Int. J. Environ. Res., 6(1):195-208, Winter 2012
ISSN: 1735-6865

Distribution and Fractions of Phosphorus and Nitrogen in Surface Sediments from Dianchi Lake, China

Li, H., Wang, Y. , Shi, L.Q. , Mi, J. , Song, D. and Pan, X. J.*

Faculty of Environment Science and Engineering, Kunming University of Science and Technology, Kunming, Yunnan 650093, P. R. China

Received 18 Feb. 2011; Revised 22 July 2011; Accepted 7 Aug. 2011

ABSTRACT: Dianchi Lake is one of the most three seriously eutrophic lakes in China. In the present study, the phosphorus (P) and nitrogen (N) fractions in 37 surface sediments samples collected in the Dianchi Lake were investigated. The total phophorus (TP) in sediments was divided into two parts: inorganic P (IP) and residual P (Res-P). The results showed that the total phosphorus content in surface sediments ranged from 1465.27 to 3650.12 mg/kg, IP was the major component of TP and the Ca bound P was the main fraction of IP. The bio-available phosphorus (BAP) in Dianchi Lake was first estimated in this study. BAP ranged from 215.66 to 678.02 mg/kgand the mean concentration was 382.78±89.77 mg/kgfor all 37 samples. The nitrogen fractions for the whole Dianchi Lake were firstly studied. It was shown that the sediment had been an important N nutrient source of the water, owing to the high content of transferable nitrogen forms in the sediment.

Key words: Phosphorus, Nitrogen, Distribution, Fraction, Bio-availability, Dianchi Lake

INTRODUCTION

Lake Eutrophication has been a severe problem since 1970s in China. Phosphorus and nitrogen are two critical elements in biogeochemical cycles due to their roles as the essential nutrient (Lü J. J. *et al.*, 2005). Phosphorus is regarded as the key factor in freshwater eutrophication (Ruban *et al.*, 2001), and also nitrogen could not be neglected. The content of total phosphorus and total nitrogen in the water body are always the most important indexes in the assessment of trophic status of lakes (Hu *et al.*, 2006).

Generally, phosphorus and nitrogen in lakes have two origins, i.e., external and internal (Ruban *et al.*, 1999). The sediments play vital roles in N and P cycle, which involves physical, chemical and biological processes (Liu *et al.*, 2009). In addition, surface sediment is the most active part in the interaction between water column and sediment. However, not all the forms of N or P would likely to be released from surface sediment into the overlying water, where they contribute to eutrophication (Gonsiorczyk *et al.*, 1998). The long-term behavior of sediment bound P in promoting eutrophication of lake can be more efficiently evaluated on the basis of different P forms, instead of total phosphorus content (Kaiserli *et al.*, 2002). Phosphorus can be found in sediment matrix in the forms of iron, calcium, aluminum complex salts and organic complexes, or adsorbed onto the surface minerals (Wang *et al.*, 2009), but the bioavailability of these phosphorus forms is most important for assessing their influences on eutrophication. Different P fractions in sediments are measured using different sequential extraction schemes such as, the so-called P fractionations (Li and Huang, 2010, Rydin, 2000). It is shown that the bio-available phosphorus (BAP) could be accurately estimated by the sum of some mobile P fractions (Li and Huang, 2010, Zhou *et al.*, 2005, Zhou *et al.*, 2001). The loosely sorbed P is considered as the immediately available form because it is easily released, moreover, it is confirmed that the 0.1 M NaOH extractable phosphorus was significantly correlated with 2 d and 14 d available phosphorus for an alga by Dorich et al. (1984). Actually, the non-apatite phosphorus, for example, BD-P and NaOH-P, which could easily be bio-available when the surroundings changed, could be considered as the potentially available form (Zhou *et al.*, 2005). Nitrogen fractions in sediments is also important to study its release capacity, bioavailability and assess lake eutrophication levels. The N/P (nitrogen phosphorus ratio) is important for the species of phytoplankton in lake. Many experiments demonstrated that the phytoplankton was limited by nitrogen while the N/P was lower than 44.2 (Elser *et al.*, 2009). However, the fraction and distribution of nitrogen in lake sediments are poorly studied.

*Corresponding author E-mail: xjpan@kmust.edu.cn

At the present, Dianchi Lake in Yunnan province, China, is under severely eutrophic conditions. However, it is designated as the city's backup water resource because the Dianchi Lake watershed, which has access to less water per capita than Israel or Jordan, is an area of severe water shortage. Gao et al. (2005) has studied the phosphorus fractions in sediment profiles in Dianchi Lake, but the sampling sites are few to get the phosphorus distribution in surface sediments of the whole lake. Hu et al. (2007) has investigated the distribution and fractionation of phosphorus in the surface sediments of Dianchi Lake which were collected in 2004, but there was no conception and estimation about bioavailable phosphorus. So it is necessary to assess the newest situation of internal phosphorus contamination in Dianchi Lake since the control on Dianchi Lake pollution reaped preliminary fruit due to some large projects were implemented during 2005 to 2010. And also, it is important to assess the internal nitrogen contamination and release capacity.

The aim of this research is to define the N and P forms and their distribution in surface sediments from Dianchi Lake, to evaluate their immediate and potential contributions to the water column in the region of Dianchi Lake, to be aware of the internal nitrogen and phosphorus loading in Dianchi Lake.

MATERIALS & METHODS

Dianchi Lake (24°402 -25°022 N, 102°36-103°402 E), the sixth largest freshwater lake in China, is located in the Yunnan-Guizhou Plateau of southwestern China (Hu *et al.*, 2007). Dianchi Lake is divided into Caohai section and Waihai section by an artificial dam near Haigeng. The Caohai section which is adjacent to Kunming City, has only 3% of the total area, but receives most of the wastewater from Kunming, and the Waihai section that is 97% of the total area and receives less wastewater (Li *et al.*, 2007). The lake's altitude is 1885 m above sea level, the maximum water depth is about 8 m (average 5 m), basin average length is about 32 km (N-S) while the average width is 7.6 km (W-E). It has a water surface of 306 km^2, with a watershed of 2920 km^2 (Lü J. J. *et al.*, 2005, Liu *et al.*, 2006).

Thirty seven surface sediment samples (0-10 cm) were collected by grab bucket from Dianchi Lake in February 2010. The sampling sites were shown in the Fig. 1. The sediment samples were taken to the laboratory in sealed plastic bags that stored in iceboxes (<4^{o}C), and were then freeze-dried, part of the samples were ground and sieved with a standard 150 μm sieve for phosphorus experimental study, and the others were conserved without grind for nitrogen fraction.

