Monitoring of inorganic nitrogen in surface and groundwater at the intensive farming villages of the Red River Delta, Viet Nam

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Abstract

The quality of surface water (canal and pond water) and groundwater (well water) was monitored with an interval of 6 months from 2002 to 2005 at two farming villages near Ha Noi, Viet Nam. In the villages, two rice and one winter crop were cultivated within a year, in which massive amounts of chemical fertilizer-N were applied consecutively. The ammonium-N concentration ranged from 0.01 to 11.6 mg/L for surface water and from trace level to 5.6 mg/L for groundwater. The nitrate-N concentration ranged from 0.04 to 0.95 mg/L for surface water and from 0.01 to 1.2 mg/L for groundwater. These concentrations did not increase with time. It was considered that surface water must be carefully used for the irrigation of agricultural crops, because the ammonium-N plus nitrate-N concentration exceeded a threshold value of 5 mg/L at several times during the monitoring period, above which some damage for crop growth might happen. The ammonium-N concentration of groundwater was proportional to the annual amount of chemical fertilizer-N applied at the villages, suggesting a positive effect of the application of chemical fertilizer-N on an ammonium-N concentration of groundwater. Groundwater was unsuitable for drinking, because the ammonium-N concentrations mostly exceeded a level of 0.78 mg/L, above which human internal organ systems might be damaged. The nitrate-N concentration of groundwater satisfied the water standard for drinking use.

Keywords: Ammonium-N, Chemical fertilizer, Farming village, Nitrate-N, Water quality

Introduction

In the Red River Delta (RRD) in northern Viet Nam, surface and groundwater are extensively used for irrigation and drinking purposes. Meanwhile, the amount of annually applied chemical fertilizer-N has rapidly increased with intensification and diversification of cropping after Doi Moi in 1986. Presently,

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cropping three times in a year, namely cropping of spring and summer rice and a winter crop, is the prevalent practice.

With an increase in the application of chemical fertilizer-N, there is a concern that the surface and groundwater in farming villages are exposed to contamination from inorganic-N originating from chemical fertilizer-N. World Bank et al.（2003）pointed out that the water of the main rivers（i.e. surface water）in Ha Noi are contaminated with ammonium.

However, contamination is not restricted to surface water. Groundwater in the surrounding area can be contaminated with ammonium by the percolation of surface water contaminated within it. Nevertheless, there are few reports on the contamination of surface and groundwater by inorganic-N related to use of chemical fertilizer-N.

Because of this, inorganic-N levels in surface and groundwater were monitored for three years with a 6-month interval at the two rural villages in the RRD, where chemical fertilizer-N is massively applied annually. Based on the monitored results, the present study aims to clarify:

1）Concentrations of ammonium-N and nitrate-N in reference to the water standards.
2）Changes of the inorganic-N concentrations with monitoring time.
3）Differences in the inorganic-N concentrations between surface and groundwater.
4）Effects of the annual amount of chemical fertilizer-N on the inorganic-N concentrations in surface and groundwater.

Materials and Methods

Study area

Monitoring was conducted at the two communes（i.e. villages）of Phu Dong（PD）and Phu Lam（PL）which are typical farming villages in the RRD. The commune's name is expressed with an abbreviation shown in the parenthesis hereafter. Fig. 1 shows the locations of the two communes. Both are situated within 20 km from the center of Ha Noi City.

Table 1 shows the province or city to which each commune belongs, land elevation, and prevailing soil types, partly quoted from Kurosawa et al.（2006）. The communes are located in Ha Noi City and Bac Ninh Province. The land elevation is below 6 m above sea level in PD and PL and the soil is classified as Eutric Fluvisols（alluvial soil rich in nutrients and with a high degree of base saturation in the surface layer）for PD and as Gleyic Fluvisols（alluvial soil formed under the effect of underground aquifer）for PL.

