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Spatial and temporal variability of agricultural pollutants in an agricultural headwater stream within a multipond system, southeastern China

MAO Zhan-po[1,2,*], YIN Cheng-qing[1], SHAN Bao-qing[2]

(1. State Key Laboratory of Environmental Aquatic Chemistry, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing 100085, China. E-mail: maozb@iwhr.com; 2. China Institute of Water Resources and Hydropower Research, Beijing 100038, China)

Abstract: The spatial and temporal variability of nutrients and suspended solids were investigated for two years in a 1.8 km agricultural headwater stream, located by Chaohu Lake, southeastern China. The stream form was greatly modified by human activities into channelized, pond and estuary shapes. The stream could be divided into 4 channelized reaches(1.3 km), a pond reach(0.15 km) and 3 estuary reaches(0.36 km). It was found that nutrients and TSS concentrations in the stream showed temporal variability, and higher concentrations occurred in months with high precipitation and intensive agricultural activities. And, retention of total nitrogen (TN), nitrate (NO_3^--N), ammonium(NH_4^+-N) and total suspended solids (TSS) predominantly occurred in the pond reach and estuary reaches with larger width and low current velocity. Pollutants retained in these reaches accounted for more than 50% of those retained in whole stream. The retention mostly happened in the rain-runoff events and it was 7 to 27 times than that in base flow. The results showed that the channelized reach was the most important source for pollutants release under either runoff or base flow, and its release accounted for more than 90% of whole stream release. There was a high spatial variability of nutrients retention in different channelized reaches. The channelized reach directly discharging into the pond did always retain nutrients and TSS under base flow and runoff conditions, whereas the other channelized reaches performed differently in different hydrological conditions. The high spatial and temporal variability of nutrients and TSS in the stream indicated that anthropogenic disturbance of the agricultural headwater stream, such as channelization and excavation, would be expected to decrease the capacity of nutrients retention in the stream.

Keywords: retention; release; nutrients; variability; stream forms

Introduction

Terrestrial nutrients(N, P) loading to aquatic ecosystem is increasing worldwide, as a result of fertilization, human and animal disposal, and industrial loading (Vitousek, 1997). A large quantity of nutrients is transported to lakes via river networks within the watershed, which accelerates the freshwater eutrophication (Alexander, 2000; Behrendt, 2000; Bowes, 2001). The nutrients retention in the river system reduces its contribution to downstream aquatic systems either in long-term or short-term (Cronan, 1999). Furthermore, the retention and subsequent resuspension alters the nutrients composition and relative physical, chemical and biological processes (Cooke, 1988; Triska, 1989). Headwater stream accounts for about 85% of total river length within a drainage network, and collects 60%—90% of water and nutrients from adjacent terrestrial ecosystems(Peterson, 2001; Vought, 1994). The headwater stream is the most important part in regulating water chemistry because of its higher surface area to volume ratios, which favors rapid nutrients uptake and processing(Alexander, 2000; Peterson, 2001). However, headwater stream is the most vulnerable to human disturbance. Therefore, some scientists (Haycock, 1993) suggested that headwater stream should be given priority to be protected for river water quality in watershed management.

The middle and downstream watershed of Yangtze River, is the key agricultural production area in China, and the rivers located in the watershed formed a complex networks (Tu, 1990). The farmers often utilize much more mineral fertilizers than the crop growth needed, and the exceeded fertilizers are finally transported to lake via river networks. However, there is little data concerning pollutants retention in the streams, especially to headwater stream. Chaohu Lake, with a surface area of 760 km^2, is located in a tributary of Yangtze River. In recent decades, agricultural surface runoff containing high concentrated nutrient, which accounts for 60% of total nitrogen(TN) and 63% of total phosphorus(TP) transported to lake, causing unprecedented eutrophication(Tu, 1990; Wei, 1992). For this purpose, we selected Liuchahe subwatershed of Chaohu Lake, which is located in southeastern China, to study the nutrients transportation and retention in a human dominated agricultural stream, Liuchahe Stream(Yin, 2001).

Since nitrogen is key factor for lake eutrophication, it was selected for this study. The index of total suspended solids(TSS) was selected, because it is also an important pollutant and it could adsorb nutrients and functioned as sources in the stream(Johnston, 1991). Several researches suggested that the ammonium(NH_4^+-N) rather nitrate(NO_3^--N) would be adsorbed preferentially by sediment in natural stream (Grimm, 1987; Martí, 1996; Peterson, 2001). Moreover, NH_4^+-N is the primary form of nitrogen release during organic matter decomposition, and it could be utilized by stream microbe assimilation and nitrification(Hill, 1987). The former research mainly concentrated on the nutrients retention in the ponds (Yan, 1998; Yin, 2001), few

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addressed the nutrients spatial and temporal variability in agricultural stream, and this study would be to quantify the characteristics of nutrients retention and transportation in agricultural stream and to contribute to a broader scope of stream nutrients retention, furthermore, it will supply information for agricultural stream restoration and protection.

