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Relationship between nutrient pollutants and suspended sediments in upper reaches of Yangtze River

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Abstract

In order to study the relationship between nutrient pollutants and suspended sediments (SS) in the upper reaches of the Yangtze River and two tributaries, water samples were collected from September 1, 2010 to September 30, 2011 at the Zhutuo, Cuntang, Beibei, Wulong, Qingxichang, Wanxian, and Fengjie cross-sections. In the laboratory, the SS concentration and the concentration of SS whose particle size was smaller than 0.02 mm were measured. The phosphorus (P), nitrogen (N), and permanganate index (COD_{Mn}) concentrations in the natural water sample, the settled water sample, and two types of filtered water samples obtained through filter membranes with pore sizes of 0.02 mm and 0.45 μm were monitored synchronously. The results show that there are strong relationships between the P and COD_{Mn} concentrations and the SS concentration. P mainly exists in particulate form, while N mainly exists in dissolved form. SS whose particle size is smaller than 0.02 mm accounts for a high proportion of sediments in the Yangtze River and has a strong effect on water quality. At the seven cross-sections, the amounts of P, N, and COD_{Mn} in particulate form in the wet season are higher than in the dry season and the adsorption amounts of P, N, and COD_{Mn} per unit mass of sediment are higher in the dry season than in the wet season.

Keywords: Suspended sediment; Phosphorus; Nitrogen; Permanganate index

1. Introduction

Sediment particles play an important role in water quality (Lopez et al., 1996). The Yangtze River is the third longest river and the Yangtze River Basin is the ninth largest catchment in the world. The discharge of the Yangtze River is the largest to the Western Pacific Ocean and the fifth largest in the world, and its sediment load is the fourth largest in the world. Sediment particles originating from soil loss in the upper reaches of the Yangtze River have been estimated to exceed 40 million tons annually (Shi et al., 1992). The adsorption behaviour of pollutants on sediments has attracted significant interest in recent years (Kan et al., 1998; Chiou et al., 1998; Kile et al., 1999; Westall et al., 1999; Liu et al., 2001, 2008; Zhao et al., 2001). Some studies have focused on the relationship between phosphorus (P) and sediment in coastal areas (Zhou et al., 2005; Wang et al., 2009a, 2009b; Cao et al., 2011). Others have focused on the relationship between nitrogen (N) and sediment in the field and in laboratory experiments (Sfriso and Marcomini, 1999; Stimson and Larned, 2000; Gardner et al., 2001; Lü et al., 2005). P and N have been identified as limiting nutrient factors for eutrophication in water (Ryther and Dunstan, 1971; Bizsel and Uslu, 2000). A large amount of monitoring work has been conducted to investigate changes in P and N concentrations and loads in other water bodies (Bowes and House, 2001; Sigua and Tweedale, 2003; Bowes et al., 2003; Salvia Castellví et al., 2005; Quilbe et al., 2006; Kangur and Mols, 2008). These studies indicate that there are different relationships between

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nutrient pollutant concentrations and the suspended sediments (SS) concentration in different water bodies.

The aim of this study was to determine the relationship between nutrient pollutants and SS in the upper reaches of the Yangtze River, as well as to determine how sediment adsorption affects the concentrations of nutrient pollutants in the water by synchronously monitoring P, N, COD_{Mn}, and SS concentrations.

2. Materials and methods

2.1. Field sampling and monitoring

The study area is shown in Fig. 1. It includes the Yangtze River and two important tributaries, the Jialing River and the Wujiang River, the inflow discharge of which accounts for 90% of the total inflow discharge from all tributaries. The study area is divided into three reaches: (1) the first reach is between the Zhutuo cross-section and the Fengjie cross-section in the Yangtze River, and includes five monitoring cross-sections (the Zhutuo, Cuntang, Qingxichang, Wanxian, and Fengjie cross-sections), of which four have monitoring stations (the Zhutuo, Cuntang, Qingxichang, and Wanxian cross-sections); (2) the second reach is between the Wulong cross-section in the Wujiang River and the Wujiang Estuary, and includes one monitoring station at the cross-section; and (3) the third reach is between the Beibei cross-section in the Jialing River and the Jialing Estuary, and includes one monitoring station at the cross-section.