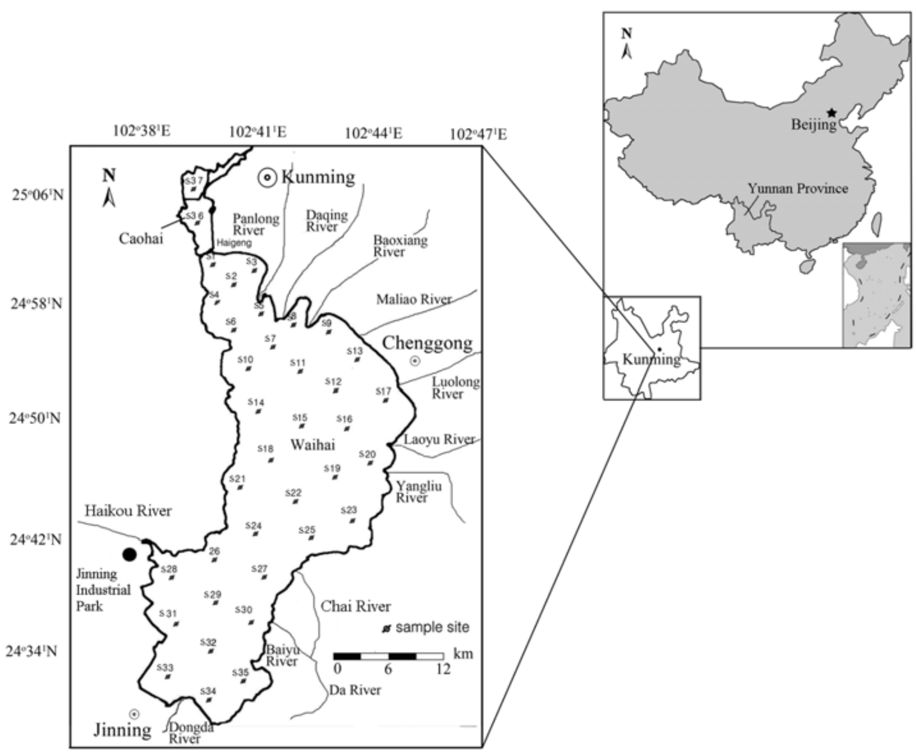


Fig. 1. Map of sampling sites of Dianchi Lake, China

The phosphorus fractionation method used in the present work was the Jin et al. scheme (Jin and Tu, 1990), with minor modifications. This extraction procedure divided inorganic P (IP) fractions into exchangeable or loosely sorbed P (Exch-P, extracted by 1 M NH_4Cl), aluminum bound P (Al-P, extracted by 0.5 M NH_4F (pH=7.0)), iron bound P (Fe-P, extracted by 0.1M NaOH), calcium bound P (Ca-P, extracted by 0.25 M H_2SO_4), occluded Al-P (Oc Al-P) and occluded Fe-P (Oc Fe-P). The two occluded forms would be removed oxidized iron film by 0.3 M sodium citrate, 1 M $NaHCO_3$ and $Na_2S_2O_4$ before the extraction. The difference between TP and IP is the residual P (Res-P), which contains organic P and refractory P compounds (Sun *et al.*, 2009).

The analysis of SRP (soluble reactive phosphorus) in each fraction was made by molybdenum-blue method. The TP analysis was achieved by an digestion with $HClO_4/H_2SO_4$ of the samples (ISSCAS, 1978). BAP could be calculated by the sum of Exch-P, Al-P and Fe-P (Tian and Zhou, 2007, Zhou *et al.*, 2005). Total nitrogen (TN) was measured using alkaline potassium persulfate digestion-UV spectrophotometric method (ISSCAS, 1978).The nitrogen fractionation method used in the present work was the Song et al. scheme (Song *et al.*, 2002), which imitated the phosphorus fraction method of Ruttenburg (Ruttenberg, 1992), with some adjustments. The TN in surface sediments was fractioned into transferable nitrogen (Trans-N) and fixed nitrogen (FN). The Trans-N was fractioned into exchangeable form (IEF-N), weak acid extractable form (WAEF-N), strong alkali extractable form (SAEF-N) and strong oxidation extractable form (SOEF-N). This extraction procedure divided transferable nitrogen (Trans-N) into ion-exchangeable form (IEF-N), weak acid extractable form (WAEF-N), strong alkali extractable form (SAEF-N) and strong oxidation extractable form (SOEF-N). The difference between TN and Trans-N is defined as fixed nitrogen (FN).
All statistical analysis was performed using SPSS 11.0. The isograms were generated by Suffer 8.0 software package as well as the histograms were made by Origin 8.0 software package.

RESULTS & DISCUSSION

Results of Waihai and Caohai sediment samples for total phosphorus and phosphorus fractions were shown in Table 1. The TP content of surface sediments ranged from 1465.27 to 3650.12 mg/kg. In previous research, the P content in surface sediments were under 250 mg/kgin most Chinese lakes and seldom above 750 mg/kg(An and Li, 2009). However, similar results were reported in some severely eutrophic lakes in China, for example, the highest concentrations of TP in surface sediments in Taihu Lake (China) can reach up to 3408 mg/kgin the Meiliang Lake region, and the TP content in the other regions of Taihu Lake (Gonghu Lake, East Taihu Lake and Wuli Lake) was under 1000 mg/kg(Jin *et al.*, 2006). It indicated that both of the two parts of Dianchi Lake were at serious eutrophication and its internal P loading was considerably high.

The spatial distribution of TP in surface sediments of Dianchi Lake was shown in the Fig. 2 (i). Total phosphorus in Caohai section was much higher than that in Waihai section because Caohai is close to the Kunming City, which is the capital of Yunnan province.

Table 1. Results of surface sediments for total phosphorus and phosphorus fractions (mg kg^{-1}) from the two parts, Caohai and Waihai sections, of Dianchi Lake

Lake part	Item	Exch-P	Al-P	Fe-P	Ca-P	Oc Fe-P	Oc Al-P	IP	Res-P	TP
	Maximum	8.33	5.59	441.45	899.71	311.10	2.14	1586.36	1304.15	2544.73
	Minimum	1.34	0.34	210.19	188.38	167.10	0.00	681.59	359.12	1465.27
Waihai	Average	4.29	2.62	360.48	240.04	240.81	1.01	1070.25	831.67	1901.92
	Stand deviation	1.51	1.47	62.83	139.56	34.20	0.53	182.54	265.62	284.19
Caohai	S36	6.85	25.85	645.32	784.26	675.21	2.46	2139.95	1510.18	3650.12
	S37	5.75	15.75	604.79	545.24	752.15	1.46	1925.14	1123.33	3048.46

Furthermore, the Caohai is enclosed water isolated by an artificial dam. Similar to this reason, the TP content of the samples near to city of Chenggong and Jinning were higher than those in the other sites. The spatial distributions of different P fractions were shown in Fig. 2(a) to Fig. 2(g). Concentrations of different P fractions were presented in Fig. 3(a) and the relative contributions of each fraction to TP were shown in Fig. 3(b). The IP content ranged from 681.59 mg/kgto 2139.95 mg/kg, Exch-P content ranged from 1.34 mg/kgto 8.33 mg/ kg, Al-P content ranged from 0.34 to 25.84 mg/ kg, Fe-P content ranged from 210.19 to 645.32 mg/kg, Ca-P content ranged from 188.38 to 899.71 mg/ kg, Oc Fe-P content ranged from 167.10 to 752.15 mg/ kg, Oc Al-P content ranged from 0 to 2.46 mg/kg, the Res-P content ranged from 359.02 to 1510.18 mg/kg, respectively.