The objectives of this paper were to: (1) describe the spatial and temporal variability of TN, NO_3^--N, NH_4^+-N and TSS in the agricultural headwater stream in eastern China, the most serious area of freshwater eutrophication in the world; (2) to determine what hydrological factors might influence pollutants variability in the stream; and (3) to quantify anthropogenic impacts on the nutrients and TSS retention in the stream under different hydrological conditions.

1 Study site

Liuchahe subwatershed, which is located on the northern bank of the Chaohu Lake, covers an area of 692 hm^2, and there are approximately 3000 inhabitants living in the 16 small villages. The introductions of watershed weather and land use types were given in former papers(Yan, 1998; Yin, 2001).

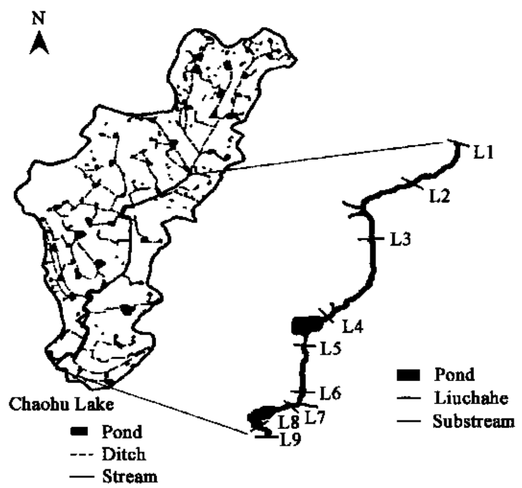

Fig.1 The multipond system in Liuchahe watershed

Liuchahe subwatershed is a typical agricultural watershed with a characteristic landscape structure, i.e. multipond system. A small creek, Liuchahe with 3 km length flows directly into Chaohu Lake. There is an integrated network structure of ponds and ditches in Liuchahe watershed(Fig.1). The system consists of 193 artificial ponds, and 23 km artificial ditches for water distribution connect the ponds. The ditches are built as dikes, and the height and width(distance between the dikes) are typically 0.3 m and 0.25 - 1.5 m. However, the heights of the dikes in the lower reaches may reach 1.5 m. The morphology of Liuchahe Stream has been completely modified during the long-term agricultural development. In the upstream, the meander water-course has been channelized for arable and drainage practices, which results in disappearance of the riffles and ponds in the stream and reduction channel width. In the middle stream, a village pond with surface area 6500 m^2 is located in the stream via a dam at the output of the pond to intercept runoff to supply water for daily washing and animal drinking, and the stream's width increased considerably. In the downstream, the farmers has excavated the channel in order to increase flood discharge to protect agricultural protection during flood seasons, which forms a wetland with area over 6000 m^2 at the mouth of stream, and the mouth width increases considerable.

2 Methods and materials

To quantify the nutrients and TSS retention patterns in the stream, the hydrological and transportation processes of nutrients and TSS were investigated during July 2001 to June 2002. The entire stream was surveyed in detail during 2001 and 2002, to investigate its major inflows, geomorphology and vegetation distribution. We also investigated the arable lands along the stream. According to the stream's morphology, we selected 1.8 km for this case study. Based on the channel form(channelized, pond and estuary), the selected stream was divided into 3 types including 8 reaches, i.e. 4 channelized reaches, a pond reach and 3 estuary reaches, with their lengths was 1.3 km, 0.15 km and 0.36 km, respectively(Fig. 1). In reach L4-5, there is a dam with dimension 3.0 by 0.4 by 0.25 m. The characteristics of the studied reaches are given in Table 1.

Table 1 The characteristics of Liuchahe Stream and aquatic plant

Reach types	Characteristics of reach				Characteristics of aquatic plant	
	Reach	Width, m	Depth, m	Length, m	Dominant	Coverage, %
Channelized reach	L1-2	2—10	1.5—2.0	168	*Phragmites*, *Acorus calamus*	85
	L2-3	3—3.5	1.5—2.0	378	*Alternanthera philoxcroides*	10
	L3-4	4—6.5	2.0—2.5	328	*Phragmites*	78
Pond reach	L5-6	5—6	0.5—1.0	404	*Phragmites*, *Alternanthera philoxcroides*	92
	L4-5	30—55	0.5—1.5	154	*Alternanthera philoxcroides*	70
	L6-7	10—35	0.5—0.8	102	*Alternanthera philoxcroides*, *Phragmites*	95
Estuary reach	L7-8	25—45	0.5—0.8	200	*Alternanthera philoxcroides*, *Acorus calamus*	90
	L8-9	25—45	0.5—0.8	54	*Alternanthera philoxcroides*, *Acorus calamus*	90

Runoff samples were taken at the monitoring sites when surface runoff flow was generated in rain-runoff events. In addition, the other sites of major tributaries were also chosen in the section. Generally, the water samples were taken every 4 h, however, it would be taken every 1 h for small rainfalls. During and after a rainfall event, 3 to 8 samples in each monitoring site could be collected and then for TSS, NO_3^--N, and NH_4^+-N were analyzed. The samples of base flow were collected from the stream every week. After sampling, 250 ml aliquots were filtered by 0.45 μm pore-size glassfiber filters. Filtrate was reserved and unfiltered water samples were stored at 4℃ and were analyzed at the Hefei Environment Monitor Station within 48 h after sampling. The unfiltered water samples were analyzed for TN; the filtered samples were analyzed for NO_3^--N and NH_4^+-N. Total nitrogen was simultaneously determined by using the method of peroxodisulfate oxidation(Ebina, 1983), and TSS analysis was done using the standard methods(American Public Health Association, 1985).

