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Evaluating river water quality through land use analysis and N budget approaches in livestock farming areas

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Abstract

This study was carried out to evaluate the quality of river water by analysis of land use in drainage basins and by estimating the N budgets. The drainage basins of Shibetsu River (Shibetsu area) and Bekkanbeushi River (Akkeshi area) in eastern Hokkaido, Japan were selected for a case study, and the evaluation of water quality was up-scaled to the regional level in Hokkaido by using the Arcview/GIS and statistical information. Water sampling was carried out in August 2001 and May 2002 in the Shibetsu and Akkeshi areas, respectively. The proportions of major land uses in drainage basins such as upland field, forest, urban area, wetland, and wasteland for each sampling site were estimated by using topographic maps scaled at 1:25000. The linear regression results showed that the correlation between NO_3-N concentration and the proportion of upland in the drainage basins was highly and positively significant for both the Shibetsu area (r=0.84, n=57) and the Akkeshi area (r=0.71, n=73) at <0.001 significance level. The regression coefficients or impact factors of river water quality were 0.015 and 0.0052 for the Shibetsu and Akkeshi areas, respectively. A comparison of these results with that of the previous study results in Hokkaido indicated that the impact factors were highest for intensive livestock farming areas (0.040), medium for mixed agriculture and livestock farming (0.020-0.030), and the lowest for grassland-based dairy cattle and horse farming areas (0.0052-0.015). The results of a simple regression analysis showed that the impact factors had a significant positive correlation with the cropland surplus N (r=0.93, $P<0.01$), chemical fertilizer N (r=0.82, $P<0.05$), and manure fertilizer N (r=0.76, $P<0.05$), which were estimated by using the N budget approach. Using the best-correlated regression model, impact factors for all cities, towns and villages of the Hokkaido region were estimated. The NO_3-N concentrations for all major rivers in Hokkaido were predicted by multiplying the estimated impact factors by the proportion of uplands. The regression analysis indicated that the predicted NO_3-N concentrations were significantly correlated (r=0.62, $P<0.001$, n=203) with the measured NO_3-N concentrations, reported previously. It can be concluded that estimating the proportions of upland fields in drainage basins, and calculating cropland surplus N enables us to predict river water quality with respect to NO_3-N concentration.

Keywords: Land use; Water quality; Impact factor; Nitrogen budgets; Surplus nitrogen; Disposal nitrogen

1. Introduction

Agricultural activities have been targeted as key contributors to nitrogen (N) pollution in the environment (Cooper, 1993). Runoff from agricultural farms is a major source of N entering rivers, lakes, and coastal waters (Carpenter et al., 1998). For agricultural production, livestock manures and chemical fertilizers are essential. However, their excessive use sometimes causes environmental problems such as water and air pollution (Hantschel and Beese, 1997). Pollution from livestock farm wastes has also caused deterioration of river water quality in recent years (Schofield et al., 1990) due to the increasing trend of intensive livestock farming, characterized by more dependence on imported feed and concentration in small areas (Zebarth et al., 1999). Previous studies have reported that the higher N application rates result in greater field surplus N in agricultural fields (Hatano et al., 2002; Pieterse et al., 2003). All fertilizers or manure N are not absorbed by the crops and most of the residual or surplus N is discharged into ground water through sub-surface drainage (Hayashi and Hatano, 1999).

In order to evaluate the impact of agricultural activities on the cycling of N at farm or regional scale and on degrading the water quality, N budget approaches have been put into practice. The N budget approach, based on a calculation of N flow associated with production and consumption of food and feed, has been developed and used to determine the impact of N cycling in farm, community, region, and national levels (Barry et al., 1993; Zebarth et al., 1999; Matsumoto, 2000; Nagumo and Hatano, 2000). Matsumoto and his co-workers developed the N Flow Model for evaluating N cycling associated with production and consumption of food and feed, which was constructed from N budgets in cropland, livestock, and human dietary subsystems (Matsumoto et al., 1992; 1992a; Matsumoto, 1997). Nagumo and Hatano (1999) estimated the N budgets for the regional level in Hokkaido, Japan, and reported that the amount of unutilzed or disposed N from agricultural areas was as high as over 200 kg N ha^{-1} agricultural land in the livestock husbandry area of southern Hokkaido. Near or around the Bay of Funka is reported to have potential N loadings due to livestock excrement, which has resulted in an eutrophication problem in the estuaries (Nagumo and Hatano, 2001). Woli et al. (2002) estimated N budgets at the community level for three towns near or around the Bay of Funka, and indicated that the intensive livestock farming town (Shiraoi) had the highest disposal N (880 Mg N yr^{-1}), which resulted in as much as 250 kg ha^{-1} yr^{-1} surplus N in croplands.

Japanese agriculture has created high N surpluses in agricultural lands due to the increasing rate of chemical fertilizer application and disposal of livestock wastes per farmland area (Mishima, 2001). Hokkaido is known as Japan's primary dairy farming area; and approximately 93% of livestock excreta are used as organic fertilizers (Hokkaido Government, 1996). A previous study indicated that river water became significantly polluted by N while flowing through dairy farming areas (Hojito, 1998). Shimura and Tabuchi (1997) found that the concentrations of NO_3-N in river water were highly correlated with the stocking density of cattle in some livestock farming areas. The studies conducted in eastern Hokkaido (Tabuchi et al., 1995) and in southern Hokkaido (Woli et al., 2002) have reported that NO_3-N concentrations in river water had a significantly positive correlation (r=0.83 and 0.78) also with the proportion of upland fields in drainage basins. Woli et al. (2002) further indicated that the regression slopes of the relation between upland proportions and NO_3-N concentrations varied among the areas investigated; being highest for the intensive livestock farming area, medium for the mixed agriculture associated with dairy farming area, and lowest for the grazing-based horse farming area. They assumed that those regression lines were the baselines for non-point source pollution and the regression slopes were therefore defined as the impact factors of river water quality. There have been very few studies on river water quality at catchment scale in the dairy cattle farming areas in eastern Hokkaido. Therefore, the purpose of this study was to evaluate the quality of river water in large drainage basins, by analyzing land use distribution in the drainage basins and by N budget approaches. The evaluation of river water quality was further up-scaled to the regional level in Hokkaido by using ArcView/GIS and statistical information.

