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Comparison of physico-chemical characteristics of sediments from different wetland types of Huihe wetland, Inner Mongolia, China

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ABSTRACT

In order to understand the characteristics of sediments in Huihe wetland, the influence of sediments on nutrient salt in overlying water was analyzed from the point of view of interface release. In this paper, the sediments of Huihe wetland were studied. And the distribution of organic carbon, total nitrogen, total phosphorus, Olsen-P and inorganic phosphorus fraction of sediments were determined. The relationship between different physical and chemical factors was analyzed. It was concluded that the content of <50 μm particle size was higher in Lake-W (permanent freshwater lake wetland), but when the particle size was >100 μm, the higher one was Marsh-W (grassy marsh wetland). Which meant that Marsh-W had stronger adsorption and fixation potentials. The content of clay and silt particles in River-W (permanent river wetland) was low and the sand content was high. The nutrient content of River-W was lower than that of Lake-W and Marsh-W. The soil organic carbon (SOC):total nitrogen (TN):total phosphorus (TP) for Marsh-W was as 122:7:1, wherein the concentration of organics and nitrogen was higher than the TP concentration. Lake-W was observed to be 30:11:1. It was the lowest ratio as compared with the other wetland types. Phosphatase (alkaline and neutral) activity was associated with the content of various nutrients and reflected the chemical properties of the sediments. Under the conditions of climate change, we advocate further use of alkaline phosphatase activity as novel ecological tool for assessing physico-chemical properties and nutrient release potential of wetland sediments in the field of study.

Keywords: Wetland types; Sediment; Phosphorus; Nutritional status; Characteristic index; Correlation analysis

1. Introduction

Huihe wetland is located in the northeast of China. It is a transitional zone of the forest ecological system of Daxinganling Mountain to Hulunbeier Grassland Ecosystem. The landscape integrates forest ecological system, grassland ecosystem and wetland ecosystem. Wetland ecosystems include river wetland, lake wetland and marsh wetland types. Since the establishment of the Huihe Nature Reserve Administration in 2004, the wetland area in the recent 10 years has remained stable (the dynamic index is – 0.178%), the average patch area has increased by 53.44% (2.64 km^2). The degree of block aggregation increased slightly from 99.81% to 99.88%, and the protective effect was good [1]. In general, wetland ecosystems are still threatened by environmental changes. Climate change is also an important factor affecting ecological condition of wetland [2]. Therefore, under the climate change conditions, the geochemical cycle within the wetland ecosystem also needs to be considered. Hope to provide a basis for the development of management policies.

The major pollutants in the Huihe wetland were mainly from organic matter contaminants from the upper reaches of the forest, except the effects from grazing [3]. At the same time, due to the slow flow of grassland rivers, pollutants can easily get accumulated in the sediments and became difficult to reduce the endogenous load, sediment under

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certain conditions through the water–sediment interface released may cause secondary pollution of waterbodies. Especially for shallow lakes, the effect of sediment as an endogenous source on the release of nitrogen and phosphorus for overlying waterbodies will become more and more important in the case of exogenous sources gradually being controlled. Sediment is the main source of lake pollution, and also a reservoir of pollutants. The deposition of a large amount of sludge not only accelerates the swampization of lakes but also becomes an important source of nutrients in the overlying water [4–6]. The physico-chemical properties of sediments are not only a historical record of the impact of human activities on lakes but also the basic information on the migration and transformation of nitrogen and phosphorus in the water–sediment interface, reflecting the changes of lake ecological environment and the interference intensity of human activities. It is also an important factor affecting endogenous release. Biodegradation of organic matter in the sediments will consume large amounts of dissolved oxygen in the waterbody, resulting in the lack of oxygen in the waterbody and release a large amount of nitrogen and phosphorus nutrients to keep the waterbody at a higher nutrient level [7–12]. Understanding the characteristics of sediments is of great importance for the study of the wetland's global environment, which is also of great concern.

Phosphatases are extracellular hydrolases that catalyze the mineralization of organic phosphorus into inorganic and more easily metabolized forms of phosphorus. One large and important group of these enzymes are the phosphomonoesterases and their pH isoforms, includes alkaline, acid and neutral phosphatases, which could be active in several kinds of sediments [13]. Traditional phosphatase activity research mainly focused on marine systems, only a few studies conducted on lake water and sediment alkaline phosphatase activity (APA) [14]. Lake APA plays a key role in organic matter mineralization and is correlated with exotic lake nutrient pollutants such as organic P (OP) and organic nitrogen. Other factors affecting APA in sediment have also been investigated including total sediment bacteria number, P release rate, P fraction and P bioavailability [15].