Nine monitoring sites were selected to measure stream flow including base flow and runoff. The positions of the monitoring sites are shown in Fig.1. At the monitoring site 5, the dam was utilized to as rectangular weir to measure stream flow. The ninth monitoring site was located at the outlet of the watershed to measure watershed runoff. This station was equipped with a rectangular notch weir to facilitate measurement of the discharge. The water flow velocity was measured by kinemometer, and the runoff volume was calculated from the shape of the notch and corresponding water level. In other stations, the water flow velocity and cross-section were measured simultaneously to calculate the water discharge during baseflow or rain-runoff periods, and the experiments were carried out in two ways. Due to low water depth and the interference by vegetation under the baseflow, water velocity was measured by traces velocity of dye. During high water level, the water velocity was measured by hydrophytes(Ellis, 1986).

According to the stream form and plant growth, a total of 90 sample sites were selected in 2002 to study the nutrients contents in sediment. In each sampling site, about 0.5 kg sediment of the upper 5 cm was collected for analysis. The samples were air-dried and passed through a 2-mm sieve. TN was analyzed as Kjeldahl (Nelson, 1972). The other nutrients were analyzed according to the standard methods (The Committee of Agrochemistry, 1983). The characteristics of macrophytes in the sampling reaches were also investigated. The plant coverage was estimated visually, and the dominance, frequency and size of plant distribution were investigated using the standard methods (Chapman, 1976). The density of plants was recorded in late autumn for different reaches.

To examine the spatial and temporal variability of pollutants in Liuchahe Stream, the discharge-weighted pollutants concentrations of different reaches were used to show its spatial variability in the stream, and monthly mean of pollutants concentrations of monitoring site 9 was used to demonstrate its temporal variability. The Stat analysis of variables was implemented by ANNOVA methods.

Mass balance approach was used to quantify the nutrients and TSS retention or release in the stream under different hydrology conditions(baseflow, runoff). The mass balance for a reach could be formulated based on the discharge and pollutants concentration as follows:

$$l_{ret}(j) = l_k(j) - l_{k+1}(j). \quad (1)$$

Where $l_{ret}(j)$ is j pollutant retained in the k to $k+1$ section (positive value means that j pollutant was retained in the section, negative value means pollutant was released from the section); $l_k(j)$, $l_{k+1}(j)$, are the j pollutants input to k and $k+1$ section, respectively. The ground water was not explicitly incorporated into the equation, but could be assessed from water-balance for the section.

Each term in Eq. (1) could be calculated on the basis of nutrients concentration and water flow rate. The j pollutant load for k section was estimated from the equation:

$$l_k(j) = \sum \Delta t_i [c_i(j) Q_i + c_{i-1}(j) Q_{i+1}]/2. \quad (2)$$

Where $c_i(j)$ and Q_i is the concentration of the j pollutant and discharge at a time of sampling i, and Δt_i is the time interval between i and $i+1$ sampling.

The nutrients and TSS retention or release in the channelized reaches, pond reach and estuary reaches could be calculated from Eq. (1) and (2), which based on the data of nutrients and TSS concentration and water discharge under baseflow and rain-runoff. During base flow and rain-runoff, some water and the nutrients of the rice fields along the stream would be diffused or infiltrated into the stream, which were not taken into consideration in mass balance for no measured data. The weirs around the rice fields were 15 cm height, and they could intercept the surface runoff under normal rainfall conditions, and we monitored the major discharge of the rice fields into the stream during heavy rainfall-runoff events, and clay soil at the bottom of the fields that could prevent infiltration. Consequently, it was not listed as a term in the mass balance.

The mass load of reaches L1-8 were calculated based on the monitored data, and the reach L8-9 was not considered for no complete velocity data caused by Chaohu Lake backwater during larger rain-runoff periods. The retention of nutrients and TSS in the stream were analyzed under different hydrological conditions including base flow and rain-runoff. Among the retention results, positive value means the reach could retain nutrients and TSS, and the negative value means the reach could release nutrients and TSS. The whole retention of nutrients and TSS in the stream was the sum of retention in base flow and runoff, and the whole net retention was the sum of pollutants retention and release in either base flow or rain-runoff conditions.

