sondergaard et al., 2017). However, more studies have verified that interruption of exogenous input cannot turn around the degradation, and that endogenous pollution during the process of eutrophication is the major reason for the lake problems (Tu et al., 2019). Among the remediation technologies such *in situ* capping, solidification/stabilization, oxidation-reduction and other *ex situ* treatment (Wang et al., 2018), sediment dredging can fundamentally solve the problem of endogenous pollution (Zhong et al., 2018)， which is widely accepted in water environment treatment, but the relevant engineering and design need to mature according to the specific situation. In most case, *ex situ* remediation is the first choice in many restoration projects because of the severity of the pollution and doubts that *in situ* remediation methods can provide stable results over the long-term. However, in the lower level of pollution area or deeper site, in situ treatments is alternative.

Shitang (ST) Lake, a typical inland lake located at the edge of a city, functions in climate regulation and landscape. In years of high speed economic development, the breeding industry both for fish and poultry has been permitted in and around the lake. Consequently, bait, fodder, and excrement have been inputted into lake system, and then the pollutants were gradually have been enriched in the sediment, this resulted in endogenous pollution (Wang et al., 2021). Hence, on the basis of exogenous control, endogenous removal is necessary and benefits

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processes for lake ecotopic recovery.

Dredging is an efficient method for removing contaminated sediment, but how to decide the dredging depth is always controversial (Wang et al., 2021). According to the adsorption-desorption equilibrium method, this study examined the release characteristics of pollutants in different stations. The dredging depth was confirmed from the point of controlling pollutants and the objective of water quality. The method and result can be consulted by some related engineering.

2 SAMPLE COLLECTION AND STUDY METHOD

2.1 Site Description

ST Lake is located in Anqin Province, a city at the lower reaches of the Yangtze River. This lake was investigated because of its function zoning, which is a standby source of drinking water. Its water quality is becoming worse, and the water quality goal is the National Standard for Surface Water (GB3838-2002) Class III (NSSW-III). There are 6 rivers flowing into lake and only 1 flowing channel out of lake (Figure 1), related water qualities are shown in Table 1. According to previous evaluation, the lake is moderate eutrophication and situation is getting worse. Moreover, the sediment deposition in the south of the lake is more serious than north, reaching more than 100 cm. The dredging engineering thus mainly focused on this area, and corresponding sediment is sampled in this site to study the release characteristics of nutrients from contaminated sediment and guide for dredging depth.

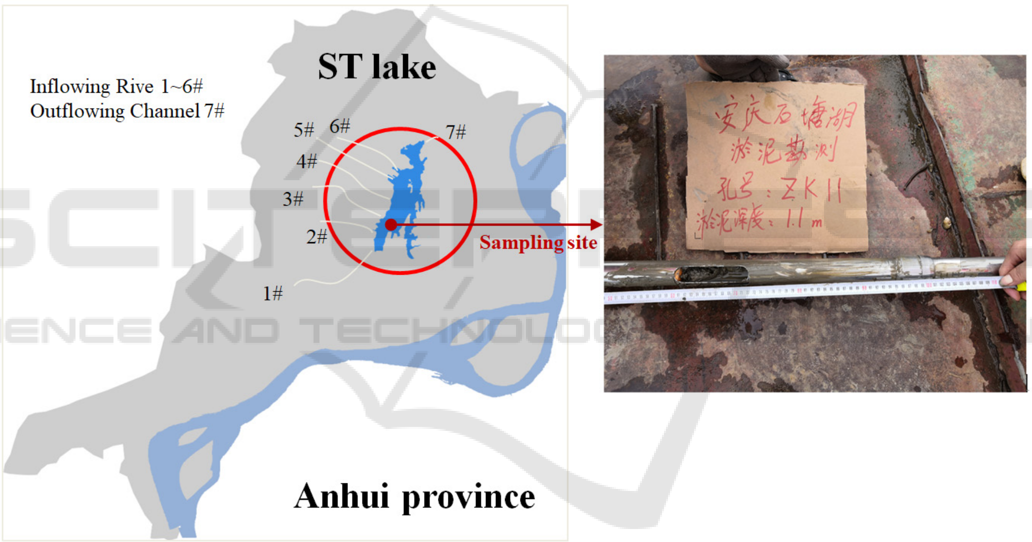


Figure 1: Investigation site and sampling exhibition.