In order to understand the characteristics of sediments in Huihe wetland, the influence of sediments on nutrient salt in overlying water was analyzed from the point of view of interface release. In this paper, the sediments of Huihe wetland were studied. And the distribution of organic carbon, total nitrogen, total phosphorus, Olsen-P and inorganic phosphorus (IP) in the sediments of the Huihe wetland was analyzed, and the relationship between the chemical and physical factors was also discussed. This paper tries to reflect the characteristics of the Huihe wetland sediments in order to understand the various changes taking place in the wetland, thus to provide the theoretical basis for rational control and management of the pollution in the Huihe wetland.

2. Materials and methods

2.1. Sampling and analysis

Sediment samples from three areas surrounding Huihe wetland, Inner Mongolia, northeast China (Fig. 1) were collected in mid of July 2015 and 2016 at 0 to 10 cm depth. According to the wetland classification system of wetland convention [16], the sediments belonged to three types of

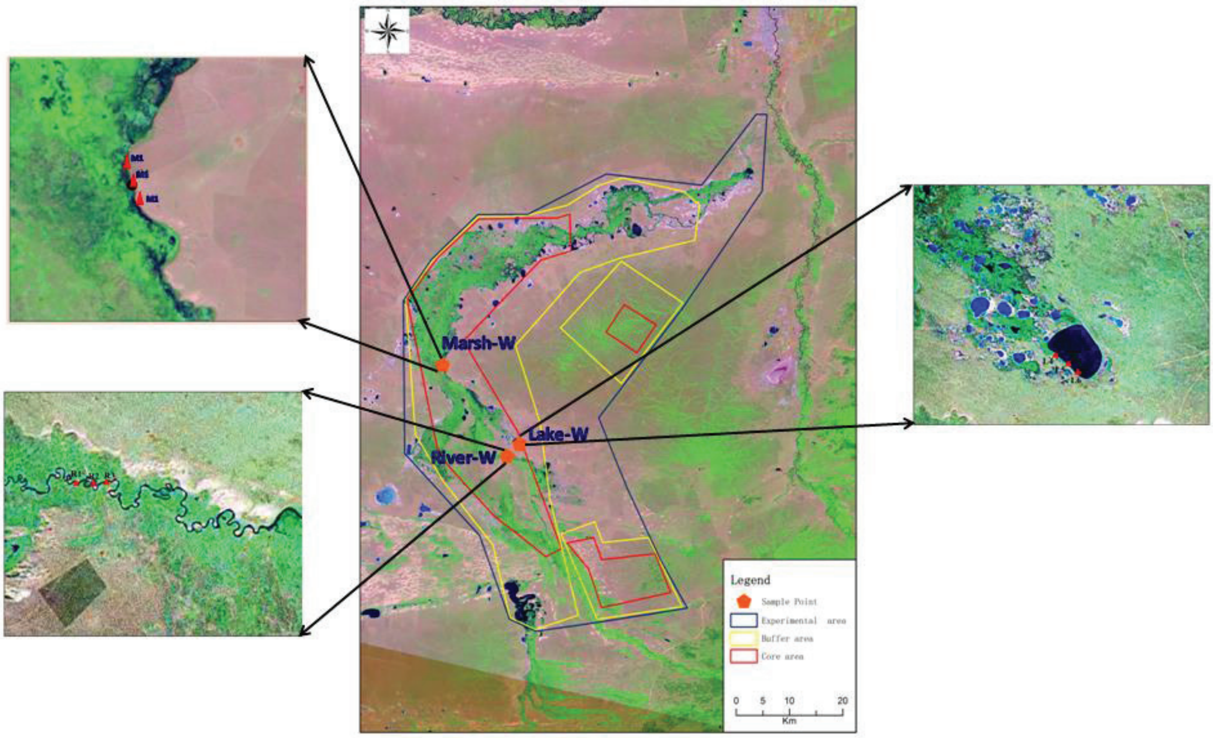

Fig. 1. Location of each monitoring site in Huihe, Inner Mongolia, China.

wetland (Fig. 1): permanent river wetland (River-W), permanent freshwater lake wetland (Lake-W) and grassy marsh wetland (Marsh-W). The Huihe wetland is an important part of the Eurasian steppe and an important ecological barrier of northeast China. All sediment sampling sites have a warm temperate continental monsoon climate with a mean annual temperature ranging from –2.4°C to 2.2°C and a mean annual precipitation ranging from 270 to 380 mm. One bulk sample was taken with a ZYQ-WN wetland sediment sampler (Beijing GRASP Science and Technology Development Co., Ltd., Beijing, China) at each site.

