Research article

The Difference of Agricultural Land Use in Watersheds and Long Term Fluctuation on the River Water Quality

YURI YAMAZAKI
Obihiro University of Agriculture and Veterinary Medicine, Hokkaido, Japan

TOSHIMI MUNEOKA*
Obihiro University of Agriculture and Veterinary Medicine, Hokkaido, Japan
Email: muneoka@obihiro.ac.jp

SACHIYO WAKOU
Ibaraki Prefectural Government, Ibaraki, Japan

MOTOKO SHIMURA
National Agriculture and Food Research Organization, Hiroshima, Japan

KUNIHIKO YOSHINO
Faculty of Engineering, Information and Systems Division of Policy and Planning Sciences, University of Tsukuba, Ibaraki, Japan

OSAMU TSUJI
Obihiro University of Agriculture and Veterinary Medicine, Hokkaido, Japan

TOSHIO TABUCHI
Former professor of the University of Tokyo, Tokyo, Japan

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Abstract This study was conducted to determine the relationship between the characteristics of fluctuations in river water quality at the normal water level and the proportion of agricultural land in watersheds of Eastern Hokkaido that have different agricultural land use, based on the 20 years observations. The investigations were carried out during late August to early September in 1992, 2003 to 2006, and 2012 at 35 watersheds in two areas, and NO_3-N, EC of river water and river discharge were measured. The Tokachi area (24 watersheds) is located in the northwestern part of the Tokachi General Subprefectural Bureau, the main land uses are upland and dairy farming. The Nemuro area (11 watersheds) is located in the western part of the Nemuro Subprefectural Bureau, the main land use is large-scale dairy farming. In the 20 years since 1992, NO_3-N concentration and EC have shown increasing tendency in some of the investigated river watersheds. The river water quality in some watersheds investigated in 2004, immediately before the full implementation of "The Law on Animal Waste Regulation", greatly differed from the observation results of several years before and after 2004. When the two areas had the same proportion of agricultural land, the NO_3-N concentration in the river water tended to be higher in Tokachi area than in Nemuro area. This is attributed to the proportion of upland fields, which require large inputs of chemical fertilizer in the Tokachi area. EC, however, tended to be high in the Nemuro area, even for watersheds with similar proportion of agricultural land. This suggests that the river water in the Nemuro area contains many materials of geological origin, in addition to containing NO_3^-.

Keywords NO_3-N concentration, EC value, agricultural land use, long-term fluctuation

INTRODUCTION

Large-scale farming under harsh climatic conditions has long prospered in Eastern Hokkaido, whose natural environment differs from those of other Asian monsoons regions. In recent years, water contamination including nitrate pollution of river water and groundwater has been pointed out (Tabuchi et al., 1995; Matsumoto and Tou, 2006).

In the Tokachi district, large-scale upland and dairy farming were established early years before World War II. In the Kushiro and Nemuro districts, however, agricultural land has expanded only since the 1960's, with the large-scale reclamation of wilderness to grassland. As the land development expands, the varieties of cultivated crops have been reduced and agricultural land use has been unified for grassland. Several studies have conducted to determine the influence of the drastic land use changes on the river water quality there since the 1990's (Kuramochi et al., 1994; Nagasawa et al., 1995; Inoue et al., 1999; Muneoka et al., 2001). In the Tokachi district, however, studies on agricultural land use and river water quality have only just begun (Okazawa et al., 2011; Muneoka et al., 2012).

Tabuchi et al., (1995) conducted investigations of the river water quality at the normal water level in watersheds of an extensive area of Eastern Hokkaido in the summer of 1992. They had shown that there was a positive correlation between the nitrate nitrogen concentration in river water and the extent of agricultural land use in each investigated area. Based on this study, the authors have conducted investigations in the Tokachi and Nemuro areas during the same periods at normal water level. There has been no similar research anywhere in which to weigh the river water quality in two large areas with the different agricultural land use over a long period.

Thus, the objective of this study was to evaluate the impact from the different agricultural land use of watersheds on the river water quality at the normal water level, based on a 20-year observation.

