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Effect of nitrogen and phosphorus on the water quality in the Three Gorges Reservoir Area during and after its construction

LIU Hong, LIU Hui-juan, QU Jiu-hui*

(State Key Laboratory of Environmental Aquatic Chemistry, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing 100085, China. E-mail: jhqu@mail.rcees.ac.cn)

Abstract: A survey concerning the concentration of the nutrients in the Three Gorges Reservoir Area was carried out. This paper presents the parameters (NO_3^--N, NO_2^--N, Kjeldahl-N, non-ionic ammonia, P-PO_4 and TP) determined at 16 sampling sites from 1997 to 1999. The dominant soluble nitrogen form was NO_3^--N followed by Kjeldahl-N, NO_2^--N and non-ionic ammonia. Mean values of NO_3^--N, NO_2^--N, Kjeldahl-N and non-ionic ammonia ranged from 0.50 to 2.37 mg/L, 0.022 to 0.084 mg/L, 0.33 to 0.99 mg/L and 0.007 to 0.092 mg/L respectively. Mean values of P-PO_4 at most sampling sites were higher than 0.1 mg/L for subject to eutrophication. The major factors influencing the concentrations of N and P might be agricultural runoff, municipal and industrial effluents. In addition, 6 kinds of soil were sampled at the area where would inundated after the dam completed. Two approaches were adopted to simulate the N and P release from the inundated soils. The results showed that the soils would release nitrogen and phosphorus to the overlying water when the soils were inundated. The characteristics of soil affected the equilibrium concentrations of N and P between the soil and the overlying water.

Keywords: Three Gorges Reservoir Area; nitrogen; phosphorus; inundated soil

Introduction

The concentrations of biologically available nitrogen and phosphorus are well known to play a key role in determining the ecological status of aquatic system(Jarvie, 1998). These nutrients in excess might lead to diverse problems such as toxic algal bloom, loss of oxygen, fish deaths, loss of biodiversity and loss of aquatic plant beds etc. Nutrient enrichment seriously degrades aquatic ecosystems and impairs the use of water for drinking, industry, agriculture, recreation and other purposes (Carpenter, 1998). Eutrophication caused by overenrichment with N and P is a widespread problem in reservoirs and lakes. The Three Gorges project on the Yangtze River has been the focus of national and international attention for its possible eutrophication, especially when the dam comes into being with the self-purification ability of the water body weakened.

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 (Zhong, 1999). In addition, the Three Gorges Reservoir Area is essentially rural with agriculture being the dominant activity. Lots of chemical fertilizers and pesticides containing N and P were used every year. Table 1 presents the result of the investigations of fertilizer application in the Three Gorges Reservoir Area from 1996 to 1998. A survey showed that the N and P fertilizer usage rate for agriculture in this area was about 35% in total and the amount of remnants in the soil was 34.5%. So much of N and P in the soil were washed down by run-off water.

Table 1 Fertilizer application in the Three Gorges Reservoir Area from 1996 to 1998

Year	Nitrogen, 10^4 tons	Phosphorus, 10^4 tons
1996	12.71	4.43
1997	9.59	1.85
1998	9.34	2.26

After the dam is completed, the water level of the reservoir will be much higher and the water surface will be much wider. It will inundate some land and bring the N and P in the soil released to the water. So the objectives of this paper are: (1) to analyze the change of N and P in the Three Gorges Reservoir during its construction; (2) to study the release of N and P from the inundating soil and the possible influence on the water quality after its construction.

1 Study area, sampling sites, sampling and analysis

1.1 Water sampling

The spatial sampling strategy was designed to cover a wide range of determinants at key sites that accurately represented the quality of water along the examined reservoir system and accounted for tributary inputs that can have important impacts upon downstream water quality. The distribution of 16 sampling sites is illustrated in Fig.1 and a description of sampling sites is presented in Table 2. Water samples were collected in Feb., May and Aug. corresponding to the low water season, mean water season

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and high water season respectively. In each water season, sampling was conducted 3 times. The water samples were collected 0.5 m below the surface of the water. All samples were filtered through 0.45-μm Millipore filter paper and analyzed the concentrations of N and P.