Collected samples were taken to the laboratory and prepared for sieve and particle size analysis. These methodologies were done to characterize the particle size that composes the sediment samples. The samples were also classified according to the particle sizes of samples using the agricultural soil textural classification of US Department of Agriculture (USDA).

All sediments were sieved (<2 mm), homogenized and stored in polyethylene bags at 4°C until the biological analysis started in October 2015 and 2016. Subsamples of sieved sediments were dried and finely ground for chemical analysis. All analysis were carried out in triplicate. Sediments pH was measured in water (ratio 1 to 2.5). Sediment electrical conductivity was measured by Thermo Russell RL060C. Total P was measured by $HClO_4$–H_2SO_4 Digestion – antimony molybdenum spectrophotometry method. Concentrations of Olsen-P were determined by $NaHCO_3$ extraction – molybdenum antimony scenery spectrophotometry. Sediment SOC was measured by potassium dichromate volumetric and thermal dilution method. Sediment total N was determined by Kjeldahl nitrogen determination method.

2.2. Inorganic P fractions

IP was fractionated according to a conventional fractionation method [17]. The sediment samples were sieved (<2 mm), air-dried and mixed thoroughly. The sequential extraction procedure was started by extracting 1 g with 1 mol L^{-1} NH_4Cl to remove the water soluble phosphorus. The sediment residue was further extracted with 0.5 mol·L^{-1} NH_4F for determining Al–P and then with 0.1 mol L^{-1} NaOH for determining Fe–P, with 0.25 mol·L^{-1} H_2SO_4 for determining Ca–P and, finally, the sediment residue was extracted with concentrated 0.1 mol·L^{-1} $Na_3C_6H_5O_7$·$2H_2O$ and 1 mol·L^{-1} $NaHCO_3$ for determining Residue-P. The sum of all these IP fractions is IP content.

2.3. Organic P

In this study OP content was the difference value between TP and IP.

2.4. Alkaline phosphatase activity and neutral phosphatase activity

The APA and neutral phosphatase activity (NPA) assay of sediments were conducted as described by Eivazi and Tabatabai [18]. Phosphatases pH isoforms, includes alkaline, acid and neutral phosphatases, which were active in several kinds of sediments. Eivazi and Tabatabai [18] found that acid phosphatase was predominant in acidic soils and that alkaline phosphatase was predominant in alkaline soils. The soils were alkaline soils in this study, so APA and NPA of sediments were taken into consideration only. All samples were run in triplicate.

2.5. Statistical analysis

The results presented in the tables were arithmetic means and expressed on an oven-dry basis (about 24 h at 105°C). All data except pH were ln-transformed to fit to a normal distribution for statistical analysis. Multiple regression models were calculated between APA and other variables, with the sediment chemical properties and phosphatase activities as dependent variables. These were selected from all properties (sediment pH, sediment chemical properties, including the contents of P fractions, as well as sediment phosphatase activities) by stepwise forward regression analysis. All regression models were tested for normality (Shapiro–Wilk), constancy of variance and absence of correlation between the residuals (Durban–Watson statistics). All data except soil pH were ln-transformed to improve the normality of distribution. Correlation and regression analysis were performed using OriginPro 9.1.0 (OriginLab Co., Northampton, USA). The significance of differences between the treatments was tested by one-way analysis of variance (ANOVA). ANOVA was performed using SAS9.1 (SAS Institute Inc., Cary, USA).