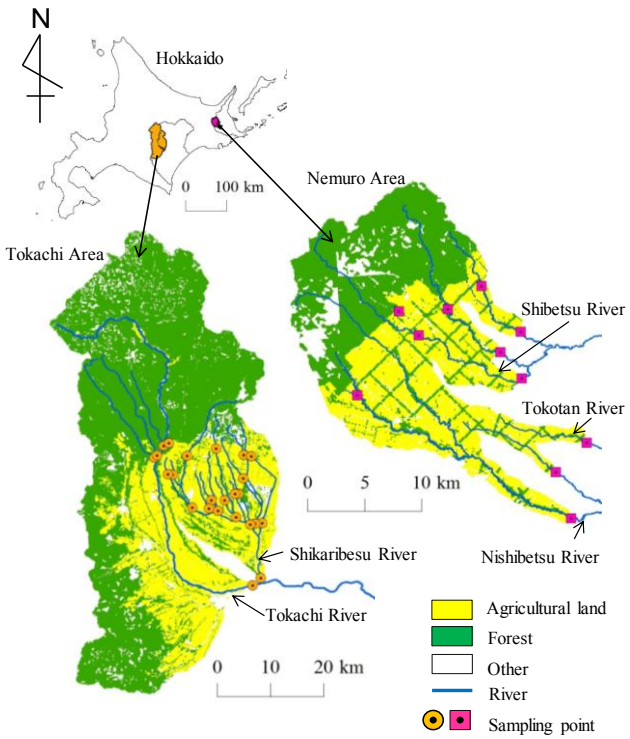
METHODOLOGY

The outline of this study sites are shown in Fig. 1. The Tokachi area, which consists of 24 watersheds on the Tokachi River system and the Shikaribetsu River system (No. 1 to 24), is located in the northwestern part of the Tokachi General Subprefectural Bureau, and it is an area with upland and dairy farming. The Nemuro area, which consists of 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 Subprefectural 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.

For the years 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. And discharge was also measured on the rivers in small watersheds (varied between 22 and 25 by year). The indices and the methods used for water quality analysis varied with each year, nitrate nitrogen (NO_3-N) concentration and EC as indices in this study. The investigations were carried out during late August to early September in 1992, 2003 to 2006, and 2012.

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 that used 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.



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	Minamil sen	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	Ponomebetsu	Akashi	19	73	21

Fig. 1 Outline of the Tokachi and Nemuro areas

RESULTS AND DISCUSSION

The characteristics of long-term fluctuations at the 35 locations in the two areas, which are indicated by using the NO_3-N concentration and the EC of the river water as indices, are shown in Fig. 2.

The NO_3-N concentration in 1992 were <0.1 to 3.9 mg/L for Tokachi area and <0.1 to 2.0 mg/L for Nemuro area. In and after 2003, a tendency of year-on-year increase in the maximum value of NO_3-N concentration was observed for both areas. The maximum NO_3-N concentration was 7.2 mg/L in Tokachi area and 2.6 mg/L in Nemuro area.

The tendency of increase in NO_3-N concentration was noticeable at four sampling points in Tokachi area (No. 10, 11, 12 and 17) and at three sampling points in Nemuro area (G, H and K). These seven points were distinctive that they were small watersheds of 5 to 28 km^2 in area and they had high proportions of agricultural land (49 to 95%). It is worth noting that the NO_3-N concentration showed drastic decreases in 2004 at six points (No. 7, 8, 14, 15, 23 and 24) in Tokachi area and at three points (C, G and J) in Nemuro area, irrespective of the watershed size and the proportion of agricultural land (Fig.2 (a), (b)).

The EC in the two areas in 1992 were 5.1 to 23.3 mS/m in Tokachi area and 5.8 to 18.6 mS/m in Nemuro area. However, the maximum values of EC tended to show slight increases in both areas in the 20-year period. The maximum EC was 26.8 mS/m in Tokachi area and 20.4 mS/m in Nemuro area for the period from 2003 to 2012. EC showed drastic increases at one point (No. 8) in Tokachi area and at three points (D, E and G) in Nemuro area in 2004 (Fig.2 (c), (d)).

Based on these data, it can be assumed that the fluctuations in river water quality, which are indicated by the decrease in NO_3-N and the increase in EC in 2004, reflect the changes in the behavior of farmers, including the management of livestock manure, that resulted from the full implementation of "The Law on Animal Waste Regulation" in November 2004.