2. Site description

The drainage basins of Shibetsu River (43º35′N, 144º52′E) and Bekkanbeushi River (43º10′N, 144º48′E) in eastern Hokkaido were selected for this study (Fig. 1). Shibetsu River and Bekkanbeushi River flow into the Okhotsk Sea and Akkeshi Lake, respectively. The drainage basin of Shibetsu River (1309 km^2) consists of Shibetsu and Nakashibetsu towns, which are collectively called ‘Shibetsu area’ in this study. The Akkeshi town and a partial

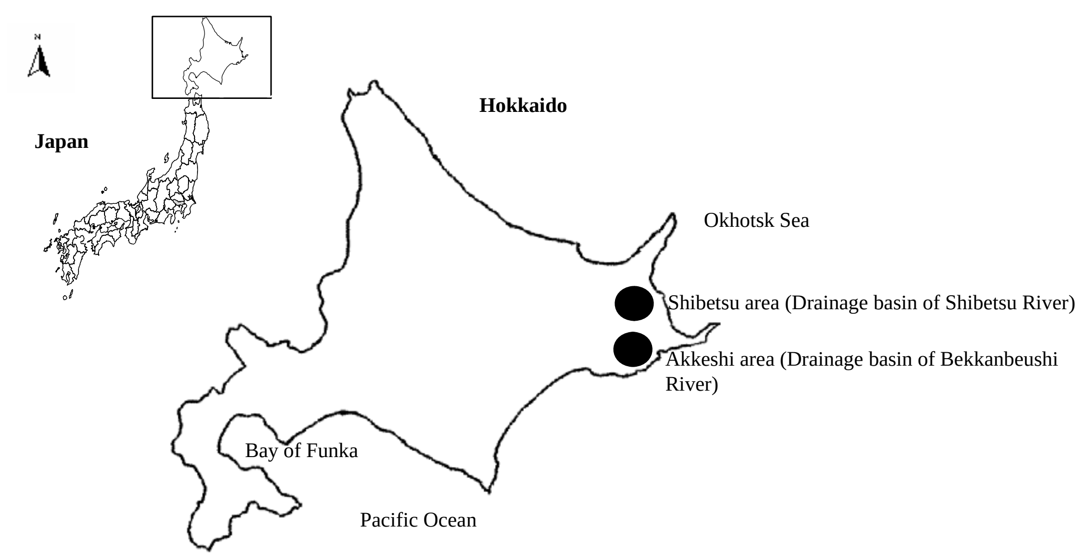

Fig. 1. Location map of the study sites in eastern Hokkaido, Japan.

area of Shibecha town are the drainage basins (1010 km^2) of Bekkanbeushi River (represented by ‘Akkeshi area’). The agricultural land (predominantly grassland) comprises approximately 28% and 18% of the total area in the Shibetsu and Akkeshi areas, respectively (Hokkaido Shinbunsha, 2002). More than 94% of the agricultural land is occupied by grassland in both areas (Table 1). The application rate of chemical fertilizer N is 80 kg ha^{-1} and equal amount of manure fertilizer N is added each year (Agricultural Department of Hokkaido Government, 2002). Dairy cattle have been the main livestock farming of these areas (Table 1). Livestock density is almost same as 1.7 and 1.6 animal unit (a.u.) ha^{-1} of agricultural land (1 a.u. equivalents to one dairy or beef cattle, 1.3 horses, or 100 poultry head based on the amount of excrement as recommended by Nyukantory Editors, 1976) for Shibetsu and Akkeshi, respectively.

Table 1
Area, population and livestock of the study sites

	Shibetsu area	Akkeshi area
Population	28970	16318
Total area (km^2)	1309	1010
Agricultural land (km^2)	368	180
Common upland	19	2
Paddy field	0	0
Grassland	348	178
Livestock (head)		
Beef cattle	8400	5150
Dairy cattle	54000	38300
Horses	730	0
Livestock density (a.u. ha^{-1})*	1.71	1.57

*1 a.u. equivalents to one dairy or beef cattle, 1.3 horses, or 100 poultry head based on the amount of excrement as recommended.

3. Materials and methods

A total of 57 sampling sites in Shibetsu and 74 sites in Akkeshi (Fig. 2) were selected along the main river channel and on various parts of its tributaries. One water sample at each site as a synoptic overview of water quality throughout each watershed was carried out in