According to the meteorological data recorded at Ha Noi City during 2001 through 2004（General Statistics Office, 2002 to 2005）, the mean seasonal rainfall from May to October（rainy season）and from November to April（dry season）amounted to 1,470 and 250 mm, respectively, with 4.9 and 2.9 hours of mean daily sunshine in the corresponding seasons. The mean annual air temperature was 24.5℃, with a monthly average ranging from 17.6℃ in January to 29.6℃ in June. The relative humidity was very high throughout the year, with an annual mean of 79%.

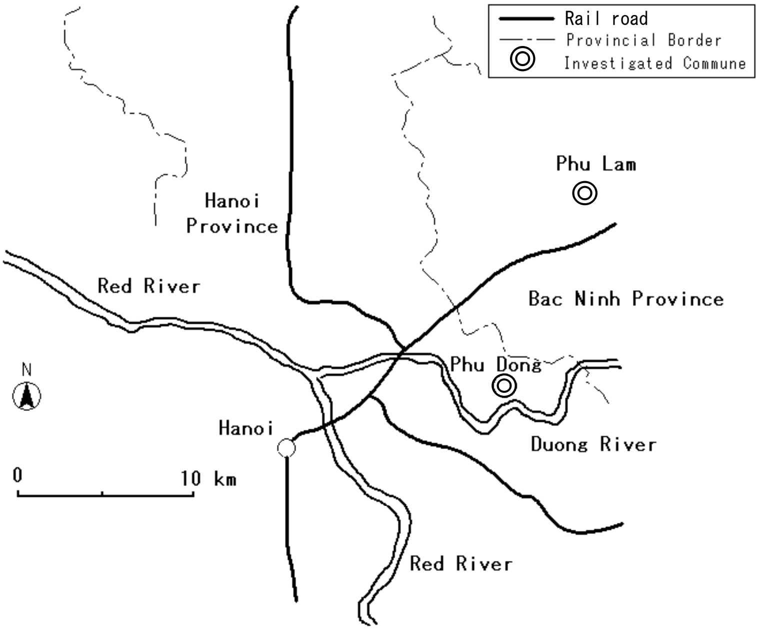

Fig. 1. Locations of the two communes investigated in the Red River Delta.

Table 1. Brief description of the investigated communes.

Commune	Province/City	Land elevation (m)	Soil type※
Phu Dong	Ha Noi	5-5.5	Eutric Fluvisols
Phu Lam	Bac Ninh	3-3.5	Gleyic Fluvisols

Partly quoted from Kurosawa et al. (2006).
※According to the FAO-UNESCO soil classification system (VSSS-NIAP, 1996).

There are two main groundwater aquifers in the RRD. One aquifer is embedded in Holocene sediments and the other in Pleistocene sediments. The former is aquifer present at a depth of 0.5 to 2 m from the ground surface during the rainy season and at a depth of 2 to 8 m during the dry season. Its thickness ranges from a few meters to 40 m. The latter aquifer is confined and underlies the former with a thickness of 10 to 100 m (World Bank, 1995).

Farming

Two rice crops and one winter-crop are cultivated in both communes. Table 2 shows the average amount of chemical fertilizer-N applied in the individual cropping and in total, quoted from Kurosawa et al. (2004). The level of fertilizer application in 2002 was applicable to the level of every year until 2005, because there was no observation of any change in the cropping pattern during the monitoring period. The winter crop indicated in the parenthesis is the main cultivation in the individual commune. Fertilizer-N

Table 2. Amounts of chemical fertilizer-N (kg/ha) applied in individual cropping and in total, averaged for each commune in 2002.

Commune	Spring rice	Summer rice	Winter crop※	Total
Phu Dong	124	113	185 (maize)	422
Phu Lam	121	108	153 (potato)	382

Quoted from Kurosawa et al. (2004).
※A main winter crop.

Table 3. Sampling depth of groundwater from the ground surface (m) in each commune.

