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Remediation effects of used brick powder on nutrient-laden sediment

Chenrong Jia[a,c], Gu Li[b], Yanran Dai[a,d], Feihua Wang[a], Wei Liang[a,*]

[a]*State Key Laboratory of Freshwater Ecology and Biotechnology, Institute of Hydrobiology, Chinese Academy of Sciences, Wuhan 430072, China, Tel. +86 27 68780951; emails: jcr.111@163.com (C. Jia), yanrandai@hotmail.com (Y. Dai), wangfeihua93@ihb.ac.cn (F. Wang), liangwei02@tsinghua.org.cn (W. Liang)*
[b]*Yangtze River Fisheries Research Institute, Chinese Academy of Fishery Sciences, Wuhan 430223, China, email: ligu667@yahoo.com*
[c]*Shenshui Baoan Water Group, Shenzhen 518102, China*
[d]*Key Laboratory of Yangtze River Water Environment, Ministry of Education, Tongji University, Shanghai 200092, China*

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ABSTRACT

Sediment is one of the major sources of internal pollution in lakes. Pollution control of contaminated sediment has become a hot topic in the world. In this paper, used brick powder was chosen as a passivator for remediating nutrient-laden sediment, and the relationships between brick powder dosages and pollutant indexes in the overlying water and sediments were determined. The results showed that in the overlying water, brick powder could be used to reduce total phosphorus (TP) concentrations; however, it had no effects on total nitrogen (TN), chemical oxygen demands, pH, and oxygen. In the sediments, organic matter (OM), TN, TP, Fe–P, Al–P, and Ca–P concentrations were decreased, while organic phosphorus (Org-P) was increased. Using principal component analysis, it was found that brick dosage could significantly affect the sediment physicochemical properties. A positive correlation was established between brick dosage and Org-P, and a negative correlation with TP and organic matter. An optimal dosage of 20 g of brick powders was determined to be effective in the sediment remediation of this study.

Keywords: Used brick; Remediation effect; Nutrient-laden sediment; Optimal dosage

1. Introduction

Eutrophication has been recognized as a major environmental problem in the world in recent years. Excess amount of nutrients, especially nitrogen and phosphorus, are responsible for the eutrophication of water bodies. However, sediment, one of the most important sources of internal pollution in lakes, contains a great number of nutrients such as nitrogen and phosphorus. As the environment is altered by nature or human activities, these nutrients could be released from the sediment into the overlying water. Therefore, to effectively control eutrophication, it may be necessary to remediate the nutrient-laden sediment.

Sediment pollution control techniques consist of *in situ* and off-site treatment technologies [1,2]. *In situ* treatment technologies include inactivation, capping, and bioremediation [3–5]. Among them, inactivation technology is a highly effective technique for reducing internal nutrient loading, and the nutrient content in the overlying water is reduced by retarding nutrient release from lake sediments [6]. Dagowsee Lake (Germany) was treated with nitrate iron compound in 2002, and the phosphorus release from sediment

*Corresponding author.

surface was effectively reduced just one year after treatment [7]. Total phosphorus (TP) concentrations in the water of Morey Lake, USA, decreased from 20–30 μg/L (1986) to 10 μg/L (1990) after alum and sodium aluminate were applied [8].

The selection of effective passivator is the key factor for inactivation technology. Among many materials, including aluminum salts (such as $Al_2(SO_4)_3$, $AlCl_3$), iron salts (such as $FeCl_3$, $Fe_2(SO_4)_3$), calcium salts (such as $CaCl_2$, CaO) [9–11], aluminum salt has been most widely used, and is the original passivator for practical application. Although these passivators are common, their cost is high. Therefore, there is a need to have a new and economical material.

In recent years, with the development of urbanization in China, building demolition has created a large amount of building wastes such as concrete and brick. The disposal of building wastes is becoming a problem; however, these wastes, which are rich in aluminum, calcium, and iron, could be used to remediate the nutrient-laden sediment.

The purposes of this study were to determine: (1) The feasibility of used brick powder to remediate the nutrient-laden sediment; and (2) the optimal dosage of used brick powder for sediment remediation.

