Research article

The Nitrate Nitrogen Concentration in River Water and the Proportion of Cropland in the Tokachi River Watershed

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Abstract It is widely known that nitrate pollution of river water and groundwater in agricultural regions has become severe in Japan and in other agricultural countries around the world. On the other hand, in the Tokachi River Watershed, where large-scale upland field cultivation with dairy farming is the main form of agriculture, few surveys and little research have addressed the impact of agriculture on water quality in the area. This study examined the relationship between the nitrogen concentration in river water at normal water level and the proportion of cropland in the Tokachi River Watershed with taking notice of both maintaining sustainable agriculture and conserving water quality environment. At 37 locations on the Tokachi River main stream and its tributaries (their downstream ends), the NO_3-N concentration in river water and the proportion of cropland in the watersheds were surveyed for three years. Nitrate nitrogen as a percent of total nitrogen in river water ranged from 84% to 91%. The maximum T-N in water from the tributaries was approx. 8.8 mg/L. There was a correlation (significance of 1%) between the NO_3-N concentration in river water and the proportion of cropland in the watersheds. The correlation coefficients ranged from 0.80** to 0.95** in the water from the main stream. It was confirmed that the impact factor, or the slope of the regression curve that represents the relationship between the two, ranged from 0.037 to 0.075, which was greater than the values reported for various other locations in Hokkaido. Future studies on conserving the water environment by reducing the nitrogen loading into the river system while maintaining the cropland in the Tokachi River Watershed in favorable condition will need to explore the feasibility of land use assessment methods based on the new viewpoint.

Keywords Tokachi River, NO_3-N concentration, proportion of cropland, impact factor

INTRODUCTION

It is widely known that nitrate pollution of river water and groundwater in agricultural regions has become severe in Japan and in other agricultural countries around the world. The close relationship between agricultural land use, which causes nitrogen loading, of the watershed in particular and the nitrate nitrogen concentration in river water has been pointed out (Carpenter et al., 1998; Shimura and Tabuchi, 2000).

In Hokkaido, where large-scale agriculture predominates, surveys and research on agricultural land use and river water quality have been conducted in many areas since the 1990's. In Eastern

Hokkaido, where the scale of dairy farming is particularly large, it has been reported in numerous studies that the high density of pasture and cattle population in the watershed tends to result in a high nitrate nitrogen concentration in river water. (Tabuchi et al., 1995; Nagasawa et al., 1995; Inoue et al., 1999).

In the Tokachi River Watershed, where large-scale upland field cultivation with dairy farming is the main forms of agriculture, few surveys and little research have addressed the impact of agriculture on water quality in the area. Tabuchi et al. (1995) and Anbumozhi and Yamaji (2001), for example, attempted to assess the impact of land use on the water quality of the northwestern area of the Tokachi River Watershed, by using the nitrate nitrogen concentration of river water as an index of land use. In each of these cases, however, investigation was based on only one water quality survey or on only a short period of such survey. Accurate understanding of secular or annual fluctuations in river water quality (N concentration in particular) has not been attempted in the Tokachi River Watershed, which possesses local characteristics that are distinct among regions with an Asian monsoon climate.

This study examined the relationship between the nitrogen concentration in river water at normal water level and the proportion of cropland in the Tokachi River Watershed based on a three-year observation. To ensure sustainable agriculture by maintaining the water quality, this study also investigates a new land use assessment method for the region, taking the current proportion of cropland in the Tokachi River Watershed into account.

METHODOLOGY

The Tokachi River Watershed measures 9,010 km^2, making it the second largest watershed in Hokkaido and the sixth largest in Japan. A map of the Tokachi River Watershed and basic data of the survey sites are shown in Fig. 1 and Table 1. In the watershed, where survey site No. 17 (Tokachikakouhashi) is located, 30% of the land is used for cropland and 62% is forests. The major upland crops in this area are wheat, sugar beets, legumes and potatoes. Feed crops are also grown.

