Research article

The Nitrogen Runoff Characteristics in Agricultural Watersheds after Enforcement of Animal Waste Regulation

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Abstract In this study, the characteristics of nitrogen in river water at the normal water level were examined for a period after the enforcement of animal waste regulation. The differences in agricultural land use in the two study sites in Eastern Hokkaido were taken into consideration. In 35 watersheds in the two areas, the total nitrogen (T-N), nitrate nitrogen (NO_3-N), nitrite nitrogen (NO_2-N) and ammonium nitrogen (NH_4-N) concentrations, and the river discharges were investigated. A total of 7 investigations were carried out during the period from late May to late November 2005. In the Tokachi area (24 watersheds), the main land uses are upland and dairy farming. In the Nemuro area (11 watersheds), the main land use is large-scale dairy farming. Irrespective of the land use in the watershed, when the proportion of the agricultural land was about 20% or lower, the value obtained by adding the standard deviation to the annual mean T-N concentration of river water in many investigated watersheds was 1.0 mg/L or lower. When watersheds whose proportion in the agricultural land was 65% or higher were examined, there were some whose values obtained by adding the standard deviation to the annual mean T-N concentration were close to 10 mg/L. Decreasing trends were not identified in the nitrogen concentration in river water investigated in the first year after enforcement of animal waste regulation. From the viewpoint of water quality conservation, it is effective to appropriately adjust the use of chemical fertilizers in the cropland in the watersheds and to encourage dairy farmers to practice appropriate management of livestock manure.

Keywords nitrogen runoff, agricultural land use, animal waste regulation, water quality conservation

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INTRODUCTION

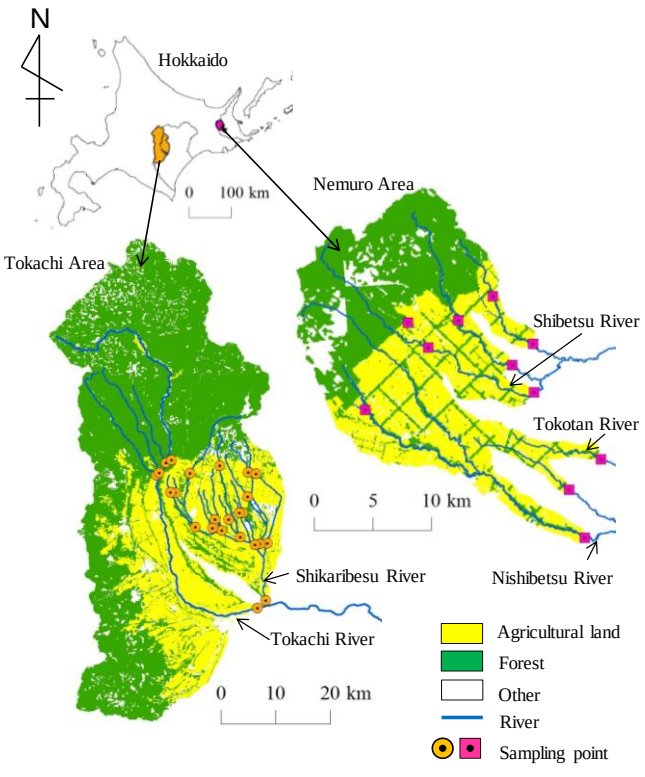
Japan is in the Asian monsoons region. In Eastern Hokkaido, where large-scale farming has been conducted under harsh climatic conditions, nitrate pollution of the local water system has been pointed out. The concentration of nitrate nitrogen in river water and the extent of agricultural land use in an investigated area were reported to have a positive correlation (Tabuchi et al., 1995; Woli et al., 2002; Woli et al., 2004; Muneoka et al., 2012).

Tabuchi et al. (1995) investigated the nitrate nitrogen concentration in river water and the agricultural land use in each area in Eastern Hokkaido in the summer of 1992. Yamazaki et al. (2013) conducted a long-term observation on the relationship between nitrate nitrogen concentration in river water and agricultural land use in the Tokachi and Nemuro areas based on the observation results of Tabuchi et al. (1995). Their observation revealed that in some of the watersheds where the nitrate nitrogen decreased in the summer of 2004 relative to the summers of previous years, the nitrate nitrogen actually increased significantly in 2005, and the increasing trends continued in successive years. On the contrary, there have been few studies that observed the seasonal fluctuation of the river water quality in agricultural watersheds immediately before and after the enforcement of animal waste regulation (Kato et al, 2006).

The present study examines the characteristics of nitrogen that flowed into river water at the normal water level in two areas in Eastern Hokkaido in the first year after the enforcement of animal waste regulation. The study focuses on the differences in agricultural land use between the two areas.