3. Results

3.1. Comparison of physical characteristics of sediments

Fig. 2 shows the cumulative particle size distribution of samples collected from three different types of wetland. The average particle size at 50% passing rate (D50) in River-W was calculated to be 0.14 mm, which was 1.2 times and 1.4 times bigger of that in Lake-W and Marsh-W, respectively. The cumulative contents of particle size of <0.1 mm in the three types of wetland were 24.21%, 42.25% and 55.04%, respectively, and decreased with the order of Marsh-W > Lake-W > River-W. This indicates that the amount of particle size of <0.1 mm in the River-W was less, the reason may be that the fine particles were difficult to precipitate with the flow of water. Huang and Liu [19] analyzed the release rate of sediment pollutants under

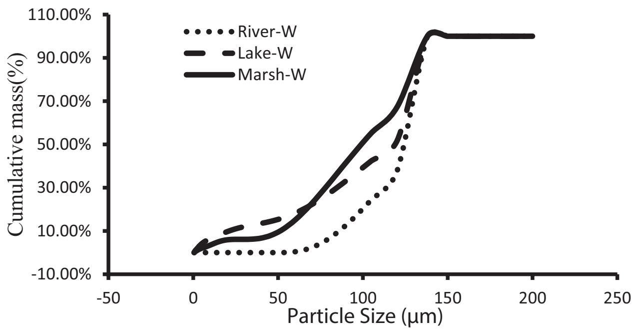

Fig. 2. Cumulative particle size distribution of samples from the different wetland types of Hui River.

different hydrodynamic conditions; it was considered that the dynamic release rate of sediment increases with the increase of water flow rate.

Fig. 3 shows the results for the particle size analysis of the sediment samples collected from the three different types of wetland sediments. It is observed that samples from Marsh-W were classified into sand and loamy sand, River-W and Lake-W were both classified into sand. In general, sediments with smaller particle sizes have bigger surface area which results to bigger pollutant adsorption capacity. Therefore, determination of particle size distribution of sediments is important [20]. The average clay contents of three types of wetland were 0.14%, 1.41% and 0.20%, respectively, and increased with the order of River-W < Marsh-W < Lake-W. The average silt content of Lake-W was 7.90% which was 50.57 times and 5.74 times bigger than that of River-W and Marsh-W, respectively. The average sand contents of three types of wetland were decreased with the order of River-W (99.70%) > Marsh-W (90.68%) > Lake-W (98.42%), indicating that the content of clay and silt particles in River-W was low and the sand content was high.

3.2. Comparison of chemical characteristics of sediments

Statistical summary of the chemical analysis of sediment samples collected from the different wetland types of Hui River is presented in Table 1. Highest average sediment pH was observed in Lake-W (8.6400 ± 0.2787) followed by River-W (8.5500 ± 0.3205) and Marsh-W (8.5400 ± 0.0700) and there were no significant difference between these three wetland sediments. Electric conductivity (E_C) was observed to be highest in Lake-W (146.900 ± 12.6787) and significantly higher than that in River-W and Marsh-W which were of no significant difference. The SOC content in sediments were significantly different from each other and decreased in the order of Marsh-W > River-W > Lake-W. The average SOC content in Marsh-W was 54.2350 ± 3.6634 which was 3.23 times and

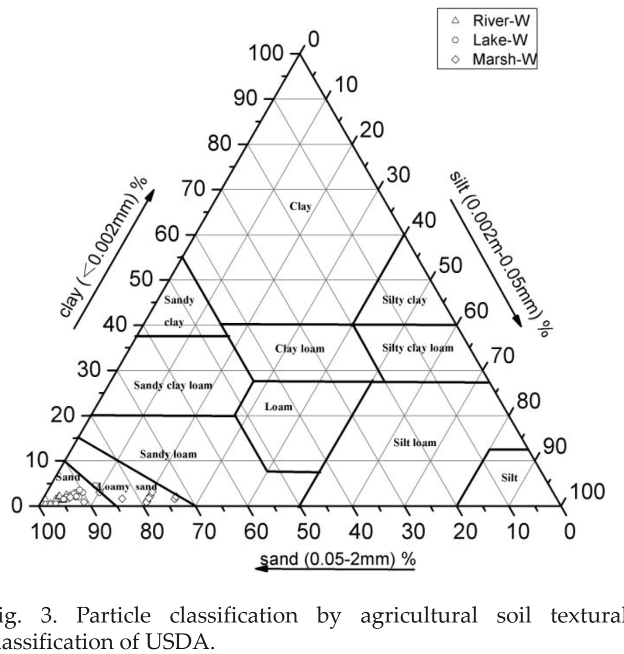

Fig. 3. Particle classification by agricultural soil textural classification of USDA.