The Water Environmental Monitoring Center in the upper reaches of the Yangtze River monitored the concentrations of nutrient pollutants and SS synchronously from September 1, 2010 to September 30, 2011 once per month. Water samples were collected using horizontal water samplers at seven cross-sections. At each cross-section, three sampling verticals were set, one 50 m from the left bank, one in the middle of the river, and one 50 m from the right bank. There were three sampling sites on each sampling vertical, one 0.5 m below the water surface, one in the middle of the water depth, and one 0.5 m above the river bed. One-thousand mL water was taken from every sampling site, and a total of 9 000 mL of mixed water was collected as one water sample. Two of the same water samples were collected at each cross-section. One was for water quality measurement, and the other was for sediment measurement. In addition, discharge data were collected during the test period from Water Environment Monitoring Center gauging stations.

2.2. Sample treatment and measurement

There were 182 water samples collected from seven cross-sections in the upper reaches of the Yangtze River. After the water samples were transferred to the laboratory, they were stored in refrigerators until measurements were taken. Ninety-one water samples for sediment measurement were used to measure the SS concentration and the concentration of SS whose particle size was smaller than 0.02 mm. Each of the other 91 water samples was treated to obtain four different types of water samples: natural water samples, settled water samples, and two types of filtered water samples. The natural water sample was the original water sample from the river. The settled water sample was obtained by removing deposited particles from the original water sample after it was placed and after it remained static for half an hour. The filtered water sample A was obtained by removing sediment particles from the original water sample through filter membranes with a pore size of 0.02 mm and the filtered water sample B was obtained by removing sediment particles from the original water sample through filter membranes with a pore size of 0.45 μm. The natural water sample was used to measure the concentrations of total phosphorus (TP), total nitrogen (TN), and total COD_{Mn}. The filtered water sample B was used to measure the concentrations of dissolved phosphorus (DP), dissolved nitrogen (DN), and dissolved COD_{Mn}. The concentrations of P, N, and COD_{Mn} in particulate form were obtained by subtracting the dissolved pollutant concentrations from the total pollutant concentrations. The settled water sample was used to measure the pollutant concentrations, except for those absorbed on the deposited particles. The filtered water sample A was used to measure the pollutant concentrations in dissolved form and the portion absorbed on SS whose particle size was smaller than 0.02 mm. The adsorption amounts of P,

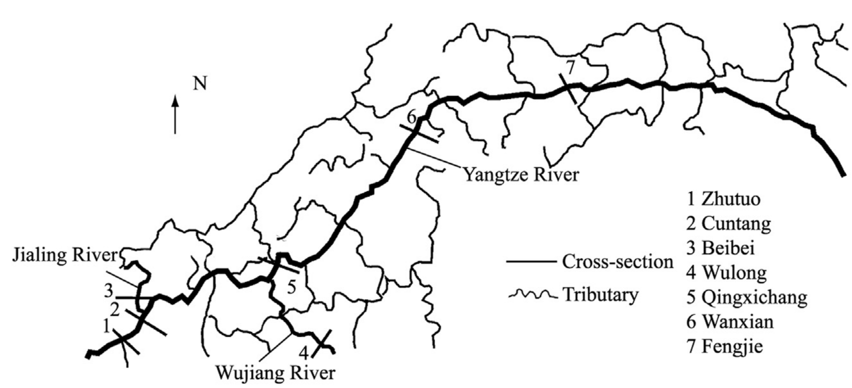

Fig. 1. Study area and cross-sections.

Table 1
Concentrations of P, N, and COD_{Mn} in different periods.