IP was the most important mass fraction of TP and represented over 55% of TP content in surface sediments of Dianchi Lake (Fig 3(b)). The rank order of IP-fraction was Ca-P>Fe-P>Oc Fe-P>Al-P>Exch-P>Oc Al-P. This distribution was similar to the results of P fractions in the Haihe River, East Taihu Lake and Gonghu Lake in China (Jin *et al.*, 2006, Sun *et al.*, 2009). Ca-P was the major form of IP, the higher content of Ca-P in surface sediments of Dianchi Lake may be due to the nearly phosphorite deposit located in the town of Kunyang next to the southwest bank of Dianchi, which was one of the largest phosphorite deposit formed at the Lower Cambrian in China. There were massive discharge of waste gas containing fluoride during the course of phosphate fertilizer production, the fluoride would enter into the water column with rainfall and finally deposit into the sediments. It was

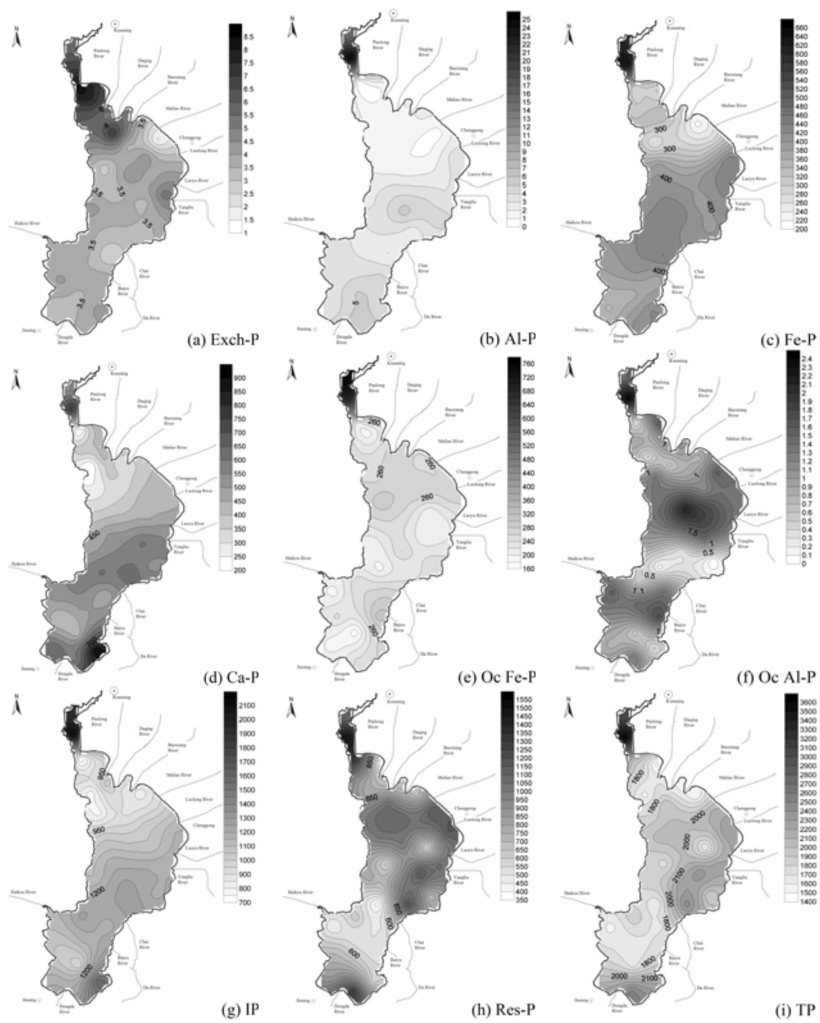


Fig. 2. Spatial distribution of total phosphorus and different P fractions (mg/ kg) in surface sediments of Dianchi Lake, China

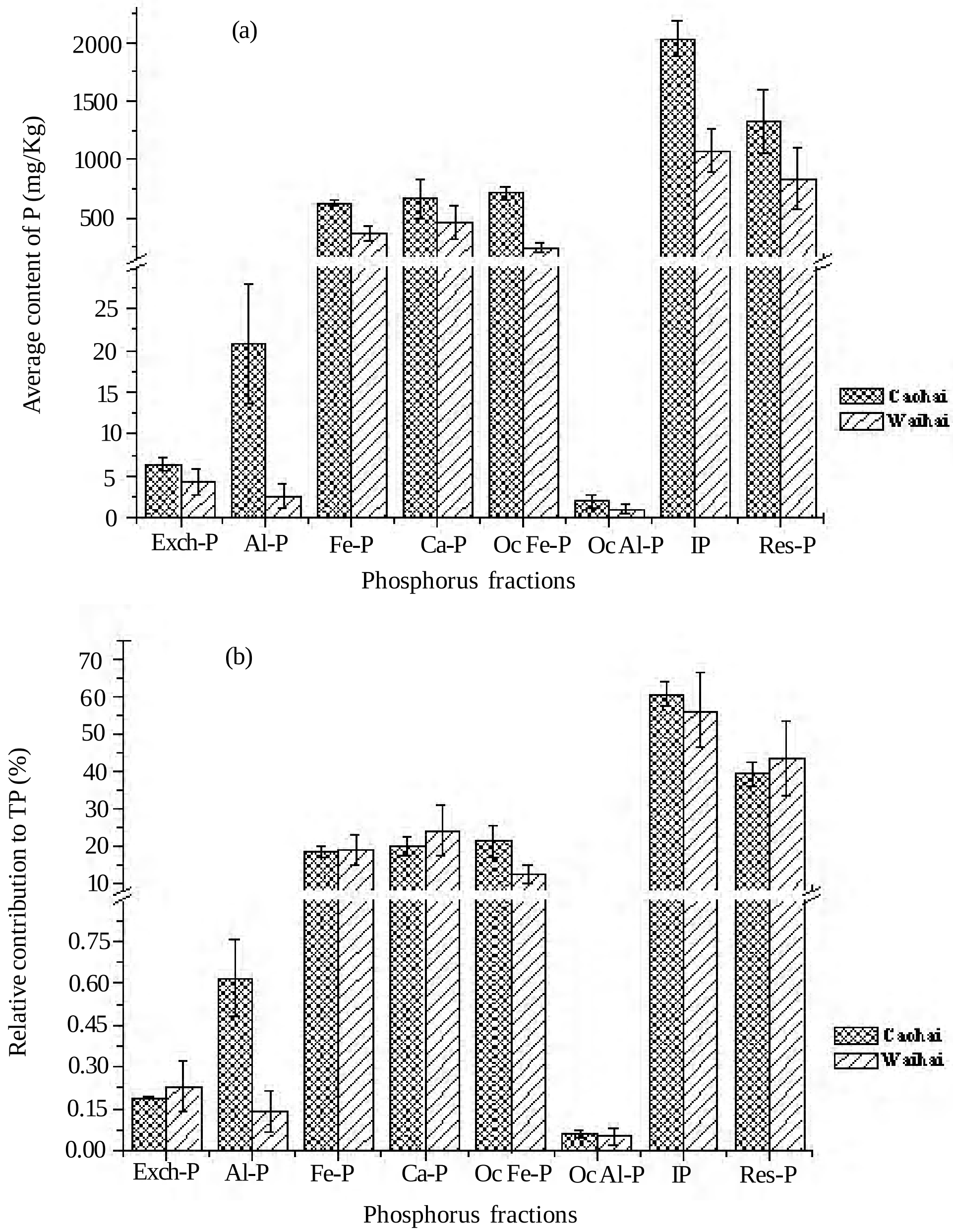


Fig. 3. Average Content of different P fractions (a) and relative contributions to TP (b) in surface sediments of Dianchi Lake, China

well known that fluoride can be a catalyst to promote the depositing of Ca and phosphate (Matzel *et al.*, 1996). It was also easy to explain that the average content of Ca-P at S33, S34 and S35 was up to 713.95 mg/kg, which was approximately three times than the average contents in the Waihai section. The highest content of Ca-P was found at S35, up to 899.71 mg/ kg. The possible reason for this was the waste gas containing phosphate and fluoride diffused in Gaussian dispersion model, so that the maximum ground concentration of air pollutants was emerged near S35. The pearson correlation coefficient between Ca-P and TP was 0.506, which was relatively lower than that between Fe-P and TP, Oc Fe-P and TP (Table. 2), and the RSD (relative standard deviation) was 25.3% at 35 sampling sites (with the exception of S1, S35), this could indicated that the Ca-P content changed not so much as the TP content at the majority of sampling sites,