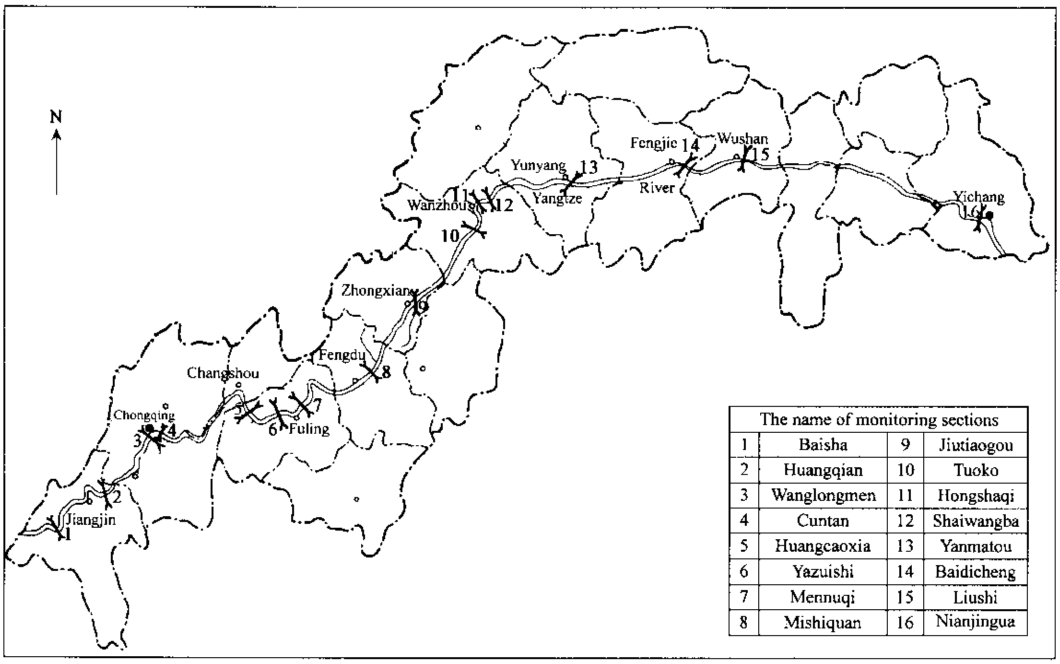

Fig.1 The map of the Three Gorges Reservoir Area and the distribution of the sampling sites

Table 2 Description of water sampling sites

Site	Location	Site description
1	Chongqing City	Upstream of the Three Gorges Reservoir
2	Chongqing City	Downstream of municipal effluent and industry discharges from Chongqing City
3	Chongqing City	Downstream of municipal effluent and industry discharges from Chongqing City
4	Chongqing City	Before confluence with Jialing River
5	Changshou	Lower part of the Three Gorges Reservoir
6	Fuling	Before confluence with Wujiang River
7	Fuling	Downstream of its confluence with Wujiang River
8	Fengdu	Mid part of the Three Gorges Reservoir
9	Zhongxian	Mid part of the Three Gorges Reservoir
10	Wanzhou	Mid part of the Three Gorges Reservoir
11	Wanzhou	Mid part of the Three Gorges Reservoir, downstream of a fertilizer plant
12	Wanzhou	Lower part of the Three Gorges Reservoir
13	Yunyang	Lower part of the Three Gorges Reservoir
14	Fengjie	Lower part of the Three Gorges Reservoir
15	Wushan	Lower part of the Three Gorges Reservoir
16	Yichang	Before the dam of the Three Gorges Reservoir

1.2 Soil sampling

The distribution of soils sampling sites is shown in Fig. 1. Six kinds of soils were taken corresponding to the six soils sampling sites at the inundating areas. It consisted of dry land soils, paddy field soils, vegetable land soils, riparian wetland soils, garden plot soils and woodland soils. Surface soil samples(0—5 cm) were taken from each kind of land. Approximately 5 kg of soil was collected at each site. Soil samples were immediately taken to the laboratory with hand-mixed thoroughly, and put through a 2 mm sieve. Then the samples were sealed in polyethylene bags and placed in a dark refrigerator at 4℃.

