Research article

Proposed the Model for Estimation of Nitrogen Load in the Agro-Forestry Watershed

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Abstract Increasing nitrogen concentration in the river water caused by agricultural activities was reported in the Tokachi River basin, Hokkaido, Japan. The water quality conservation is required for the compatibility between the agricultural production and the environmental protection. It is important to analyze the nitrogen load in the watershed for water quality restoration. Nitrogen load is estimated by the nitrogen concentration in the river water and the water discharge. However, this model needs frequent samples of the nitrogen concentrations and water discharges. Also, many observations at multipoint have been required to figure out where and how much the nitrogen load occurs in the watershed. Here, we proposed a model to estimate the nitrogen load by land use in a watershed. The land use data such as watershed area and land use classification could be taken easily from a satellite image. Also, it can estimate the nitrogen load at any investigation point by using land use data for the estimation model. In the Tokachi River basin, the nitrate-nitrogen concentration in the river water had a positive correlation with the proportion of agricultural land in the watershed. Further, the water discharge was proportional to the watershed area. Thus, the estimation model of nitrogen load could be substituted the nitrogen concentration with the proportion of agricultural land, and the watershed discharge with the watershed area. From this, there is a high possibility to estimate the nitrogen load in the watershed by the agricultural land area in the Tokachi River basin. Future subject of this model is how to correct for the variations of nitrogen concentration and river water discharge at different investigation periods.

Keywords nitrogen load, estimation model, land use, nitrogen concentration, water discharge

INTRODUCTION

The Tokachi River basin is a large scale agricultural land located in the eastern part of Hokkaido, Japan. Although Japan's food supply is heavily dependent on imports from overseas because of the low self-sufficiency in food production, the Tokachi River basin plays an important role as a major food base of Japan and has been expected to help develop a sustainable food supply. However, pollution of the river water by nitrogen caused by agricultural activities has been reported in this basin (Okazawa et al., 2011; Muneoka et al., 2013; Yamazaki et al., 2013, 2014). From the investigation in 2007 carried out by Okazawa et al. (2011), total nitrogen (T-N) concentrations in the river water were in the range of 0.30-7.00 mg/L (mean: 1.81 mg/L), and positive correlations were observed between the T-N concentration in the river water and the proportion of agricultural land in the watershed in the Tokachi River basin. Methods to mitigate the nitrogen pollution of the river water in the Tokachi River basin include changing the method and amount of nitrogen fertiliser, proper management of livestock manure and modifying the land use in the watershed. The development of adequate and effective measures to determine the source and amount of the nitrogen component runoff into the river is essential for reducing the amounts of the nitrogen load from agricultural areas.

Estimation of Nitrogen Loads

Different methods exist for estimating loads in rivers. For example, one method is to estimate the amount of emerging toxic substances by a basic unit and then multiplying by a runoff ratio. Another method is to calculate the load based on the water discharge and the concentration of substances in the river water. For the first method, we need to validate the accuracy and time variation of the basic unit and the runoff ratio. The second method, Walling and Webb (1985) introduced a typical model formula for toxic substances. The basic model formula to estimate the river loads was computed by multiplying the river discharge and the concentration of substances in the river water (Eq. 1).

$$N_{load} = C \cdot Q \tag{1}$$

where N_{load} is the base flow of nitrate load in the river water (g/s), C is the base flow of the T-N concentration in the river (mg/L), and Q is the river discharge rate (m^3/s).

Walling and Webb (1985) provided some comments regarding the reliability of load estimates derived using instantaneous water sampling data. They reported that high frequency (i.e. continuously sampled) and multipoint observation data was required to obtain correct river loads. However, extensive work is required to obtain the water sample, investigate the discharge rate and analyse the water quality at high frequency and accuracy in large-scale watersheds.

The nitrogen concentration present in one of the parameters of the model formula to estimate the nitrogen loads of the river has been correlated with the land use in the watershed (Eq. 2). Muneoka et al. (2012) reported that there is a significant and positive correlation between the nitrate-nitrogen (NO_3-N) concentration in the river water and the proportion of agricultural land in the Tokachi River basin. Also, the river discharge has a proportional relationship with the associated watershed area in general (Eq. 3).

$$C = \alpha \cdot \frac{A_{crop}}{A} \pm \beta \tag{2}$$

$$Q = \gamma \cdot A \tag{3}$$

where A_{crop} is the agricultural land area in the watershed (km^2), A is the watershed area (km^2) and α, β and γ are the coefficient factors.