3 Results

The amount of monthly precipitation during July 2001 to June 2002 is given in Fig.2. The precipitation in 2001 was 160 mm, and it was 466 mm in 2002. There were channelized, pond, and estuary reaches in the stream, which constituted a complex landscape system-multipond system. The sediments particle showed obvious spatial variability in the stream(Table 2). The larger particles(particle diameters

> 0.05 mm) in the stream presented as estuary reach > channelized reach > pond reach, and middle particles (0.005 mm < particle diameters < 0.05 mm) showed as channelized reach > estuary reach > pond reach. TN, NO_3^--N, NH_4^+-N contents in sediments also showed obvious spatial variability in the stream (Table 3).

3.1 Spatial and temporal variability of nutrients and TSS

The TN, NO_3^--N, and NH_4^+-N concentrations in the Liuchahe Stream exhibited spatial and temporal variability on several scales, and significant differences among TN, NO_3^--N, and NH_4^+-N concentrations was found (ANNOVA, $p < 0.01$). Spatial variability of pollutants concentration occurred between stream reaches. Temporal variability exhibited within month and different precipitation, and between base flow and rain-runoff.

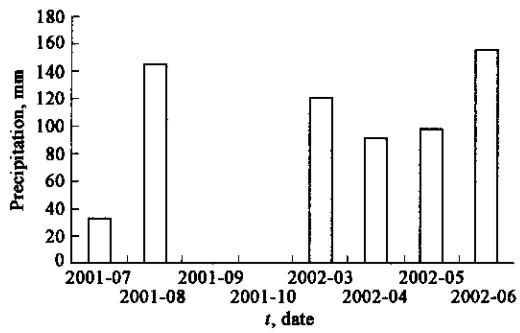

Fig.2 The characteristics of precipitation during July, 2001 to June, 2002

Table 2 The particle composition and OM of the sediment in Liuchahe Stream

Reach type	Particle composition, %						OM,
	1—0.25 mm	0.25—0.05 mm	0.05—0.01 mm	0.01—0.005 mm	0.005—0.001 mm	< 0.001 mm	%
Channelized reach	1.4	8.2	24.5	21.9	16.1	27.9	1.43
Pond reach	1.4	3.6	24.5	18.3	16.2	36.0	2.37
Estuary reach	2.8	7.6	29.3	13.7	14.0	37.6	1.70

Table 3 Nutrients contents of the sediment in Liuchahe Stream

Reach type	Reach	Pollutants (Mean ± *SD*)		
		TN, g/kg	NO_3^--N, mg/kg	NH_4^+-N, mg/kg
Channelized	L1-2	1.6 ± 0.5	1.35 ± 0.99	1.71 ± 1.44
Reach	L2-3	1.4 ± 0.3	1.67 ± 0.12	1.18 ± 0.28
	L3-4	0.9 ± 0.2	1.50 ± 0.11	1.68 ± 0.45
	L5-6	1.7 ± 0.2	2.18 ± 1.11	1.63 ± 0.64
Pond reach	L4-5	1.4 ± 0.5	1.19 ± 0.15	1.26 ± 0.25
Estuary reach	L6-7	1.6 ± 0.6	0.96 ± 0.71	2.54 ± 2.21
	L7-8	1.6 ± 0.6	0.81 ± 0.09	1.97 ± 0.94
	L8-9	1.4 ± 0.5	1.45 ± 1.15	2.38 ± 1.47

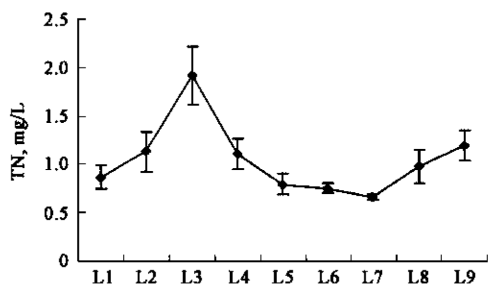

Fig.3 The spatial variability of TN concentrations in Liuchahe Stream
Errors bars show standard errors

3.1.1 Total nitrogen (TN)

The spatial variability of TN along the stream is shown in Fig.3, and the linear relation between TN concentrations and contents in the sediments was found ($r = -0.97$; $p < 0.01$). The TN concentrations varied among the stream reaches: higher and lower concentrations occurred in channelized reaches. TN concentrations in channelized reaches showed different characteristics, which might be related to vegetation, reach form, and velocity. The temporal variability of TN is shown in Fig.4. There was no significant relationship between TN concentration and precipitation was found, because it was related to nitrogen contents and agricultural activities in watershed. Due to low precipitation before July 2001, there was a larger nitrogen accumulation in the soils, and farmers often utilized much fertilizer to rice fields in August. Consequently, the rice fields along the stream would discharge more nutrients into the stream in July and August, 2001. During 2002, with agricultural activities (plaguing, fertilizing and planting) coupled with the precipitations, thus TN concentration increased gradually (Fig.4).

