Research article

Effect of Land Use Agglomeration on Nitrogen Concentrations in River Water in the Tokachi River

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Abstract Since in the nineties, contamination of river water by nitrogen from cultivated land has been an issue in major agricultural region of Hokkaido. This study examines the effects of the ratios of cropland or forestland to the watershed area on the nitrogen concentration in the river water, taking as its survey area the Tokachi River basin in eastern Hokkaido, Japan. The study also investigates the impact of cropland and forestland agglomeration on the nitrogen concentration in river water. Survey samples were taken at 37 locations on the Tokachi River. Nitrogen concentrations in the river water were measured at all locations in June, August, and October of 2007, when water levels were normal. In addition, a GIS land use analysis was conducted using a land use map of the region with a grid resolution of 100 m. This analysis determined that cropland and forestland accounts 90% of the total area in the study watershed. Moreover, spatial continuity (*SC*) was calculated as an index of cropland and forestland agglomeration. *SC* represents the average area of a contiguous patch of cropland or forestland in this study. Based on the accumulated data, the followings were found; 1) nitrogen concentration in river water are positively correlated with the proportion of cropland, but are negatively correlated with the proportion of forestland. It is clear that the proportion of each land use is a factor affecting nitrogen concentrations in the river water. 2) The correlation between river nitrogen concentrations and *SC* values is positive for cropland, but negative for forestland. This indicates that nitrogen concentrations in river water likely decreases if the land use pattern is changed: scattering cropland to reduce its patch size, or connecting forestland together to make the forest patch size larger.

Keywords cropland, forestland, land use, agglomeration, nitrogen, river, watershed

INTRODUCTION

It is known that in agricultural watersheds where cropland is abundant, there is a high correlation between the proportion of cropland area and the nitrogen concentration in river water (Jordan et al., 1997; Ahearna et al., 2005; Zampella et al., 2007). This correlation is reported particularly in many agricultural watersheds in Hokkaido, the prefecture with the largest area of agricultural land in Japan (Tabuchi et al., 1995; Woli et al., 2002 and 2004; Okazawa et al., 2003 and 2010). As the results, this high correlation between the nitrogen concentration in river water and agricultural land use in watersheds in upland farming regions highlights the importance of managing land use to protect the quality of river water (Okazawa et al., 2010).

Table 1 Summary of data collected from different locations in the surveyed watershed