Substituting Eq. 2 and Eq. 3 into the Eq. 1 provides a method to estimate the nitrogen loads (Eq. 4):

$$Nload = \alpha' \cdot A_{crop} \pm \alpha'' \cdot A \tag{4}$$

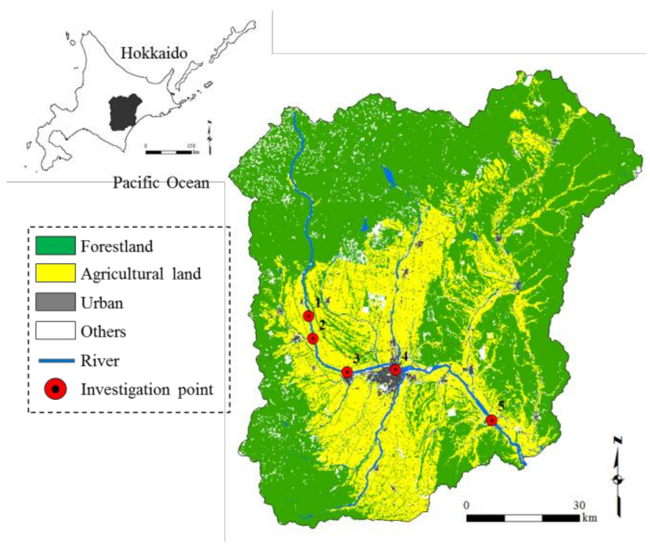
where α' and α'' are the coefficient factors. The agricultural area of the watershed can be calculated easily from the public land use information or satellite images.

In this study, we examined the correlations between the T-N concentration and proportion of agricultural land, river discharge and watershed area using a decade of investigation data. Additionally, we considered the construction of a model formula to estimate the nitrogen loads from the size of the agricultural area in the Tokachi River basin.

METHODOLOGY

The Tokachi River basin is located in the eastern part of Hokkaido, Japan (142.68–144.02°N, 42.55–43.65°E, 0–2,077 m altitude), with a stream length of 156 km and a drainage area of 9,010 km^2 (Fig. 1). The annual mean air temperature is 6.8°C, with the highest and lowest recorded temperatures of 25.2°C (in August) and −13.6°C (in January), respectively, as measured in Obihiro City from 1981 to 2010. The annual precipitation is 887.8 mm/year. The soil types in the Tokachi River basin are volcanic, lowland, upland and peat soils. The upper part of the Tokachi River and the tributaries are forested areas covered with mixed forests of conifers and broad-leaved trees. The low-lying areas are used for agricultural purposes, such as cropland, grass and pasture. The crop cultivation period of this basin is from May to November, and the cultivated crops are rotated through wheat, potato, sugar beet and beans. Both chemical fertilisers and livestock manure are applied to the agricultural land to provide the required nutrients for crop growth.

The daily river discharge rates and the total nitrogen concentration of the river water were obtained from the Water Information System provided by the Ministry of Land, Infrastructure, Transport and Tourism, Japan to determine the trends and fluctuations of the water information on the Tokachi River. Five investigation points on the Tokachi River were selected in the decade between 2004 and 2013. However, we selected the water information during April to November to exclude the impact of snow cover in the winter season and subsequent melting.



Investigation point	Area km^2	Proportion of land use (%)		
		Agriculture	Forest	Urban
1	806	3	92	5
2	858	5	87	8
3	1,531	19	73	8
4	2,686	32	59	9
5	8,224	33	62	5

Fig. 1 Watershed and land use information in the Tokachi River basin

We analysed the land use in the watershed with GIS software to utilise the watershed information as an influencing factor on the river discharge and water quality. The National Land Numerical Information provided by the Ministry of Land, Infrastructure, Transport and Tourism, Japan was used for basic watershed information. The watershed area of each investigation point was calculated based on the 'river' and 'watershed boundaries' of the National Numerical Information with GIS. We also calculated the area and proportion of agricultural land in the watershed based on the 'Land use fragmented mesh' released in 2009 because there was almost no variation in the cultivation area in the Tokachi River basin from 2000 to 2015 according to the Census of Agriculture and Forestry provided by the Ministry of Agriculture, Forestry and Fisheries, Japan.

RESULTS AND DISCUSSION

Correlations Between the T-N Concentration and the Proportion of Agricultural Land, River Discharge and Watershed Area

Figure 2 (a) shows the correlation between the T-N concentration of the river (decade mean values) and the proportion of agricultural land, and Figure 2 (b) shows the relationship between the river discharge (decade mean values) and the watershed area. In the Tokachi River basin, the T-N concentration had a positive correlation with the proportion of agricultural land ($y = 0.043x + 0.26$, r = 0.96), and the river discharge also had a positive correlation with the watershed area ($y = 0.036x$, r = 0.95) over the investigation points. Based on these results, the T-N concentration could be replaced by the proportion of agricultural land and the river discharge could be replaced by the watershed area to develop an estimation model of the nitrogen load of the river. Thus, the nitrogen load of the Tokachi River basin could be estimated by the size of the agricultural land area in the watershed and the associated coefficients.