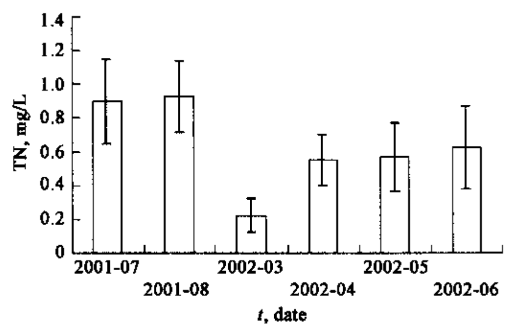

Fig.4 The temporal variability of TN concentrations in Liuchahe Stream
Errors bars show standard errors

3.1.2 Nitrate (NO_3^--N)

The spatial variability of NO_3^--N is shown in Fig.5. The significant difference was not discovered between NO_3^--N concentrations and contents in sediments. The NO_3^--N concentrations varied among the stream reaches. In the channelized reach L3-4, NO_3^--N concentration reduced rapidly, but sediment contents increased. NO_3^--N concentration and sediment content all reduced in estuary reach, which was related to following factors: macrophyte and phytoplankton could supply litter and carbon, higher temperature and long retention time. The temporal variability of NO_3^--N concentration showed reduce-increase characteristics (Fig. 6), which was explained by it ' s transportation channel and agricultural activities. In July 2001, NO_3^--N accumulated in the lower soils would discharged into the stream by the effects of precipitation and runoff, whereas higher soil water contents in August that would be value for nitrate leach to the ground, which would reduce NO_3^--N concentration in stream.

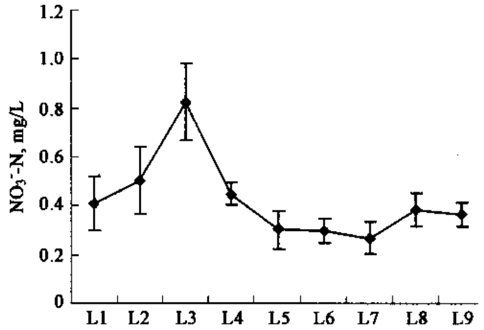

Fig.5 The spatial variability of NO_3^--N concentration in Liuchahe Stream
Errors bars show standard errors

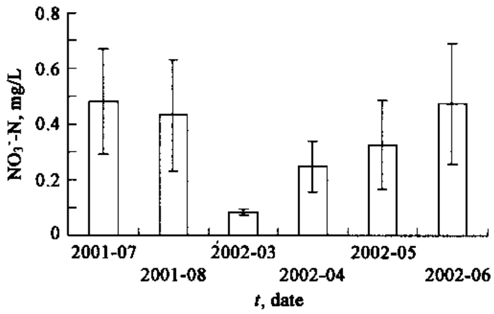

Fig.6 The temporal variability of NO_3^--N concentration in Liuchahe Stream
Errors bars show standard errors

3.1.3 Ammonium(NH_4^+-N)

The spatial variability of NH_4^+-N is shown in Fig.7. The inverse relationship was discovered between NH_4^+-N concentrations and contents in sediments ($p < 0.01$; $r = -0.55$). The NH_4^+-N concentrations varied among the stream reach, higher concentrations occurred in channelized reaches, and lower concentrations happened in estuary reaches. In the pond and estuary reach, concentration and

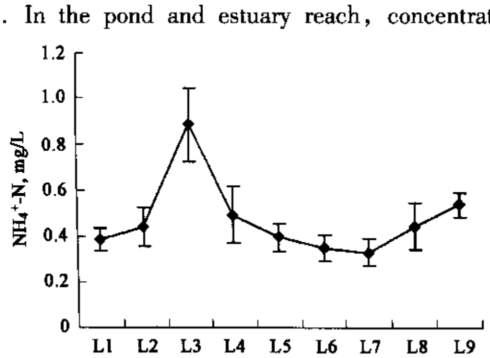

Fig.7 The spatial variability of NH_4^+-N concentrations in Liuchahe Stream
Errors bars show standard errous

contents all reduced, which might be explained as the reaches had stable bio-membrane, long retention time, and large contacting area between water body and sediments. In 2001, there was no obvious changes of NH_4^+-N concentrations(Fig. 8), whereas the inverse relationship between NH_4^+-N concentration and precipitation was found in 2002($p < 0.01$; $r = -0.79$).

3.1.4 Total suspended solids(TSS)

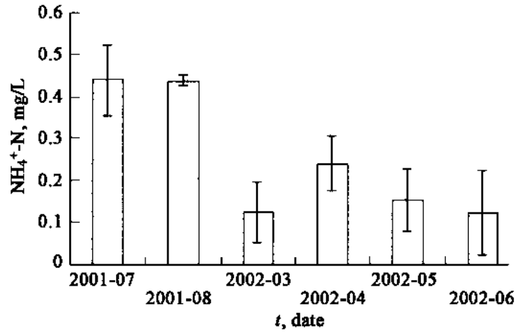

Fig.8 The temporal variability of NH_4^+-N concentrations in Liuchahe Stream
Errors bars show standard errous

The spatial variability of TSS concentrations along the stream is presented in Fig.9. The TSS concentrations varied among the stream reaches, and higher concentrations were found in estuary reaches. TSS concentrations in estuary reaches varied threefold from high(L9) to low(L7). The large particles(> 0.005 mm) were mainly retained in the channelized reach, while the pond reach and the estuary reach could trap more tiny particles than the channelized reach(< 0.005 mm; Table 3).