Table 1
Characteristics of sediments collected from three different wetland types

Parameter	River-W			Lake-W			Marsh-W		
	Min	Max	Mean ± S.D.	Min	Max	Mean ± S.D.	Min	Max	Mean ± S.D.
pH	8.2400	8.8800	8.5500 ± 0.3205^{a}	8.3300	8.8700	8.6400 ± 0.2787^{a}	8.4900	8.6200	8.5400 ± 0.0700^{a}
E_C (us)	79.6000	87.8000	84.300 ± 4.2297^{b}	132.4000	155.9000	146.900 ± 12.6787^{a}	84.2300	95.1100	88.5000 ± 5.8052^{b}
SOC g kg^{-1}	28.8325	34.5210	32.5325 ± 3.2073^{b}	15.0210	17.8990	16.8018 ± 1.5560^{c}	50.0210	56.6620	54.2350 ± 3.6634^{a}
TN g kg^{-1}	1.2281	1.9994	1.5096 ± 0.4258^{b}	5.5280	7.2153	6.4349 ± 0.8508^{a}	2.0125	3.3154	2.7966 ± 0.6908^{b}
TP mg kg^{-1}	400.1215	563.1235	494.1196 ± 84.3265^{a}	581.0130	639.7714	606.6358 ± 30.0910^{a}	472.1230	578.1200	505.1543 ± 63.2843^{a}
Olsen-P mg kg^{-1}	15.6724	25.4151	19.4362 ± 5.2355^{b}	29.2878	38.2145	33.6466 ± 4.4670^{a}	37.2415	52.1452	44.1898 ± 7.5027^{a}
Al–P mg kg^{-1}	68.3528	76.7637	72.7995 ± 4.2262^{a}	75.6337	79.3033	77.7631 ± 1.9044^{a}	72.4731	77.2356	74.4540 ± 2.4802^{a}
Fe–P mg kg^{-1}	43.5091	49.2534	46.6287 ± 2.9040^{a}	20.3345	24.5541	22.2041 ± 2.1504^{b}	19.1324	24.3352	21.4640 ± 2.6430^{b}
Ca–P mg kg^{-1}	48.3321	57.3475	52.7542 ± 4.5101^{b}	253.1230	305.4810	286.2432 ± 28.8077^{a}	75.1238	93.1240	88.4457 ± 9.2867^{b}
Oc–P mg kg^{-1}	68.2431	80.2135	72.7995 ± 6.4766^{a}	75.3245	87.1234	82.7267 ± 6.4481^{a}	70.1124	84.6280	79.4176 ± 8.0779^{a}
APA μmol/g soil/h	1.5900	2.0300	1.8037 ± 0.2203^{c}	18.9900	22.3100	20.1808 ± 1.8483^{a}	4.8900	5.4005	5.2068 ± 0.2767^{b}
NPA μmol/g soil/h	0.7282	0.8800	0.7827 ± 0.0844^{c}	4.0100	4.2800	4.1859 ± 0.1525^{a}	3.0600	3.3500	3.1649 ± 0.1607^{b}

Note: lowercase is showing the significance between wetland types.

1.67 times bigger than that in Lake-W and River-W, respectively. IP fractions were different among these wetlands, especially Fe–P and Ca–P content. The trends of APA and NPA were the same, and increased with the order of River-W < Marsh-W < Lake-W. The APA ranged from 1.5900 to 22.3100 while NPA changed between 0.7282 and 4.2800. Overall, the nutrient content of River-W was relatively low, which may be related to better blending effect of pollutants and water in the dynamic waterbody, which was beneficial to the diffusion of pollutants. When the flow rate is high, a large amount of sediment will be resuspended, and the pollutant concentration in the downstream river will be increased [21].

3.3. Ratios of the nutrients and organic

Fig. 4 shows the calculated ratios of SOC to TN, SOC to TP and TN to TP for River-W, Lake-W and Marsh-W, respectively. The SOC to TN ratio in River-W was highest about 22.44, followed by the Marsh-W 20.09 and Lake-W 2.62. The SOC to TP ratio was observed to be the highest in Marsh-W 108.22, followed by River-W 66.44 and Lake-W 27.71. Conversely, TN to TP ratio was highest in Lake-W followed by Marsh-W and River-W, about 10.60, 5.53 and 3.06, respectively.