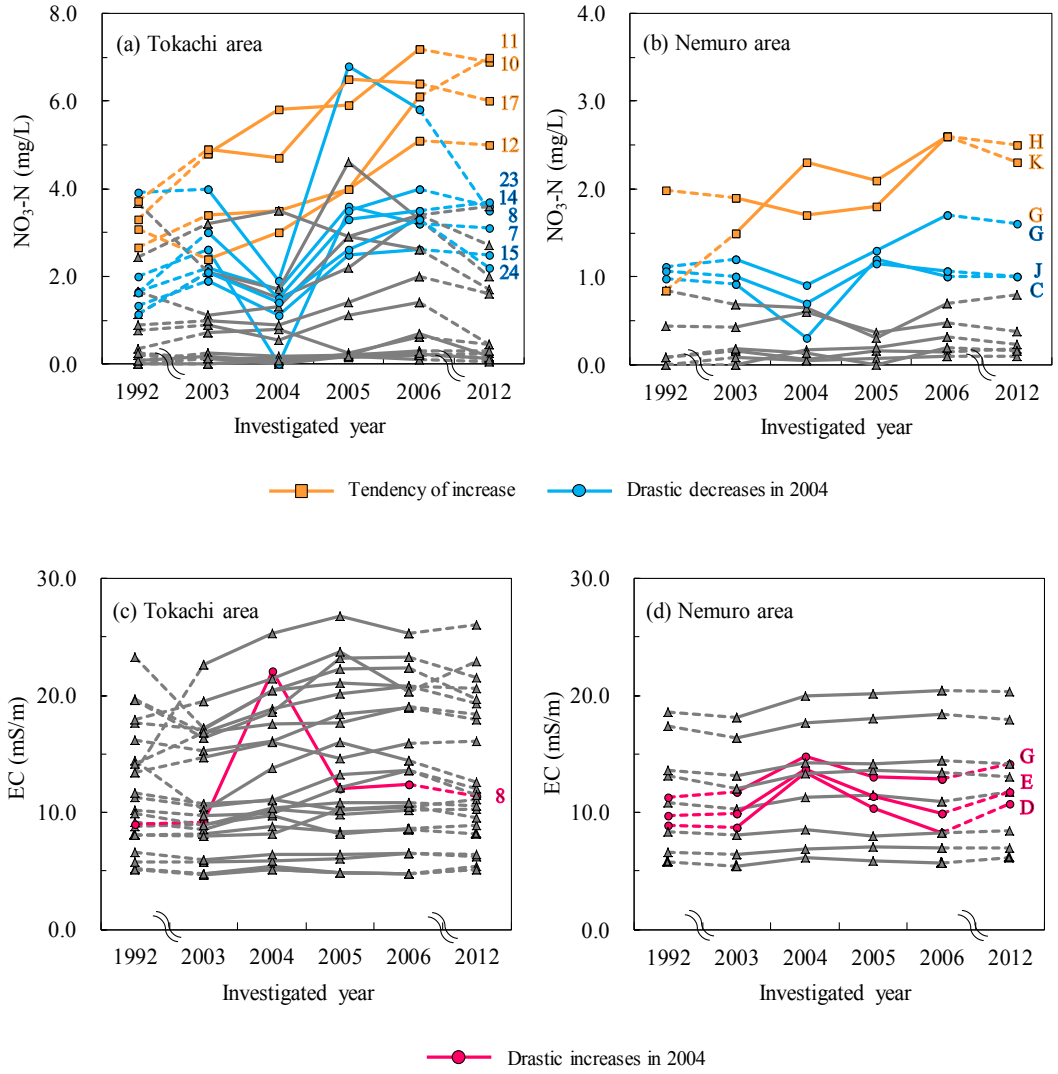


Fig. 2 Long-term fluctuation on the NO_3-N concentration and the EC of the river water in the Tokachi and Nemuro areas

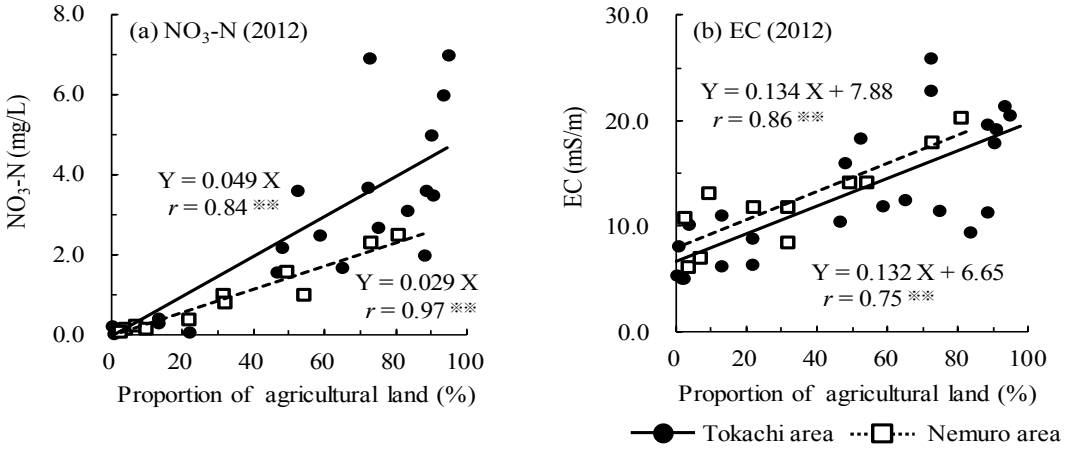
Fig. 3 shows the regression lines and the results of calculation for the coefficients of correlation *r*, which indicate the relationship between the NO_3-N concentration of the river water and the proportion of agricultural land and that between the EC of the river water and the proportion of agricultural land in watersheds at the two areas.