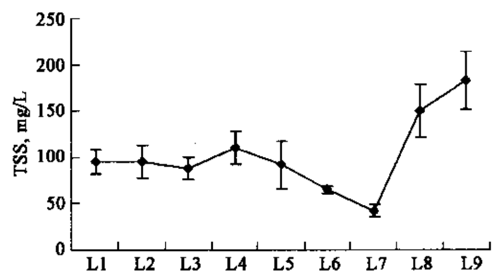

Fig.9 The spatial variability of TSS concentrations in Liuchahe Stream
Errors bars show standard errors

3.2 Spatial variability of nutrients and TSS retention

3.2.1 Total nitrogen(TN)

Under the baseflow, TN retention in the stream reached 14.1 kg, and release was 14.9 kg(Fig.10). During rain-runoff events, TN retention was up to 195 kg, and release was 126 kg. The TP retention in the pond reach and estuary reach accounted for 63% of the whole retention. The pond reach L4-5 and estuary reach L6-7 released nutrient as interior pollutant sources under baseflow, whereas they retained TN as sinks in rain-runoff periods. The whole net retention was only 68.2 kg, and retention in the channelized reach, pond reach and estuary reach was −54.0 kg, 51.2 kg and 71.0 kg, respectively.

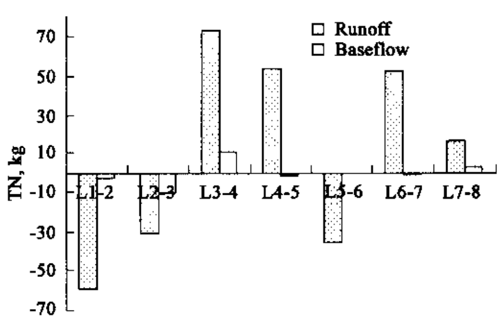

Fig.10 The spatial variability of TN retention in Liuchahe Stream

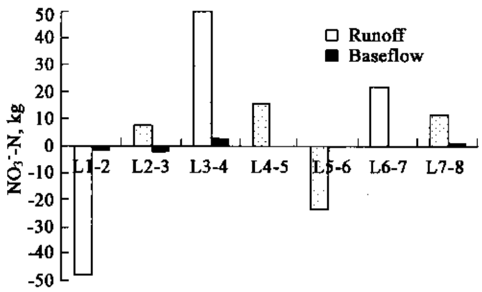

Fig.11 The spatial variability of NO_3^--N retention in Liuchahe Stream

3.2.2 Nitrate(NO_3^--N)

The nitrate(NO_3^--N) retention under base flow reached 3.9 kg, and release was up to 4.0 kg(Fig.11). The whole retention of NO_3^--N was amounted to 109 kg, and release reached 71 kg. The retention in the pond and estuary reach was accounted for 48% of the whole retention. The estuary reach L6-7 was transformed from pollutant sources under base flow to sinks during rain-runoff events. The whole net retention was only 37.9 kg, of which in the channelized reach, pond reach and estuary reach was - 14.9 kg, 16 kg and 36.8 kg, respectively.

3.2.3 Ammonium(NH_4^+-N)

The ammonium(NH_4^+-N) retention under base flow reached 10.7 kg, and the amount of release was 11.2 kg (Fig.12). Under rain-runoff events, NH_4^+-N retention was amounted to 82.7 kg, of which in the pond reach and estuary reach was 68 kg. The pond reach was transformed from pollutant sources under base flow to sinks in rain-runoff periods, whereas the channelized reach L2-3 continuously released NH_4^+-N. The whole net retention was 29 kg, of which in the channelized reach, pond reach and estuary reach was - 37.8 kg, 42.1 kg, and 24.7 kg, respectively.

3.2.4 Total suspended solids(TSS)

The TSS retention in the stream was 566 kg under the base flow(Fig.13). Under rain-runoff, the retention was up to 15152 kg, of which in the pond reach and estuary reach was 8747 kg. The channelized reach showed different retention patterns under different hydrological conditions. The whole net retention was 3290 kg, and the retention in the channelized reach, pond reach and estuary reach was - 4813 kg, 3624 kg, and 4479 kg, respectively.