Reach	Period	Discharge (m^3/s)	SS (g/L)	P (mg/L)			N (mg/L)			COD_{Mn} (mg/L)		
				Total	Particulate	Dissolved	Total	Particulate	Dissolved	Total	Particulate	Dissolved
Yangtze River	Dry season	3 420	0.022	0.15	0.09	0.06	1.84	0.25	1.59	2.51	0.52	1.99
	Wet season	20 947	0.627	0.37	0.34	0.03	1.91	0.77	1.14	6.52	4.80	1.72
Jialing River	Dry season	300	0.012	0.09	0.06	0.03	2.34	0.27	2.07	3.02	0.77	2.25
	Wet season	1 759	0.219	0.15	0.12	0.03	2.20	0.72	1.48	4.89	2.28	2.61
Wujiang River	Dry season	399	0.011	0.09	0.05	0.04	1.94	0.20	1.74	1.64	0.52	1.12
	Wet season	1 761	0.093	0.10	0.08	0.02	2.48	0.38	2.10	2.81	1.48	1.33

N, and COD_{Mn} per unit mass of sediment were defined, respectively, as the P, N, and COD_{Mn} concentrations divided by the SS concentration.

The P concentration was measured using the molybdate spectrophotometric method according to the *Water Quality — Determination of Total Phosphorus Ammonium Molybdate Spectrophotometric Method* (GB 11893–89). The N concentration was measured using the alkaline potassium persulfate digestion UV spectrophotometric method according to the *Water Quality — Determination of Total Nitrogen Alkaline Potassium Persulfate Digestion UV Spectrophotometric Method* (GB 11894–89). The COD_{Mn} concentration was measured using the potassium permanganate method according to the *Water Quality — Determination of Permanganate Index* (GB 11892–89). The SS concentration was measured according to the *Technical Standard for Determination of Sediment Particle Size in Open Channels* (SL 42–2010).

3. Results and discussion

3.1. P, N, and COD_{Mn} concentrations and adsorption amount

In the Yangtze River Basin, the wet season is from May to October, and the dry season is from November to April of the next year. In the dry season, the average discharges of the Yangtze River, the Jialing River, and the Wujiang River are 3 420 m^3/s, 300 m^3/s, and 399 m^3/s, respectively, and in the wet season, the average discharges are 20 947 m^3/s, 1 759 m^3/s, and 1 761 m^3/s, respectively.

Table 2
Adsorption amounts of P, N, and COD_{Mn} per unit mass of sediment in different periods.

River	Period	Adsorption amount per unit mass of sediment (mg/g)		
		P	N	COD_{Mn}
Yangtze River	Dry season	4.09	11.36	23.64
	Wet season	0.54	1.23	7.66
Jialing River	Dry season	5.00	22.50	64.17
	Wet season	0.55	3.29	10.41
Wujiang River	Dry season	4.55	18.18	47.27
	Wet season	0.86	4.09	15.91

Table 1 shows that the SS concentration in the Yangtze River is higher than that in the Jialing River and the Wujiang River. P mainly exists in particulate form, which accounts for 55.6%–91.9% of TP, while N mainly exists in dissolved form, which accounts for 59.7%–89.7% of TN.

Table 2 shows that the adsorption amounts of N and COD_{Mn} per unit mass of sediment in the tributaries are higher than those in the Yangtze River. Compared with the results in published studies on the adsorption amounts of P, N, and COD_{Mn} on bed sediments in other water bodies (Lü et al., 2005; Quilbe et al., 2006; Kangur and Mols, 2008; Wang et al., 2009a; Cao et al., 2011), the adsorption amounts of P, N, and COD_{Mn} per unit mass of sediment in the Yangtze River are high, which may be due to the serious water pollution in the upper reaches of the Yangtze River.

The relationship between the concentrations of nutrient pollutants and SS shows that, although the total adsorption amounts of nutrient pollutants on sediments increase with the SS concentration, the adsorption amounts of nutrient pollutants per unit mass of sediment decrease with the increase of the SS concentration. In the wet season, the SS concentration is 8–29 times as high as that in the dry season, but the pollution level in SS in the dry season is high. Therefore, the adsorption amounts of P, N, and COD_{Mn} per unit mass of sediment in the dry season are 3–9 times as high as those in the wet season.