1.3 The inundating experiments of soil for studying N and P releasing

About 120—150 g of soil was placed in 1 L polyethylene beakers to give about a 9 cm depth of soil. 800 ml distilled water was added into the baker carefully. The overlying water was sampled in two approaches. Approach 1: The overlying water was sampled at 9:00 am every day by carefully inserting a siphonal pipe between the soil surface and the top of the water column. The water column height was maintained by carefully adding distilled water with a syringe after every sampling. This approach was to simulate the situation of the overlying water and soil was relatively static. Approach 2: Beakers were modified to permit the floodwater pass through the soil surface by drilling holes(1 cm diam.) at 9 cm from the bottom of the beakers. The overlying water was drained through the soil surface via gravity with rate of 800 ml/d. A strainer was affixed to the insides of the holes to filter soil particles out of solution. The overlying water was gradually injected with distilled water (800 ml/d) to maintain the height of water column. Water samples were withdrawn at 9:00 am every day. This approach was to simulate the state of the overlying water and soil was relatively flowing.

1.4 Analytical methods

NO_3^--N, NO_2^--N and P-PO_4 were analyzed by ion-chromatographer(4500i, Dionex); non-ionic ammonia was measured by nesslerization spectrophotometry; Kjeldahl-N was determined using macro-Kjeldahl method; TP was analyzed using acid-hydrolysis method. The detail analytical procedures employed for each parameter were based on the standard methods of monitoring and analyzing water and wastewater in China(NEPA, China 1989).

2 Results and discussion

2.1 Effect of N and P on the water quality during the construction of the Three Gorges project

2.1.1 Speciation of nitrogen

The N and P concentrations of the Three Gorges Reservoir from 1997 to 1999 were surveyed. Mean and range of concentrations for nitrogen and phosphorus in different species at each sampling site are shown in Table 3.

Table 3 Mean and range of concentrations for nutrient species at each sampling site

Site	NO_2^--N	NO_3^--N	Non-ionic ammonia	Kjeldahl-N	P-PO_4	TP
1	0.042 0.008—0.093	0.89 0.74—1.09	0.012 0.005—0.021	0.40 0.32—0.51	0.04 0.03—0.07	0.07 0.05—0.10
2	0.050 0.014—0.15	1.02 0.80—1.61	0.02 0.007—0.031	0.77 0.41—1.34	0.11 0.036—0.19	0.21 0.066—0.28
3	0.043 0.014—0.113	1.08 0.76—1.77	0.014 0.001—0.03	0.56 0.49—0.68	0.12 0.07—0.17	0.19 0.11—0.25
4	0.050 0.017—0.13	1.08 0.79—1.29	0.013 0.002—0.22	0.64 0.56—0.73	0.09 0.034—0.16	0.15 0.068—0.26
5	0.084 0.019—0.14	1.12 0.65—1.80	0.010 0.002—0.018	0.47 0.39—0.57	0.10 0.043—0.12	0.15 0.096—0.18
6	0.046 0.003—0.085	1.46 0.92—2.11	0.0073 0.003—0.015	0.73 0.43—1.21	0.12 0.071—0.15	0.17 0.13—0.27
7	0.046 0.003—0.084	1.49 0.96—2.07	0.007 0.002—0.015	0.77 0.49—1.34	0.11 0.052—0.16	0.19 0.11—0.30
8	0.068 0.01—0.18	0.95 0.20—1.41	0.022 0.005—0.049	0.61 0.52—0.79	0.10 0.053—0.15	0.15 0.13—0.28
9	0.022 0.011—0.029	1.28 0.91—1.86	0.015 0.003—0.030	0.56 0.39—0.67	0.03 0.010—0.071	0.06 0.018—0.095
10	0.031 0.003—0.083	1.09 0.61—1.50	0.025 0.014—0.059	0.68 0.42—1.23	0.05 0.051—0.09	0.11 0.077—0.14
11	0.030 0.004—0.083	2.37 0.59—13.1	0.024 0.013—0.058	0.99 0.62—1.59	0.06 0.043—0.08	0.12 0.083—0.14
12	0.031 0.005—0.083	1.11 0.70—1.54	0.025 0.016—0.056	0.82 0.521—1.25	0.07 0.045—0.10	0.12 0.083—0.15
13	0.080 0.009—0.174	0.99 0.67—2.06	0.006 0.001—0.026	0.33 0.20—0.57	0.12 0.042—0.14	0.17 0.082—0.20
14	0.032 0.008—0.09	1.14 0.70—1.94	0.009 0.001—0.024	0.62 0.41—1.01	0.11 0.080—0.16	0.16 0.10—0.23
15	0.023 0.007—0.031	0.50 0.09—1.22	0.092 0.007—0.304	0.54 0.32—0.71	0.10 0.054—0.13	0.14 0.092—0.21
16	0.029 0.008—0.054	0.89 1.29—1.70	0.014 0.006—0.032	0.50 0.29—0.71	0.13 0.0721—0.16	0.17 0.11—0.23