METHODOLOGY

The maps of study sites are shown in Fig.1. The Tokachi area, which has 24 watersheds on the Tokachi River system and the Shikaribetsu River system (No. 1 to 24), is located in the



Sampling Point	River name	Bridge name	Area (km^2)	Land use (%) Agricultural land	Forest
Tokachi area					
1	Tokachi	Oojika	632	1	94
2	Penkenai	Pennai	23	0	98
3	Penkenikorbetsu	Penkenikorobetsu	48	2	96
4	Penkenikoro	Minamiiwamatsu	72	2	97
5	Tokachi	Nakajima	1798	21	70
6	Shikaribetsu	Urimaku	217	4	91
7	Sikanosawa	Kikuchi	5	83	13
8	Kamihoronai	Kamihoronai	3	88	12
9	Shikaribetsu	Momiji	256	13	81
10	Minami1sen	Nakashikakann2gou	13	72	17
11	Iketo	Minamisawa	9	95	2
12	Pankebibaushi	Kousui	27	90	7
13	Urimaku	(no bridge)	9	13	66
14	Poronai	(no bridge)	3	90	7
15	Urimaku	Mutsu	49	58	32
16	Penkeutorei	Honnmaki	3	88	11
17	Pankeutorei	(no name)	5	93	6
18	Pankeutorei	Komadome	17	65	25
19	Penkechin	Okuyama	26	22	49
20	Ponchin	Kamimaki	13	75	18
21	Penkechin	Isami	63	46	33
22	Pankechin	Sinnei	10	52	32
23	Pankechin	Taneuma	72	72	15
24	Shikaribetu	Kunimi	667	48	45
Nemuro area					
A	Kanjiushi	Yourouushi	11	4	71
B	Keneka	Minori	41	7	81
C	Keneka	Hakuyou	82	32	57
D	Shibetsu	Nagori	54	3	91
E	Shibetsu	Kamisibetu	82	22	72
F	Masu	Masukawa	10	32	64
G	Masu	Kenebetsu	28	49	46
H	Tokotan	Houtoku	12	81	14
I	Nishibetsu	Kousai	19	10	60
J	Nishibetsu	Nishisyunnbetsu	149	54	32
K	Pononnebetsu	Akashi	19	73	21

Fig. 1 Outline of the Tokachi and Nemuro areas

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northwestern part of the Tokachi General Sub prefectural Bureau, and it is an area with upland and dairy farming. The Nemuro area, which has 11 watersheds on the Shibetsu River system, the Tokotan River system and the Nishibetsu River system (A to K), is located in the western part of the Nemuro Sub prefectural Bureau, and it is an area mainly of dairy farming. In both of these areas, large-scale farming has been operated, and there have been no considerable changes in agricultural land use in either area since 1985.

In year 1981 to 2010, the annual mean air temperature and the yearly precipitation were 5.9℃ and 840.7 mm at Komaba in the Tokachi area, and 5.4℃ and 1158.0 mm at Nakashibetsu in the vicinity of the Nemuro area. Both areas have a relatively cold climate with less rainfall.

The investigation of the river water quality was conducted at the normal water level at 35 sampling points. Electric conductivity (EC) and water temperature were measured at sampling points. Discharge was also measured on the rivers in small watersheds (21 to 24 samples per month). Analysis for some water quality components were done after the field investigation. The total nitrogen (T-N), nitrate nitrogen (NO_3-N), nitrite nitrogen (NO_2-N) and ammonium nitrogen (NH_4-N) concentrations were used as indices in this study. The 7 investigations were carried out during the period from late May to late November 2005.

The GIS software application ArcGIS Desktop (Ver. 10, ESRI) was used for analyzing land use in the study sites. The data were "rivers", "watershed boundaries" and "detailed land use mesh" from digital national information to determine the proportion of agricultural land in watersheds. The detailed land use mesh (100 m × 100 m) shows 11 types of land uses; however, we redefined the mesh into the three items of "agricultural land", "forest" and "other". The proportion of agricultural land was determined for each watershed by overlaying the watershed map created for the sampling points on the detailed land use mesh.

RESULTS AND DISCUSSION

In Japan, there are two major water quality standards that use nitrogen as indices. "The Environmental Standards Concerning the Protection of Human Health" specifies the highest acceptable combined concentration of NO_3-N and NO_2-N as 10 mg/L. Some standards with "The Environmental Standards Concerning the Conservation of the Living Environment" specify the highest acceptable concentration of T-N as 1.0 mg/L.