Table 1: Rivers and lake water quality.

Site	pH	TP (mg/L)	NH_3-N (mg/L)	TOC (mg/L)
NSSW-III	6~9	0.05	1.0	-
1#	8.8	0.12	0.42	11.3
2#	8.5	0.10	0.63	14.7
3#	8.9	0.10	0.64	9.8
4#	8.8	0.17	0.58	15.5
5#	8.9	0.12	0.52	12.4
6#	8.8	0.11	0.39	25.6
7#	8.9	0.14	0.59	15.2
Sediment Sampling Site	8.9	0.14	0.461	7.7

Note: 1~6# is 6 inflowing river and water sample is collected at estuary, 7# is outflowing channel and water sample is collected at the head of the channel.

2.2 Sediment Collection

Two sites in the serious deposition area (approximately 1.1 m) were decided for sediment collection according to the lake district survey data. The sediment from the surface layer to the depth of 1 m were equally divided into five layers (0-20 cm, 20-40 cm, 40-60 cm, 60-80 cm, and 80-100 cm), collected by a cylindrical sampler, sealed, and transported to the laboratory.

2.3 Experiment and Analytical Method

2.3.1 Settleability Testing

The mixture sediment (1 g, dry weight) was transferred into a 1,000 mL graduated cylinder, and water was added up to the scale mark. The settling times were 0, 12, 24, 36, 48, and 72 h, and we recorded the process of settling. Moreover, five different layer sediments (0.1 g, dry weight) were placed into respective 500 mL beakers, and 500 mL of water was added. After standing for 48 h, the sedimentation effect was recorded. The settleability was determined by diaphaneity according to disk method.

2.3.2 Static Releasing

In order to simulate the pollutant release characteristics of the different layer sediments, five different layer sediments were blended with water at a ratio of 1:10 in consideration of both the ratio of water and sediment in the lake and the effect of the hinge suction method. The mixture was fully stirred by magnetic stirrers for 2 min at indoor temperature (23±2 ℃). After standing for 7 days, the concentration variations of TP and NH_4-N and solution pH were recorded.

2.3.3 Dynamic Release

In order to simulate the pollutant release characteristics of the hinge suction process and to evaluate the maximum release capacity, five different layer sediments were blended with water at a ratio of 1:10, and stirred by magnetic stirrers. We then recorded the TP and NH_4-N concentrations of the liquor at 2, 4, 6, 8, 12, 24, 36 and 48 h and solution pH.

2.3.4 Analytical Method

In this study, all solution TP and NH_4-N are measured by persulfate digestion and Nessler's reagent method, respectively.

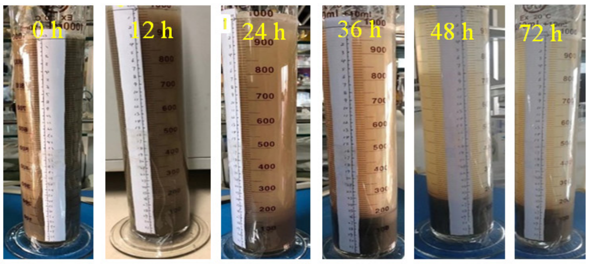
3 RESULTS

3.1 Settleability of the Sediment

Sediment settleability is one of the important properties for dredging engineering (Polrot et al., 2021). After the sediment and water mixture was dredged and transported to land, its settleability parameter was used to decide the scale of sediment treatment plant especially for pretreatment such as preliminary precipitation (Smith et al., 2009). As shown in Table 2 and Figure 2, the diaphaneity of sedimentation process was clearly recorded from 0 to 72 h, in which the higher value of diaphaneity means better settleability. At the beginning (<12 h), the sedimentation process and layer separation was not obvious, the diaphaneity was only 0.3 cm. At 24 h, layer separation and the muddy water interface could be observed clearly. After that, the liquid supernatant became more limpid. Until 72 h, the diaphaneity of the liquid supernatant is 12 cm that was unchanged and showed no difference with 48 h; thus, the optimum precipitation time was determined to be 48 h.