2. Materials and methods

2.1. Experimental materials

2.1.1. Used brick

The used bricks used in the experiment were obtained from a housing project in Wuhan, China. The bricks were crushed into coarse grain and ground into fine powder, followed by sieving through 100-mesh sieve prior to air dry. The quantities of Fe_2O_3, Al_2O_3, CaO, MgO, and SO_3 were determined by titrimetry with EDTA. SiO_2 and the loss on ignition were determined using potassium fluosilicate volumetric and incandescent methods, respectively. The composition of these materials is shown in Table 1.

2.1.2. Sediment and overlying water

Sediment samples used in the static experiments were collected from the top 0–10 cm of the sediment in a fish pond, Wuhan, China. The main physicochemical properties of the sediment are shown in Tables 2 and 3.

The overlying water was taken from Donghu Lake (30˚33´N, 114˚23´E), Wuhan, China. The basic physicochemical characteristics of the water for total nitrogen (TN), TP, and chemical oxygen demands (COD) were 2.19 ± 0.02, 0.316 ± 0.001, 26 ± 2.1 mg/L, respectively.

2.2. Experimental system

Twelve glass cylinders (20 × 15 × 30 cm) were used in the experiment. All cylinders were shaded against the light on four sides. A layer of sediment with 5 cm in thickness was placed in each cylinder; the brick powders were laid over the sediment, and then filled with water of 15 cm in height. In the experiment, there were four different brick powders dosage groups: 10, 20, 50 g, and 0 (the control).

2.3. Sampling and analysis

The experiment was carried out from April 4 to July 1, 2012. The overlying water was sampled every three days at the beginning, and then every five days during the last period. After the sampling, the water level was maintained using water from Donghu Lake.

The water samples were determined according to the standard method [12]. TP was determined using the ascorbic acid method at 700 nm with a SHIMADZU UV1800 spectrophotometer. TN was measured using alkaline potassium persulfate. COD was measured using a spectrophotometer (Hach DR 3900). Meanwhile, other physical and chemical characteristics, including pH, dissolved oxygen (DO), and temperature, were obtained using the portable Multimeter (Thermo ORION 5-STAR).

2.4. Sediment analysis

Sediment was sampled at the beginning and end of the experiment, then naturally air-dried and sieved with a standard 100-mesh sieve. OM was measured as loss in a muffle furnace at 550˚C for 2 h. The content of TP in the sediments was determined by heating the samples at 450˚C for 3 h, extracted by 20 ml of 3.5 M

Table 1
Composition of the brick (%)

Components	Fe_2O_3	Al_2O_3	CaO	MgO	SO_3	SiO_2	Loss on ignition
Content (%)	7.07	16.50	1.28	1.60	0.11	69.71	1.64

Table 2
The main physicochemical properties of the initial sediment (mean value ± SD)

Components	Water content (%)	pH	Organic matter (g/kg DW)	Total nitrogen (g/kg DW)	Total phosphorus (mg/kg DW)
Value	3.65 ± 0.8	7.06 ± 0.05	77.94 ± 0.99	2.15 ± 0.05	1,644.97 ± 24.39

Table 3
The contents of different forms of phosphorus in the initial sediment (mean value ± SD)

Parameter	NH_4Cl-P	Fe–P	Al–P	Org-P	Ca–P	Res-P
Content	21.62 ± 5.04	517.61 ± 5.04	378.50 ± 0.00	156.94 ± 40.35	235.62 ± 45.40	334.69 ± 24.39

HCl for 16 h, and then determined using ascorbic acid method [13]. The content of TN in the sediments was measured by digesting the samples with potassium persulfate.

Different forms of phosphorus in the sediment under various sequential extraction schemes were performed using dry sediment. Phosphorus can be separated into NH_4Cl-P, Fe–P, NaOH-TotP (Al–P and Org-P), and Ca–P, and they were extracted by NH_4Cl, $Na_2S_2O_4/NaHCO_3$, NaOH, and HCl solutions, respectively. In addition, Res-P was calculated by taking the difference between TP and the other [14].

2.5. Statistical analysis

The experiments were conducted in triplicate, and data were reported as mean values ± standard deviation. Statistical analysis was performed using SPSS 13.0, Origin Pro 8.0, and Canoco 4.5. Differences between groups were evaluated by one-way analysis of variance (ANOVA) and covariance analysis. Relationships were investigated using Pearson correlation. A probability level of 0.05 was used to establish significance ($p < 0.05$). Principal component analysis (PCA) was used for evaluating the compositive effect of brick dosage on the overlying water and sediment.