For an examination of the characteristics of the seasonal fluctuations in nitrogen concentration of river water at 35 sampling points in the two investigated areas in 2005, the annual mean nitrogen concentration and the standard deviation are shown in Fig.2 (a), (b).

The T-N concentration in river water in the two areas was compared using the coefficient of variation (standard deviation divided by the mean). The values for the Tokachi area (24 sampling points) were 12% to 77% and those for the Nemuro area (11 sampling points) were 7% to 27%. The range of seasonal fluctuation of T-N concentration in river water was smaller in the Nemuro area than in the Tokachi area.

Among the all sampling points, the number of sampling points where the sum of annual mean T-N concentration and the standard deviation were 1.0 mg/L or lower was 7 points in the Tokachi area and 6 points in the Nemuro area. The proportion of agricultural land in the watersheds in these areas were <1 - 22% in the Tokachi area and 3 - 32% in the Nemuro area. It was found that irrespective of the land use differences, if the proportion of agricultural land was 20% or lower, the nitrogen concentration in the river water in many watersheds was 1.0 mg/L or lower.

Differences were clearly found in the characteristics of the fluctuations in nitrogen concentration between the two areas when the value of T-N concentration in the watersheds exceeded about 3.0 mg/L. There were some sampling points in the Tokachi area whose values for T-N concentration and standard deviation combined were close to the 10 mg/L, specified in "The Environmental Standards Concerning the Protection of Human Health". At 5 sampling points (No.11, 14, 16, 18 and 20) among the above 14 points, the coefficient of variation was 30% or greater. These five watersheds had features that are in common, such as small areas of 3 - 17 km^2 and a high proportion of agricultural land of 65% - 95%. In the Nemuro area, however, only one watershed

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had the T-N concentration and standard deviation combined that exceeded about 3.0mg/L. For this watershed, the coefficient of variation was 13%, which was relatively small, the area was 23 km^2, and the proportion of agricultural land was 81%.

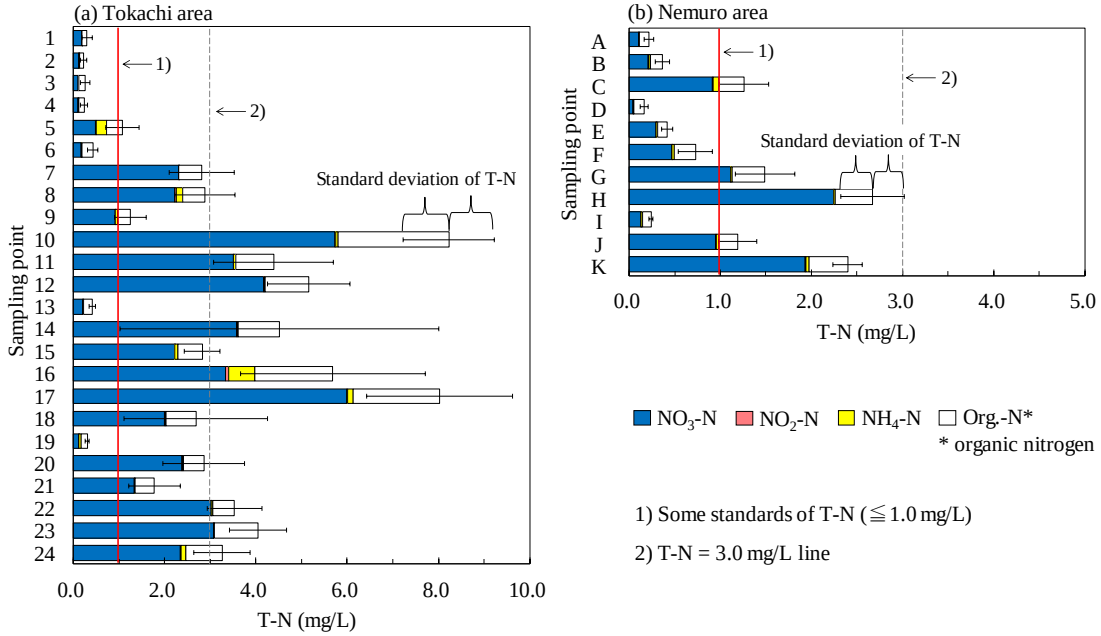

Fig. 2 The annual mean nitrogen concentration and the standard deviation of the river water in the watersheds in the Tokachi and Nemuro areas

Fig.3 shows the regression lines and the calculated coefficients of correlation, which indicate the relationship between the NO_3-N concentration in river water and the proportion of agricultural land in the watersheds. The NO_3-N was used as the index on this study, because T-N in the river water mainly consisted of NO_3-N in general.