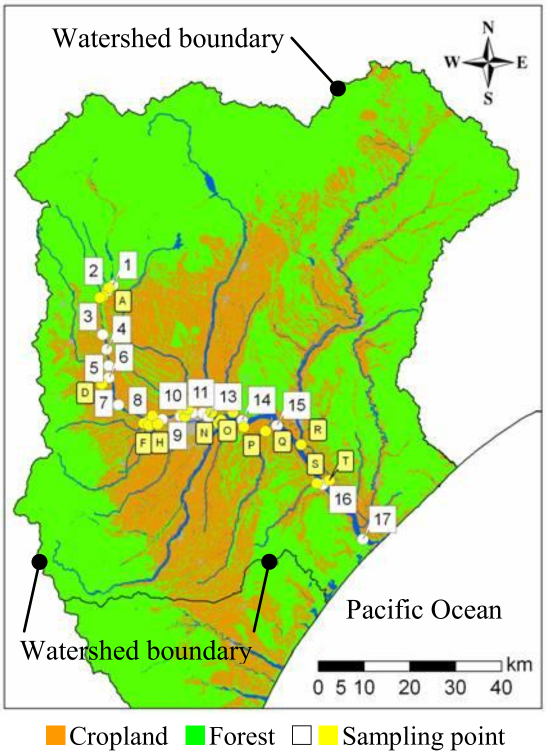

Fig. 1 Location and sampling points of the Tokachi River Watershed

In the Tokachi River Watershed we conducted river water sampling at ordinary water level, water quality analysis and land use evaluation. The survey sites numbered 37: 17 on the main stream of the Tokachi River (No. 1 to No. 17), and 20 on tributaries that flow into the Tokachi River's main stream. The tributary sites were all at the downstream end of the tributaries (A to T; Fig. 1, Table 1). The samples were kept in airtight containers at low temperature and carried to the laboratory for analysis of total nitrogen (T-N) and nitrate nitrogen (NO_3-N) according to the Japan Industrial Standards (JIS). The period for water sampling was the three years from 2007 to 2009, nine times in total. Samplings for each year were done in late June, late August (or early September) and late October.

The GIS software application ArcGIS Desktop (Ver9.3, ESRI) was used for analyzing the land use of the Tokachi River Watershed. The data on land use and watershed boundaries were extracted from digital national information (National and Regional Planning Bureau, Ministry of Land, Infrastructure, Transport and Tourism). The data on administrative boundaries, rivers and elevations were extracted from 1/25000 national digital cartographic data (Geographical Survey Institute). Land was categorized as forest or agricultural land based on the digital national land data (1997). Vector data were created for the land use in each watershed. These created data were then converted into raster data with 100-m grids.

Table 1 Land use of the Tokachi River Watershed

Sampling point		River name	Area	Land use (%)		
No.	Bridge name		(km^2)	Cropland	Forest	Others
Main stream						
1	Oojikahashi	Tokachi River	632	1	88	11
2	Iwamatsuhashi	Tokachi River	658	1	88	11
3	Shinseihashi	Tokachi River	801	2	88	10
4	Kyoueihashi	Tokachi River	806	3	87	10
5	Kamikawahashi	Tokachi River	840	5	85	10
6	Shimizuoohashi	Tokachi River	858	7	84	10
7	Tokachihashi	Tokachi River	1,289	15	77	8
8	Shoueihashi	Tokachi River	1,531	19	72	8
9	Memurooohashi	Tokachi River	1,777	21	70	9
10	Nakajimahashi	Tokachi River	1,798	21	70	9
11	Heigenoohashi	Tokachi River	2,669	31	60	9
12	Suzuranoohashi	Tokachi River	2,683	32	59	9
13	Tokachioohashi	Tokachi River	2,686	32	59	9
14	Tokachichuuouoohashi	Tokachi River	4,479	32	58	10
15	Chiyodaoohashi	Tokachi River	5,098	36	54	10
16	Moiwaoohashi	Tokachi River	8,224	30	61	8
17	Tokachikakouhashi	Tokachi River	8,982	30	62	8
Tributaries (downstream ends)						
A	Pennaihashi	Penkenai River	23	0	98	2
B	Penkenikorobetsuhashi	Penkenikorobetsu River	48	1	98	1
C	Minamiiwamatsuhashi	Penkenikorochin River	72	1	98	1
D	Sahorohashi	Sahoro River	337	26	68	2
E	Kenenakajimahashi	Memuro River	210	38	56	6
F	Motomachihashi	Piuka River	26	71	12	17
G	Bimanhashi	Bibaushi River	35	79	19	3
H	Biseihashi	Bisei River	180	16	74	8
I	Kitanisenhashi	Shinobihiro River	164	74	16	10
J	Shinshibusarahashi	Shibusarabibaushi River	33	53	43	3
K	Kunimihashi	Shikaribetsu River	667	48	45	8
L	Houraihashi	Otofuke River	693	19	69	12
M	Satsunaihashi	Satsunai River	704	30	61	9
N	(Downstream end)	Obihiro River	197	66	14	20
O	Asahihashi	Shihoro River	316	64	29	7
P	Senjyuuhashi	Tobetsu River	127	79	13	8
Q	Yamuwakkahashi	Sarubetsu River	449	69	26	5
R	Kawaioohashi	Toshibetsu River	2,850	20	75	5
S	Noyaushihashi	Ushisyubetsu River	173	24	61	3
T	Houeihashi	Rebunnai River	66	43	51	6

For the main stream and tributaries (the lowest reaches), tests for noncorrelation for the regression coefficients (significance of 1% to 5%) were conducted to clarify the relationship between the NO_3-N concentration in river water and the proportion of cropland in each watershed.