3. Results

3.1. Effect of brick powders on the overlying water

3.1.1. Total phosphorus

As seen from Fig. 1, TP in the overlying water kept relatively stable in the first 30 d, while increased significantly during the final 30 d, among them, the control increased to 0.764 mg/L, which was much higher than the initial concentration. Meanwhile, TP in the experimental group also increased, and experimental group for 10 g of brick powder increased to 0.681 mg/L, which was significantly higher than those of 20 g (0.310 mg/L) and 50 g (0.196 mg/L) groups ($p < 0.05$).

3.1.2. Total nitrogen

As shown in Fig. 2, TN in the overlying water increased firstly, then decreased quickly, and finally, remained relatively stable. No significant difference for TN concentrations in all the groups was detected ($p > 0.05$).

3.1.3. Chemical oxygen demands

Throughout the experimental period, COD concentrations in all the groups fluctuated, and no significant difference among the four groups was found ($p > 0.05$).

3.1.4. pH, DO and temperature

As seen in Figs. 4 and 5, temperature increased with the time, while DO decreased. During the experimental period, pH in all the groups remained relatively stable (7.6). The tendency of DO in the experimental groups and control was similar.

3.2. Effect of brick powder on the sediment

3.2.1. Organic matter

Comparing Table 4 with Table 2, we found that OM in the sediment after the experiment was lower

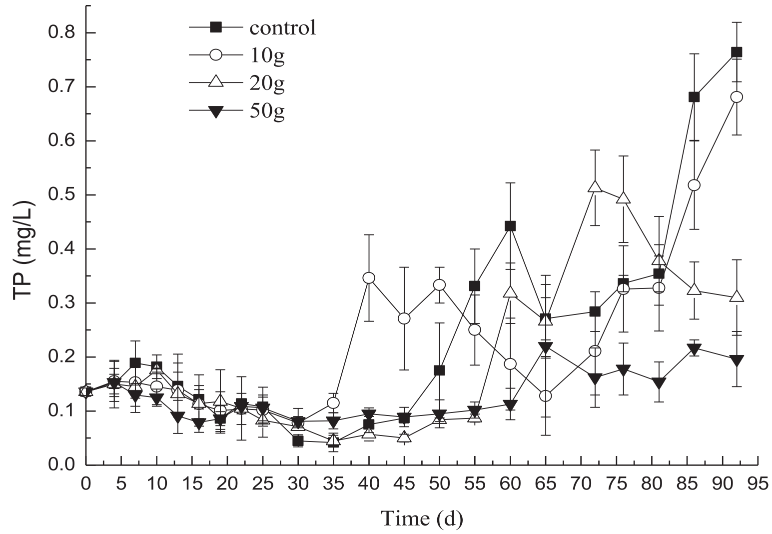

Fig. 1. TP in the overlying water.

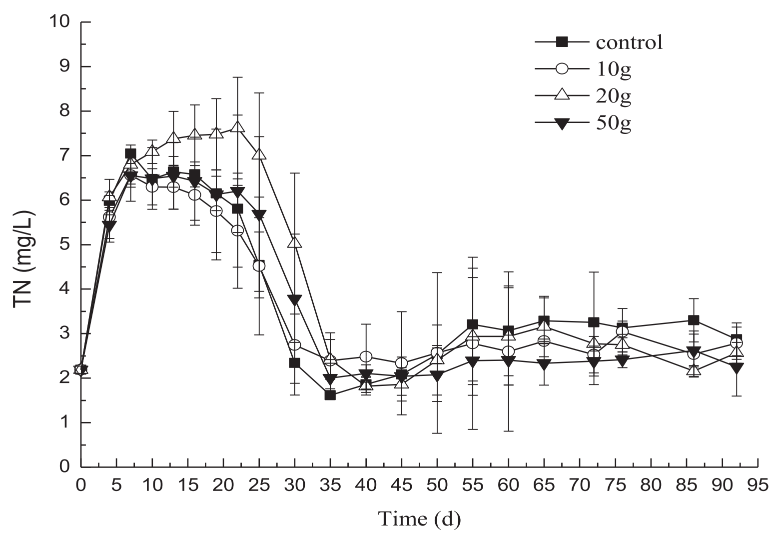

Fig. 2. TN in the overlying water.

than those of the initial. The experimental groups were much lower than that of the control, and OM in the experimental groups decreased with brick powder dosage.