The relationship between the NO_3-N concentration in river water (Y) and the proportion of agricultural land in the watershed (X) is expressed as $Y = aX$. The slope "a", which indicates the impact factor (IF) value, for the both areas in 2005 were 0.026 - 0.054 in the Tokachi area and 0.020 - 0.029 in the Nemuro area. When two watersheds, one from the Tokachi area and the other from Nemuro area, that had similar proportion of agricultural land were compared, the NO_3-N concentration in the river water at the similar investigation period tended to be higher in the Tokachi area. The IF in the Tokachi area showed particularly high values that exceeded 0.050 from July to September.

When the coefficient of correlation *r* for both areas was examined by using the NO_3-N concentration as the index, *r* for the Tokachi area were $0.67^{※※}$ - $0.89^{※※}$, and that for the Nemuro area were $0.94^{※※}$ - $0.96^{※※}$. These coefficients are all positive and significant at the 1 percent level. The correlation was constantly higher in the Nemuro area throughout 2005.

As discussed above, comparison between the annual mean nitrogen concentrations in river water in the two areas in the first year after the enforcement of animal waste regulation (2005) showed that the nitrogen concentration was relatively low and stable in the Nemuro area, while it was high and varied greatly in the Tokachi area.

In the Nemuro area, agricultural land use had been unified into grassland, and the major loading source of water contamination derives from livestock manure. Therefore, it can be assumed that the seasonal variation in the nitrogen concentration of the river water was relatively small and had a high correlation with the proportion of agricultural land in the watershed.

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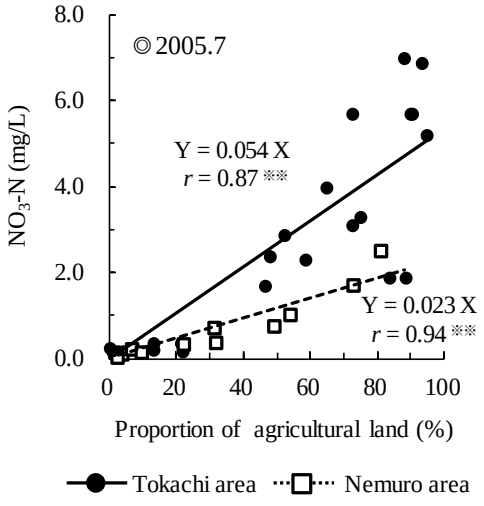

Investigated month	NO_3-N (mg/L) [Y = a X] Tokachi area a*	Tokachi area *r*	Nemuro area a*	Nemuro area *r*	N.B
2005.5	0.028	0.69 ※※	0.020	0.95 ※※	
2005.6	0.026	0.67 ※※	0.020	0.95 ※※	
2005.7	0.054	0.87 ※※	0.023	0.94 ※※	◎
2005.8	0.051	0.89 ※※	0.024	0.95 ※※	
2005.9	0.052	0.84 ※※	0.028	0.96 ※※	
2005.10	0.041	0.73 ※※	0.025	0.95 ※※	
2005.11	0.042	0.76 ※※	0.029	0.96 ※※	

* The impact factor (IF)
※※ significance of 1%

Fig. 3 Relationship between the NO_3-N of the river water and the proportion of agricultural land in watersheds in the Tokachi and Nemuro areas

In the Tokachi area, land use was for dairy farming and the farming of various upland crops. In addition to livestock manure, the loading source includes chemical fertilizers that were applied in large quantities to the upland fields. It is assumed that the use of chemical fertilizers contributed to the higher concentration of nitrogen in river water and that the larger range of seasonal variation in the nitrogen, concentration was attributable to the use of chemical fertilizers during the peak season of agricultural farming.

CONCLUSION

By focusing on the difference in agricultural land use in the watersheds of two areas in Eastern Hokkaido, the nitrogen outflow characteristics were examined for river water at the normal water level at 35 sampling points in the two areas. The examinations found that, in the first year after the enforcement of animal waste regulation (2005), the nitrogen concentration in river water in the two areas showed different behavior depending on the differences in agricultural land use. In the Tokachi area, the nitrogen concentration in river water tended to be high in many watersheds. In small watersheds with a high proportion of agricultural land, the nitrogen concentration in river water during the summer period (July to September) showed great increases. To conserve the water environment by decreasing the concentration of nitrogen in river water, it is necessary to control nitrogen loading during the summer seasons not only by promoting appropriate use of chemical fertilizers in croplands but also by encouraging individual farmers to practice appropriate management of livestock manure.

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