*Point	River name	Area (km^2)	Land use (%)				*SC*		T-N (mg/L)		NO_3-N (mg/L)		
			①Cropland	②Forest	①+②	Other	Cropland	Forest	③**Mean**	SD	④**Mean**	SD	④/③
1	Tokachi	632	1	88	89	11	33	3690	**0.32**	0.06	**0.12**	0.06	0.36
2	Tokachi	658	1	88	89	11	31	4125	**0.36**	0.15	**0.21**	0.07	0.59
3	Tokachi	801	2	88	90	10	41	2199	**0.68**	0.27	**0.35**	0.18	0.51
4	Tokachi	806	3	87	90	10	49	2136	**0.42**	0.14	**0.20**	0.04	0.47
5	Tokachi	840	5	85	90	10	75	1131	**0.44**	0.02	**0.21**	0.04	0.47
6	Tokachi	858	7	84	90	10	85	1009	**0.63**	0.17	**0.28**	0.02	0.44
7	Tokachi	1,289	15	77	91	8	151	352	**0.82**	0.12	**0.56**	0.12	0.68
8	Tokachi	1,531	19	72	92	8	195	242	**1.15**	0.18	**0.65**	0.15	0.56
9	Tokachi	1,777	21	70	91	9	225	223	**1.07**	0.14	**0.73**	0.13	0.69
10	Tokachi	1,798	21	70	91	9	225	214	**1.47**	0.32	**0.82**	0.16	0.56
11	Tokachi	2,669	31	60	91	9	393	123	**1.49**	0.14	**0.97**	0.25	0.65
12	Tokachi	2,683	32	59	91	9	386	122	**1.69**	0.25	**1.10**	0.10	0.65
13	Tokachi	2,686	32	59	91	9	377	122	**1.92**	0.37	**1.20**	0.00	0.63
14	Tokachi	4,479	32	58	90	10	367	117	**1.85**	0.51	**1.23**	0.25	0.67
15	Tokachi	5,098	36	54	90	10	418	99	**2.94**	0.52	**2.33**	0.21	0.79
16	Tokachi	8,224	30	61	92	8	219	142	**1.90**	0.24	**1.43**	0.23	0.76
17	Tokachi	8,982	30	62	92	8	207	148	**1.85**	0.21	**1.57**	0.21	0.85
A	Penkenai	23	0	98	98	2	1	2250	**0.37**	0.10	**0.20**	0.08	0.53
B	Penkenikorobetsu	48	1	98	99	1	9	2366	**0.30**	0.09	**0.15**	0.03	0.51
C	Penkenikorochin	72	1	98	99	1	10	7059	**0.34**	0.08	**0.17**	0.07	0.52
D	Sahoro	337	26	68	95	2	161	163	**1.36**	0.13	**0.98**	0.11	0.72
E	Memuro	210	38	56	94	6	248	80	**1.28**	0.08	**0.98**	0.11	0.77
F	Piuka	26	71	12	83	17	262	12	**6.54**	0.77	**5.63**	0.95	0.86
G	Bibaushi	35	79	19	97	3	301	31	**1.69**	0.79	**1.30**	0.82	0.77
H	Bisei	180	16	74	91	8	225	211	**1.17**	0.30	**0.89**	0.20	0.76
I	Shinobihiro	164	74	16	90	10	630	17	**3.97**	1.49	**3.27**	1.25	0.82
J	Shibusarabibaushi	33	53	43	96	3	1	56	**1.17**	0.28	**0.83**	0.18	0.71
K	Shikaribetsu	667	48	45	92	8	867	54	**2.44**	0.28	**2.23**	0.25	0.92
L	Otofuke	693	19	69	88	12	254	190	**1.94**	0.08	**1.53**	0.21	0.79
M	Satsunai	704	30	61	91	9	262	115	**1.85**	0.21	**1.53**	0.32	0.83
N	Obihiro	197	66	14	80	20	442	16	**5.64**	1.56	**4.07**	0.23	0.72
O	Shihoro	316	64	29	93	7	443	32	**5.14**	0.81	**3.43**	0.67	0.67
P	Tobetsu	127	79	13	92	8	494	13	**4.65**	1.27	**4.13**	0.85	0.89
Q	Sarubetsu	449	69	26	95	5	558	27	**7.00**	1.04	**5.57**	0.64	0.80
R	Toshibetsu	2,850	20	75	95	5	84	306	**0.77**	0.05	**0.32**	0.04	0.42
S	Ushisyubetsu	173	24	61	85	3	96	224	**0.36**	0.02	**0.16**	0.13	0.44
T	Rebunnai	66	43	51	93	6	97	82	**1.35**	0.41	**0.93**	0.15	0.69

*1 to 17 : Mainstream, A-T : Tributary

Since in the eighties, the water purification mechanism of vegetation found nearby rivers called riparian buffers zone which are composed of forests and marshes has been drawn in attention. Many studies have demonstrated that preserving forest areas near rivers helps keep the nitrogen concentration in river water to a low level. Excess nitrogen compounds discharged from agricultural land are captured and absorbed by riparian buffers, reducing the amount of nitrogen released into rivers (Johnston et al., 1984; Lowrence et al., 1984; Hill et al., 2000). However, there are only few studies with the same topic conducted in Asia which is distinguished by Asia monsoon climate area (Okazawa et al., 2010).

It is believed that nitrogen concentrations in river water vary even among watersheds with identical ratios of forestland and cropland, depending on whether the forests are concentrated near rivers or distributed across the watershed. Such spatial distributions of land use are called land use agglomeration. Not many studies have examined the relationship between land use agglomeration and nitrogen concentration in river water (Okazawa et al., 2009).

This study examines the relationship of nitrogen concentration in river water in agricultural areas. In particular, the study demonstrates the relationship between the proportions of cropland and forestland in agricultural watersheds and the concentration of nitrogen, and the effects of the agglomeration of cropland and forestland on the nitrogen concentration.