Mean values of NO_3^--N and NO_2^--N at various sampling sites ranged from 0.50 mg/L to 2.37 mg/L and 0.022 to 0.084 mg/L respectively, which were lower than the standard of surface water quality of China (10 mg/L for NO_3^--N and 0.1 mg/L for NO_2^--N respectively).

Kjeldahl-N is an important parameter to reflect the level of eutrophication of the surface water. Mean values of Kjeldahl-N at various sampling sites of the Three Gorges Reservoir ranged from 0.33 mg/L to 0.99 mg/L, which were lower than the standard of water quality of grade III of China (1.0 mg/L). However, at nearly half of sampling sites(e.g. 2, 6, 7, 10, 11, 12, 14), maximum Kjeldahl-N concentrations were detected higher than 1.0 mg/L, so the water quality was poorer than grade III of surface water quality standard. The highest nitrate and Kjeldahl-N concentrations were observed at site 11. Site 11 is downstream of the point where effluents from a nitrogen fertilizer producing plant are discharged, and exhibits the highest concentrations for all nitrogen species.

Mean values of non-ionic ammonia concentrations ranged from 0.007 up to 0.092 mg/L. At certain sampling sites(e.g. 2, 8, 11, 12, 15) mean non-ionic ammonia concentrations were higher than the state-prescribed standard (0.02 mg/L). The maximum concentration (0.304 mg/L) was found at site 15, which is more than 15 times of the state-prescribed standard. Site 2 is in the middle of the big city of Chongqing and the high concentration of non-ionic ammonia is likely to be influenced by domestic effluent. Site 11, 12 are influenced by the downstream of a nitrogen fertilizer producing plant. Site 8, 15 were intensive agricultural land, the high concentration of non-ammonia due to high nitrogen inputs.

Fig.2 shows the nitrogen species distribution in each sampling site. Nearly at all sampling sites, the dominant nitrogen form was NO_3^--N followed by Kjeldahl-N, NO_2^--N and non-ionic ammonia. The relative contribution of NO_3^--N to TN varied between 58%—70%. The contribution of Kjeldahl-N to TN varied between 23%—40%. It has been reported that when NO_3^- comprises a substantial fraction of TN it may indicate diffuse agricultural sources of N

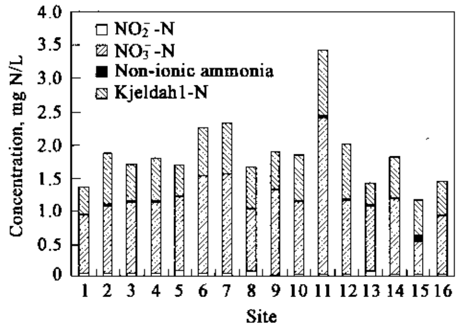

Fig.2 Nitrogen species in each sampling site

(Martinelli, 1999). Similar results have been got in this study. Site 6, 7 were intensive agricultural land and the contribution of NO_3 to TN at these two sites reached to nearly 60%.

2.1.2 Phosphorus distribution in each sampling site

Phosphorus enters the reservoir in different forms depending on its origin. In surface waters it occurs as particulate P and dissolved P. Dissolved P, consisting mainly of orthophosphates, is 100% bioavailable to plants, while particulate P also represents a long-term source of P for algae and plants. The sum of immediately available P and P that can be transformed into an available form by naturally occurring processes in defined as bioavailable P and are responsible for the eutrophication in fresh water systems (Gerdes, 1998).

Table 3 shows that mean values of P-PO_4 at half of sampling sites were higher than 0.1 mg/L, which making freshwaters subject to eutrophication (Young, 1999). The contribution of P-PO_4 to TP varied between 50%—76%.