The SOC:TN:TP for each wetland type was also determined. For the Marsh-W, the ratio was 122:7:1, wherein the concentrations of organic and nitrogen were higher than the TP concentration. This implies that the Marsh-W was affected by the discharge of non-biodegradable organic matters. Furthermore, the ratio in River-W was observed to be 72:3:1, in which the concentration of nitrogen was higher than the TP concentration. This implies that the River-W has high nitrogen and phosphorus concentrations coming from the upper forest area and the livestock waste water from the surrounding river bank. On the other hand, the ratio for the Lake-W was observed to be 30:11:1, which was the lowest ratio compared with the other wetland types. This simply implied that organic substances were naturally degraded through self-purification by aquatic organisms, plants and microorganisms throughout the flow process in the stream. Moreover, a large amount of nitrogen was removed through the processes of nitrification and denitrification.

3.4. Correlation analysis

The APA was significantly and positively correlated with E_C, TN, Ca–P, TN/TP and NPA (r = 0.914, 0.969, 0.982, 0.963 and 0.905, respectively, $p < 0.01$; Table 2). At the same time, it was significantly and negatively correlated with Fe–P, SOC/TN and SOC/TP (r = –0.776, –0.911 and –0.680, respectively, $p < 0.05$). The NPA was significantly and positively correlated with TN, Olsen-P, Ca–P and TN/TP (r = 0.873, 0.873, 0.817 and 0.892, respectively, $p < 0.01$; Table 2). At the same time, it was significantly and negatively correlated with Fe–P (r = –0.944 and $p < 0.01$). APA and NPA were significantly and negatively correlated with Fe–P, respectively, while they were not correlated with pH (r = 0.237 and 0.185) and SOC (r = –0.217 and –0.599). This indicated that phosphatase (alkaline and neutral) was associated with the content of various nutrients, reflecting the chemical properties of the sediments in the field of study and was more sensitive to the nutrient content. Researchers suggest that phosphatase activity was a potentially valuable early warning indicator of wetland eutrophication when used in conjunction with other complementary indicators [22].

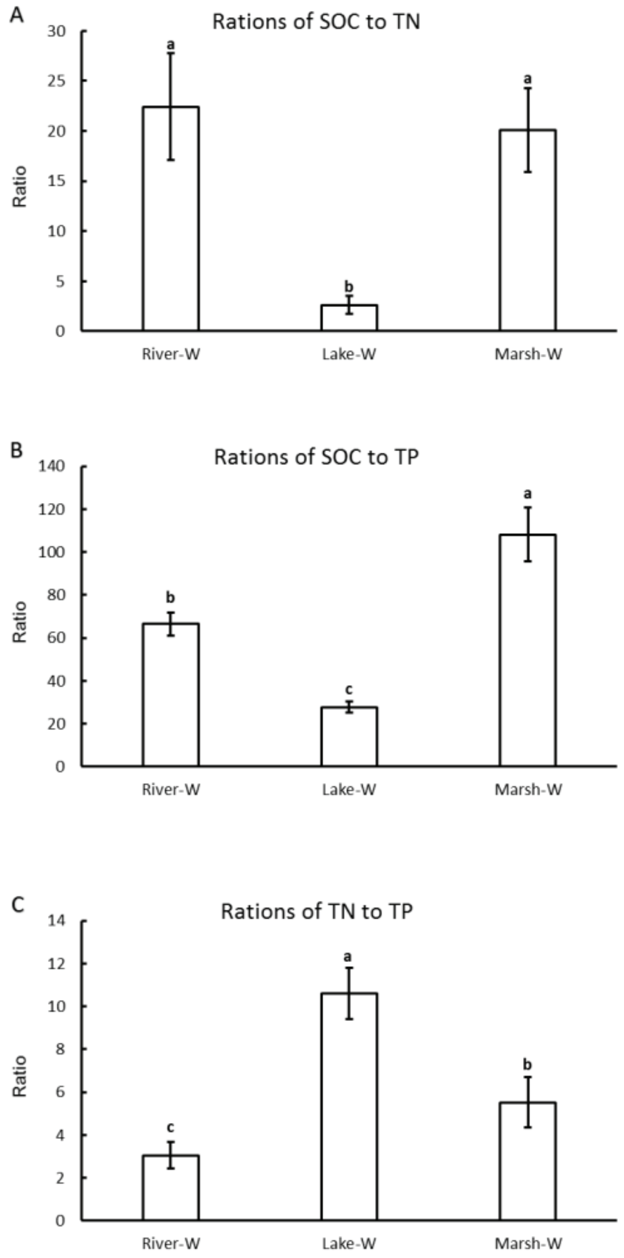

Fig. 4. Ratios of SOC to TN, SOC to TP and TN to TP for the three different wetland types.