3.2. Correlations between P, N, and COD_{Mn} concentrations and SS concentration

Fig. 2 shows the relationships between the DP, DN, and dissolved COD_{Mn} concentrations and the SS concentration in the natural water sample. There is no evident correlation between the DP, DN, and dissolved COD_{Mn} concentrations and the SS concentration. Fig. 3 shows that the TP and COD_{Mn} concentrations have a positive correlation with the SS concentration, but the TN concentration does not show a significant correlation with the SS concentration. The reason is that P is more adhesive to sediment particles and is likely to be absorbed on sediments, while N mainly exists in dissolved form. The results show that the adsorption characteristics of P are similar to those of COD_{Mn}, but different from those of N.

Figs. 4 and 5 show the correlations between the P, N, and COD_{Mn} concentrations in the natural water sample, settled water sample, and filtered water sample A. The results show that the pollutant concentrations in the filtered water sample A have a stronger correlation with those in the settled water sample than with those in the natural water sample, and the P, N, and COD_{Mn} concentrations in the settled water sample are lower than those in the filtered water sample A. The results from the measurement of the SS concentration show that the particle size of more than 60% of SS in the settled water sample is lower than 0.02 mm, especially in the water with a low SS concentration. This indicates that SS with a particle size smaller than 0.02 mm has a strong effect on the water quality.

4. Conclusions

The concentrations of P, N, and COD_{Mn} in dissolved form and particulate form were monitored for thirteen months at seven cross-sections along the Yangtze River. The concentrations showed that there were strong relationships between nutrient pollutants and SS in the Yangtze River.

(1) The TP and COD_{Mn} concentrations had positive correlations with the SS concentration, but the TN concentration did not have a strong correlation with the SS concentration. The N concentration in the Yangtze River was less affected by SS than the P and COD_{Mn} concentrations were. Thus, it was concluded that P mainly exists in particulate form,

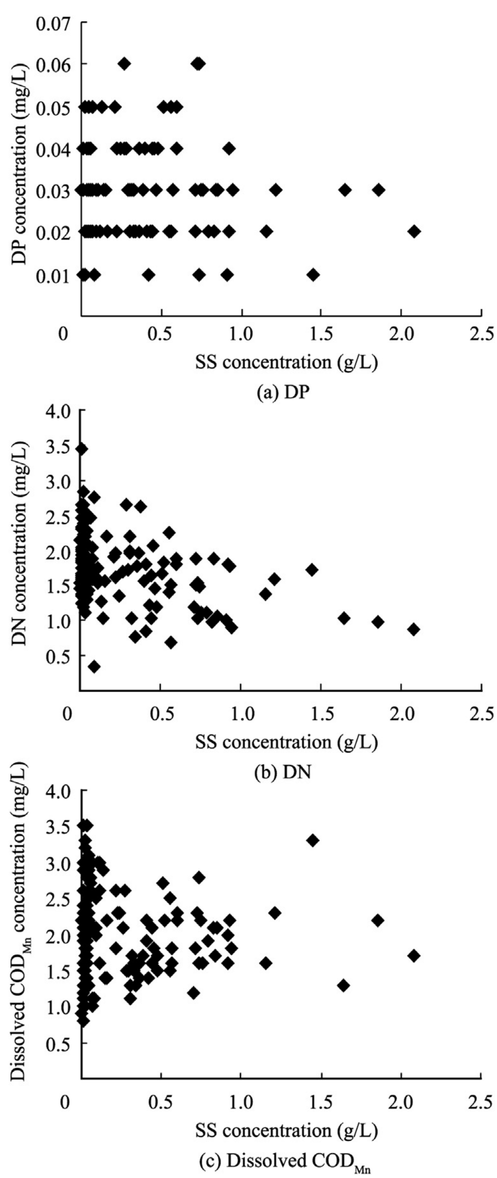

Fig. 2. Correlations between DP, DN, and dissolved COD_{Mn} concentrations and SS concentration.