Commune	n	Maximum	Minimum	Average
Phu Dong	6	29	6	14
Phu Lam	6	27	6	15

Quoted from Kurosawa et al. (2004).
n: number of sampling sites.

was applied separately 2 to 5 times per cropping season. As shown in Table 2, amounts of fertilizer-N applied were in the levels of 121 to 124 and 108 to 113 kg/ha for spring and summer rice, respectively, and 153 to 185 kg/ha for winter crop, totaling 382 to 422 kg/ha of an annual amount.

Surface and Groundwater sampling

Samples of groundwater were collected from 5 to 6 wells from the selected farm households in the commune. Table 3 shows the maximum, minimum, and average sampling depths from the ground surface in each commune. The sampling depth ranged from 6 to 29 and 6 to 27 m in PD and PL, respectively. The depth in average was generally shallow with 14 to 15 m in both communes. From these depths, groundwater was thought to belong to the aquifer in Holocene sediments.

500-mL of surface water was sampled from the surface (<5 cm deep) of the irrigation/drainage canal or pond.

The sampling was done 7 times from October 2002 to September 2005 with a 6-month interval. March is the transition period from dry to rainy seasons, and September/October is another transition period from rainy to dry seasons in the RRD.

Measurement of concentrations of ammonium and nitrate ions

Ammonium and nitrate ion concentrations were determined colorimetrically with a spectrophotometer (UV-mini 1240, Shimadzu Co., Ltd.), according to the Nessler method and the Cataldo method, respectively. Ammonium and nitrate ion concentrations were converted to concentrations of ammonium-N and nitrate-N, by applying the molecular weight ratio of N to NH_4^+ and NO_3^-.

Table 4. Concentrations of ammonium-N and nitrate-N (mg/L) in surface and groundwater at each monitoring in Phu Dong and Phu Lam Communes in the Red River Delta.

Item	Commune	Max & Min	Oct. 2002	Mar. 2003	Sep. 2003	Mar. 2004	Sep. 2004	Sep. 2005	All monitorings
Surface water ammonium-N	PD (n = 5)	Max	1.59	4.32	7.00	9.53	5.68	2.80	9.53
		Min	0.76	0.01	1.11	3.82	0.57	1.35	0.01
	PL (n = 6)	Max	6.16	3.17	3.27	11.6	2.38	2.44	11.6
		Min	1.43	1.44	0.84	2.7	0.06	0.24	0.06
Surface water nitrate-N	PD (n = 5)	Max	0.37	0.92	0.13	0.80	0.35	0.16	0.92
		Min	0.09	0.29	0.05	0.15	0.04	0.05	0.04
	PL (n = 6)	Max	0.19	0.95	0.72	0.50	0.22	0.11	0.95
		Min	0.16	0.28	0.06	0.11	0.05	0.06	0.05
Groundwater ammonium-N	PD (n = 6)	Max	2.36	5.64	5.18	4.37	1.71	2.82	5.64
		Min	0.59	0.85	0.80	0.32	0.21	1.26	0.21
	PL (n = 6)	Max	1.08	3.85	2.80	2.49	0.98	3.22	3.85
		Min	0.77	1.21	1.14	0.73	0.67	trace	trace
Groundwater nitrate-N	PD (n = 6)	Max	0.29	0.49	0.44	0.82	1.24	0.75	1.24
		Min	0.08	0.09	0.11	0.11	0.08	0.03	0.03
	PL (n = 6)	Max	0.13	0.35	0.08	0.12	0.04	0.11	0.35
		Min	0.09	0.02	0.04	0.07	0.01	0.01	0.01

PD: Phu Dong; PL: Phu Lam
n: number of observation
Surface water concentrations of a site in PL at the 1st monitoring was not available

Results

Table 4 shows maximum and minimum concentrations of ammonium-N and nitrate-N in both surface and groundwater recorded at each monitoring. Monitoring was done 7 times in total. However, the ammonium-N concentration in groundwater in the monitoring conducted March 2005 was revealed to be an outlier by the Smirnov-Grubbs' outlier test. Therefore, the data from the March 2005 monitoring was excluded in the present study. Average concentrations of ammonium-N and nitrate-N are illustrated in Fig. 2 for surface water and in Fig. 3 for groundwater.

