第30卷第6期 水生生物学报 Vol. 30, No. 6
2006年11月 ACTA HYDROBIOLOGICA SINICA Nov., 2006

TEMPORAL AND SPATIAL DISTRIBUTION OF PHOSPHORUS IN THE XIANGXI RIVER

FU Chang-Ying[1,2], FANG Tao[1], DENG Nan-Sheng[2] and YU Hai-Qiao[1,3]

(1. Institute of Hydrobiology, the Chinese Academy of Sciences, Wuhan 430072, China; 2. School of Environmental Sciences and Resources, Wuhan University, Wuhan 430079; 3. School of Resources and Environmental Engineering, Wuhan University of Technology, Wuhan 430070)

Abstract: The phosphorus in water and sediment collected at different time from the Xiangxi River were analyzed. The results indicated that the phosphorus pollution have significant relations to human activities (especially the phosphorus industry). The concentrations of total-phosphorus (TP), total dissolved phosphorus (TDP) and dissolved phosphorus (DP) in Dec. 2004 were higher than those in Jul. 2005; the TP contents of sites 15 and 16 were much higher than others', the TP content of the largest site 16 was 1946.29mg/kg in Dec. 2004 and 1756.11mg/kg in Jul. 2005, respectively, which was much higher than the average (1497.51 mg/kg and 1369.38mg/kg, respectively). The TP content in the sediment of the Xiangxi River was from 1179.53mg/kg to 1851.20mg/kg. The TP contents of most sites except site 18, 19 and 20 were higher in Dec. 2004 than those in Jul. 2005. The aluminium-phosphorus (Al-P) content in the sediment was obviously higher in Jul. 2005 than that in Dec. 2004, which indicated that the stability of Al-P has a significant relation to the change of season.

Key words: Phosphorus; Sediment; Adsorption and release; Xiangxi River; Three Gorges

CLC number: X832 **Document code:** A **Article ID:** 1000-3207(2006)06-0647-05

Phosphorus is an essential and often limiting nutrient in both marine and freshwater ecosystems, yet its oversupply is of concern in many environments due to its role in eutrophication[1]. Phosphorus enters rivers from diffuse catchment sources (particularly agriculture) and point (effluent) sources. However, river systems have an important internal capacity to remove or release phosphorus from/to the water column and to trans-form phosphorus between organic, inorganic, particulate and dissolved forms. River bed sediments can play an important role in buffering concentrations of soluble reactive phosphorus (SRP) in surface waters[2—4]. This buffering is strongest under low-flow conditions, when there is a relatively long contact time between the water column and the bed sediment and where the sediment surface area to water volume is high. Under certain environmental conditions, phosphorus can be released from the sediments to the overlying water[5—7]. The characteristics of sediment affected the equilibrium concentrations of phosphorus between the sediment and the overlying water[8]. Algal growth in nearly all eutrophic lakes is limited by the concentration of phosphorus rather than nitrogen[9—11]. There are about 3000 pollution sources along the banks of the Three Gorges Reservoir. The total industrial and urban wastewater discharge into the reservoir area amounts to about 10^8 tons/year in which contains much N and P pollutants[12].

The Xiangxi River is the first middling tributary of the Changjiang River nearby the Three Gorges Dam. The River is subject to phosphorus pollution from industrial wastewater. After the sluice of the Three Gorges Dam Locks become fully functional, the water-flow profile of the Xiangxi River would change (mainly decelerate), which may have adverse environmental effects on the entire system. As the water quality of the River could directly influence the water quality of the Three Gorges Reservoir, the research on phosphorus distributions and

Received date: 2004-11-4; **Accepted date:** 2006-3-9

Foundation item: Key Project of the Chinese Academy of Sciences (KSCX2-SW-111); National Key Project for Basic Research (2002CB412304)

Corresponding author: Fang Tao, Tel: +86-27-68780710, Fax: +86-27-68780712, E-mail: fangt@ihb.ac.cn

its change in the sediment profile of the Xiangxi River could provide useful information in the dynamic changes in the system, thereby offering options for mitigative measures.