Table 2. Pearson correlation coefficients between various phosphorus fractions in surface sediments (n=37)

	Exch-P	Al-P	Fe-P	Ca-P	Oc Fe-P	Oc Al-P	IP	Res-P	TP
Exch-P	1.000	0.173	-0.067	-0.248	0.239	-0.051	-0.044	0.251	0.135
Al-P		1.000	0.789**	0.530**	0.836**	0.361*	0.864**	0.337*	0.781**
Fe-P			1.000	0.633**	0.649**	0.305	0.902**	0.135	0.673**
Ca-P				1.000	0.243	0.076	0.811**	-0.032	0.506*
Oc Fe-P					1.000	0.396*	0.738**	0.378*	0.725**
Oc Al-P						1.000	0.298	0.187	0.417**
IP							1.000	0.183	0.768**
Res-P								1.000	0.769**
TP									1.000

* Correlation is significant at the 0.05 level (2-tailed)

** Correlation is significant at the 0.01 level (2-tailed).

even between the two different eutrophic status sections, Waihai and Caohai section. That's because the Ca-P was autogenetic and had little relevance to the eutrophic status. Therefore, the Ca-P was considered as a relatively stable fraction of sedimentary P and contributed to a permanent burial of P in sediments (Kaiserli *et al.*, 2002).

On the contrary, the Fe-P, Al-P and Occluded Fe-P were bound up with the pollution status. Apatite in sediments was the only phosphorus mineral, which, to a great degree, was conserved in its original form (allogenic mineral), thus Al-P, Fe-P, Oc Fe-P and Oc Al-P generally might be formed in the sediments by diagenetic processes (authigenic minerals) (Wang *et al.*, 2009). Hence, anthropogenic phosphorus would first bind to aluminum and iron oxides/hydroxides in the surface sediments of Dianchi Lake. And also, it can be explained furthermore that the Fe-P content in Caohai section were almost twice as that in Waihai and the Al-P content in Caohai were almost 10 times as that in Waihai. Some sewage interception projects were implemented after 2005, such as, Daqing River sewage interception and comprehensive improvement project were completed in June 2006, so that the concentrations of Fe-P and Al-P in the northern part of Waihai were lower than that in the southern part. The phosphate ion and the phosphorus compounds in the domestic sewage would be adsorbed on the surface of iron, aluminum and hydroxides firstly for the reason that active Fe and Al have been deemed to be the main sorbent for adsorbing P in natural sediments (Danen-Louwerse *et al.*, 1993). It was verified that the Fe exhibited positive association with Fe-P as expected by Moturi et al. (2005) and that the maximum phosphate sorption capacity and phosphate sorption efficiency of the sediments showed positive affinities with Fe content by Wang et al. (2005). The reason for the relatively high content of Fe-P and low content of Al-P was that the surface sediment in Dianchi was ferrosols and low alumina. Fe-P was once used to estimate the available P in sediments and was an indicator of algal available P (Ribeiro *et al.*, 2008, Zhou *et al.*, 2001), because the Fe-P and Al-P were exchangeable with hydroxyl ion. Therefore, the Fe-P and Al-P would be released to the water column if the pH and DO (dissolved oxygen) of surroundings were changed.
The Oc Fe-P and Oc Al-P were that the Fe-P and Al-P was encapsulated within $Fe(OH)_3$ and $Al(OH)_3$ adhesive film and eventually became forms of insoluble P by collide ageing, the occluded phosphorus fractions were considered unavailable. It was shown in Fig. 2 that the Oc Al-P content was much lower compared with other P fractions because the Al-P content was low and the concentration of alumina in sediments was low. It was illustrated in Fig. 2(e) that the content of Oc Fe-P in Waihai changed slightly and relatively stable, that's because the K_{sp} of Oc Fe-P is very low so that the Oc Fe-P was difficult to exchange with compounds in the overlying water (Han and Wen, 2004).

Exch-P represented the loosely sorbed P in the sediments, and this fraction may include dissolved P in the pore water (Kaiserli *et al.*, 2002), thus Exch-P was considered to be immediately bio-available. The P was released from $CaCO_3$ associated P or leached P from decaying cells of bacterial biomass in deposited phytodetrital aggregates and it was seasonally variable pool (Wang *et al.*, 2006). In Dianchi Lake, the mean content of Exch-P at sampling sites was very low: 4.29 mg/kgin Waihai and 6.8 mg/kgin Caohai respectively. The mean relative contribution to TP was 0.23% in Waihai and 0.19% in Caohai respectively. This was in accordance with the previous reports that Exch-P contribution to IP was lower than 1% (Kaiserli *et al.*, 2002). In addition, the Exch-P showed little variation among sites, it was in accordance with the results in previous study in Hanjiang River, China (Tian and Zhou, 2008).

The Res-P was mainly consisted of organic compounds bound with P. It was mainly derived from dead plants, animals and stable organophosphorus pesticide, such as trichlorfon. A part of organic P was easily transferred to IP by microbiological degradation and the rest was Res-P, thus the Res-P was considered unavailable. It was illustrated in Fig. 3(b) that the Res-P's relative contribution to TP in Caohai was lower than that in Waihai.

The content of TP, IP, Fe-P in the lake region near the entrances of Baoxiang River and Maliao River was obviously lower than the others. That's because some sewage interception projects on the northeastern lake bank and pollution abatements on the two rivers was implemented. And also, the IP and Fe-P was closely related to human activities.

The intercorrelations among various phosphorus fractions were shown in Table 2. The relationship between TP content and Al-P, Fe-P, Ca-P, Oc Fe-P, Oc Al-P, OP and Res-P content was significant. With the observed correlations among the various phosphorus fractions, IP and Fe-P had the most significant relationship, it was indicated that Fe-P was the most important form of IP.

Bio-available P has been defined as the sum of the P which could be transformed into available forms by natural processes and the P immediately available. Previous studies have used sequential chemical extraction methods to estimate the bio-availability of sedimentary P (Boström *et al.*, 1988, Zhou *et al.*, 2005). The BAP had been estimated by the sum of NH_4Cl-P, BD-P and NaOH-P and regarded as non-apatite inorganic P(Stone and English, 1993). Among them, NaOH-P was the most algal-available phosphorus pool in most studies. Furthermore, for soil samples and tributary water particulate matter, NaOH-P had often been found to be equal to algal extractable P (Boström *et al.*, 1988). A part of the organic phosphorus or the Ca-P was assumed available to micro-organisms, nevertheless, the results were shown that the organic phosphorus and Ca-P did not play an significant important role in fuelling local primary production, at least on the short term (Jonge *et al.*, 1993).

The BAP was calculated by the sum of Exch-P, Al-P and Fe-P in present study. The methods for the estimation scheme were proposed by Stone and English. (1993) and Zhou et al. (2005). It was slightly modified in order to be suitable for the phosphorus fractionation in this study. The BAP content in surface sediments of Dianchi Lake ranged from 215.66 to 678.02 mg/kgand the mean concentration was 382.78±89.77 mg/kgfor all samples. The spatial distribution of BAP in Dianchi Lake was shown in Fig. 4. The BAP can contribute substantially to the local primary production when this fraction reaches the water column caused by bioturbation or resuspension during one growing season. The BAP in Caohai section was much higher than that in Waihai, it was confirmed that the BAP was seriously affected by human activity again. The BAP content in the northeastern part of Waihai section was lower than that in other parts. That's because the Fe-P and Al-P were lower due to some sewage interception projects.