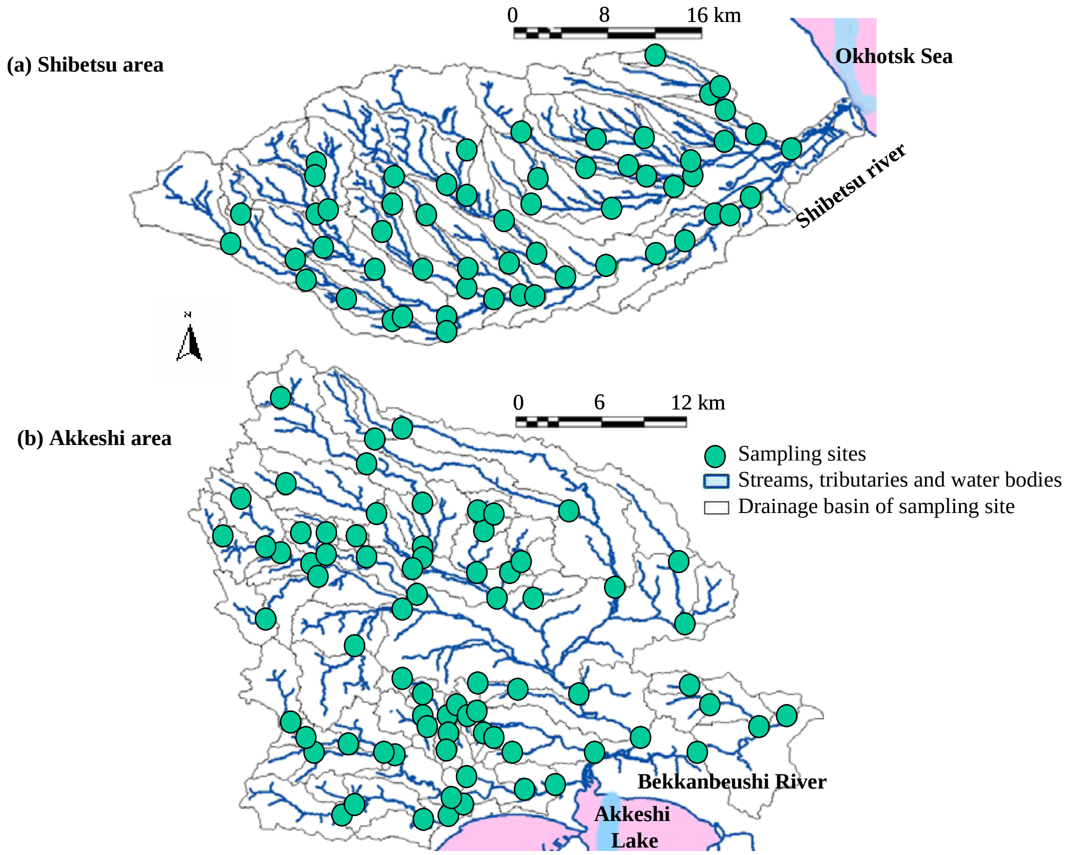

Fig. 2. River system and distribution of sampling sites and drainage basins of each sampling site in Shibetsu area (a) and Akkeshi area (b).

August 2001 in the Shibetsu area and May 2002 in the Akkeshi area. NO_3-N concentration was determined by Ion Chromatography (Dionex QIC Analyzer). Major land uses such as fertilized and grazed upland field, forest, urban area, wetland, and wasteland (barren land which does not fall under land uses mentioned above) of drainage basins of each sampling site were estimated by dividing the respective drainage basins into square messes of 4X4 mm^2 on the topographic maps (1 square thus equivalents to 1 ha). The drainage basin of lower reach streams for each sampling site was calculated by including the drainage basins of all upper streams and tributaries that mix into it. The common upland fields and grasslands were defined as uplands in this study. The proportion of land use was estimated as the percentage of total drainage area of sampling sites. The statistical analyses such as linear and multiple regressions were performed to evaluate the correlation between impact factors of water quality obtained in this study along with those reported in the previous studies, and various parameters of N budgets in drainage basins, which were reported in the previous studies. The ArcView/Geographical information system software (Environmental Systems Research Institute, 2000) was applied for data presentation and for up scaling the results from the catchment level to the regional level.

4. Results and discussion

The results of land use distribution in drainage basins of all sampling sites for Shibetsu and Akkeshi are presented in Fig. 3. In the Shibetsu area, the upper parts of the catchment consisted mainly of forest areas. The proportion of forests in the drainage basins of sampling sites ranged from 9 to 100% in the Shibetsu area. The range of upland fields distributed in the basins was 0-90%, and about one third of the sampling sites had upland proportions above 40% (Fig. 3a). The proportion of urban areas and wasteland ranged as low as 0-3% and 0-4%, respectively.

However, the Akkeshi area had a different pattern of land use distribution in the drainage basins in that the upstream drainage basins also had a high proportion of upland field. The range of upland fields was 0 to 98% in the overall drainage basin, and about half the sampling sites had upland proportions above 40% (Fig. 3b). There were a number of small drainage basins in the upper part having high wasteland proportions reaching up to 40%. The proportion of wetland in the drainage basins varied from 0 to18%, while the range in urban areas was 0-10%.

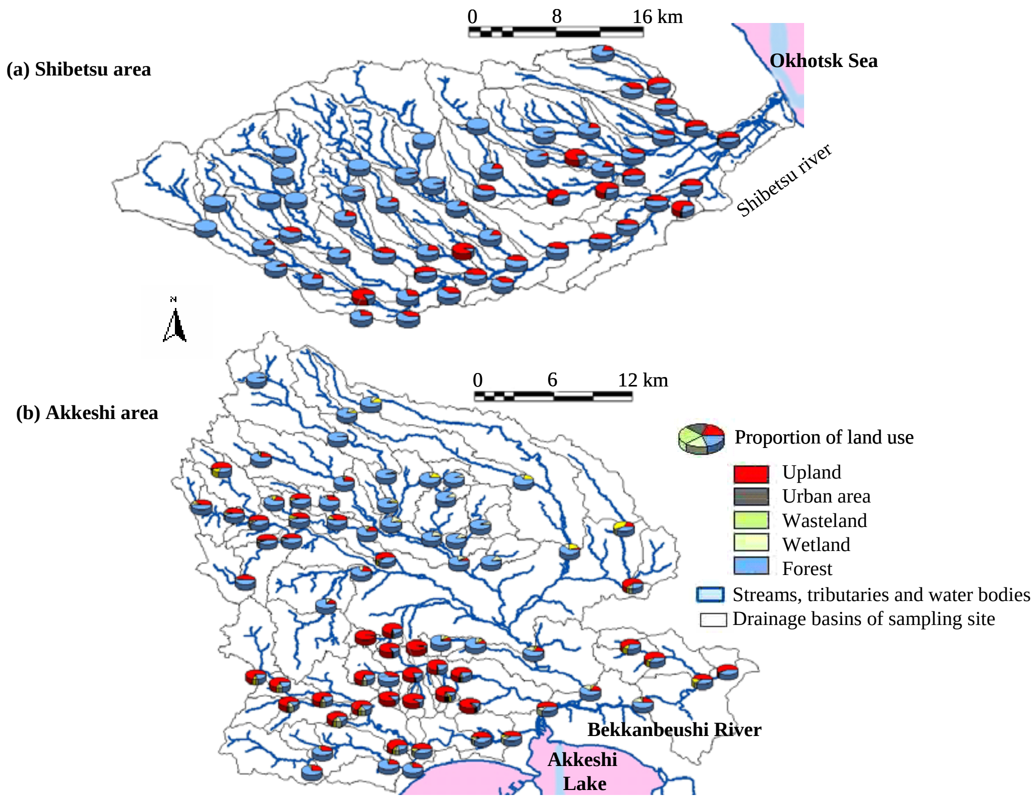

Fig. 3. Proportion of major land use types in drainage basins of sampling sites in Shibetsu area (a) and Akkeshi area (b).