From the relationship between the NO_3-N concentration (Y) and the proportion of agricultural land (X) in the watershed is expressed as Y = a X. The slopes "a", which indicates impact factor (IF) values, were 0.030 to 0.055 in Tokachi area and 0.020 to 0.031 in Nemuro area during the period. When two watersheds, one from the Tokachi area and the other from Nemuro area, that had similar proportions of agricultural land were compared, the NO_3-N concentration in the river water tended to be higher in Tokachi area. 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.

From the relationship between the EC of the river water (Y) and the proportion of agricultural land (X) in the watershed is expressed as Y = a` X + b`. The slopes "a`" were 0.102 to 0.150 in Tokachi area and 0.119 to 0.149 in Nemuro area during the period. The intercepts "b`" of the areas were 6.11 to 6.65 for Tokachi area and 6.81 to 8.78 for Nemuro area. As shown above, when the watersheds in Tokachi area had the same proportion of agricultural land as that in the Nemuro area,

the EC of the river water tended to be higher in Nemuro area. It is assumed that the river water in the Nemuro area contains considerable amount of dissolved ions derived from geologic material, in addition to the nitrate ions (NO_3^-) from farmland.

When the coefficient of correlation *r* was examined by using NO_3-N concentration as the index, *r* for Tokachi area was 0.65$^{※※}$ to 0.89$^{※※}$, and *r* for the Nemuro area was 0.85$^{※※}$ to 0.97$^{※※}$. When EC was used as the index, *r* for Tokachi area was 0.70$^{※※}$ to 0.82$^{※※}$ and *r* for Nemuro area was 0.77$^{※※}$to 0.89$^{※※}$. As described above, *r* for Nemuro area was constantly higher during the period. A factor contributing to this result could be that the agricultural land in Nemuro area is unified into grassland, whereas the agricultural land uses in Tokachi area are more diverse.



Investigated year	NO_3-N (mg/L) [Y = a X] Tokachi area a	*r*	Nemuro area a	*r*	EC (mS/m) [Y = a` X + b`] Tokachi area a`	b`	*r*	Nemuro area a`	b`	*r*	N.B
1992	0.031	0.88 **	0.020	0.85 **	0.111	6.29	0.76 **	0.127	7.09	0.86 **	
≈											
2003	0.036	0.84 **	0.022	0.96 **	0.102	6.39	0.70 **	0.124	6.81	0.88 **	
2004	0.030	0.65 **	0.022	0.93 **	0.133	6.63	0.77 **	0.119	8.78	0.77 **	
2005	0.051	0.89 **	0.024	0.95 **	0.150	6.11	0.80 **	0.132	7.73	0.84 **	
2006	0.055	0.89 **	0.031	0.96 **	0.148	6.28	0.82 **	0.149	6.85	0.89 **	
≈											
2012	0.049	0.84 **	0.029	0.97 **	0.132	6.65	0.75 **	0.134	7.88	0.86 **	(a), (b)

**significance of 1%

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

CONCLUSION

Fluctuations in river water quality at the normal water level were investigated during a period of 20 years at 35 sampling points in two areas in Eastern Hokkaido, with a focus on the differences in agricultural land use between the watersheds. This study evaluated that, in the Tokachi area, upland-field-derived NO_3-N constantly flowed into the rivers in high concentrations at the normal water level. As a result of the long-term observation, the concentration of river water quality hasn't drastically decreased in spite of the full implementation of "The Law on Animal Waste Regulation" in November 2004. Toward improving the river water quality in extensive agricultural areas from the standpoint of conserving the water environment, it is necessary to evaluate and review the management of livestock manure by individual farms as well as examining the relative positions of farmland and rivers and the land in between these.

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