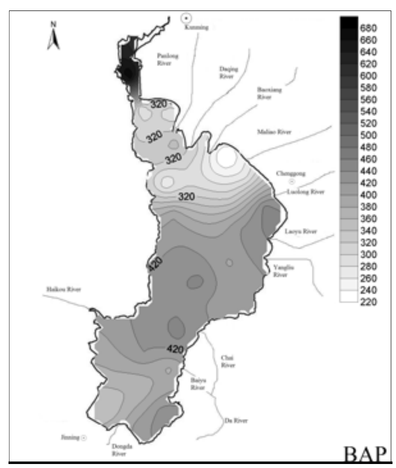
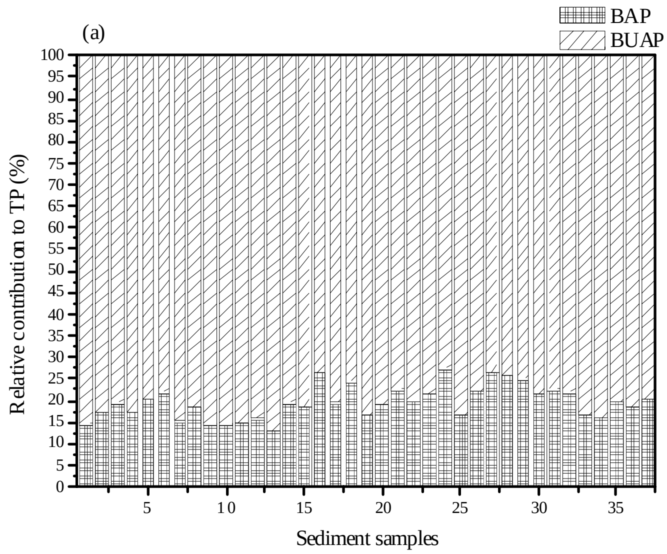


Fig. 4. Spatial distribution of bio-available P (mg/ kg) in surface sediments of Dianchi Lake, China

Fig. 5(a) (b) showed the relative contributions of BAP and BUAP (bio-unavailable phosphorus) to the total sedimentary phosphorus (TP) and inorganic sedimentary phosphorus (IP). In Dianchi Lake, from 13.0% to 27.3%, on average 19.6%, of TP is bio-available (Fig. 5(a)). Moreover, the BAP accounted for 26.1% to 43.8%, on average 34.4%, of IP (Fig. 5(b)).

Results of Waihai and Caohai surface sediments for total nitrogen and nitrogen fractions were shown



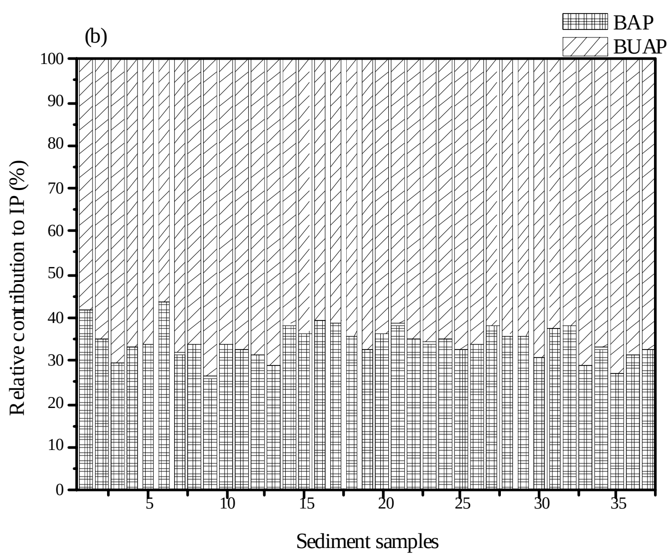


Fig. 5. Relative contributions of BAP and BUAP to TP content (a) and IP content (b)

in Table 3. The TN content of surface sediments ranged from 1775.36 to 22384.12 mg/kgand the spatial distribution of TN in surface sediments of Dianchi was shown in the Fig. 6(g). Similar to the TP, the TN content in Caohai was much higher than that in Waihai, because the Caohai section was close to Kunming City and directly received most of the city's domestic and industrial sewage which had not been totally treated prior to discharging into the lake. Therefore, the large volume of sewage discharged into Caohai section resulted in gross contamination (Lü J. J. *et al.*, 2005). Similarly, it was illustrated in Fig. 6(g) that TN content in Waihai presented little change. However, the TN in the region near the entrance of Baoxiang River and Maliao River was relatively a little lower. That's because some pollution abatements were carried out on the two rivers, the input nitrogen into water was reduced, so that content of TN in the surface sediment was lower accordingly.

The spatial distributions of different N fractions in surface sediments were shown in the Fig. 6(a) to Fig. 6(f). The IEF-N in surface sediment was very easy to release to the overlying water, thereby it was important for the N cycling (Lü X. X. *et al.*, 2005). In the part close to the town of Haikou, and the entrance of Chai River, the IEF-N content was higher (Fig. 6(a)). It was illustrated that there may be some unknown emission sources along the Chai River bank. In the middle of the lake, the IEF-N content was lower than

Table 3. Results of surface sediments for total nitrogen and nitrogen fractions (mg kg^{-1}) from the two parts, Caohai and Waihai sections, of Dianchi Lake

Lake part	Item	IEF-N	WAEF-N	SAEF-N	SOEF-N	Trans-N	FN	TN
Waihai	Maximum	1172.24	529.53	317.08	990.75	2752.89	1314.43	3104.76
	Minimum	147.36	284.76	44.95	260.39	881.41	29.83	1775.36
	Average	506.83	395.02	200.71	749.44	1852.00	611.74	2463.74
	Stand deviation	235.67	59.37	63.86	162.80	378.06	353.28	389.33
Caohai	S36	390.21	690.12	17408.27	3026.22	21514.82	869.30	22384.12
	S37	213.91	603.87	13134.25	1383.01	15335.05	686.40	16021.45