Surface water

Ammonium-N concentration

As understood from Table 4, the ammonium-N concentration (mg/L) in surface water varied from 0.01 to 9.53 for PD and from 0.06 to 11.6 for PL for the whole monitoring. It was manifested from Fig. 2 (A) that the average ammonium-N concentration ranged from 1.2 (1st monitoring) to 6.2 (4th monitoring) for PD and from 0.8 (7th monitoring) to 7.1 (4th monitoring) for PL. A large variation in the average ammonium-N concentration between monitoring times was noticed in each commune. No consistent difference in concentrations was shown between the communes.

Nitrate-N concentration

As understood from Table 4, the nitrate-N concentration (mg/L) in surface water ranged from 0.04 to 0.92 for PD and from 0.05 to 0.95 for PL for the whole monitoring. It was manifested from Fig. 2(B) that the average nitrate-N concentration ranged from 0.09 (3rd monitoring) to 0.53 (2nd monitoring) for PD and from 0.08 (7th monitoring) to 0.53 (2nd monitoring) for PL. It was observed that there was a large variation in the average nitrate-N concentration between the monitoring times in each commune. No consistent difference in the concentration was shown between the communes. The highest value in the average concentration was recorded at the 4th monitoring for ammonium-N and at the 4th and 2nd monitoring for nitrate-N.

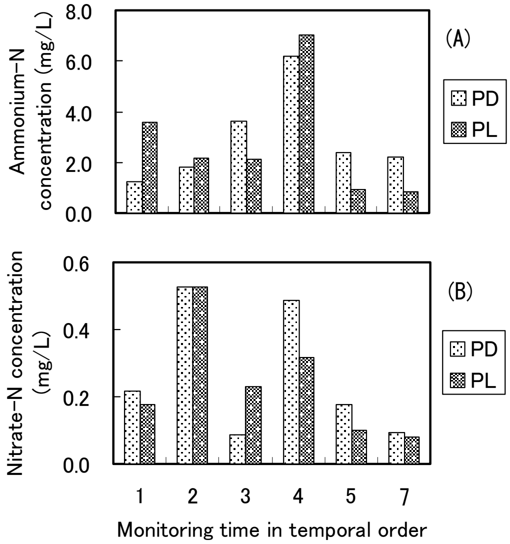

Fig. 2. Average ammonium-N and nitrate-N concentrations in surface water at each monitoring in each commune. Monitoring time 1: Oct. 2002; 2: Mar. 2003; 3: Sep. 2003; 4: Mar. 2004; 5: Sep. 2004; 7: Sep. 2005

Groundwater

Ammonium-N concentration

As understood from Table 4, the ammonium-N concentration (mg/L) in groundwater varied from 0.21 to 5.64 for PD and from trace level to 3.85 for PL for the whole monitoring. It was manifested from Fig. 3(A) that the average ammonium-N concentration ranged from 0.9 (5th monitoring) to 2.6 (3rd monitoring) for PD and from 0.8 (5th monitoring) to 2.1 (2nd monitoring) for PL. The average ammonium-N concentration of groundwater had a smaller variation for monitoring time than that of surface water, and was consistently larger for PD than for PL.

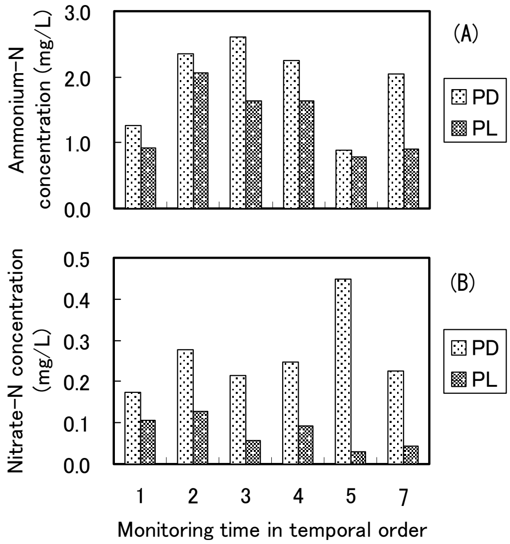

Fig. 3. Average ammonium-N and nitrate-N concentrations in groundwater at each monitoring in each commune. Monitoring time 1: Oct. 2002; 2: Mar. 2003; 3: Sep. 2003; 4: Mar. 2004; 5: Sep. 2004; 7: Sep. 2005