1 Materials and methods

1.1 Area descriptions The Xiangxi River has two easterly and westerly derivations, is the largest tributary draining into the Three Gorges Reservoir of the Changjiang River in Hubei Province. The Xiangxi River is 469.7 km long, with a watershed area of 3099.4km^2. The reserves of phosphate of this area are among the top three in China. Some sites of the River are under mesotrophic or eutrophic conditions due to agro-chemical and chemical fertilizer overusage, discharge of the municipal sewage, large-scale cultivation, and high-density population in the watershed. The distance between the Xiangxi River and the Three Gorges Dam is about 20km. The distribution of 22 sampling sites is illustrated in Fig. 1. The altitude of the water level of the Three Gorges Dam is 135m at first, then 156m, finial it will reach 175m after the Dam is completed. When the water level is 135m, the submerged range (from the river mouth) would be near sampling site 12, when water level is 156m, the submerged range would reach site 10. After the Dam is completed, the water level (175m) of the reservoir will be much higher and the water surface will be much wider. The reach of the Xiangxi River below sampling site 8 will be submerged.

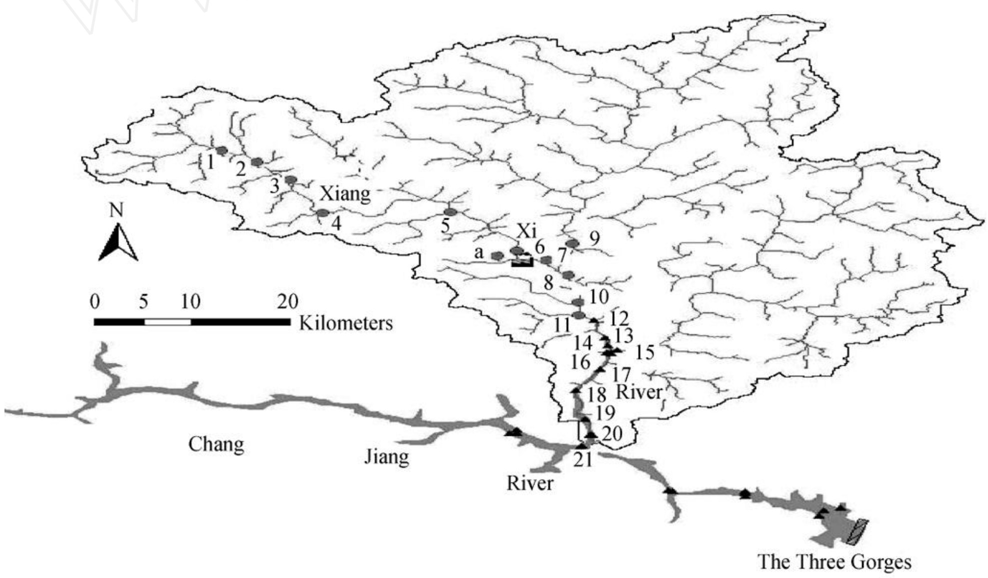

Fig. 1 Sampling stations in the Xiangxi River and the Changjiang River

1.2 Sampling and analysis The water samples were collected from the Xiangxi River in Dec. 2004 and Jul. 2005 using Go-Flo bottles. The water samples were kept at 0—4 ℃ until analysis which took place within 24 hours. Some water samples of some sites (9, 10, 11, 15, 16 and a) were also collected and analyzed from Oct. 1996 to Jul. 1997. Sediment samples were collected using an Ekman Dredge sampler in the Xiangxi River in Dec. 2004 and Jul. 2005; samples were placed into plastic containers, sealed and kept at 0—4 ℃ until analysis. Fig. 1 shows the locations of sampling stations in the Xiangxi River.

Water samples from the river were analyzed by the following procedures. Filtered samples (< 0.45mm) were analyzed for the concentration of dissolved P (DP). Unfiltered samples and filtered samples (< 0.45mm) were used to determine the TP concentration and the total dissolved P, by digestion with $K_2S_2O_8$. The P concentration of all samples was analyzed spectrophotometrically by the ammonium molybdate method of Murphy and Riley[13] with ascorbic acid as a reducing agent.

An aliquot of each sediment sample was freeze-dried then ground to a fine powder. Extraction of the various phosphorus species from the sediment was based on the fractionation scheme[14,15]. Organic phosphorus (Org-P) was calculated as the difference between the various mineral phosphorus phases and total sedimentary phosphorus.

Phosphorus in the labile or "available" aluminum (Al-P) and iron (Fe-P) oxide phases were extracted using sequential leaches of 0.5mol/L NH_4F and 0.1mol/L NaOH, respectively. Apatite P (Ca-P) was extracted with a 0.5mol/L H_2SO_4 solution after extraction of Al-P and Fe-P. Phosphate from all solutions was measured as soluble reactive phosphate by the molybdenum blue method.