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In Shibetsu area, the majority of upstream sampling sites had NO_3-N concentration of less than 0.2 mg l^{-1} (Fig. 4a). Although a tendency of increasing the concentration towards the downstream was found, NO_3-N concentration ranged from 1.0 to 2.15 mg l^{-1} in some of the small tributaries and in the middle of the main river channel, which had upland proportions in the drainage basins ranging from about 70% to 90%. On the other hand, the NO_3-N concentration in the main river channel and in the outlet of Shibetsu River was below 0.6 mg l^{-1}, which could be due to dilution of concentration by forested upstream waters.

The distribution pattern of NO_3-N concentration in the Akkeshi area (Fig. 4b) showed different patterns than that in the Shibetsu area. Some of the uppermost part of the streams and tributaries also had high concentrations ranging from 0.5 to approximately 1.0 mg l^{-1} and the concentration decreased towards the downstream to as low as <0.5 mg l^{-1}. This may be possibly due to the purification function of riverine wetland (Casey and Klaine, 2001;

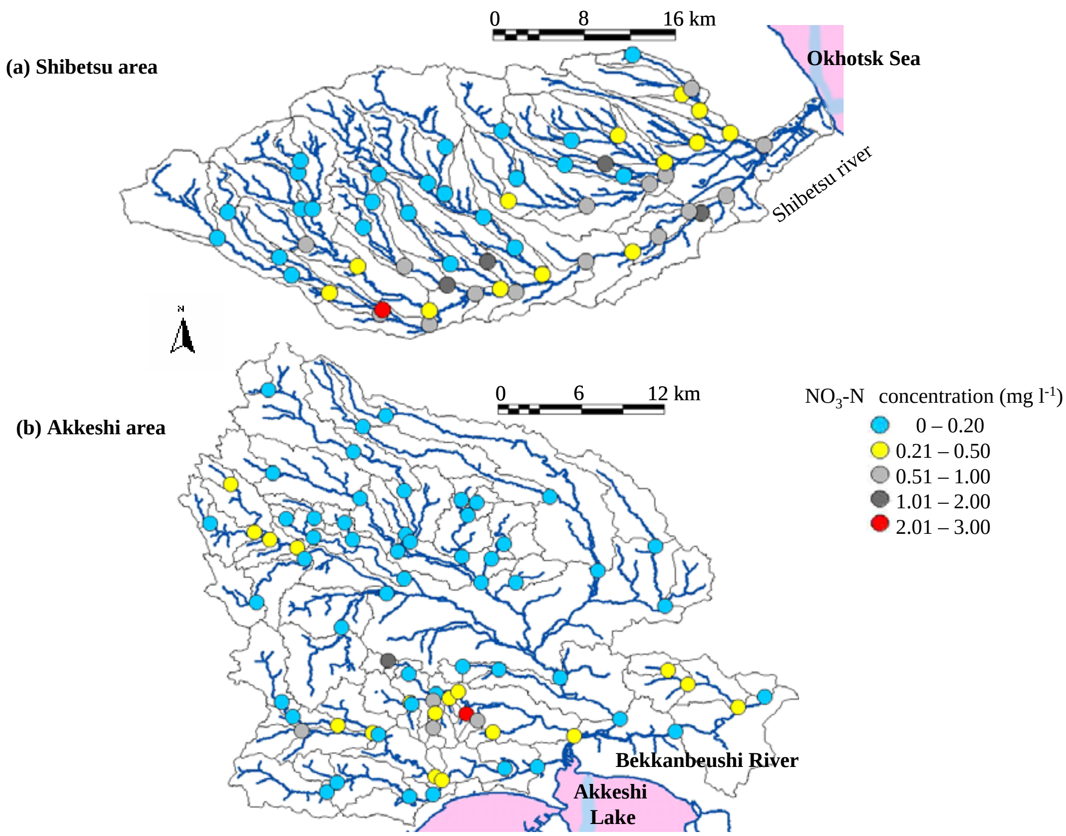

Fig. 4. Distribution of measured NO_3-N concentration in river and tributaries in Shibetsu area (a) and Akkeshi area (b).

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Cosandey et al., 2002; Prior and Johnes, 2002) as most of the sampling sites in the upper as well as lower reach of streams had wetland proportions in the drainage basins reaching up to 18%. Although almost all of the sampling sites had NO_3-N concentrations <1.0 mg l^{-1}, only one site had a concentration reaching up to 2.5 mg l^{-1}, which could have been affected by a possible point source of pollution.

The relationship between the proportion of upland fields in the drainage basins and NO_3-N concentration in river water for both areas is presented in Fig. 5. The result showed that NO_3-

N concentrations were directly proportional to upland field percentages in the drainage basins. Correlation was highly and positively significant for both the Shibetsu area (r=0.84, P<0.001, n=57) and the Akkeshi area (r=0.71, P<0.001, n=73). The regression slopes or impact factors (IF) were 0.015 and 0.0052 for Shibetsu and Akkeshi, respectively. One sampling site of the Akkeshi area remained far from the regression line, which was excluded in the regression analysis due to the possibility of point source pollution. However, the increase in proportion of forests decreased NO_3-N concentration (r=0.84, P<0.001, n=57 and r=0.69, P<0.001, n=73 for the Shibetsu and Akkeshi areas, respectively), as the IFs were negative in both cases (Table 2). Regression analysis showed also that the proportion of urban areas had a significant positive correlation with NO_3-N concentration in both the areas; wetland proportions present in the Akkeshi area had significantly negative correlation and the wasteland in both areas had no correlation at all (Table 2).