The phosphorus species in each sampling site are shown in Fig. 3. A clear distinction between sampling sites is obvious. The TP concentration of site 1, the upstream of the Three Gorges Reservoir, was 0.07 mg/L, while the TP concentration of other sites located in Chongqing City were much higher than that of site 1. The TP concentration in other main city such as Fuling and Wanzhou was higher too. This suggested that sewage effluents are significant P sources into the reservoir. Fig.4 shows annually P loads discharged from the 5 main cities and the average concentrations of TP in the 4 cities. It can be seen that the concentration of TP was related to the loads discharged. The higher phosphorus loads

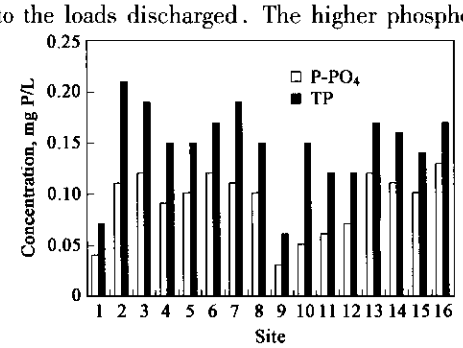

Fig.3 Phosphorus species in each sampling site

in Chongqing, Fuling and Wanzhou led to higher TP concentration of the sampling sites in these cities.

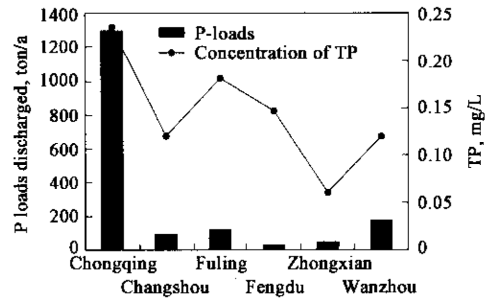

Fig.4 Annual phosphorus loads discharged and the TP concentrations of 5 cities in 1999

2.2 The possible influence of N and P release from inundated soils on water quality

2.2.1 Content of N and P in sampling soils

Mean and range of concentrations of TN and TP in six kinds of sampled soils are illustrated in Table 4. For the agricultural soil, mean concentrations of TN and TP of vegetable land soils were 0.760 g/kg and 0.613 g/kg respectively, which were higher than those of the dry land soils and paddyfield soils. For the non-agricultural soil, the woodland soil had relatively higher concentration of TN and TP, which were 0.555 g/kg and 0.774 g/kg respectively.

Table 4 Concentrations of TN and TP in the sampled soils

Unit: g/kg

Type of soils	TP		TN	
	Range	Mean	Range	Mean
Dryland soils	0.255—0.759	0.385	0.440—1.06	0.613
Paddyfield soils	0.205—0.620	0.473	0.460—0.810	0.653
Vegetable land soils	0.465—0.700	0.613	0.520—0.930	0.760
Garden plot soils	0.271—0.905	0.523	0.360—0.920	0.673
Riparian wetland	0.267—0.767	0.397	0.350—0.900	0.562
Woodland soils	0.215—0.773	0.555	0.521—0.950	0.774

2.2.2 Nitrogen and phosphorus release from the inundated soils

Although research has shown the release of nitrogen and phosphorus to soil solutions during anoxic incubations, the actual mobilization of phosphate from the soil to overlying water has received little attention. In this paper, two approaches were designed to simulate the nitrogen and phosphorus release from the inundated soils. Fig.5 and Fig.6 show the results of Kjeldahl-N and TP release from the inundated soils as a function of inundating time respectively.

The soils had the same trends in nitrogen and phosphorus releasing to the overlying water. The concentration of Kjeldahl-N and TP reached to the maximum value after one or two day's inundating. In addition, with the inundating time prolonged, the concentrations of Kjeldahl-N and TP decreased gradually in water because some nitrogen and phosphorus re-transferred to the soil again. After about 7 day's inundating, the concentration of Kjeldahl-N