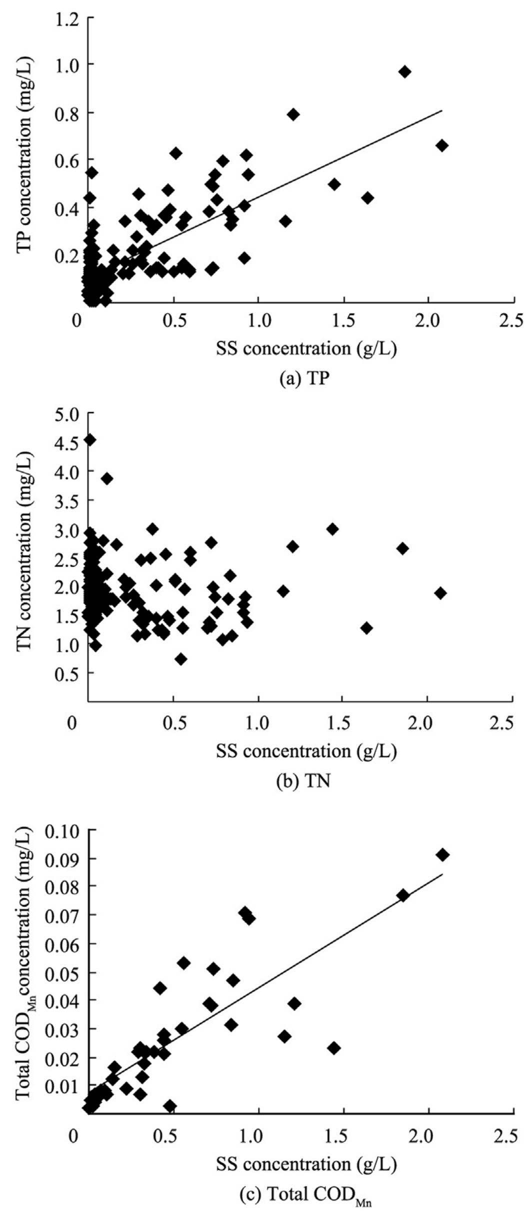

Fig. 3. Correlations between TP, TN, and COD_{Mn} concentrations and SS concentration.