RESULTS AND DISCUSSION

When the data from the main stream and tributaries of the Tokachi River were examined, a high correlation was found between the T-N concentration and NO_3-N concentration of the river water (significance of 1%). The coefficients of determination $\mathbf{r^2}$ were 0.93** and 0.97**, respectively (Fig. 2 (a), (b); Table 2 (a), (b)). NO_3-N as a percent of T-N in the river water ranged from 84% to 91%, which is extremely high.

The relationship between the NO_3-N concentration in river water when the water level is normal and the proportion of cropland in the watershed will be examined.

First, there was a positive correlation (significance of 1%) between the NO_3-N concentration in the river water and the proportion of cropland in the watershed of the Tokachi River main stream. The coefficients of correlation **r** showed extremely high values, ranging from 0.80** to 0.95** (Fig. 3 (a); Table 3(a)). The same relationship for the tributaries was also positively correlated (significance of 1%) (Fig. 3 (b); Table 3 (b)). The coefficients of correlation **r**, however, were not very high, ranging from 0.66** to 0.82**.

As discussed above, regardless of the survey year or season, for the watershed with a high proportion of cropland, the NO_3-N concentration in the river water at the ordinary water level is high. The correlation between the two is remarkably high in the Tokachi River Watershed as a whole. The difference between the data for the main stream and its watershed and that for the tributaries and their watersheds seems to be because the size of the watershed and the distances of croplands from the river greatly varied according to the history of development of each area. These differences seemed to be reflected in the difference between the coefficients of correlation of the two.

The slopes of the regression curves that represent the relationship between the NO_3-N

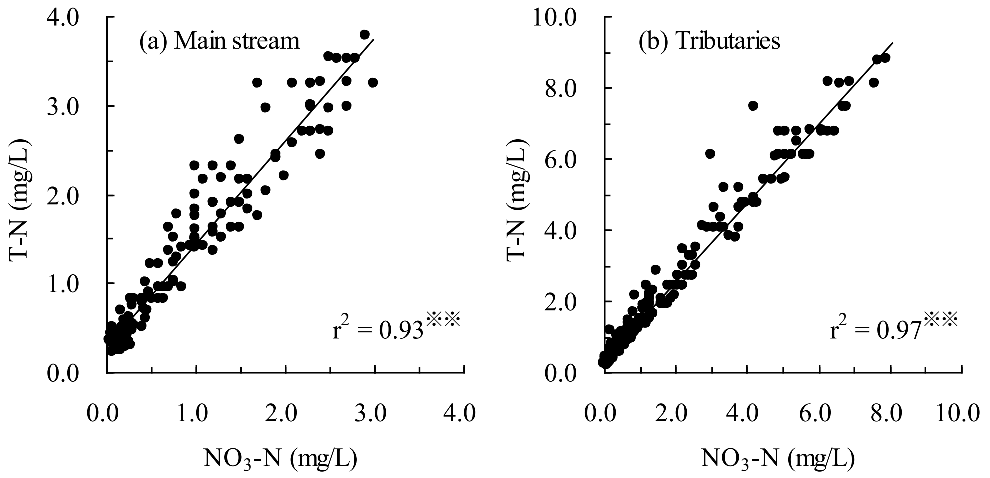

Fig. 2 The relationship between T-N and NO_3-N (2007-2009)

Table 2 The regression curve between T-N and NO_3-N (2007-2009)

Sampling point	Regression curve	Coefficient of determination $\mathbf{r^2}$	Number of data
(a) Main stream	T-N = 1.2 NO_3-N + 0.28	0.93 **	147
(b) Tributaries	T-N = 1.1 NO_3-N + 0.34	0.97 **	180

*** significance of 1%*

concentration in the river water and the proportion of cropland in the watershed (Table 3 (a), (b)) were examined. The values were evaluated as the impact factors (IF values). The IF values reported in the studies on the watersheds in the agricultural areas of Hokkaido ranged from 0.0052 to 0.040. (Tabuchi et al. 1995; Woli et al. 2002; Woli et al. 2004; Okazawa et al. 2009).

Our survey shows that the IF values for the Tokachi River main stream were between 0.037 and 0.075, and those for the tributaries were between 0.042 and 0.071. The highest IF value (0.075 and 0.071) was observed for the main stream and tributaries in 2009 respectively. One thing to note here is the high IF values in the Tokachi River Watershed. Nitrogen components in the chemical fertilizers that are applied to cropland in large amounts and nitrogen components in cattle manure in the watershed ultimately turn into NO_3-N and seep into the ground. Because of these agricultural activities, NO_3-N constantly flows into rivers in relatively high concentrations at the ordinary water level in the Tokachi River Watershed.