METHODOLOGY

Overview of watersheds

The Tokachi River basin located in eastern Hokkaido has a total area of 9,010 km^2 (Fig.1), the sixth largest river in the country and second in Hokkaido. More than 2,500 km^2 of this area is mainly consists of potatoes, beans, wheat, corn feedstuff, and sugar beets cropland.

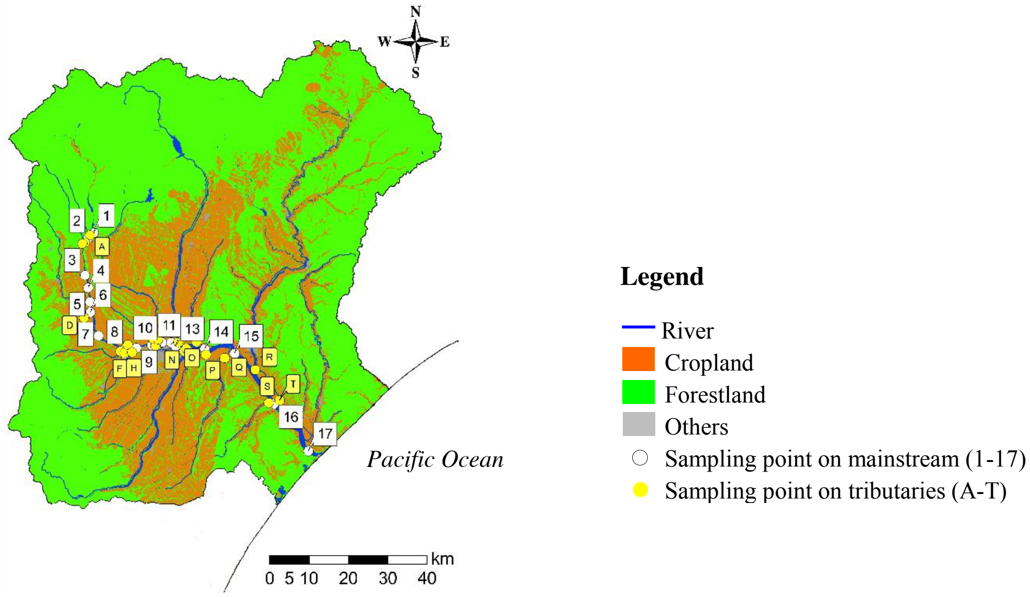


Fig. 1 Map of the Tokachi River basin

The summary of the surveyed watershed areas is given in Table 1. There were thirty-seven watersheds chosen for this study. The proportions of cropland and forestland in each watershed area varied significantly ranging from 0% to 79% and 12% to 98%, respectively. In all watersheds, however, cropland and forestland areas accounting at least 80% of the total land area. Meanwhile, the proportion of other land use patterns (such as residential or industrial) was small.

Water quality survey

Water quality was surveyed on sunny days to avoid the effects of flood. The field survey was conducted three times in June, August, and October of 2007. Samples were taken from river water at the downstream end of each watershed. Seventeen survey locations were chosen between the upstream end (Sampling Point 1) and the downstream end (Sampling point 17) of Tokachi River's main stream, and 20 locations (A–T) along its primary tributaries. The samples were taken back to the laboratory and their nitrogen concentration was analyzed using the Japanese Industrial Standards (JIS) method.