The whole net retention of nutrients and TSS in the channelized reach, pond reach and estuary reach is given in Table 4 and Table 5. The order of the whole net retention of

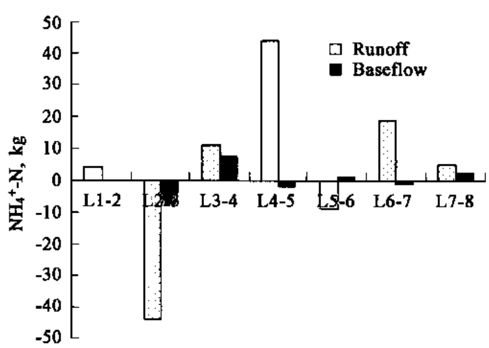

Fig.12 The spatial variability of NH_4^+-N retention in Liuchahe Stream

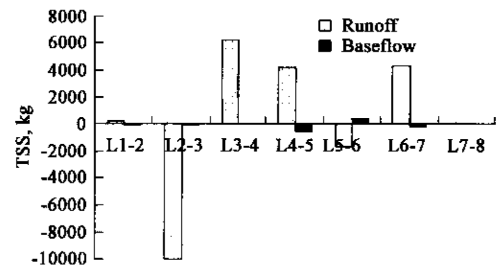

Fig.13 The spatial variability of TSS retention in Liuchahe Stream

pollutants in the stream (amount or unit area retention) was TSS > TN > NO_3^--N > NH_4^+-N. From the results, it could be concluded that the channelized reach was an important interior source. The retention of pollutants showed various characteristics in the pond reach and estuary reach. The unit area retention of NH_4^+-N in the pond reach was larger than that in the estuary reach, while TN, NO_3^--N and TSS retention was less than that in the estuary reach.

Table 4 The whole net retention of nutrients and TSS in Liuchahe Stream

Reach type	TN, kg	NO_3^--N, kg	NH_4^+-N, kg	TSS, kg
Channelized reach	- 54.0	- 14.9	- 37.8	- 4813
Pond reach	51.2	16.0	42.1	3624
Estuary reach	71.0	36.8	24.7	4479
Liuchahe Stream	68.2	37.9	29	3290

Notes: The value of Liuchahe Stream was the sum of retention and release of channelized reach, pond reach and estuary reach, and the retention value of the channelized reach, pond reach and estuary reach was the sum of retention and release of the same type reach

Table 5 The unit area(m^2) retention rate of pollutants in Liuchahe Stream

Reach type	TN, g/m	NO_3^--N, kg	NH_4^+-N, kg	TSS, kg
Channelized reach	- 9.37	- 2.58	- 6.56	- 834.9
Pond reach	7.82	2.44	6.43	553.7
Estuary reach	11.54	5.98	4.02	728.3
Liuchahe stream	3.69	2.05	1.57	178.2

Notes: The area of the channelized reach, pond reach and estuary reach was 5765 m^2, 6545 m^2 and 6150 m^2, respectively. The value of Liuchahe Stream was the sum of retention and release of channelized reach, pond reach and estuary reach divided by the stream area (sum of channelized reach, pond reach and estuary reach)

4 Discussion

4.1 Spatial variability of nutrients concentrations

The spatial variability of nutrients and TSS concentrations along the stream was influenced by natural (hydrological, biological, chemical processes) and anthropogenic factors(Haag, 2001; Jansson, 1994; Reddy, 1999). In the pond reach and estuary reach, the contact area of water body with sediment amounted to 3000—6000 m^2 that was larger than that of a channelized reach, and water velocity decreased for cross section increasing and vegetation interfering(Yin, 2001), which increased retention time of nutrients and enhanced the chance of interaction between nutrients and sediments(Fleischer, 1994; Johnston, 1991). In the estuary reach, the composition of aquatic vegetation (emergent and submerge) was conserved and emergent species coverage reached 70%—95%, and organic matters (dissolved and particulate) produced by vegetations (living plants, plant litters) was accumulated in the sediments. The shallow water depth ranged from 0.5 to 0.8 m, which made for sun transmission and aquatic vegetation (emergent and submerge macrophyte) develop. These factors would increase stream rigesity and decrease water velocity, which would accelerate small particle sedimentation and nitrogen retention (Fleischer, 1994; Johnston, 1991).

An interesting phenomena found was that channelized reach L3-4 ahead of the pond reach L4-5 always did retain nutrients, and it's channel form and macrophyte were no significant changes comparing with the other channelized reaches (Table 1). It was caused by the dam constructed at the output of the pond reach L5. During the experiment periods, we found water velocity reduced from 15 cm/s (L3) to 9 cm/s (L4), and the water velocity reduced to zero in the pond reach (Fig. 14), and water level of the channelized reach L3-4 increased gradually. The higher water level would enhances the interaction area between water and sediment, and increase water and nutrient retention time to accelerate nutrients retention. The channelized reaches release nutrients and TSS during rain-runoff periods for different reasons. In the channelized reach L1-2 water velocity amounted to 150 cm/s, which would incur matters resuspension to increase pollutants concentration. Whereas, the farmers excavated channelized reach L2-3 in 2001 to intercept water for irrigation, which destructed stream aquatic ecosystem including vegetation composition, sediment biofilm and affected bank stability (Naiman, 1997), thus decreased the stream ecosystem resistance to external disturbance as flood and nutrients input. These direct or indirect human disturbances accelerated the spatial dynamics of concentration or retention patterns, which was also confirmed by other researches (Auble, 1994).