Nitrate-N concentration

As understood from Table 4, the nitrate-N concentration (mg/L) in groundwater ranged from 0.03 to 1.24 for PD and from 0.01 to 0.35 for PL throughout the monitoring. It was concluded as shown in Fig. 3(B) that the average nitrate-N concentration ranged from 0.18 (1st monitoring) to 0.45 (5th monitoring) for PD and from 0.03 (5th monitoring) to 0.12 (2nd monitoring) for PL. The average nitrate-N concentration was consistently larger for PD than for PL.

Differences in the inorganic-N concentrations between surface and groundwater and between the communes

Whether there was a significant difference between surface and groundwater in the ammonium-N and nitrate-N concentrations or not was examined in the two communes by the t-test. Individual concentrations from 6 times monitoring were used for analysis, and the results are shown in Table 5.

According to Table 5, the ammonium-N concentration was significantly larger for surface water than for groundwater in both PD and PL. The nitrate-N concentration was significantly larger for surface water than for groundwater in PL but there was no difference between them in PD.

Regarding the ammonium-N concentration in surface and groundwater, whether or not there was a significant difference between the two communes, was tested by the t-test, and the results are shown in Table 5. The ammonium-N concentration was not significantly different between PD and PL in the surface water but significantly larger for PD than for PL in the groundwater.

Table 5. Results of the t-test between surface and groundwater in the concentrations of ammonium-N and nitrate-N in each commune and between the two communes in the ammonium-N concentration in surface and groundwater.

Item	Component for comparison	number of observation	T-value	Relationship between the component
Ammonium-N	SW vs. GW	PD: 30(SW), 36 GW)	PD: 2.08*	SW>GW
		PL: 35(SW), 36(GW)	PL: 2.93**	SW>GW
Nitrate-N	SW vs. GW	PD: 30(SW), 36(GW)	PD: 0.02	not significant
		PL: 35(SW), 36(GW)	PL: 4.36**	SW>GW
Ammonium-N	PD vs. PL for SW	PL: 30(PD), 35(PL)	0.23	not significant
	PD vs. PL for GW	PL: 36(PD), 36(PL)	2.21*	PD>PL

SW: surface water; GW: groundwater
PD: Phu Dong, PL: Phu Lam
*, **: significance at 5 % and 1% levels, respectively.

Discussion

Level of the concentrations of ammonium-N and nitrate-N in reference to the water standards

When surface water is used for irrigation, the concentration of soluble N (inorganic N plus soluble organic N) is usually evaluated. According to Ayers and Westcot (1985), a soluble N concentration of less than 5 mg/L has little adverse effect on crop growth. Although some sensitive crops may be affected severely when the concentration exceeds 5 mg/L, most other crops are relatively unaffected in growth until the concentration exceeds 30 mg/L. However, a soluble N concentration of 5 to 30 mg/L in surface water is considered to be an alarming level for irrigation purposes.

The authors did not measure the soluble organic N concentration in surface water, but the average inorganic-N (i.e. ammonium-N plus nitrate-N) concentration (mg/L) ranged from 1.5 to 6.7 for PD and from 0.9 to 7.4 for PL, calculated from the concentrations shown in Fig. 2 (A and B). Here, the inorganic-N concentration exceeded 5 mg/L one time in each commune. If the soluble organic N, which could exist in some concentrations, is taken into consideration, the number of times exceeding a concentration of 5 mg/L could increase. It was considered, therefore, that the inorganic-N concentration in the surface water was close to an alarming level. Subsequently, surface water must be carefully used for irrigation to prevent damage from crop growth.