3.2.2. TN

Compared with Table 2, Fig. 6 shows an increase of TN in control, and decreases of TN in the experimental groups.

It was noted that there was a significant difference for TN between the experimental groups and control ($p < 0.05$), but no significant difference among the three experimental groups.

3.2.3. Total phosphorus

Compared with Table 2, Fig. 7 shows decreases of TP in both experimental groups and control. It was noted there was no significant difference for TP in the sediment between 10 g group (1,437.36 mg/kg DW) and control (1,464.96 mg/kg DW) ($p > 0.05$); however, there were significant differences between 20 g

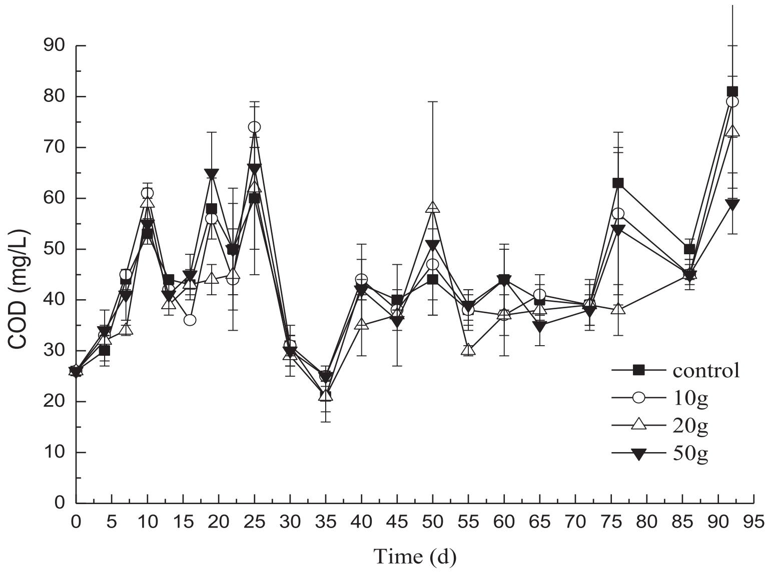

Fig. 3. COD in the overlying water.

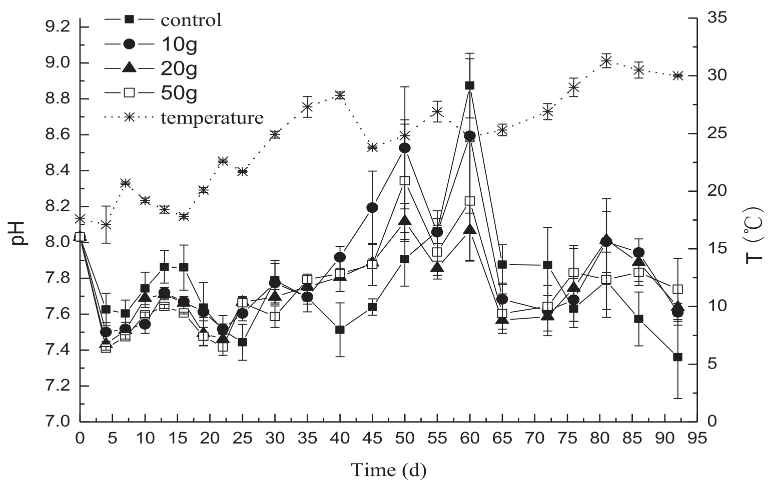

Fig. 4. pH value and temperature in the overlying water.

(1,322.67 mg/kg DW) and 50 g groups (1,206.64 mg/kg DW) and 10 g group & control ($p < 0.05$).

3.2.4. Different forms of phosphorus

As shown in Table 5 and Fig. 8, NH_4Cl-P in both experimental groups and control differed slightly, and did not change greatly compared with the initial value (Table 3). Fe–P in 10 g group and control were similar, but higher than those of 20 and 50 g groups. The change trend of Al–P was similar with Fe–P. There was a significant difference for Org-P between 50 g group and the other groups ($p < 0.05$). Ca–P in the experimental group was similar, but the control was different from 20 to 50 g groups ($p < 0.05$). Res-P concentration in 50 g group was different from the other groups ($p < 0.05$).