2 Results

2.1 The comparison of TP concentration of the Xiangxi River before and after the impoundment of the Three Gorges Dam (Fig. 2)

Before sluiced, the TP concentration of the Xiangxi River changed largely, the upstream of the location 10, the TP concentrations of sites were very low (less than 0.05mg/L), the largest concentration (0.34mg/L) was located the site of 16. All of those had a significant relation with people behaviors (especially the phosphorus industry).

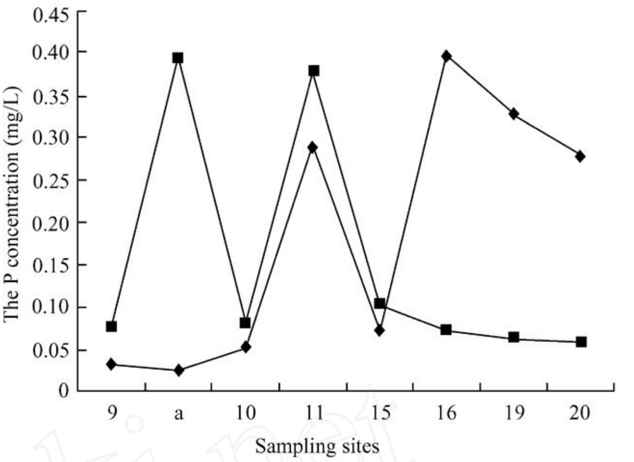

Fig. 2 The comparison of TP concentrations of the Xiangxi River before and after the impoundment of the Three Gorges Dam
(—◆— before, —■— after)

2.2 The difference of phosphorus concentration of the Xiangxi River between perish period and freshet period (Fig. 3):

The concentrations of TP, TDP and DP in Dec. 2004 were higher than those in Jul. 2005. The P concentrations of the site (from 4 to 16) changed a larger degree than other sites.

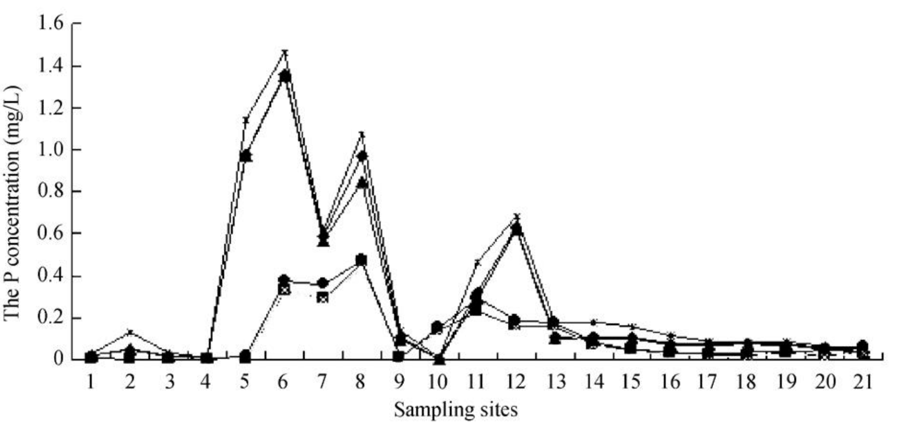

Fig. 3 The comparison of different P concentrations of the Xiangxi River between different periods

Perish period(TP TDP DP), fresther period(TP TDP DP)

2.3 The difference of phosphate content in sediment of the Xiangxi River between perish period and freshet period (Tab. 1)

The content of inorganic phosphorus (In-P) was the main part of TP in sediment of the Xiangxi River. The main content of different phosphate in In-P was Ca-P. The T-P contents of sites 15, 16 were much higher than others'. The TP content of the largest site 16 was 1946.29mg/kg in Dec. 2004 and 1756.11mg/kg in Jul. 2005, respectively; which was much higher than the average (1497.51mg/kg and 1369.38mg/kg, respectively); The TP content in sediment of the Xiangxi River was from 1179.53mg/kg to 1851.20mg/kg. The TP contents of most sites except site 18, 19 and 20 were higher in Dec. 2004 than those in Jul. 2005. The content of In-P didn't have much change between two seasons. The Org-

P contents in most sites except sites 18 and 19 were higher in Dec. 2004 than those in Jul. 2005. The Al-P contents were much lower in Dec. 2004 than those in Jul. 2005. The Fe-P and Ca-P in sediment of the Xiangxi River were not obviously disciplinary between two seasons.