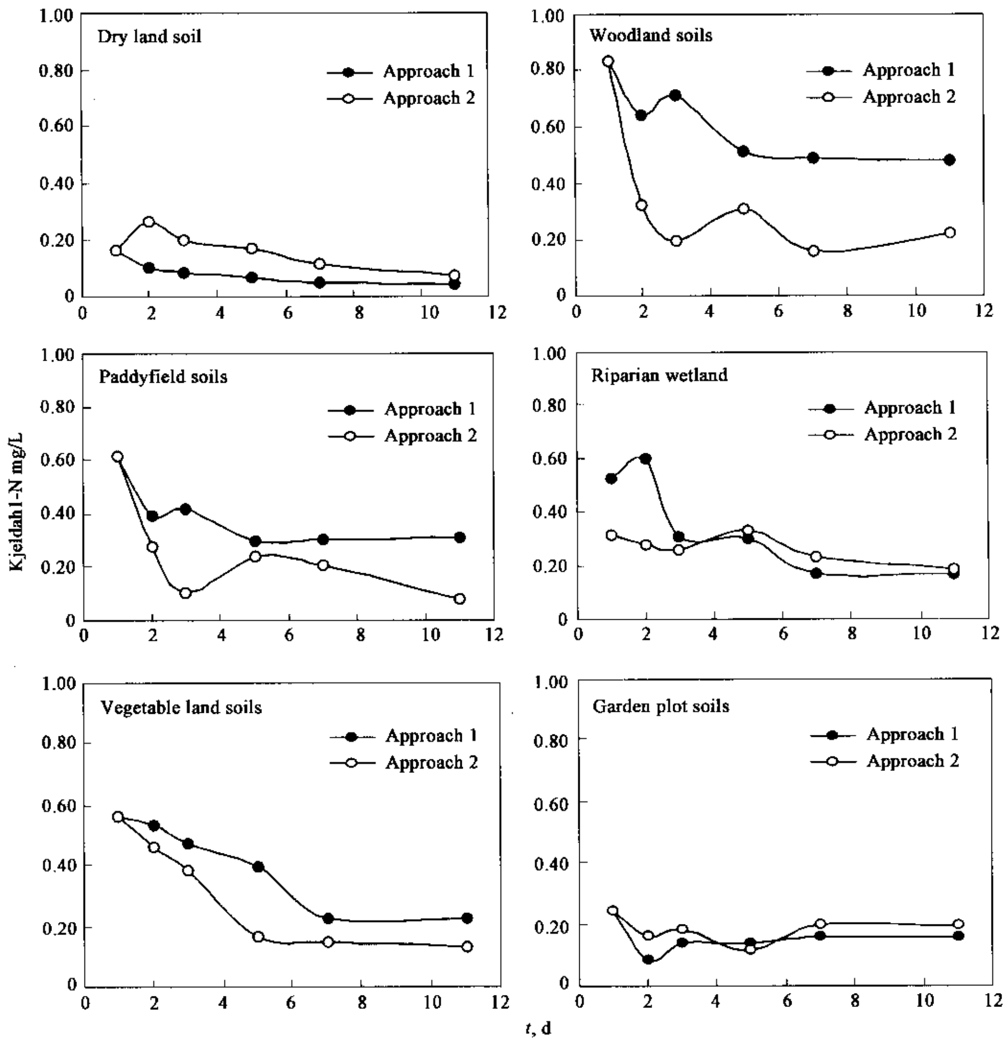

Fig.5 Changes of Kjeldahl-N concentrations in overlying water of 6 kinds of soil as a function of inundating time

and TP in the overlying water reached equilibrium with the Kjeldahl-N and TP concentrations of the soil.

For different kinds of soil, the equilibrium concentration was different too. The woodland soils released more nitrogen than those of other kinds of soils, and the equilibrium concentration of Kjeldahl-N reached to 0.48 mg/L. While the Garden plot soils release more phosphorus, the equilibrium concentration of TP reach to 0.16 mg/L, which was higher than the standard of water quality. Although the concentrations of Kjeldahl-N and TP in the vegetable land soil were higher than those of other soils, the equilibrium concentration of Kjeldahl-N and TP between overlying water and vegetable land soil was only 0.23 mg/L and 0.051 mg/L respectively. This result indicated that the Kjeldahl-N and TP release from soils was not only influenced by the content in the soil but also affected by N and P sorption capacities of the soils.

2.3 Effect of N and P releasing on water quality

With the dam come into being, a lot of soils would be inundated in the Three Gorges Reservoir Area. In the beginning of storage of water, a lot of N and P would release from soil to surface water and the concentration of N and P would be increased. The average concentration of Kjeldahl-N and TP from 1997 to 1999 were 0.9 mg/L and 0.15 mg/L respectively, which nearly reach to maximum limitation for eutrophication. In some inundated area, the N and P releasing from the inundated soil would result in an additional N and P content in the water. According to the experimental results above, the increase of N and P in the inundating water should depend on the water quantity and the concentration of the soil. However, the N and P released from soil will influence on the water quality for a long time. So it is important to find a way for controlling the inputs of nutrients from all of possible aspects.