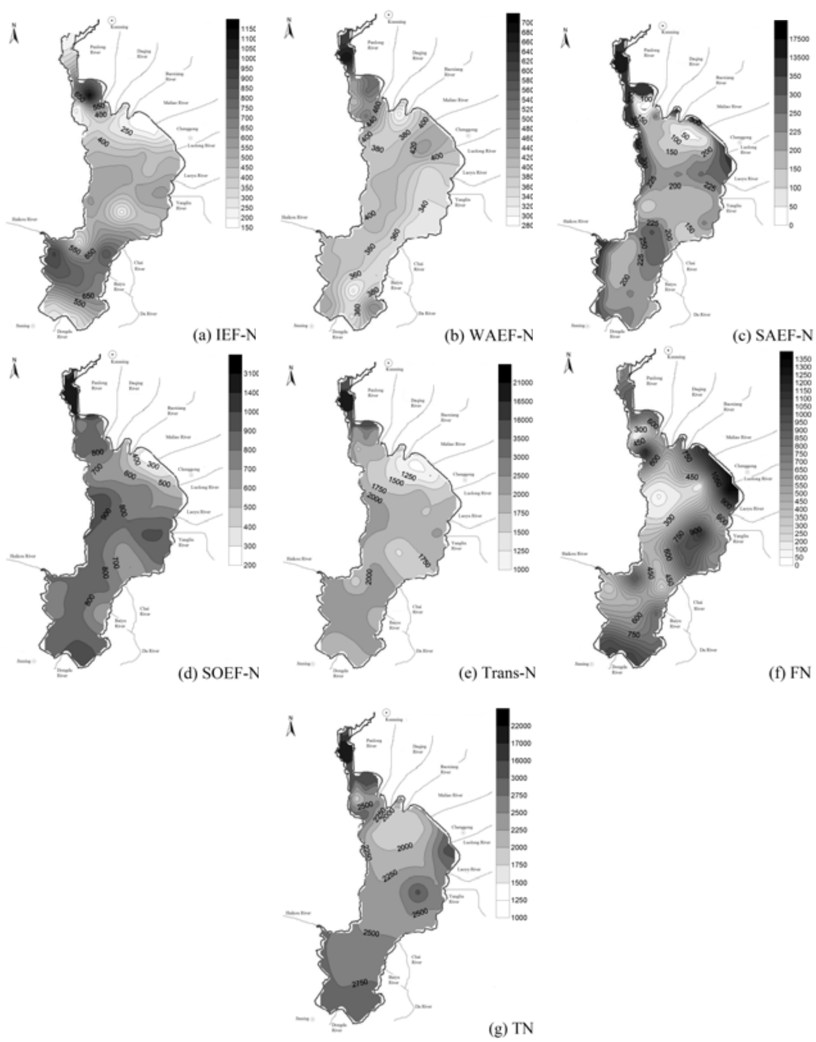


Fig. 6. Spatial distribution of total nitrogen and nitrogen fractions (mg/kg) in surface sediments of Dianchi Lake, China

that along the bank (Fig. 6(a)). It also confirmed that the farm drainage and surface runoff brought into a relatively large volume of wastewater.

However, the WAEF-N content along the east bank of Waihai were lower, in addition, the WAEF-N content didn't have great changes among the majority of sampling sites (Fig. 6(b)). That's because the WAEF-N was the nitrogen bounded up with carbonate mineral, it might have to do with the $CaCO_3$ content in the sediments.

There was a great difference between SAEF-N content in Caohai and in Waihai (Fig. 6(c)). The SAEF-N was the nitrogen bounded up with the Fe and Mn oxides, it was more difficult to release compared with the other two inorganic nitrogen forms, IEF-N and WAEF-N. The most important reason for such high content of SAEF-N in Caohai was that a mass of organic nitrogen from the plant residue in sediment was mineralized by the active microflora, and then the mineralized nitrogen, NH_4^+ and NO_3^-, were bounded up with the sediments with high content of Fe and Mn oxide. Furthermore, the plant residue could provide carbon and nitrogen nutrition and balance the C/N (carbon nitrogen ratio), which was very important for microbiological activity, thereby the mineralization rate would be increased. In addition, It was stated that the surrounding conditions were important for the content of SAEF-N, the anaerobic conditions would make for keeping SAEF-N stable (He *et al.*, 2009), and DO in the sediments of Caohai exceeds Waihai because Caohai was shallower than Waihai, it may be a reason for the results in present study.

The Trans-N content ranged from 881.41 to 21514.82 mg/ kg, and the IEF-N, WAEF-N, SAEF-N, SOEF-N content ranged from 147.36 to 1172.24 mg/ kg, from 284.76 to 690.12 mg/ kg, from 44.95 to 17408.27 mg/ kg, from 260.39 to 3026.22 mg/ kg, respectively, the FN content ranged from 29.83 to 1314.43 mg/ kg.

Concentrations of different N fractions were presented in Fig. 7(a) and the contributions of each fraction relative to TN in surface sediments were shown in Fig. 7(b). It was shown that transferable nitrogen form was the most important mass fraction of TN content in surface sediments of Dianchi Lake and represented over 75% and 95% in Waihai and Caohai, respectively (see Fig. 7(b)). The rank order of Trans-N fraction was different in the two parts, Waihai and Caohai. The order was SAEF-N>SOEF-N>WAEF-N>IEF-N in Caohai section and SOEF>IEF-N>WAEF-N>SAEF-N in Waihai section. Consequently**,** SOEF-N was the main fraction in surface sediments of Dianchi Lake, the results were consistent with previous reports on surface sediments of southwestern Nansha Trough (Zheng *et al.*, 2008) and Jiaozhou Bay (Dai *et al.*, 2007).

The SOEF-N was mainly constituted by organic nitrogen and its content was predominantly associated with the organic matter. It was the most difficult part to release in the transferrable nitrogen fractions. However, it could be transferred to be bio-available pool by nitrogen mineralization, so it can be considered as a potential source of nitrogen. SOEF-N presented little variation among most of sites, besides from northeastern lake region (Fig. 6(d)). This might be related to the mass of dead plants and animals in surface sediments at this region. The fixed nitrogen content didn't seem to fluctuate much in the whole Dianchi Lake, this may be because the fixed nitrogen was provided with a very stable chemical structure. This fraction was barely contributed to the lake eutrophication.

The intercorrelations among various nitrogen pools were shown in the Table 4. Trans-N and TN had the most significant relationship. The relationships between TN content and WAEF-N, SAEF-N and SOEF-N were also significant.

Table 4. Pearson correlation coefficients between various nitrogen fractions in surface sediments (n=37)

Item	IEF-N	WAEF-N	SAEF-N	SOEF-N	Trans-N	FN	TN
IEF-N	1.000	0.030	-0.182	0.027	-0.100	-0.352*	-0.130
WAEF-N		1.000	0.713**	0.644**	0.733**	0.070	0.731**
SAEF-N			1.000	0.862**	0.995**	0.113	0.994**
SOEF-N				1.000	0.897**	-0.030	0.885**
Trans-N					1.000	0.078	0.996**
FN						1.000	0.166
TN							1.000

* Correlation is significant at the 0.05 level (2-tailed)