Table 2
Results of linear regression analysis between proportion of land use and NO_3-N concentrations (mg l^{-1}) in stream water in Sbibetsu area and Akkeshi area

	Land use variables	Impact factor	r value
Shibetsu area	Upland	0.015	0.84^{***}
	Urban area	0.32	0.51^{***}
	Wasteland	0.041	0.09^{ns}
	Forest	-0.014	0.84^{***}
Akkeshi area	Upland	0.0052	0.71^{***}
	Urban area	0.076	0.50^{***}
	Wasteland	-0.0075	0.22^{ns}
	Wetland	-0.014	0.36^{**}
	Forest	-0.0055	0.69^{***}

Note: * P<0.05; **P<0.01; *** P<0.001; ^{ns} not significant

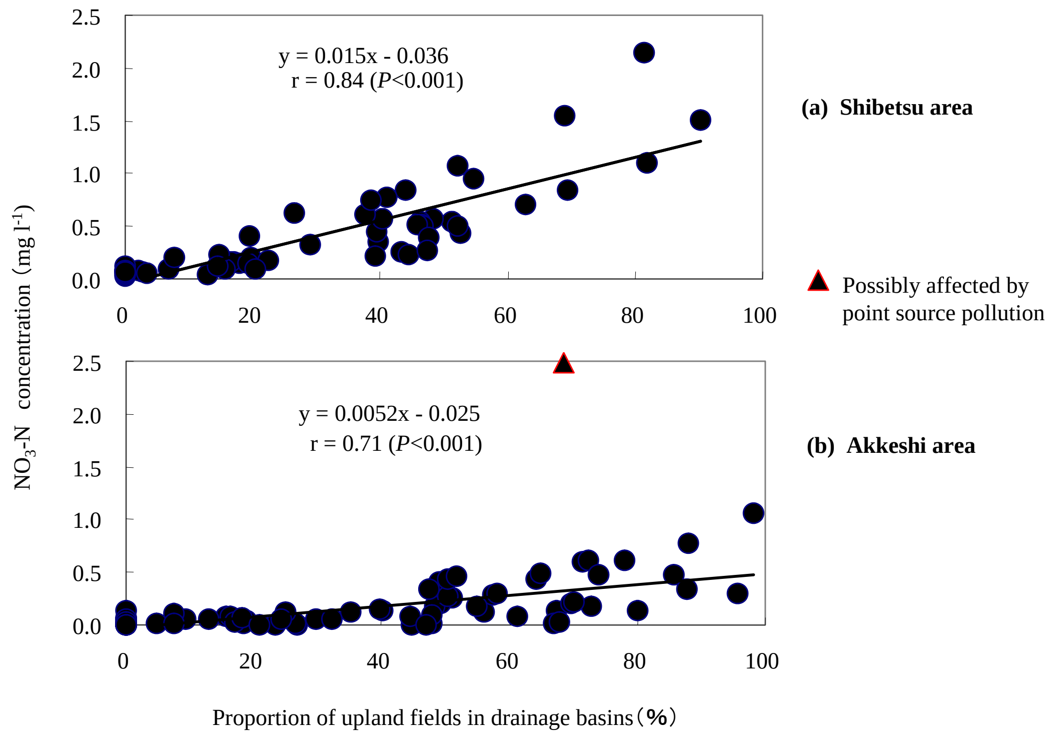

Fig. 5. Relationship between the proportion of upland fields in drainage basins and NO_3-N concentration in river water in Shibetsu area (a) and Akkeshi area (b).

A correlation between the proportion of agricultural land in drainage basins and NO_3-N concentration in river water was significant in this study, as has been frequently reported in the previous studies (Smart et al., 1985; Neill, 1989; Tabuchi et al., 1995; Jordan et al., 1997; Cronan et al., 1999; Sauer et al., 2001, Woli et al, 2002). However, the magnitude of regression slope or IF seemed to vary according to land use management. The IF obtained in the studies carried out in Hokkaido (Tabuchi et al., 1995; Woli et al., 2002), along with those in the present study, were compiled and presented in Fig. 6. It appeared that the IF was higher for intensive livestock and mixed agriculture-based livestock farming areas compared to that for grassland-based dairy cattle and horse farming areas.

Although there have been a number of studies in the past, which reported on the relationship between agricultural land use proportions and NO_3-N concentration, very few

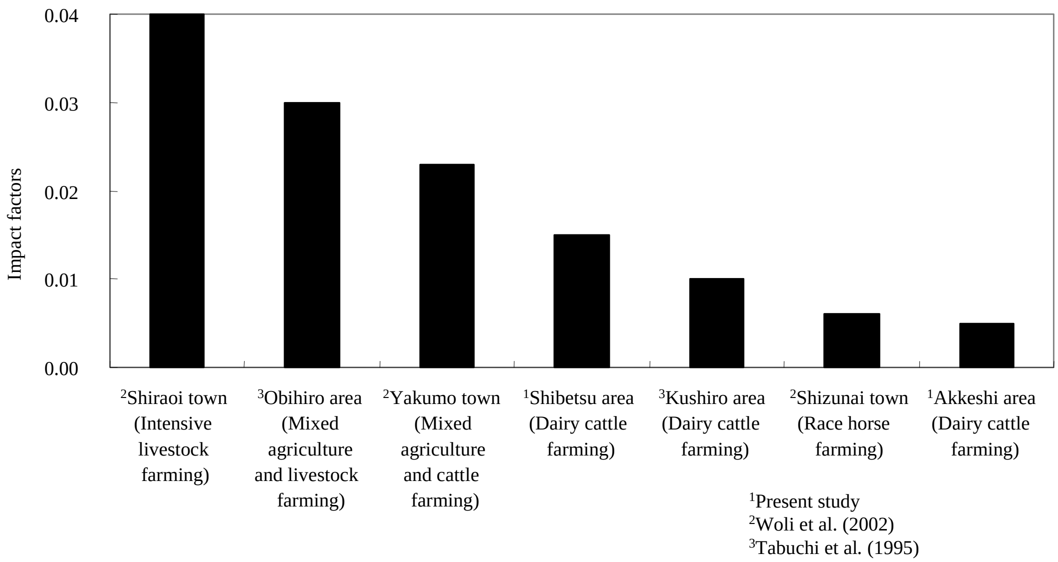

Fig. 6. Varying impact factors according to land use management in various locations of Hokkaido.