According to Fig. 3(A), the average ammonium-N concentration in groundwater mostly exceeded 0.78 mg/L in both PD and PL, which exceeds the level at which human internal organ systems may be damaged from long-term ingestion (Oregon Department of Human Services, 2000). In contrast, the average nitrate-N concentration in the groundwater (Fig. 3(B)) was always below 11.3 mg/L of the World Health Organization drinking water standard. Therefore, the groundwater in the communes is unsuitable for drinking use in terms of the ammonium-N concentration, and some water treatment is necessary before its use. As a treatment, infiltration of the water through a zeolite layer is effective, because of its absorption of NH_4^+. According to Chiemchaisri et al. (2003), the removal efficiency of ammonium-N by infiltration of the polluted water through a plastic - zeolite layer for 24 hours, was 92%.

Temporal changes in the concentrations of ammonium-N and nitrate-N

Despite consecutive input of N to the field, no obvious increasing trend was recognized from the changes of the ammonium-N and nitrate-N concentrations in surface and groundwater during the periods of monitoring, shown in Figs. 2 and 3. Although a detailed amount of the recharge in the study area is relatively unknown, estimation by World Bank (1995) showed that the groundwater recharge, mainly due to rainfall, irrigation water and rivers, was 280 mm per year for the aquifer in the Holocene sediments of the RRD. It is, therefore, considered that through groundwater recharge of the aquifer, an increase in the inorganic-N concentrations by consecutive application of chemical fertilizer-N is mitigated considerably.

Differences in the concentrations of ammonium-N and nitrate-N between surface and groundwater

Based on a significantly larger concentration of ammonium-N for surface water than for groundwater (Table 5), it was estimated that ammonium in groundwater possibly occurred by percolation of the surface water contaminated within it. A nitrate-N concentration of less than 0.6 mg/L (Figs. 2(B) and 3(B)) and not significantly different between surface and groundwater in PD, suggests a negligible occurrence of the nitrification of ammonium to nitrate in both surface and groundwater in PD. Concerning PL, the ammonium-N and nitrate-N concentrations were significantly larger for surface water than for groundwater (Table 5), though the concentrations themselves were small as shown in Figs. 2(B), 3(B). This may be due to the progress of nitrification to some extent in surface water in PL In this context, however, further examination is still necessary.

Effects of chemical fertilizer-N applications on the concentrations of ammonium-N and nitrate-N in surface and groundwater

The ammonium-N concentration of groundwater was significantly larger for PD than for PL (Table 5). According to Table 2, the average amount of annually applied chemical fertilizer-N was larger for PD (422 kg/ha) than for PL (382 kg/ha). The larger ammonium-N concentration in groundwater along with the larger amount of annually applied chemical fertilizer-N for PD suggests that ammonium-N concentration of groundwater depends on the application amount of chemical fertilizer-N to the field.

Conclusions

The ammonium-N plus nitrate-N concentration of surface water exceeded 5 mg/L in some monitoring, above which a small amount of damage for crop growth will happen. Therefore, surface water must be carefully used for irrigation. The ammonium-N concentration in groundwater mostly exceeded the critical level for human health in the two villages. Thus, some treatment to lower the ammonium-N concentration in groundwater is necessary before its use for drinking. Nitrate-N concentration in groundwater has always been lower than the WHO drinking water standard.

Irrespective of the consecutive application of chemical fertilizer-N to the farmland, the ammonium-N and nitrate-N concentrations in the groundwater did not increase with advancement of monitoring. For this reason, the effect of natural groundwater recharge on dilution of the ammonium-N and nitrate-N concentrations was conceivable. The ammonium-N concentration was larger for surface water than for groundwater, showing that ammonium in groundwater was created by percolation of surface water contaminated within it. The ammonium-N concentration of groundwater depended on the application amount of chemical fertilizer-N to the field, because this concentration was proportional to the annual amount of chemical fertilizer-N applied at the villages.

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