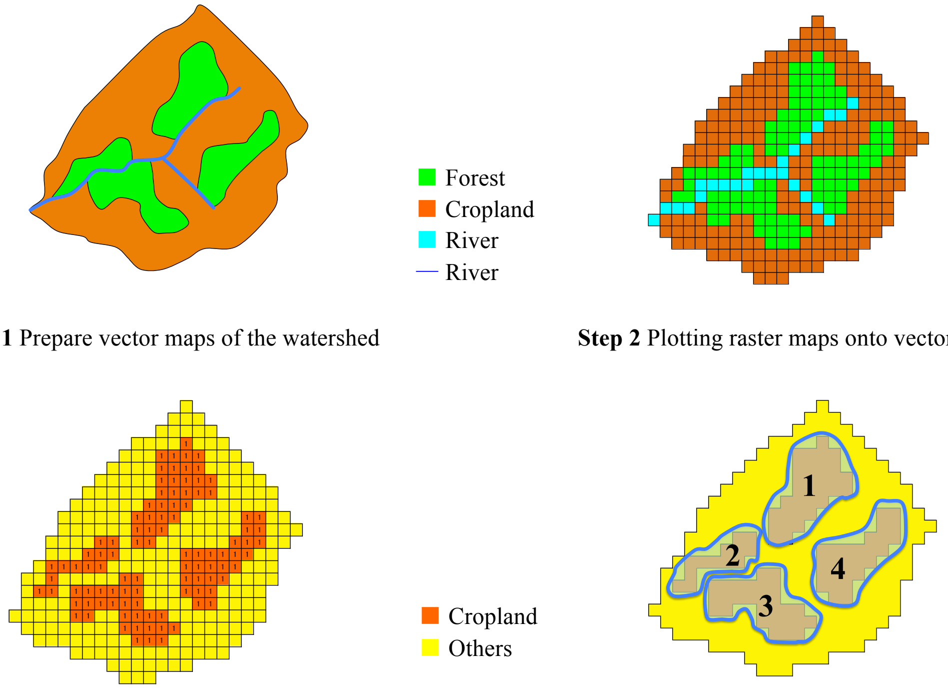
The nitrogen concentrations of river water in respective watersheds (mean values obtained from three survey results) are shown in Table 1. T-N ranges from 0.30 to 7.00 mg/L (mean: 1.81 mg/L), and NO_3-N from 0.12 to 5.63 mg/L (mean: 1.32 mg/L). The percentage of NO_3-N constituting T-N ranged from 33% to 92% (mean: 64%), showing that the majority of T-N is composed of NO_3-N.

Land use analysis

Rivers and their respective watershed boundaries were determined by using 1:25,000 topographic map. In addition, a land use map with a 100 m grid resolution, published by the Ministry of Land, Infrastructure, Transport and Tourism was used to determine the land use system such as cropland

and forestland. Land use ratios and agglomeration were analyzed using GIS software (ArcGIS 9.1, ESRI).

Two types of land use index were used in this study; the percentage of forestland or cropland in a watershed and the agglomeration of land use. Indices for the land use agglomeration include those that showed how ‘joined’ or ‘clumped’ land use areas are, as well as the ‘spatial continuity’ (*SC*) index of identical land use. In this study, *SC* which can be simply derived from GIS was employed as the index for land agglomeration. *SC* was proposed by Tsunekawa et al. (1991). A land use map with a grid resolution of 100 m was used to calculate *SC*.



Step 1 Prepare vector maps of the watershed

Step 2 Plotting raster maps onto vector maps

Step 3 Extracting cropland grid cells

Step 4 Adding up the number of patches (4 patches).

Fig. 2 Method of calculating spatial continuity or *SC*

Vector maps of the investigated watersheds were prepared (Step 1). Then raster data maps of each investigated watersheds were plotted onto the vector maps (Step 2), and only cropland grid cells were extracted from each watershed (Step 3). To obtain an *SC* index, grids representing cropland were grouped into ‘patch’ units (Step 4). Patch refers to a group of grid cells connected in a vertical, horizontal, or oblique direction. Referring to Fig.2, cropland of 100 grid cells evolve and are in four patches as in Step 4. The value of *SC* was obtained by using Eq. 1 as shown below.

$$SC = k \,/\, C_{\mathrm{patch}} \tag{1}$$

Where k is the number of grid cells representing the cropland area in a watershed and C_{patch} is the number of patches represents the grouping of grid cells. In the example given in Fig.2, the number of grid cells representing cropland k is 100 (Step 3) and C_{patch} is 4 (Step 4), so *SC* is equal to 25. In other words, *SC* is equivalent to the average area of a patch in each watershed. The spatial continuity for forestland was also calculated using the same method.