Tab. 1 The distribution of different phosphorus in sediment of the Xiangxi River

Time	Samples in perish period						Samples in perish period					
Site	TP	In-P	Org-P	Al-P	Fe-P	Ca-P	TP	In-P	Org-P	Al-P	Fe-P	Ca-P
13	1454.24	953.13	501.11	1.23	19.83	787.55	1164.44	696.53	467.91	41.88	20.57	541.26
14	1650.46	886.71	763.74	0.91	24.80	862.87	1267.08	817.28	449.79	37.74	10.38	682.34
15	1940.26	1173.49	766.76	5.06	14.11	952.53	1517.63	1393.86	123.77	30.24	13.86	964.49
16	1946.30	1339.53	606.77	3.15	7.39	991.99	1756.11	1345.56	410.55	7.13	6.40	1037.42
17	1288.21	883.69	404.51	0.44	4.16	786.35	1070.86	841.43	229.42	40.13	34.50	884.39
18	1454.24	1146.33	307.91	12.71	21.82	889.17	1641.40	1200.67	440.74	47.46	10.63	884.39
19	1203.68	705.59	498.09	0	9.88	700.27	1236.89	735.78	501.11	30.88	18.83	354.76
20	1091.99	506.35	585.64	3.46	39.22	463.55	1309.34	892.75	416.59	26.10	8.39	736.14
21	1448.2	1007.46	440.74	0.91	8.64	944.16	1360.66	986.33	374.33	28.17	16.35	516.16

3 Discussion

The concentration of phosphorus in the Xiangxi River has changed notably. In the lower reaches it was once higher than that of upper reach in 1996 to1997 and now it has reversed in 2004 to 2005. The turning point was the site 15, the TP concentrations of the lower stream from it of the Xiangxi River were lower than those in 1996 to 1997, but the water quality of river didn't change well. After the construction of the Three Gorges Dam, the waterflow of river obviously decreased and so the purge ability diminished.

The concentrations of TDP and DP were the main part of the TP, which would be a risk of algae bloom. The TP concentrations of river were higher in Dec. 2004 than those in Jul. 2005. It indicated that the pollution source of P in the Xiangxi River is the industrial pollution and much attention should be paid on controlling industrial pollutions in perish period of river. The phosphorus for the chemical plant and iron alloy production is from the local support industry, which induced heavy phosphorus pollution release into the Xiangxi River. There are two phosphorus plants located in this area between Pingyikou and Xiakou which produce about 14,000 t of phosphorus each year. They discharge 1.868 t of phosphorus per day into the Xiangxi River. Owing to the output of phosphorus from the chemical plant and subsistence sewage, the concentrations of phosphorus are superfluous at six of eight sections of the Xiangxi River.

It can be seen in Tab. 1 that the Ca-P ratio was the highest form among P species. The accumulated acid matter which produced at anaerobic environment in the sediment may induce the dissolution and release of Ca-P as the water level increases. Because the DO would decrease, Ca-P could be a contributing factor enlarging the concentration of phosphorus. The Ca-P is a very stabile phosphorus form. The average contents of Fe-P in sediment of river were similar between different seasons, the content of sites 14, 17, 18 and 20 had changed notably, where should receive attention by the environmental agency as Fe-P could be absorbed adequately by algae. The Al-P contents in sediment were obviously higher in Jul. 2005 than those in Dec. 2004, which indicated that the stability of Al-P have a significant relation with the change of season. We noted that peach blossom around the site of 16 appeared as an obvious band of algae in May 2004, which suggested that the nutrient availability at this site was very high. Algal bloom occurred at the sites of 19 and 18 in July 2004, although these have not continued for a long time. Tab. 2 shows the concentrations of different forms of phosphorus in sediment of some rivers in China. It can be seen from this table that the concentrations of total phosphorus in the sediments of the lower reaches of the Xiangxi River was higher than that of other rivers, which indicated that the P pollution is serious in this area. The ratio of inorganic phosphorus to total phosphorus of the lower reaches of the Xiangxi River was much higher than that of others, while the ratio of organic to total phosphorus was lower. As the drainage area of the Xiangxi River covers ninety percent of the area of Xingshan County, all the industries and most of the agriculture are also located in this area, contributing greatly to the inorganic phosphorus input into the river. On the other side, Xingshan is a small city with a small population, so the concentration of organic phosphorus in the lower reaches of Xiangxi River is not so high, compared with those of other rivers near the big cities in China.