4. Discussion

4.1. Effect of brick powder on the overlying water

It was found that the brick powder could reduce TP in the overlying water. As seen in Table 6, TP in 50 g group was obviously different from that of 20 g ($p < 0.05$), and significantly different from those of 10 g

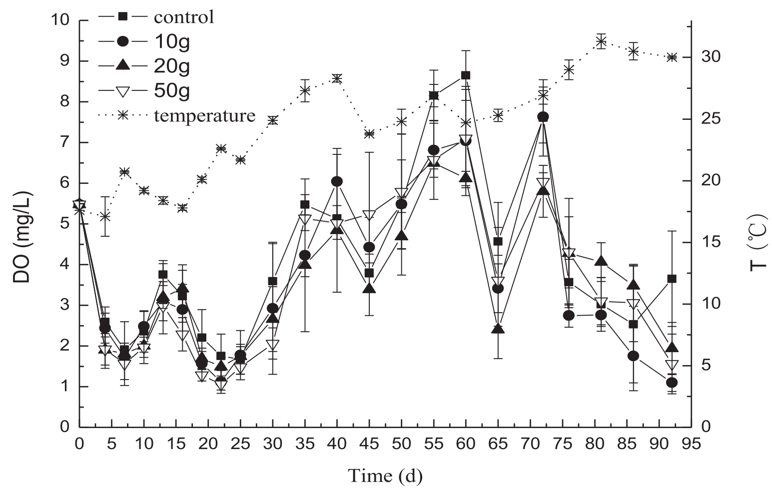

Fig. 5. DO and temperature in the overlying water.

Table 4
The main physicochemical properties of the sediments after the experiment (mean value ± SD)

Group	Water content (%)	OM (g/kg DW)	pH	TN (g/kg DW)	TP (mg/kg DW)
Control	1.90 ± 0.32	68.90 ± 6.09	7.41 ± 0.07	2.38 ± 0.17	1,464.96 ± 61.22
10 g	1.89 ± 0.22	68.40 ± 3.00	7.46 ± 0.07	2.00 ± 0.32	1,437.36 ± 69.48
20 g	2.39 ± 0.84	64.12 ± 7.20	7.54 ± 0.06	1.98 ± 0.16	1,322.67 ± 39.86
50 g	2.39 ± 0.28	58.79 ± 2.25	7.46 ± 0.03	1.76 ± 0.14	1,206.64 ± 125.01

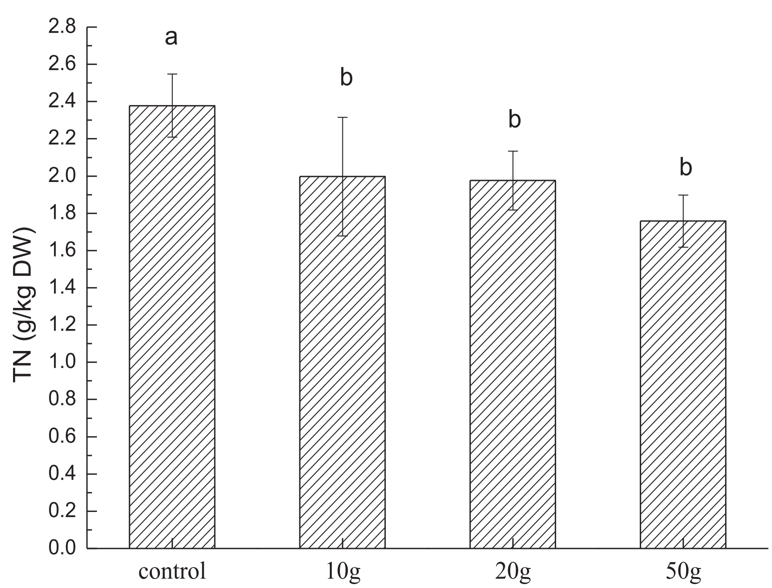

Fig. 6. TN in the sediment.

and the control ($p < 0.01$). A significant correlation between brick powder dosage and TP in the overlying water was achieved.