have presented the relationship in graphical forms of x, y ordinates (Smart et al., 1985; Jordan et al., 1997; Cronan et al., 1999). Even among the relations presented in ordinates, very rarely have been illustrated the regression coefficients of the relationship. We took some case studies and further analyzed those relationships by reading x,y ordinates of the data on graphs, and finally estimated the regression slopes or IFs. The results are presented in Table 3, which also summarizes the results of the present study and of those reported in the previous studies. For a Chesapeake Bay watershed, having a combined land use characteristic of grassland and intensive agriculture (Jordan et al., 1997), the IF was 0.035. Similarly, in another study conducted for vegetable crop field in the Aroostook River basin (Cronan et al., 1999), the IF was as high as 0.043. These results of IFs are consistent with the IF for the intensive livestock-farming town (Shiraoi in Hokkaido), which had 0.040 (Woli et al., 2002). On the other hand, for the Missouri Ozark Plateau Province (Smart et al., 1985) predominantly having pastureland, the estimated IF was as low as 0.012. In a case study conducted in eastern Hokkaido, Tabuchi et al. (1995) also found a high IF for an agricultural area

Table 3
Compilation of impact factors, NO_3-N concentration, and cited references

S.N.	Study site	Land use characteristics	Study period	Area (km^2)	Sampling sites	NO_3-N conc (mg l^{-1})	Impact Factor	Source
1	Chesapeake Bay watershed	Grassland and intensive agriculture	Dec 1990-Nov 1991	146	17	0.1-3.5	0.035 only cropland 0.029 also grassland	Jordan et al. (1997)
2	Missouri Ozark Plateau Province	Pasture land	Jun 1978-Sept 1979	1680	21	0.05-1.5	0.012	Smart et al. (1985)
3	Aroostook River Basin	Vegetable crop field (Potato, broccoli, etc.)	Dec 1994-Apr 1996	6440	22	<0.05-2.0	0.043	Cronan et al. (1999)
4	North Bosque River of Central Texas	Intensive agriculture and dairy farming	1992-1995	932	16	0.10-5.6 (TN)	0.090 waste appl field	McFarland and Hauk (1999)
5	Obihiro area	Agricultural area including upland field and grassland	1992-1993	2847	20	0.1-0.5	0.030	Tabuchi et al. (1995)
7	Kushiro area	Grassland area with dairy cattle farming	1992-1993	2147	10	0.1-0.5	0.010	Tabuchi et al. (1995)
8	Shiraoi town	Intensive livestock farming	Aug-Sep 1999	426	23	0.1-9.3	0.040	Woli et al. (2002)
9	Yakumo town	Mixed agriculture and dairy cattle farming	Aug-Sep 1999	618	31	0.1-3.2	0.023	Woli et al. (2002)
10	Shizunai town	Race horse farming	Aug-Sep 1999	731	23	0.05-0.9	0.0059	Woli et al. (2002)
11	Akkeshi area	Grassland dominated dairy cattle farming area	Sep 2001	1010	77	0.05-2.5	0.0052	Present study
12	Shibetsu area	Grassland dominated dairy cattle area	May 2002	1309	63	0.05-1.55	0.015	Present study

including upland field and grassland as 0.030, but lower IF for grassland-based dairy cattle farming area as 0.010. These were similar to the study results of IFs in the study conducted by Woli et al. (2002) for the dairy cattle farming town (Yakumo) and race horse farming town (Shizunai) in southern Hokkaido, and with the results of this study (Akkeshi area and Shibetsu area), because the IFs for all these areas ranged from 0.0052 to 0.023 (Table 3). In contrary to these, for a drainage basin of North Bosque of Central Texas, which received livestock wastes as high as 336 kg ha^{-1} of agricultural land, the IF was 0.09 for N (McFarland and Hauck, 1999) and thus as low as 0.02 for nitrate N (by extrapolation). This could be due to the fact that much of the run off from livestock manure may occur as organic forms of N resulting in low concentration of inorganic N in the form of nitrate-N.

In order to evaluate the impact of agricultural activities on the values of IFs, the data and

Table 4
Compilation of Ifs and N loading variables estimated by N budget approaches

Study site	Human disposal	Livestock disposal	Field surplus	Chemical fertilizer	Manure fertilizer	Impact factor
	(kg N ha^{-1})					
Shibetsu area[2]	2.08	7.42	-45.86	41.77	101.0	0.015
Obihiro area[1]	2.70	12.6	51.60	81.84	84.30	0.030
Kushiro area[1]	15.5	8.78	-44.34	42.41	100.9	0.010
Akkeshi area[2]	2.60	6.88	-57.50	40.66	92.85	0.0052
Yakumo town[3]	9.34	9.32	30.73	84.04	124.1	0.023
Shiraoi town[3]	97.1	1170	250.3	74.50	368.3	0.040
Shizunai town[3]	16.0	0.88	-64.08	47.64	50.12	0.0059

[1] Impact factors data - referred to Tabuchi *et al.* (1995)
Human disposal N, livestock disposal N, field surplus N, chemical fertilizer N, manure fertilizer N data - referred to Nagumo (2000)

[2] Impact factors data - present study
Human disposal N, livestock disposal N, field surplus N, chemical fertilizer N, manure fertilizer N data – referred to Nagumo (2000)

[3] Woli *et al.* (2002)

information on various parts of N budgets such as human and livestock disposal N, cropland surplus N, chemical and manure fertilizer N applied (these are termed as ‘N loading variables' in this study) were compiled in Table 4. The data on N cycling were referred to Nagumo (2000) and Woli et al. (2002), which were estimated by N budget approaches. The excreted N from humans and livestock, which were not used or recycled but disposed, was defined as disposal N. The surplus N in cropland was estimated by subtracting outputs such as crop uptake, denitrification, and ammonia volatilization, from inputs on croplands such as fertilizers, manure, rainfall, irrigation, and N fixation (Nagumo, 2000; Woli et al., 2002).

Table 5
Results of simple linear regression analysis between IFs and N loading variables

	Correlation coefficient (r value)
Human disposal N (kg ha^{-1})	0.67
Livestock disposal N (kg ha^{-1})	0.73
Cropland surplus N (kg ha^{-1})	0.93[b]
Chemical feritilizer N applied (kg ha^{-1})	0.82[a]
Manure fertilizer N applied (kg ha^{-1})	0.76[a]

[a]$P<0.05$.
[b]$P<0.01$.