RESULTS AND DISCUSSION

The relationship between the proportion of cropland in each watershed and the concentration of T-N in the river is shown in Fig.3. There was a significant positive correlation between the two parameters. However, even in areas with a comparable cropland ratio, there were variations in the T-N concentration. For example, the watersheds G and P both had a cropland ratio of 79% but the nitrogen concentrations were 1.68 mg/L and 4.65 mg/L respectively.

Fig.4 shows the relationship between the proportion of forestland and the T-N concentration. In contrast to Fig.3, the larger the forest area, the lower the nitrogen concentration was. The correlation was stronger than that of cropland area ratio and nitrogen concentration.

The relationship between *SC* for cropland or the agglomeration of cropland use and the nitrogen concentration is shown in Fig.5. A rise in *SC* was often observed with a rise in T-N concentration and a significant correlation (r^2 = 0.48; significance level at 0.01) was found between the T-N concentration and *SC* of cropland. This demonstrates that the nitrogen concentration is higher in a watershed where croplands are contiguous but lower where croplands are scattered. In other words, since the *SC* index of cropland represents the average area of a patch of cropland in each watershed, therefore the larger the cropland's patch area in a watershed, the higher the nitrogen concentration of river water and vice versa.

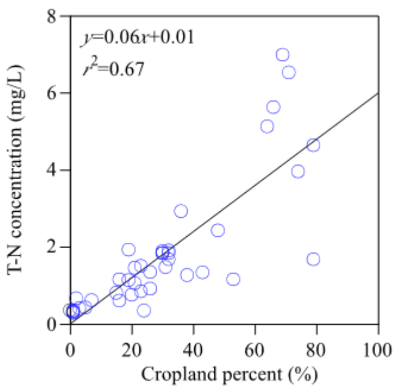


Fig. 3 Relationship between cropland and total nitrogen

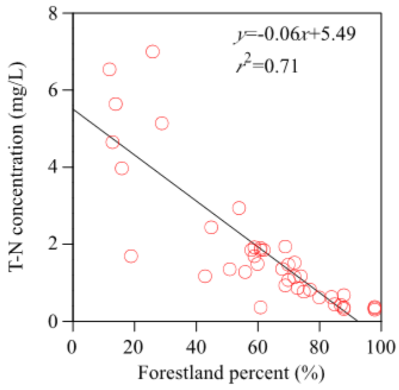


Fig. 4 Relationship between forestland and total nitrogen

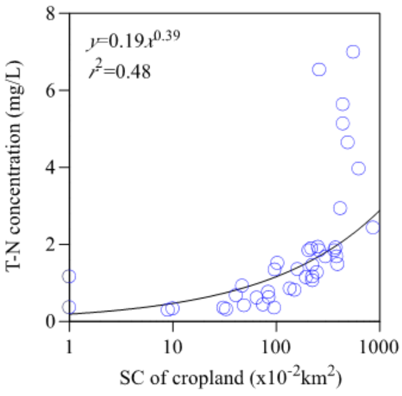


Fig. 5 Relationship between *SC* of cropland total nitrogen

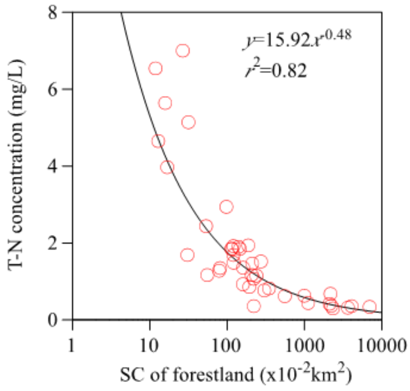


Fig. 6 Relationship between *SC* of forestland and total nitrogen

CONCLUSION

The effect of land use agglomeration on the concentration of nitrogen in river water in the Tokachi River basin in Hokkaido, Japan was examined. The results indicated that in addition to the proportion of cropland and forestland, their contiguity or *SC* had an impact on the quality of river water. This shows that decreasing the patch area of cropland or increasing the patch area of forestland could likely improve the quality of river water. However, the grid resolution of the land use data in this study was set at 100 m; reassessment of the appropriateness of the grid size may be required in future studies.

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