Table 2: The diaphanetity of the mixture sediment at different standing time point and different layer sediments after standing 48 hours.

Mixture sediment	Diaphaneity	Different layer sediment	Diaphaneity
0 hour	0 cm	**Original state**	0 cm
12 hour	0.3 cm	**0~20 cm**	16 cm
24 hour	2 cm	**20~40 cm**	12 cm
36 hour	6 cm	**40~60 cm**	7 cm
48 hour	12 cm	**60~80 cm**	5 cm
72 hour	12 cm	**80~100 cm**	4 cm



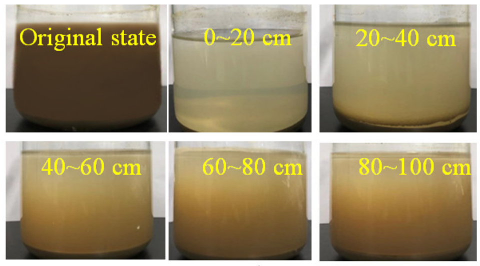


Figure 2: The sedimentation of the mixture sediment from 0 to 72 h (a) and sedimentation efficiency of different layer sediments from 0 to 100 cm (b).

The settleability of the different layer sediments in another test is also shown in Table 2. After 48 h static settlement, there was an obvious difference between the superficial-layer (0-40 cm) and deeper-layer (40-100 cm) sediments. The deeper the sediment was, the worse was the sedimentation efficiency. In the upper layer (0-40 cm), the water can become clarifying, and the diaphaneity is ≥12 cm . But at deeper layers, the sediment stays almost suspended, the diaphaneity from 60 cm to 80 cm is ≤4 cm. The settling property is the most important parameter that decides the dosage of flocculating agent in the process of sediment treatment, as well as the water-body turbidity or the water environment recovery efficiency after dredging (Li et al., 2021). Moreover, the settling property of the sediment controlled by many sides included particle size, particle concentration, particle charge, disturbance, and so forth (Wang et al., 2020). Among these aspects, particle size is a deciding factor. As shown in Table 3, the difference in size distribution of the different layer sediments is clear. The 0-20 cm layer contained lower content of clay particles, which suggests better setting property and vice versa.

Table 3: The size distribution of different layer sediments.

Size distribution	Depth (cm)				
	0-20	20-40	40-60	60-80	80-100
Clay particle (<0.005 mm)	18	24	43	41.9	53
Silt (0.075–0.005 mm)	76.5	51.3	52.3	53.5	42.3
Fine gravel (0.25–0.075 mm)	5.5	13.7	4.7	4.6	4.7
Medium sand (0.5–0.0.25 mm)	0	6.3	0	0	0
Coral sand (2–0.5 mm)	0	3.8	0	0	0
Gravel (10–2 mm)	0	0.9	0	0	0

3.2 Release Characteristics of P

The release characteristics of P from different layer sediments in the static and dynamic states are shown in Figure 3. The release characteristics of P from different layer sediments were similar both in the static and dynamic tests, as well as pH value that is 8-9 in all test solution. The concentration of P increased for a certain period and then decreased until equilibrium. Other study also concluded that disturbance can make pollutants increase in water for a period of time and then decrease to the initial state resulting from desorption and adsorption. However, in Hu's study this phenomenon also found in release characteristics of COD and TN instead of TP (Hu et al., 2021). The released amounts were different for various sediment layers. The release capacities for the 20-40 cm and 80-100 cm layers were the maximum and minimum, respectively. The highest concentration was 0.18 mg/L at the first day in static test and was almost equal to the dynamic, but the dynamic concentrations were higher than the static concentrations for any sediment layer in equilibrium station that is similar with other study. In the static test, the equilibration time and the equilibration concentration were about 3 day and 0.10 mg/L, respectively, and those in the dynamic test were 12 h and 0.16 mg/L, respectively. The equilibration in the static test showed less reaction time related to the dynamic test.