Simple linear regression analysis was performed between the IFs and N loading variables. The results (Table 5) showed that only cropland surplus N, applied rate of chemical fertilizer N, and manure fertilizer N correlated significantly with the IFs (Table 5). The regression models of these correlations are given as bellow:

$$IF = 1.09 \times 10^{-4} * \text{Cropland surplus N} + 0.017$$

$$(r = 0.93, p<0.01, n=7) \quad \text{(I)}$$

$$IF = 5.35 \times 10^{-4} * \text{Chemical fertilizer N} - 0.013$$

$$(r = 0.82, p<0.05, n=7) \quad \text{(II)}$$

$$IF = 9.40 \times 10^{-5} * \text{Manure fertilizer N} + 0.0061$$

$$(r = 0.76, p<0.05, n=7) \quad \text{(III)}$$

Among these correlations, cropland surplus N had the best correlation with the IFs. This result indicated that the surplus N in croplands in a drainage basin could have a direct impact on river water quality. The results also indicated that there was a stronger correlation of chemical fertilizer N applied with the IF for uplands compared to that of manure fertilizer N, because runoff associated with chemical fertilizer generally occurs as inorganic N in the form of nitrate-N.

Pollution arising from agricultural activities increases mainly because of the intensification of the food production system. The demand for food production is generally met by a combination of high yielding varieties and greater reliance to fertilizers, and on imported animal feed in livestock husbandry areas (Hooda et al., 2000). Woli et al. (2002) reported that the main flow of N in the agricultural system was the import of feed to, and the excretion of livestock, in the intensive livestock-farming town of southern Hokkaido. They reported that as much as 76% of the total livestock excretion was disposed of without recycling on croplands, and that the unutilized livestock excretion was 12 times greater than the total excrement produced by human population in the town. They also found that the cropland surplus N in the town was also as high as 250 kg N ha^{-1} yr^{-1}. These results indicate that among agricultural activities, application of livestock manure accompanied by chemical fertilizers to obtain greater production enhances the N pool in the soil system, and that the N not taken up by agricultural crops is accumulated in the soil resulting in higher surplus N, ultimately discharged into ground water through sub-surface drainages (Hayashi and Hatano, 1999; Hatch et al., 2002). The regression results obtained in this study also indicated that factors such as cropland surplus N, applied rate of chemical and manure fertilizer N affected the IFs of water quality (Table 5). Among these three factors, the cropland surplus N had the best correlation with the IFs, which is the product obtained by subtracting the outputs of cropland system from inputs such as applied rates of chemical and manure fertilizer N, including others as described earlier.

Dierberg (1991) indicated that the amount of N in surface run off is strongly influenced by a combination of land use and management practices, soil types, and climatic conditions. The transport of N in runoff from sites where livestock manure has been applied is dependent on the timing and rate of manure application, together with site (i.e. soil type, slope). For instance, Kaleel et al. (1980) reported that the total N lost in runoff from a grassland, which received livestock manure during the winter, was much higher (18.7 kg ha^{-1} yr^{-1}), compared to the lower loss (9.1 kg ha^{-1} yr^{-1}) when applied in the spring. In Hokkaido, livestock manure is applied to agricultural land or disposed of during the autumn, just before the onset of

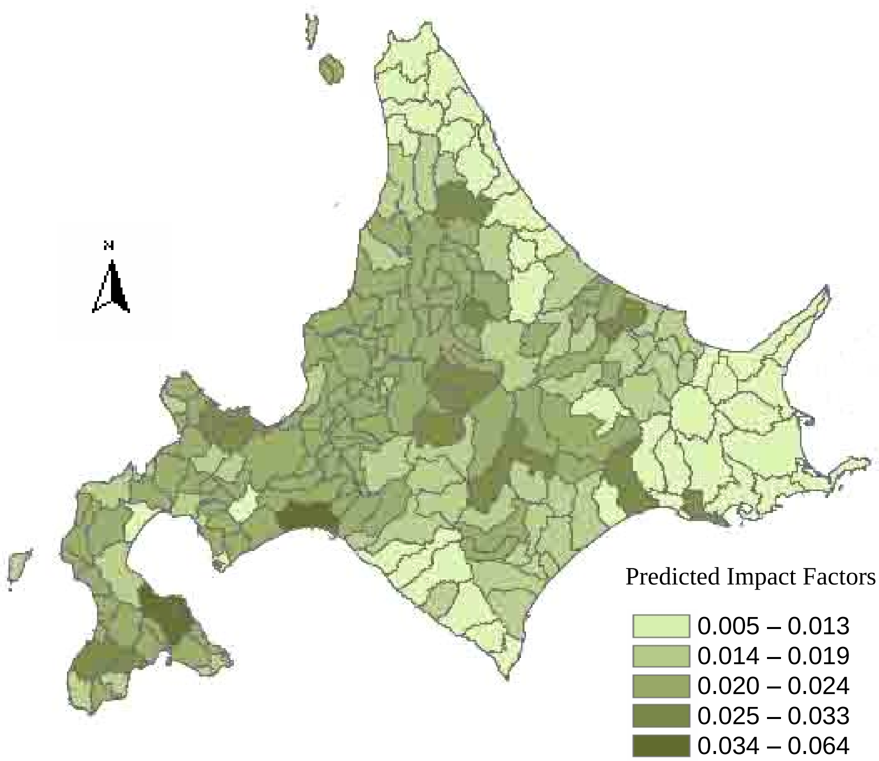

Fig. 7. Distribution of predicted impact factors of water quality for Hokkaido region by using the simple regression models.

snowfall. In this season, crop uptake does not take place, and the applied manure is washed away to a large extent during the snowmelt season. A recent study indicated that the large loading of nutrients to rivers occurred during the early stage of snowmelt period in Hokkaido (Hayakawa et al., 2003). These facts suggest that careful attention should be given in timely application and handling of livestock manure to reduce the surplus N in cropland and dispose of livestock excreta, eventually reducing pollution in river water.