3.5. Interactions between APA and physico-chemical properties

Ca–P and APA were significantly ($p < 0.001$ and n = 72) interrelated R^2 = 0.964, whereas sediment Ca–P showed the strongest correlation with microbial biomass P (R^2 = 0.667 and p = 0.0007). The relationship between APA and NPA was additionally affected by the contents of IP and SOC (Table 3). Multiple regression analysis revealed the closest relationships of APA with Ca–P, Al–P and OP. The concentration of APA

Table 2
The correlation coefficient of physico-chemical characteristics of sediments

	pH	E_C	TP	TN	Olsen–P	SOC	Al–P	Fe–P	Ca–P	Oc–P	SOC/TN	SOC/TP	TN/TP	NPA	APA
pH	1.000	0.390	0.609	0.368	0.310	–0.076	0.607	0.003	0.290	0.665	–0.271	–0.216	0.273	0.185	0.237
E_C		1.000	0.761*	0.916**	0.308	–0.804**	0.724*	–0.475	0.972**	0.592	–0.978**	–0.876**	0.879**	0.680*	0.914**
TP			1.000	0.738*	0.386	–0.489	0.859**	–0.296	0.714*	0.638	–0.710*	–0.667*	0.606	0.520	0.678*
TN				1.000	0.632	–0.567	0.656	–0.687*	0.967**	0.765*	–0.915**	–0.668*	0.984**	0.873**	0.969**
Olsen-P					1.000	0.258	0.377	–0.780*	0.457	0.707*	–0.276	0.124	0.644	0.837**	0.579
SOC						1.000	–0.354	0.047	–0.716*	–0.123	0.851**	0.976**	–0.540	–0.217	–0.599
Al–P							1.000	–0.422	0.682*	0.560	–0.591	–0.516	0.547	0.561	0.657
Fe–P								1.000	–0.652	–0.402	0.460	0.114	–0.732*	–0.944**	–0.776*
Ca–P									1.000	0.613	–0.966**	–0.789*	0.951**	0.817**	0.982**
Oc–P										1.000	–0.548	–0.263	0.734*	0.620	0.610
SOC/TN											1.000	0.904**	–0.891**	–0.662	–0.911**
SOC/TP												1.000	–0.612	–0.315	–0.680*
TN/TP													1.000	0.892**	0.963**
NPA														1.000	0.905**
APA															1.000

Note: * Correlation is the significance at the 0.05 level-2-tailed and there is a significant correlation between the two indicators; and
** Correlation is the significance at the 0.01 level-2-tailed and there is a very significant correlation between the two indicators.

Table 3
Multiple regression models between APA and other sediment physico-chemical characteristics, the APA, APA/TP, APA/Olsen-P, APA/IP and APA/OP ratios as dependent variables and different variables selected from all properties by stepwise forward regression analysis; all data except soil pH were ln-transformed to improve the normality of distribution

	Intercept	Regressor 1	Regressor 2	Adjusted R^2 (%)	Pr > F
APA	–1.516*	1.148***Ca–P	–0.635**Fe–P	99.4	0.001
APA/TP	0.372	2.454***Ca–P	–3.540**E_C	98.9	0.001
APA/Olsen-P	–10.620***	2.206**Ca–P	–1.278**TN	98.3	0.002
APA/IP	–3.163***	0.877***NPA	–0.440***SOC	98.9	<0.0001
APA/OP	–7.439***	2.270***TN/TP		90.6	<0.0001

All models passed the constant variance test; Durbin–Watson statistics indicated the absence of correlation between the residuals in all models.
*$p < 0.05$.
**$p < 0.01$.
***$p < 0.001$.

increased with the increase of Ca–P. APA/TP ratio generally increased with the increase of Ca–P content (Table 3), especially in sediments with low E_C. The APA/Olsen-P generally increased with the increase of Ca–P, particularly in sediments with low TN. The contribution of APA/IP totally increased with the increase of NPA, especially in sediments low with SOC. The contribution of APA to OP generally increased with the increase of TN/TP.