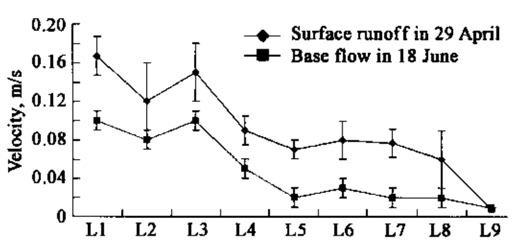

Fig.14 The flow velocity dynamics in Liuchahe during surface runoff and baseflow in 2002

Errors bars show standard errors

4.2 The spatial variability of pollutants retention

The spatial variability of pollutants retention in the channelized reach, pond reach and estuary reach, which was related to stream form, retention mechanisms of nutrients, hydrological conditions and macrophytes (Martí, 1996), among which stream form and hydrological conditions (base flow, rain-runoff) might be the most important factor (Grimm, 1987; Haag, 2001; House, 1998; Jansson, 1994).

The nitrogen retention in the stream was controlled by sedimentation, denitrification and uptake of the vegetation (Jansson, 1994). The denitrification was the permanent retention, but the others were temporary storage, which contributed substantially to the transitory attenuation of NO_3^--N (Fennessy, 1997; Haag, 2001). The pond reach and estuary reach possessed the feasible denitrification factors, i.e. enough organic material for carbon sources (Table 2), higher temperature (water temperature 10—20℃), and enough nitrogen load (Jansson, 1994), which resulted in NO_3^--N and NH_4^+-N retention in these reaches accounted for 49% and 82% of whole retention (no considering release) in the stream. This result was identical to finding of Jansson (Jansson, 1994): nitrogen retention in the stream mainly occurred in the pond, but unit area retention rate was lower than that of Svendsen and Kronvang (Svendsen, 1993; 25—40 Ng/m), which was related to low concentration of nutrients in Liuchahe Stream.

From the results of nitrogen retention in the stream, we found obvious difference between NO_3^--N and NH_4^+-N retention, which might be explained by nutrients retention mechanisms. Some researchers pointed out that NH_4^+-N uptake and removal processes in the stream mainly occurred on the sediment and biofilm covered on the submerged surface, and nitrification process of NH_4^+-N would release NO_3^--N to reduce NO_3^--N retention (Peterson, 2001; Weisner, 1994). And, Peterson *et al*. (Peterson, 2001) suggested that 20%—30% NH_4^+-N remove in the stream due to denitrification, the other was adsorbed into the sediments. Consequently, the channelized reach released TSS during rain-runoff periods with higher velocity, which incurred particle resuspension resulting in NH_4^+-N transported to the downstream. NO_3^--N removal from water mainly depended on the denitrification and vegetation uptake (Fennessy, 1997). The denitrification could occur in the whole stream with suitable conditions rather than mainly occurred in the pond reach and estuary reach with larger areas, and the mean denitrification rate in Liuchahe Stream was 0.094 mg/g, which was larger that in rice fields, 0.031 mg/g (Peterson, 2001; Weisner, 1994; Yan, 1999). TN, NO_3^--N retention (Table 4) in the estuary reach was higher than that in the pond reach, which might also be related to the vegetation composition in the stream (Engelhardt, 2001). There were many macrophytes (emergent and submerge species) in the estuary reach rather than emergent macrophytes in the pond reach, and macrophyte species (emergent and submerge) took up little nutrients comparing with the whole retention in the stream. However, emergent macrophytes would produce more organic material than submerged macrophytes, and the submerged macrophytes serves as an attachment surface for epiphytes and denitrification bacteria, which might result in an efficient exchange with the surface water flow to accelerate NO_3^--N retention (Engelhardt, 2001; Weisner, 1994).

5 Conclusions

This study evaluated the spatial and temporal variability of nitrogen and TSS in an agricultural headwater stream, Liuchahe. The main conclusions were given as follows.

The retention of nutrients and TSS main occurred in rain-runoff periods. The mass retention of TN, NO_3^--N, NH_4^+-N and TSS under rain-runoff events was 195 kg, 109 kg, 82.7 kg, 15152 kg, which was 14 times, 28 times, 8 times, and 26 times of that under base flow.

The mass retention mainly happened in the pond reach and estuary reach. The retention of pollutants in the pond and estuary reach accounted for approximately 50% of the whole retention.

There was a high spatial variability of nutrients retention in different channelized reaches. The channelized reach was the most interior sources in the stream, TN, NO_3^--N, NH_4^+-N and TSS release accounted for more than 90% of the whole release. However, the channelized reach directly discharging into the pond reach did always retain nutrients and TSS under base flow and runoff.

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