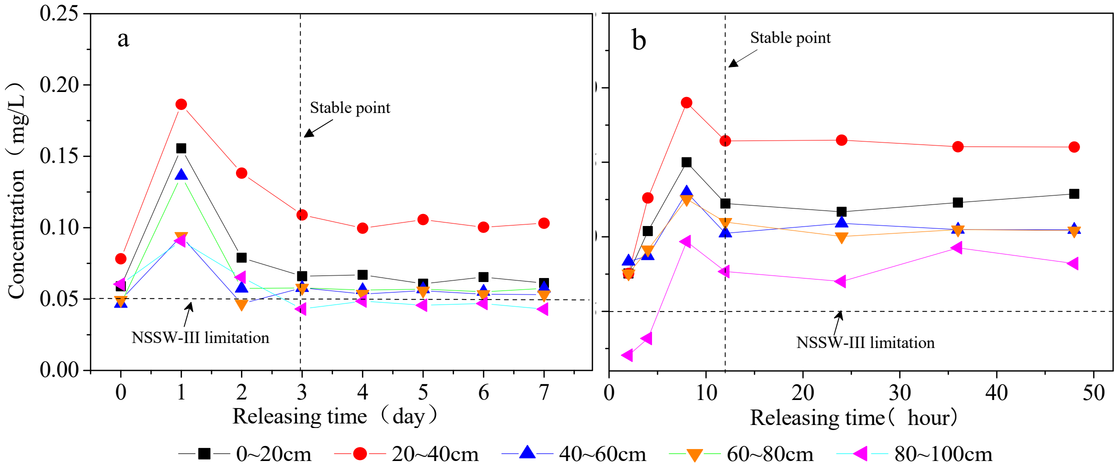


Figure 3: The static (a) and dynamic (b) release of P from different depths of contaminated sediment.

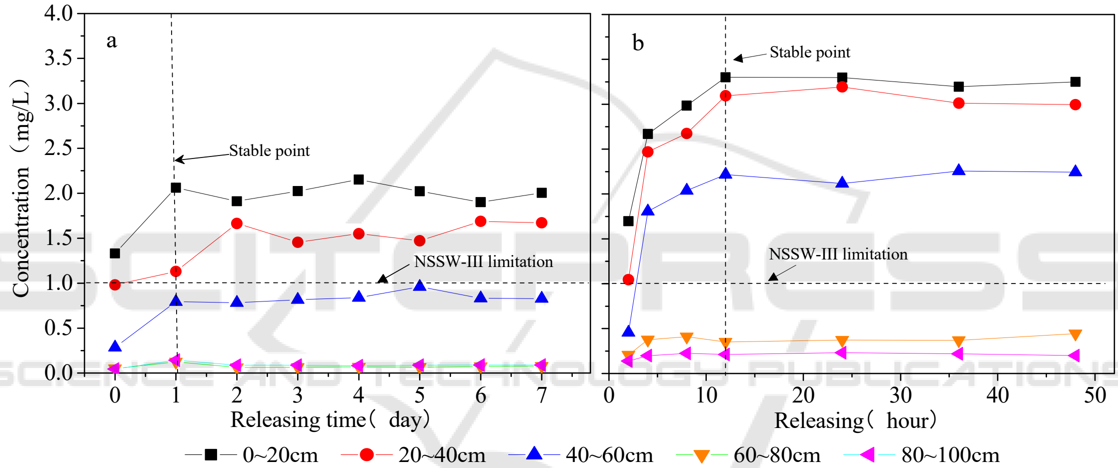


Figure 4: The static (a) and dynamic (b) release of NH4-N from different depths of contaminated sediment.

3.3 Release Characteristics of NH_4-N

The release characteristics of NH_4-N from different layer sediments in the static and dynamic states are shown in Figure 4. All layer sediments for NH_4-N release characteristics were similar to those of P in general. The release process of NH_4-N is shown as "L" as well as other studies (Hu et al., 2021; Pan et al., 2019). Unlike P, the release capacity of NH_4-N for the 0-20 cm and 80-100 cm layers were the maximum and minimum, respectively. The equilibrium concentration was 0.2 mg/L on the first day in the static test; this concentration was lower than that in the dynamic test. Moreover, in the static test, the 60-80 cm and 80-100 cm layers barely released NH_4-N into the water. However, intense disturbance can promote nitrification resulting in the decrease of NH_4-N, and this phenomenon has no appeared in this study (Pan et al., 2019), in which NH_4-N concentration has no decline with time.