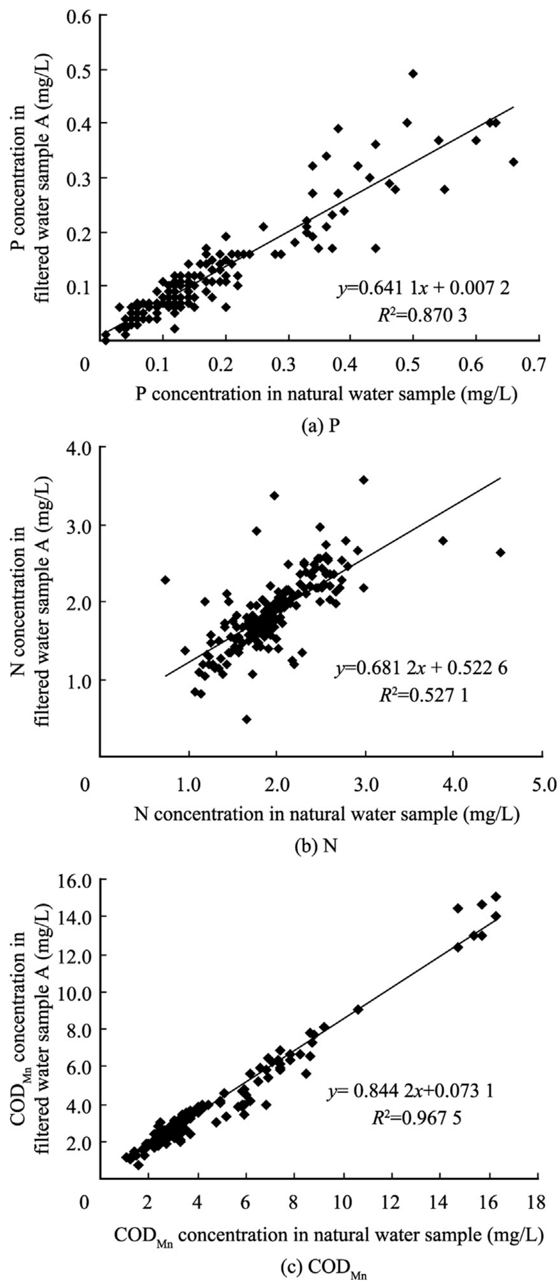

Fig. 4. Correlations between P, N, and COD_{Mn} concentrations in natural water sample and in filtered water sample A.

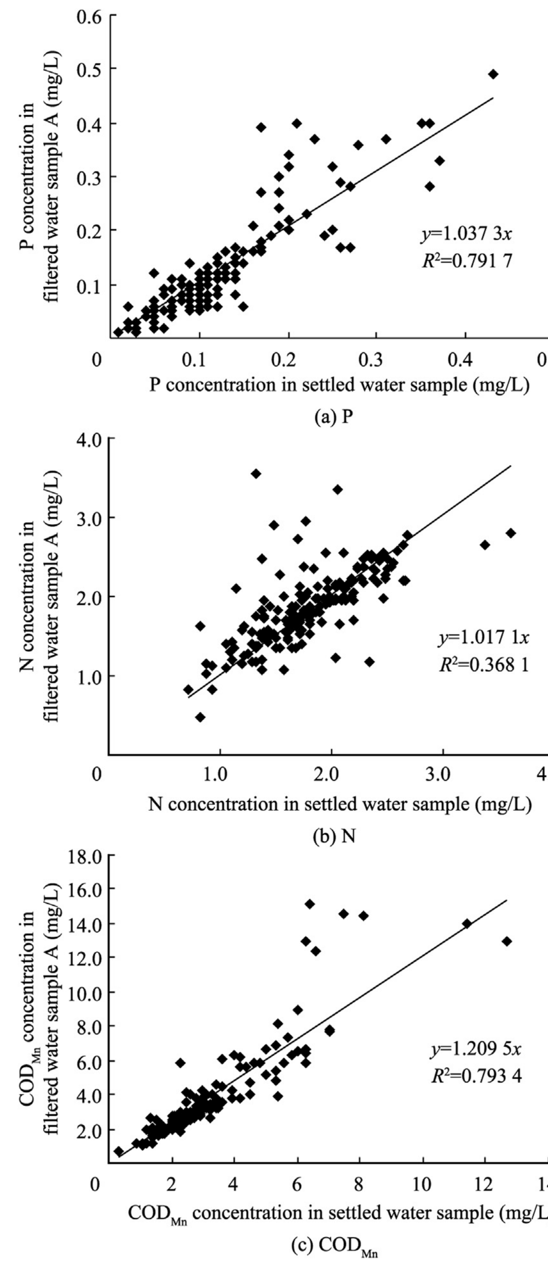

Fig. 5. Correlations between P, N, and COD_{Mn} concentrations in settled water sample and in filtered water sample A.

which accounted for 55.6%–91.9% of TP, while N mainly exists in dissolved form, which accounted for 59.7%–89.7% of TN.

(2) SS with a particle size smaller than 0.020 mm made up a proportion greater than 60% of the SS in the Yangtze River. This portion of the SS had strong effects on the water quality.

(3) The adsorption amounts of nutrient pollutants per unit mass of sediment decrease with the increase of the SS concentration. At seven cross-sections in the upper reaches of the Yangtze River, the SS concentration in the wet season is 8–29 times as high as that in the dry season. The adsorption amounts of nutrient pollutants per unit mass of sediment in the dry season are 3–9 times as high as those in the wet season.

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