Meanwhile, no significant relationship between the brick powder dosage and removal for TN and COD in the overlying water was found. TN and

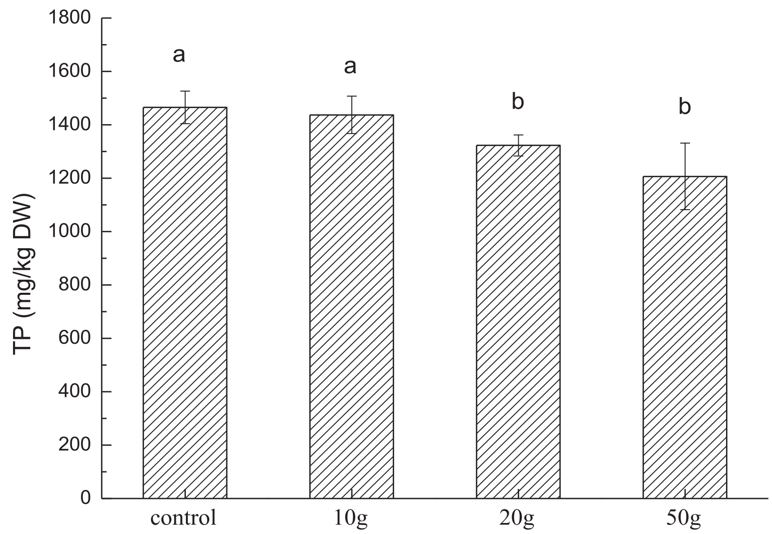

Fig. 7. TP in the sediment.

Table 5
The contents of different forms of phosphorus in the sediments after the experiment (mean value ± SD) (mg/kg DW)

Group	NH_4Cl-P	Fe–P	Al–P	Org-P	Ca–P	Res-P
Control	28.71 ± 4.10	349.39 ± 6.98	503.93 ± 6.32	8.71 ± 7.42	175.89 ± 24.04	366.08 ± 28.43
10 g	24.07 ± 2.00	292.34 ± 2.90	552.31 ± 22.69	173.94 ± 23.50	163.80 ± 9.90	159.08 ± 15.14
20 g	31.14 ± 7.27	253.35 ± 42.80	488.71 ± 2.75	159.80 ± 11.52	152.94 ± 8.89	226.24 ± 26.38
50 g	29.43 ± 4.48	232.97 ± 17.77	452.08 ± 67.51	459.05 ± 46.59	149.16 ± 12.16	9.07 ± 15.92

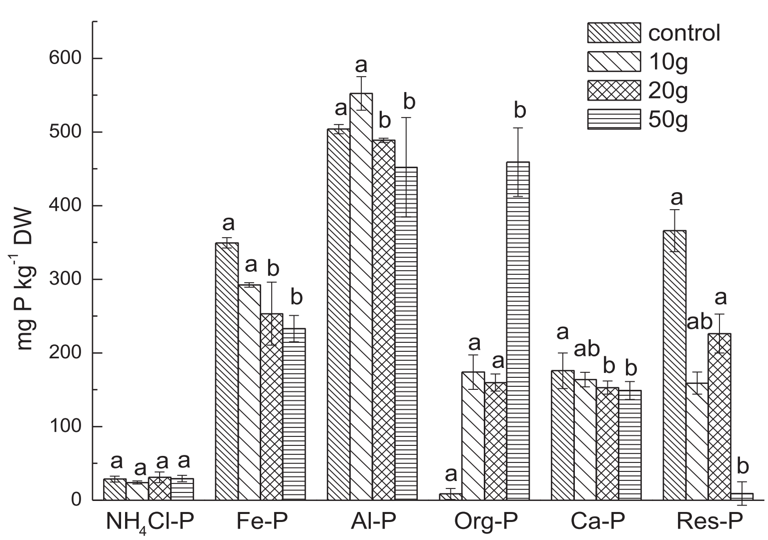

Fig. 8. Different forms of phosphorus in the sediment.

COD in both experimental groups and control group followed the same change trend, and no obvious effect was found. Correlation analysis showed that there were negative correlations between TN and pH, and DO and temperature ($p < 0.01$).

Table 6
Comparative analysis of TP between treatment groups

Variable	Groups	Control	10 g	20 g	50 g
		p	*p*	*p*	*p*
TP	Control	1	.764	.149	.001**
	10 g	.764	1	.251	.002**
	20 g	.149	.251	1	.044*
	50 g	.001**	.002**	.044*	1

*$p < 0.05$.
**$p < 0.01$.