** Correlation is significant at the 0.01 level (2-tailed)

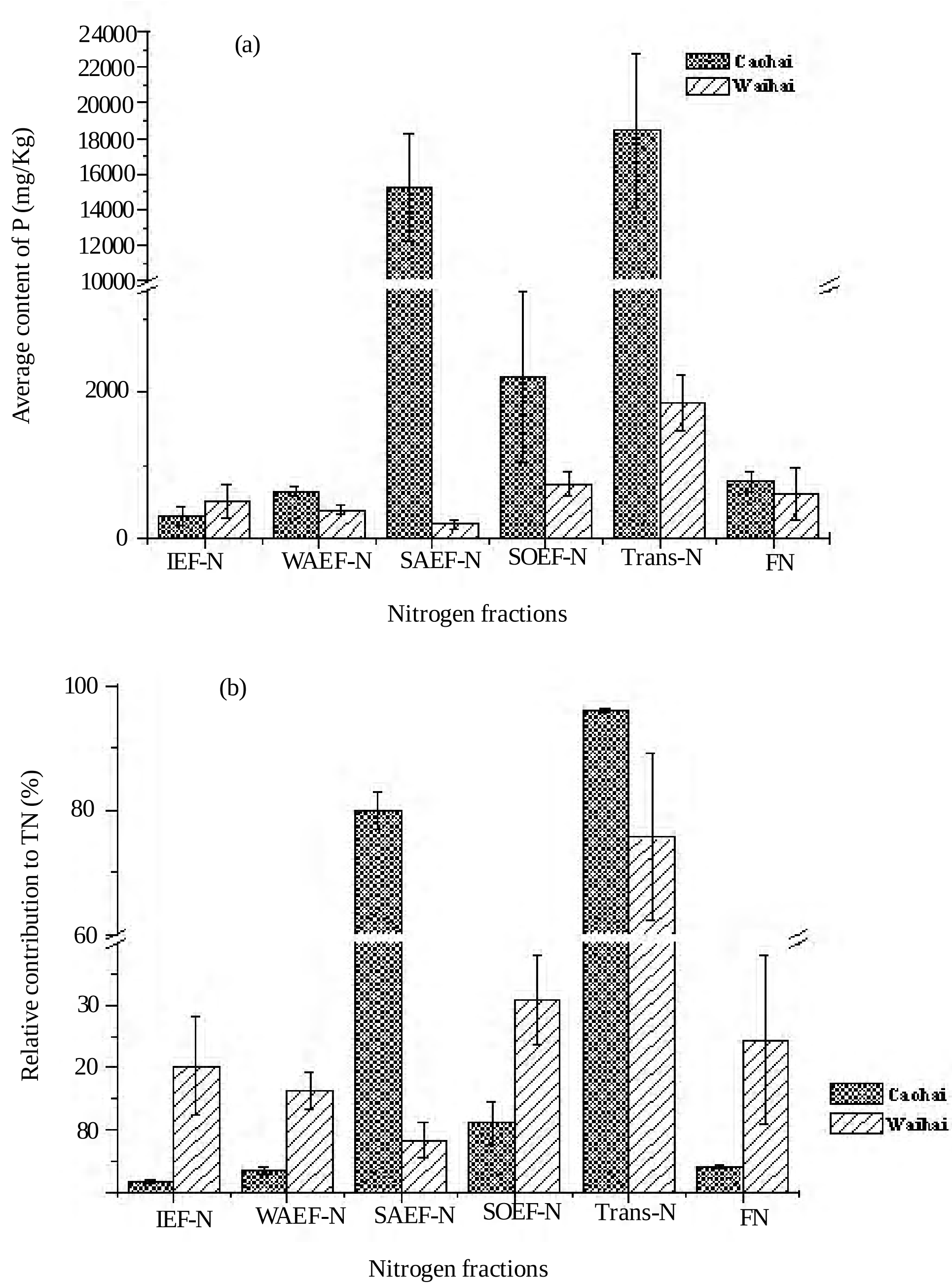


Fig . 7. Average content of different N fractions (a) and relative contributions to TN (b) in surface sediments of Dianchi Lake, China

CONCLUSION

In this study, fractions, spatial distribution and variations of phosphorus and nitrogen in surface sediments of Dianchi Lake were investigated. From the data presented in this study, the following conclusions can be drawn:

(1) The percentages of BAP to TP and IP indicated that most of the internal P loading was not bioavailable, and less than 20% of TP in surface sediments of Dianchi Lake were active for algae bloom. However, the percentage of Trans-N and potential mineralizable nitrogen to TN were so high that would be an internal nitrogen source. Consequently, the surface sediment in Dianchi Lake proved to be more as the nitrogen source of water rather than phosphorus source. This conclusion was significant for the decision on the water diversion project from the Niulanjiang River to Dianchi Lake, with a total static investment of nearly 11.6 hundred million US dollars. Re-suspension caused by this project was a potential threat of green algae outbreak because of the phosphorus and nitrogen release from the sediment. The results showed present study might be positive for the implementation of this project, because the relative low P release capacity would basically not bring a shape rise of P in the water column.

(2) Meanwhile, the low relative contribution of BAP to TP also showed that the dredging in the Waihai section might be not at all perfect and the environmental benefit brought by dredging would be undermined. Perhaps the water restoration by aquatic plants would be a better method in some eutrophic lakes like Dianchi Lake, which BAP was low in the surface sediment.

(3) The content of some P pools related closely to human activities was obviously lower, yet the content of some P pools which was less with human activities did not exhibit a significant change between the region before and after treatments. Similar regularity was also found in nitrogen distribution. It was demonstrated that some sewage interception projects and pollution abatements on rivers into lake implemented at the northeastern Dianchi Lake were effective.

(4) The distribution of the pollutants in the present study would become an important basis for the water pollution control projects' decision-making at the Dianchi Lake watershed. And also, this study would support the simulation of the sediment-water interface behavior of N and P in Dianchi Lake, the prediction on the lake's eutrophic status in the future and the policy making of environment management for the government.

ACKNOWLEDGEMENT

This work was supported by the National High Technology Research and Development Program of China (863 Program 2010AA06Z301). In this study, the authors acknowledge the opportunity to obtain surface sediments provided by Mr. Lei Zhao, Mr. Xiang Zhu, Prof. Xiaohai Liu and Prof. Bin He from Yunnan Institute of Environmental Science.

REFERENCES

An, W. C. and Li, X. M. (2009). Phosphate adsorption characteristics at the sediment-water interface and phosphorus fractions in Nansi Lake, China, and its main inflow rivers. Environmental Monitoring and Assessment, **148 (1-4)**, 173-184.

Boström, B., Persson, G. and Broberg, B. (1988). Bioavailability of different phosphorus forms in freshwater systems. Hydrobiologia, **170 (1)**, 133-155.

Chen, Y. C., Tang, L., Chen, L. and Li, J. (2005). Spatially and Temporally Dynamic Variation of Phosphorus in Water of Dianchi Lake. Journal of Agro-Environment Science, **24 (6)**, 1145-1151.

Chen, Y. C., Zhang, D. G. and Tang, L. (2010). The Spatial and Temporal Variation of Nitrogen and Its Relationships with Algal Growth in Lake Dianchi China. Journal of Agro-Environment Science, **29 (1)**, 139-144.

Dai, J. C., Song, J. M., Li, X. G., Zheng, G. X., Yuan, H. M. and Li, N. (2007). Geochemical characteristics of nitrogen and their environmental significance in Jiaozhou Bay sediment. Quaternary Sciences, **27 (3)**, 347-356.

Danen-Louwerse, H., Lijklema, L. and Coenraats, M. (1993). Iron content of sediment and phosphate adsorption properties. Hydrobiologia, **253 (1)**, 311-317.

Dorich, R. A., Nelson, D. W. and Sommers, L. E. (1984). Availability of phosphorus to algae from eroded soil fractions. Agriculture, Ecosystems and Environment, **11 (3)**, 253-264.

Elser, J. J., Andersen, T., Baron, J. S., Bergstrom, A.-K., Jansson, M., Kyle, M., Nydick, K. R., Steger, L. and Hessen, D. O. (2009). Shifts in Lake N:P Stoichiometry and Nutrient Limitation Driven by Atmospheric Nitrogen Deposition. Science, **326 (5954)**, 835-837.

Gao, L., Zhou, J. M., Yang, H. and Chen, J. (2005). Phosphorus fractions in sediment profiles and their potential contributions to eutrophication in Dianchi Lake. Environmental Geology, **48 (7)**, 835-844.

Gonsiorczyk, T., Casper, P. and Koschel, R. (1998). Phosphorus-binding forms in the sediment of an oligotrophic and an eutrophic hardwater lake of the Baltic Lake District (Germany). Water Science and Technology, **37 (3)**, 51-58.

Han, S. S. and Wen, D. M. (2004). Phosphorus release and affecting factors in the sediments of eutrophic water. Chinese Journal of Ecology, **23 (2)**, 98-101.

He, T., Xie, J., Yu, H. S., Fang, H. D. and Gao, Q. Z. (2009). Distribution characteristics of different forms of nitrogen in surface sediments of Daya Bay. Journal of Tropical Oceanography, **28 (2)**, 86-91.