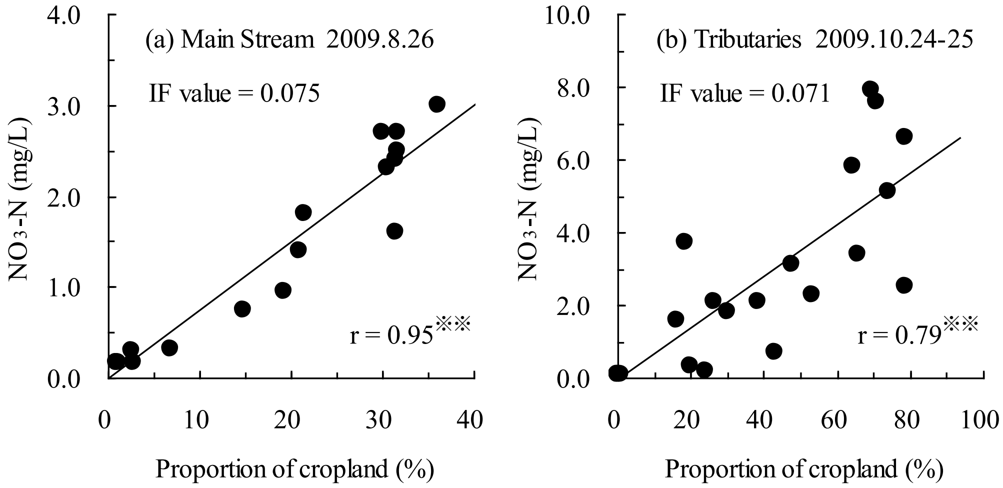

Fig. 3 The relationship between NO_3-N and proportion of cropland

Table 3 The impact factor between NO_3-N and proportion of cropland

Sampling date			IF value※ (Impact factor)	Coefficient of corelation **r**	Number of data	N.B.
(a) Main stream						
2007	June	22	0.039	0.87※※	17	
	August	20	0.048	0.90※※	17	
	October	23-24	0.044	0.87※※	17	
2008	June	28	0.037	0.81※※	16	
	September	9	0.045	0.80※※	16	
	October	28-29	0.044	0.80※※	16	
2009	June	30	0.062	0.92※※	16	
	August	26	0.075	0.95※※	16	Fig. 3 (a)
	October	24-25	0.068	0.91※※	16	
(b) Tributaries						
2007	June	22	0.055	0.77※※	20	
	August	20	0.042	0.70※※	20	
	October	23-24	0.048	0.82※※	20	
2008	June	28	0.049	0.74※※	20	
	September	9	0.049	0.74※※	20	
	October	28-29	0.044	0.66※※	20	
2009	June	30	0.058	0.71※※	20	
	August	26	0.064	0.77※※	20	
	October	24-25	0.071	0.79※※	20	Fig. 3 (b)

※ IF value = NO_3-N concentration / Proportion of cropland ※※ significance of 1%

Generally, the greater is the proportion of forested area in the watershed, the lower is the NO_3-N concentration in the river water, because the water from the forest dilutes the NO_3-N-polluted water from the cropland. To reduce inflow into rivers of nitrogen components that are not used or fixed in cropland, it is worth considering changing the uses of land adjacent to the rivers. Such changes would include the establishment of buffer zones such as riparian forests (Okazawa et al., 2010). In recent years, some basic research has addressed the influence of land agglomeration in watersheds on the nitrogen concentration of the river water (Okazawa et al., 2009, 2011). Incorporating the new viewpoint of the positional relationship between cropland and forests in watersheds into assessment of the impact of land use, we will investigate desirable land use in the Tokachi River Watershed from the standpoint of conserving the water environment, which will make it possible for us to provide ideas for better land uses.

CONCLUSION

The relationship between the NO_3-N concentration in the river water and the proportion of cropland in the watershed was investigated for 37 locations on the Tokachi River main stream and its tributaries (their lowest reaches). The maximum slope of the regression curve (IF value) that represents the relationship between the NO_3-N concentration and the land use was found to be 0.075. It was clarified that the IF values for the investigation locations were far greater than those for other areas in Hokkaido. In future study, it will be necessary to explore the feasibility of land use assessment methods that are based on the new viewpoint, in examining water environment conservation by reducing the nitrogen loading into the river system while maintaining the cropland in the Tokachi River Watershed in favorable condition.

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