4. Discussion

4.1. Physico-chemical characteristics between different wetlands

For the particle size of <50 μm, the content of Lake-W was higher, while when the particle size was >100 μm, the content in Marsh-W was higher, which indicates that Marsh-W sediments contain more small particle size soil. In the geology of particles, generally particles smaller than 0.004 mm particles were classified into clay minerals. Due to its special crystal structure, clay was relatively easy to adsorb other substances in the environment, leading to that the adsorption mainly occurs in smaller particles. The higher the content of fine particles was, the greater the adsorption was. On the contrary, the higher the content of coarse particles was, the lower the adsorption capacity was [23,24]. This indicated that Marsh-W had stronger adsorption and fixation potentials.

4.2. Relationship analysis

Through correlation analysis, it was found that both APA and NPA in sediments were significantly related to the physical and chemical properties of sediments. APA, which can reflect the comprehensive status of wetland sediment, was related to various chemical factors and their ratios.

Phytoplankton and bacteria can induce enzymes, alkaline phosphatase was one of the products. Alkaline phosphatase can hydrolyze organic phosphorus compounds into orthophosphate [25]. Alkaline phosphatase was a specific phosphate esterase [26,27]. The alkaline phosphatase activity in the sediments of Venice lagoon was positively correlated with the release rate of phosphorus [28]. Alkaline phosphatase activity in sediments from Taihu Lake [29] showed that the distribution of alkaline phosphatase activity in sediments was related to the organic matter content of sediment (especially organophosphate), which was associated with the pollution. The relationship between the activity of alkaline phosphatase and available phosphorus in water can be generalized as "inhibition-inducing mechanism." The increase of organic phosphorus or hydrolyzable phosphorus can induce the increase of alkaline phosphatase activity. The high orthophosphate (dissolved IP) had an inhibitory effect on alkaline phosphatase activity [30]. The ecological function of extracellular phosphatase can be summarized as follows: to prevent phosphorus deficiency, to indicate the growth and decline of phosphorus [31,32].

In the present paper, the activity of alkaline phosphatase was affected by the content of Ca–P and Fe–P in sediment. The relationship between alkaline phosphatase and total phosphorus was affected by Ca–P and conductivity while the relationship between alkaline phosphatase and Olsen-P was affected by Ca–P and total nitrogen. The relationship between alkaline phosphatase and IP was affected by the SOC content of sediments, and the relationship between alkaline phosphatase and organic phosphorus was affected by the ratio of TN to TP. This indicates that alkaline phosphatase can reflect the physical and chemical properties of wetland sediment and its nutritional status.

4.3. Comprehensive analysis

The dynamic release rate of sediment increases with the increase of water flow rate. When the flow rate was high, a large amount of sediment will be resuspended, and the pollutant concentration in the downstream river will increase. So the contents of particle size of <0.1 mm and nutrient in River-W were lower than that in Marsh-W and Lake-W. There was a significant correlation between nutrient content and phosphatase activity. Microbial synthesis and extracellular secretion of enzymes such as phosphatase was a multifaceted biological process. Factors influencing soil biomass and the associated microbial community structure, such as temperature, pH, macronutrients and heavy metals [33,34], would control soil enzyme production and consequently, P availability. Zhang et al. [35] pointed out that the increase of phosphatase activity (neutral and/or alkaline) enhanced the function of the ecological source in terms of sediment P under warming, particularly in wetland sediments low in P. Increasing temperatures increased the activities of soil acid phosphatase activity in the summer and alkaline phosphatase activity in the spring for a Mediterranean shrubland [36]. APA was more sensitive to the content of other nutrients than NPA in wetland sediments through the relationship between phosphatase and other nutrients in wetland sediments. Under the conditions of climate change [37], we advocate further use of APA as novel ecological tool for assessing physico-chemical properties and nutrient release potential of wetland sediments in the field of study.

5. Conclusions

The content of <50 μm particle size was higher in Lake-W, while when the particle size was >100 μm, the higher one was Marsh-W. It means Marsh-W has stronger adsorption and fixation potentials. The content of clay and silt particles in River-W was low and the sand content was high. The nutrient content of River-W was lower than that in Lake-W and Marsh-W. The SOC:TN:TP for Marsh-W was as 122:7:1, wherein the concentration of organic and nitrogen were higher than the TP concentration. Lake-W was observed to be 30:11:1, which is the lowest ratio as compared with the other two wetland types. Phosphatase (alkaline and neutral) activity was associated with the content of various nutrients and reflected the chemical properties of the sediments. Under the conditions of climate change, we advocate further use of APA as novel ecological tool for assessing physico-chemical properties and nutrient release potential of wetland sediments in the field of study.

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