Hu, J., Liu, Y. D. and Liu, J. T. (2006). The comparison of phosphorus pools from the sediment in two bays of Lake Dianchi for cyanobacterial bloom assessment. Environmental Monitoring and Assessment, **121 (1-3)**, 1-14.

Hu, J., Shen, Q., Liu, Y. D. and Liu, J. T. (2007). Mobility of different phosphorus pools in the sediment of Lake Dianchi during cyanobacterial blooms. Environmental Monitoring and Assessment, **132 (1-3)**,141-153.

ISSCAS, (1978). Soil physics chemical analysis. (Shanghai: Basic Books) Jin, X. C. and Tu, Q. Y. (1990). Investigation method for the lake eutrophication. (Beijing: China Environmental Science Press).

Jin, X. C., Wang, S. R., Pang, Y. and Wu, F. C. (2006). Phosphorus fractions and the effect of pH on the phosphorus release of the sediments from different trophic areas in Taihu Lake, China. Environmental Pollution, **139 (2)**, 288-295.

Jonge, V. N., Engelkes, M. M. and Bakker, J. F. (1993). Bio-availability of phosphorus in sediments of the western Dutch Wadden Sea. Hydrobiologia, **253 (1)**, 151-163.

Kaiserli, A., Voutsa, D. and Samara, C. (2002). Phosphorus fractionation in lake sediments - Lakes Volvi and Koronia, N. Greece. Chemosphere, **46 (8)**, 1147-1155.

Lü, J. J., Yang, H., Gao, L. and Yu, T. Y. (2005). Spatial variation of P and N in water and sediments of Dianchi Lake, China. Pedosphere, **15 (1)**, 78-83.

Lü, X. X., Song, J. M., Yuan, H. M., Li, X. G., Zhang, T. R., Li, N. and Gao, X. L. (2005). Geochemical characteristics of nitrogen in different grain size sediment from the southern Huanghai Sea. Acta Oceanologica Sinica, **27 (1)**,64-69.

Li, D. P. and Huang, Y. (2010). Sedimentary phosphorus fractions and bioavailability as influenced by repeated sediment resuspension. Ecological Engineering, **36 (7)**, 958-962.

Li, R. Y., Yang, H., Zhou, Z. G., LÜ, J. J., Shao, X. H. and Jin, F. (2007). Fractionation of Heavy Metals in Sediments from Dianchi Lake, China. Pedosphere, **17 (2)**, 265-272.

Liu, J. Y., Wang, H., Yang, H. J., Ma, Y. J. and Cai, O. C. (2009). Detection of phosphorus species in sediments of artificial landscape lakes in China by fractionation and phosphorus-31 nuclear magnetic resonance spectroscopy. Environmental Pollution, **157 (1)**, 49-56.

Liu, Y. M., Chen, W., Li, D. H., Shen, Y. W., Li, G. B. and Liu, Y. D. (2006). First report of aphantoxins in China—waterblooms of toxigenic Aphanizomenon flos-aquae in Lake Dianchi. Ecotoxicology and Environmental Safety, **65 (1)**, 84-92.

Matzel, L. D., Rogers, R. F. and Talk, A. C. (1996). Bidirectional regulation of neuronal potassium currents by the G-protein activator aluminum fluoride as a function of intracellular calcium concentration. Neuroscience, **74 (4)**, 1175-1185.

Moturi, M. C. Z., Rawat, M. and Subramanian, V. (2005). Distribution and partitioning of phosphorus in solid waste and sediments from drainage canals in the industrial belt of Delhi, India. Chemosphere, **60 (2)**, 237-244.

Ribeiro, D. C., Martins, G., Nogueira, R., Cruz, J. V. and Brito, A. G. (2008). Phosphorus fractionation in volcanic lake sediments (Azores - Portugal). Chemosphere, **70 (7)**, 1256-1263.

Ruban, V., Brigault, S., Demare, D. and Philippe, A. M. (1999). An investigation of the origin and mobility of phosphorus in freshwater sediments from Bort-Les-Orgues Reservoir, France. Journal of Environmental Monitoring, **1 (4)**, 403-407.

Ruban, V., Lopez-Sanchez, J. F., Pardo, P., Rauret, G., Muntau, H. and Quevauviller, P. (2001). Harmonized protocol and certified reference material for the determination of extractable contents of phosphorus in freshwater sediments - A synthesis of recent works. Fresenius Journal of Analytical Chemistry, **370 (2-3)**, 224-228.

Ruttenberg, K. C. (1992). Development of a sequential extraction method for different forms of phosphorus in marine-sediments. Limnology and Oceanography, **37 (7)**, 1460-1482.

Rydin, E. (2000). Potentially mobile phosphorus in Lake Erken sediment. Water Research, **34 (7)**, 2037-2042.

Song, J. M., Ma, H. B. and Lü, X. X. (2002). Nitrogen forms and decomposition of organic carbon in the southern Bohai Sea core sediments. Acta Oceanologica Sinica, **21 (1)**, 125-133.

Stone, M. and English, M. C. (1993). Geochemical composition, phosphorus speciation and mass transport of fine-grained sediment in two Lake Erie tributaries. Hydrobiologia, **253 (1)**, 17-29.

Sun, S. J., Huang, S. L., Sun, X. M. and Wen, W. (2009). Phosphorus fractions and its release in the sediments of Haihe River, China. Journal of Environmental Sciences, **21 (3)**,291-295.

Tian, J. R. and Zhou, P. J. (2007). Phosphorus fractions of floodplain sediments and phosphorus exchange on the sediment-water interface in the lower reaches of the Han River in China. Ecological Engineering, **30 (3)**,264-270.

Tian, J. R. and Zhou, P. J. (2008). Phosphorus fractions and adsorption characteristics of floodplain sediments in the lower reaches of the Hanjiang River, China. Environmental Monitoring and Assessment, **137 (1-3)**, 233-241.

Wang, P., He, M. C., Lin, C. Y., Men, B., Liu, R. M., Quan, X. C., and Yang, Z. F. (2009). Phosphorus distribution in the estuarine sediments of the Daliao river, China. Estuarine, Coastal and Shelf Science, **84 (2)**, 246-252.

Wang, S. R., Jin, X. C., Pang, Y., Zhao, H. C., Zhou, X. N. and Wu, F. C. (2005). Phosphorus fractions and phosphate sorption characteristics in relation to the sediment compositions of shallow lakes in the middle and lower reaches of Yangtze River region, China. Journal of Colloid and Interface Science, **289 (2)**, 339-346.

Wang, S. R., Jin, X. C., Zhao, H. C. and Wu, F. C. (2006). Phosphorus fractions and its release in the sediments from the shallow lakes in the middle and lower reaches of Yangtze River area in China. Colloids and Surfaces A: Physicochemical and Engineering Aspects, **273 (1-3)**, 109-116.

Zheng, G. X., Song, J. M., Sun, Y. M., Dai, J. C. and Zhang, P. (2008). Characteristics of nitrogen forms in the surface sediments of southwestern Nansha Trough, South China Sea. Chinese Journal of Oceanology and Limnology, **26 (3)**, 280-288.

Zhou, A. M., Wang, D. S. and Tang, H. X. (2005). Phosphorus fractionation and bio-availability in Taihu Lake(China) sediments. Journal of Environmental Sciences-China, **17 (3)**, 384-388.

Zhou, Q. X., Gibson, C. E. and Zhu, Y. M. (2001) Evaluation of phosphorus bioavailability in sediments of three contrasting lakes in China and the UK. Chemosphere, **42 (2)**, 221-225.