4.2. *Effect of brick powders on the sediment*

4.2.1. *Organic matter*

OM was an important variable, which had great effect on the adsorption and the release of phosphorus in the sediment. Phosphorus release could be promoted by the increase of OM content, which could help in maintaining the crystalline products of phosphate and calcium phosphate in metastable or poorly crystalline forms [15]. In addition, OM could increase the net negative surface charge and reduce the soil phosphate adsorption capacity [16]. On the other hand, OM may compete with P for sorption on the soil particle surface through blocking the adsorption sites and therefore, enhances the rate of P desorption [17]. In this study, a negative relationship between brick powder dosage and OM content was found. OM content decreased with the increased brick dosage, which may reduce the release of phosphorus.

4.2.2. *Total phosphorus*

Compared with the initial value, TP decreased in all groups, which seems to suggest that phosphorus in the sediment was released to the overlying water. However, TP in the overlying water in the experimental groups were lower than that of the control. One possible explanation was that the brick powder could adsorb and restrain the phosphorus releasing from sediment to the overlying water. Meanwhile, no significant difference for TP was found between 20 and 50 g groups. In this study, it was determined that 20 g of brick powder was an optimal dosage for the sediment remediation.

4.2.3. *Different forms of phosphorus*

Compared with the control, the content of Org-P in the experimental groups increased, and the contents of Fe–P, Al–P, and Ca–P decreased with the increase in brick powder dosage. While there was no significant difference between 20 and 50 g group, 20 g was determined to be the optimal brick powders dosage.

It was reported that the exchange among these forms of phosphorus in the sediment existed [18–21]. In this paper, correlation analysis also showed that

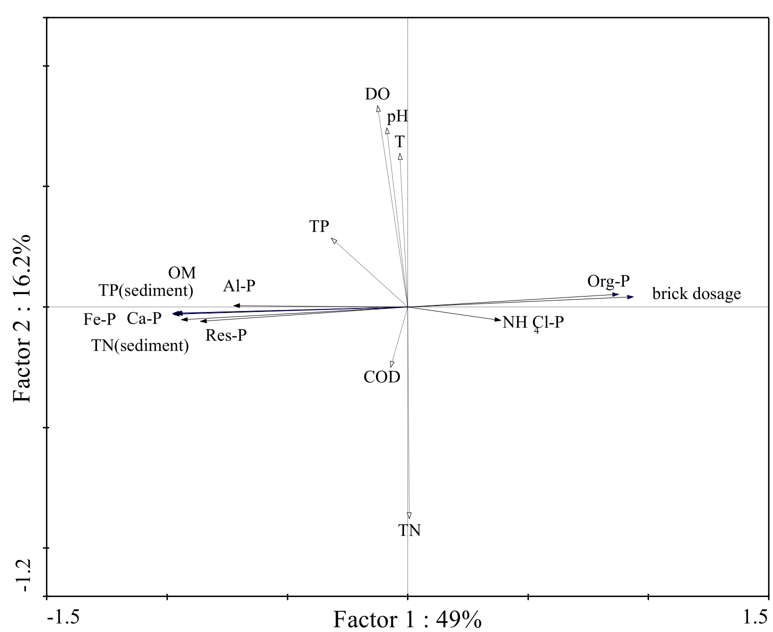

Fig. 9. The PCA of brick dosage and parameters.

Org-P exhibited negative correlations with Ca–P and Res-P.

4.3. The comprehensive effect of brick powder

PCA was used to describe the comprehensive effect of brick powder on the overlying water and sediment. As seen from Fig. 9, the first principal component (PC1) had a positive relationship with brick dosage, NH_4Cl-P, and Org-P, and negative relationship with OM, sediment TN, sediment TP, Fe–P, Al–P, Ca–P, and Res-P. PC2 was positively correlated with TP, DO, pH, and temperature, and negatively correlated with TN and COD. PC1 explained brick dosage and sediment variables. However, PC2 explained the variables in the overlying water. Therefore, brick dosage had a greater impact on sediment physicochemical properties.

In addition, heavy metal concentrations of used brick had been monitored in order to make sure whether the application of used brick would be harmful to water body. The results showed that heavy metal concentrations (such as Cu, Zn, Cr, Pb, As, Cd, and Se) were far below the environmental quality standard of surface water.

5. Conclusions

(1) Brick powder could reduce TP in the overlying water, OM and TN in the sediments.
(2) Org-P was increased, and Fe–P, Al–P, and Ca–P were reduced with the increase of brick dosage.
(3) PCA demonstrated that brick dosage had a greater impact on sediment physicochemical properties.
(4) Twenty grams of brick powders was determined to be the optimal dosage for the sediment remediation in this experiment.

Acknowledgments

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