Tab. 2 The concentrations of different forms of phosphorus in the sediments of some rivers in China (mg/kg)

River	TP	Org-P	Org-P/TP (%)	In-P	In-P/TP (%)
Xiangxi River	1433	460.55	32.1	972.9	67.9
Qiantangjiang River	413.7	32.8	7.9	380.9	92.1
Huangpujiang River	971.2	486.5	50.1	484.6	49.9
Haihe River	772.7	397.8	51.5	374.9	48.5
Luanhe River	358.9	102.3	28.5	256.6	71.5
Yalvjiang River	328.2	74.8	22.8	253.4	77.2
Sanchahe River	481.8	168.5	35.0	313.3	65.0

4 Conclusion

After the sluices of the Three Gorges Reservoir have become operational, the water quality of the Xiangxi River maintains a temporary equilibrium with regard to phosphorus. The initial concentrations of phosphorus in the overlying water and in the sediments have an obvious effect on the phosphorus mobilization potential. There is a potential hazard of phosphorus pollution in this area and proper measures are needed to prevent this adverse effect.

References :

[1] Thomas, E. A. Phosphorus and eutrophication. In: Griffith, E. J., A. Beeton, J. M. Spencer & D. T. Mitchell (editors). Environmental Phosphorus Handbook [M]. John Wiley, New York. 1973. 630

[2] House, W. A. & F. H. Denison. Phosphorus dynamics in a lowland river [J]. Water Research, 1998, 32(6): 1819—1830

[3] House, W. A. & F. H. Denison. Exchange of inorganic phosphate between river waters and bed-sediments [J]. Environmental Science and Technology, 2002, 36(20): 4295—4301

[4] House, W. A. & M. S. Warwick. Interactions of phosphorus with sediments in the River Swale, Yorkshire, UK [J]. Hydrological Processes, 1999, 13(7): 1103—1115

[5] Gomze, E., C. Durillon, G. Rofes & B. Picot. Phosphate adsorption and release from sediments of brackish lagoons: pH, O2 and loading influence [J]. Water Research, 1999, 33(10): 2437—2447

[6] Wu, F. C., H. R. Qing & G. J. Wan. Regeneration of N, P and Si Near the Sediment/water Interface of Lakes from Southwestern China Plateau [J]. Water Research, 2001, 35(5): 1334—1337

[7] Wu, F. C., H. R. Qing, G. J. Wan, D. G. Tang, R. G. Huang & Y. R. Cai. Geochemistry of HCO3- at the sediment-water interface of lakes from the southwestern Chinese plateau [J]. Water, Air and Soil Pollution, 1997, 99(1—4): 381—390

[8] Liu, H., H. J. Liu & J. H. Qu. Effect of nitrogen and phosphorus on the water quality in the Three Gorges Reservoir Area during and after its construction [J]. Journal of Environmental Sciences, 2004, 16: 358—363

[9] Schindler, D. W. Evolution of phosphorus limitation in lakes [J]. Science, 1977, 195: 260—262

[10] Berge, D. Phosphorus loading and response in shallow lakes, Norwegian Institute for Water Research ISBN 82-577-1250-7, 1987: 45 (in Norwegian)

[11] Faafeng, B. A. & D. O. Hessen. Nitrogen and phosphorus concentrations and N: P ratios in Norwegian lakes: perspectives on nutrient limitation [J]. Verhandlungen Internationale Vereinigung fur Theoretische und Angewandte Limnologie, 1993, 25: 465—469

[12] Zhong, Z. C. & Y. S. Qiu. Major problems of ecological environment and its strategies in the Three Gorges Reservoir of Chongqing [J]. Chongqing Environmental Science, 1999, 21(1): 1—2. [钟章成,邱永树]. 重庆三峡库区主要生态环境问题与对策[J]. 重庆环境科学, 1999, 21(1): 1—2.]

[13] Murphy, J. & J. P. Riley. A modified single solution method for determination of phosphate in natural waters [J]. Analytica Chimica Acta, 1962, 27: 31—36

[14] Chang, S. C. & M. L. Jackson. Soil phosphorus fractions in some representative soils. Journal of Soil Science, 1958, 9: 109—119

[15] Pardo, P., J. F. Lopez-Sanchez, G. Rauret. Relationships between phosphorus fractionation and major components in sediments using the SMT harmonised extraction procedure [J]. Analytical and Bioanalytical Chemistry, 2003, 376(2): 248—254