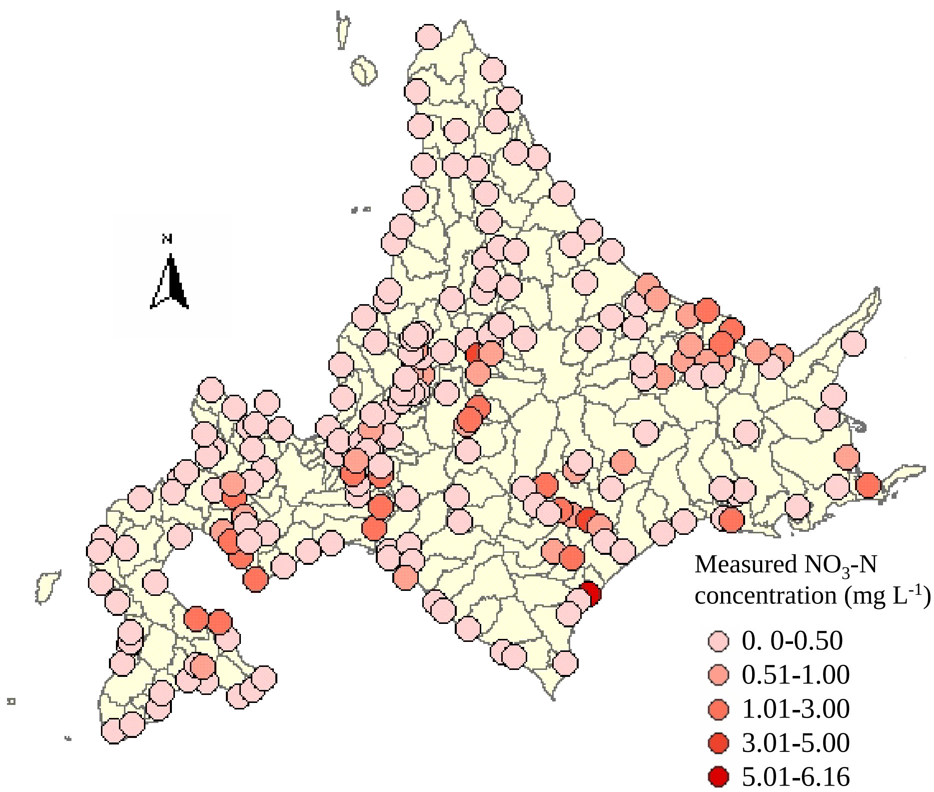

Fig. 8. Distribution of measured NO_3-N concentration in outlets of major rivers in Hokkaido during the snowmelt season (after Nagumo, 2000).

We performed an up scaling of the evaluation associated with IFs for overall Hokkaido by using the GIS software and the available statistical information. We used the best-correlated regression model (Eq. (I)) to predict the IFs for all cities, towns, and villages of Hokkaido by using the reported cropland surplus N for these areas (Nagumo, 2000). The estimated IFs for cities, towns, and villages of Hokkaido are plotted in the Fig. 7. The result indicated that the predicted IFs reflected a pattern of N surpluses in croplands. Major livestock husbandry areas showed high IFs, which could be due to heavy application of animal excreta and chemical N fertilizers in these areas. The distribution pattern for predicted IFs was very close to the pattern of measured NO_3-N concentration for all major rivers in Hokkaido (Fig. 8), as reported by Nagumo (2000). As the proportion of upland in drainage basins also significantly correlated with NO_3-N concentration in this and in past studies, we estimated NO_3-N concentration for all those sampling sites in Hokkaido by multiplying the predicted IFs by the proportion of uplands. Regression analysis indicated that the predicted NO_3-N concentrations were significantly correlated ($r=0.62$, $P<0.001$, $n=203$) with the measured NO_3-N concentrations (Fig. 9). The result also indicated that the prediction underestimated the measured values to some extent. This may possibly be due to the fact that the measured values of NO_3-N concentration were from the snowmelt season, when relatively higher discharge of nutrients can be expected (Hayakawa *et al.*, 2003). The measured values for about 7% of the total sites were higher than the predicted values. These sites were basically the outlets of rivers flowing through major livestock farming and urban areas, therefore it is considered that these sites may be influenced by possible point source pollution.

Conclusions

The land use pattern in a drainage basin affected the quality of river water, and the increase in proportions of upland in drainage basins increased NO_3-N concentration. The impact intensity of land use on water quality was as great as the amount of N in cropland surpluses in the respective drainage basins. The study results also indicated that the analysis of land use patterns and estimation of N budgets were very effective in predicting NO_3-N concentration in river water. A proper management of upland proportions in drainage basins and of cropland surplus N, is very important in protecting the quality of river water.

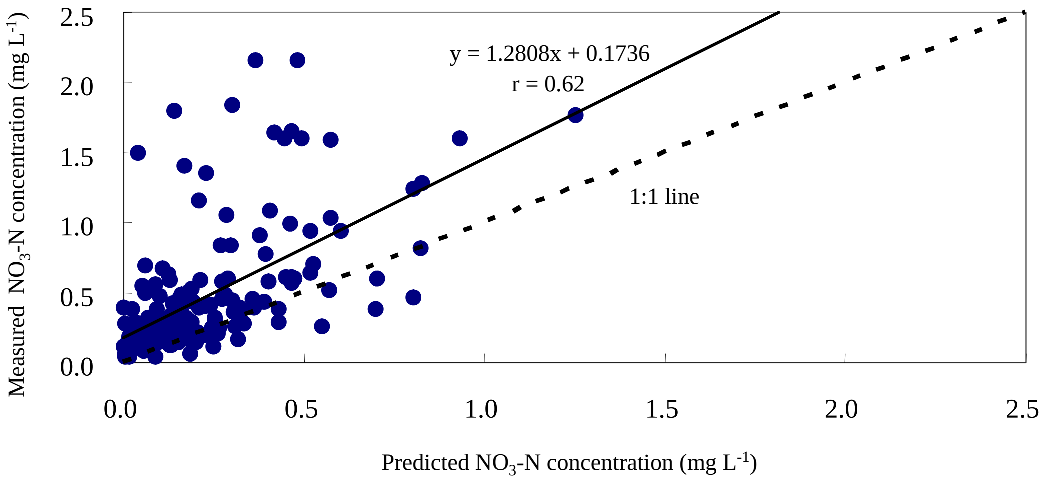

Fig. 9. Measured NO_3-N concentration in outlets of major rivers in Hokkaido during the snowmelt season (Nagumo, 2000) vs predicted NO_3-N concentration by using the proportion of upland field and the predicted impact factor values estimated by simple regression model.

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