3 Conclusions

A considerable body of data concerning the nitrogen and phosphorus of the Three Gorges Reservoir during the construction of the Three Gorges project has been studied. The concentrations of N and P in some sampling sites exceeded the water quality standard of China. Kjeldahl-N and P pollution was more seriously than any other form because it makes the surface water subject to eutrophication. The major factors were suggested to be agricultural runoff, municipal

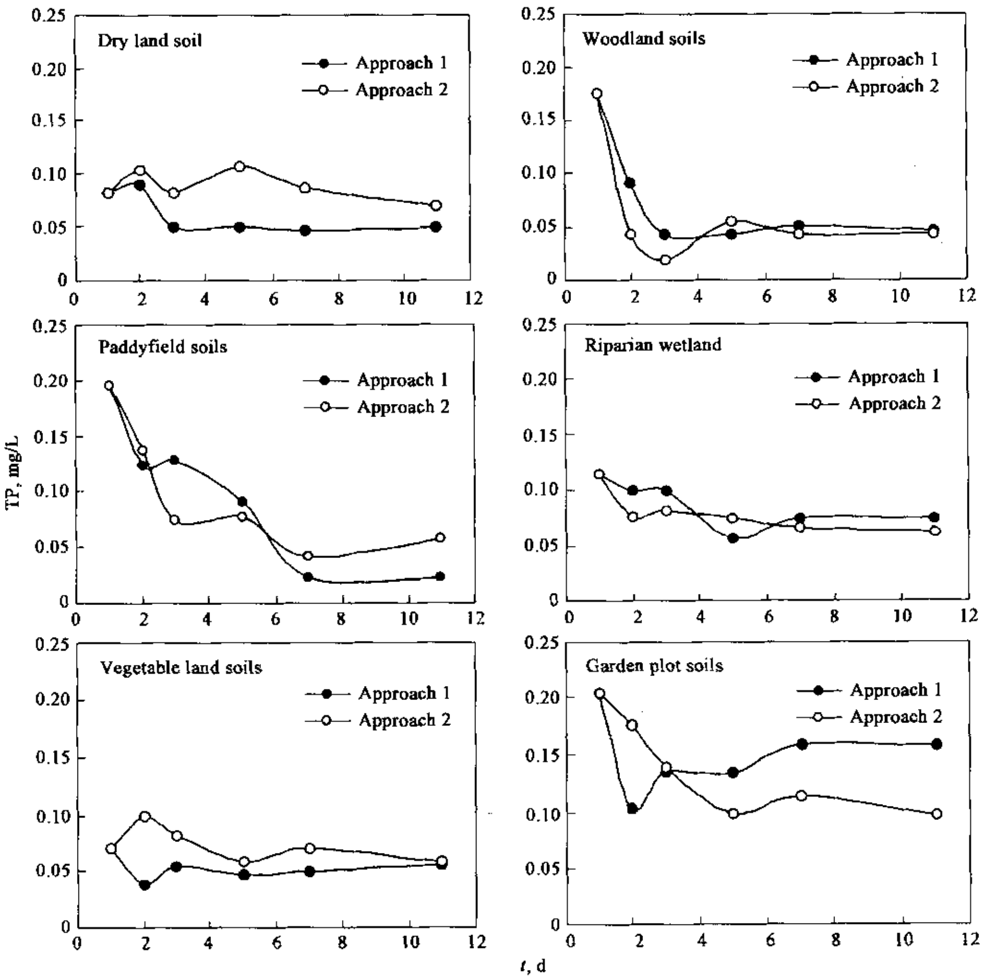

Fig.6 Changes of TP concentrations in overlying water of 6 kind of soil as a function of inundating time

and industrial effluents.

Inundated soils can release nitrogen and phosphorus to the overlying water. The concentrations of released N and P were influenced by the characteristics of the soils. So with the dam comes into being and lots of land be inundated, some N and P in the soil would release into the surface water. The increasing concentration of N and P will lower the water quality further. So it is urgent for the determine measures to be taken to control the pollution.

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