4 DISCUSSION

The design of dredging depth is an important part in dredging engineering (Bianchini et al., 2019). Normally, the process of adsorption and release is balanceable between the interfaces of water and sediment (Horppila, 2019). When dredging engineering is conducted, the balance is broken, the sub-layer sediment is exposed to water, and the unstable pollutants can be released from the sediment to the water. However, this process of pollutant release is almost static after dredging from sediment. The release equilibrium of P and NH_4-N at different depths of contaminated sediment in static are shown in Figure 5. According to bathmometry, the dredging depth was about 60 cm for P, and that for NH_4-N was 80 cm. Moreover, taking the NSSW-III into consideration, which was 0.05 mg/L for P and 1.0 for NH_4-N, the dredging depth needed to be designed as 85 cm for P and 56 cm for NH_4-N.

The recovery of transparency in the water system and mud-water mixture also needed to be taken into consideration. According to our experiment results, the deeper sediments had less effective sedimentation, which meant deeper dredging needs more time to recover transparency in the water system, as well as more time and more coagulant to pretreat the mud-water mixture in a sediment treatment plant (Wang et al., 2020). Moreover, dredging more sediment from the water system to land increased the comprehensive cost, and there were studies also indicating that dredging deep was not positive correlated with water quality recovery and ecology restoration (Wasserman et al., 2016; Zhang et al., 2010). Overall, the dredging depth was designed as 80 ± 5 cm under the cost control and goal control.

However, dredging is just one method of remediation water environment. In order to recover water sysem's ecological function effectively, other projects also need to be conducted such as controlling area source pollution, harnessing sewage outlet, protecting inflowing river water quality and so on. Besides, ecological remediation under water is necessary to keep a long-term benefit for water system following dredging engineering.

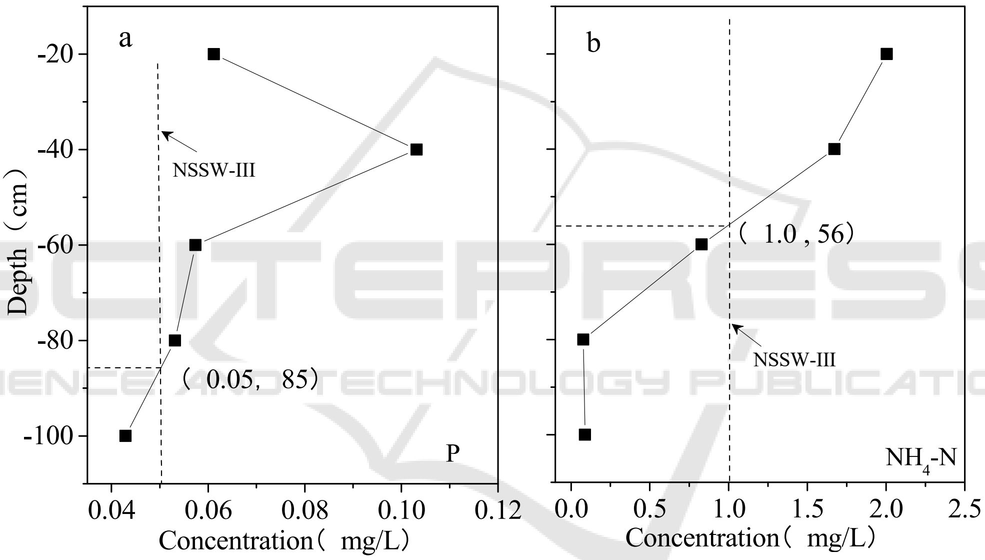


Figure 5: The release equilibrium of P (a) and NH4-N (b) at different depths of contaminated sediment.

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