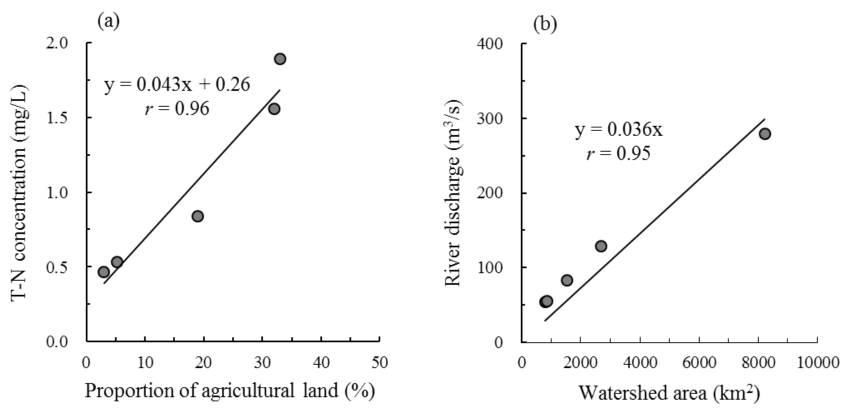


Fig. 2 (a) and (b) Relationships between the T-N concentration and the proportion of agricultural land (a); the river discharge and the watershed area (b)

However, there were variations in the correlational equations between the T-N concentration and the proportion of agricultural land and the river discharge and the watershed area by annual mean values (Table 1). Muneoka et al. (2013) reported variations in the correlational equations between the NO_3-N concentrations and the proportion of agricultural land from their water quality investigation in the Tokachi River basin from 2007 to 2009. Yamazaki et al. (2013) also reported similar variations in their investigation of the northwestern region of the Tokachi River basin from 1992 to 2012. The nitrogen concentrations of the river were considered to have been affected by the agricultural schedule and the meteorological environment, and the river discharges fluctuated due to daily and seasonal changes in the precipitation and evaporation in the Tokachi River basin. In other words, we had to set some parameters that considered the impact of the fluctuation of the T-N concentrations and the river discharges to estimate the nitrogen loads accurately by the agricultural land area in the watershed.

Relationships Between the Nitrogen Load and the T-N Concentrations or the River Discharges

Table 1 Regression expression and coefficient correlation (*r*) between the T-N concentration and the proportion of agricultural land and the river discharge and the watershed area by annual mean values

	T-N and proportion of agricultural land		River discharge and watershed area	
	Regression expression	*r*	Regression expression	*r*
2004	y = 0.035x + 0.21	0.99	y = 0.030x	0.96
2005	y = 0.040x + 0.26	0.99	y = 0.032x	0.94
2006	y = 0.043x + 0.37	0.98	y = 0.041x	0.98
2007	y = 0.036x + 0.15	0.92	y = 0.030x	0.88
2008	y = 0.043x + 0.16	0.91	y = 0.021x	0.89
2009	y = 0.047x + 0.34	0.99	y = 0.039x	0.96
2010	y = 0.048x + 0.46	0.99	y = 0.043x	0.96
2011	y = 0.043x + 0.38	0.99	y = 0.043x	0.94
2012	y = 0.056x + 0.31	0.96	y = 0.039x	0.95
2013	y = 0.041x + 0.32	0.99	y = 0.041x	0.98

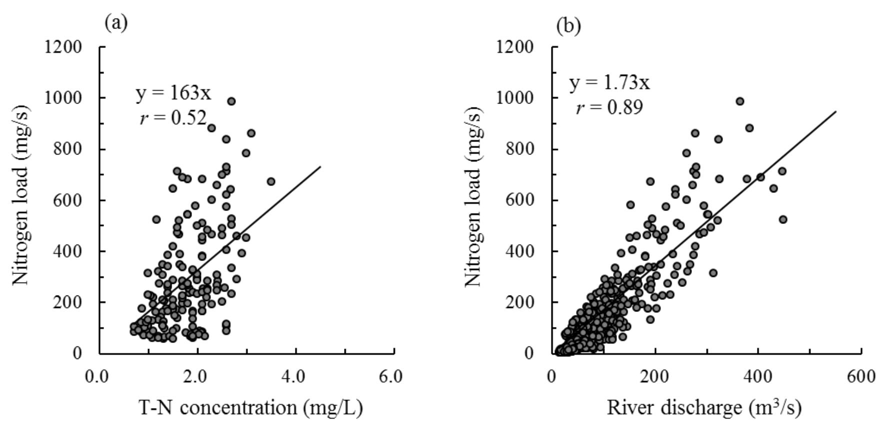


Fig. 3 (a) and (b) Relationships between the nitrogen load and the T-N concentration (a) and the river discharge (b)

We calculated the nitrogen load of the river by the T-N concentrations and the river discharges at 5 investigation points in the Tokachi River basin. The T-N concentrations and the river discharges used for calculation of nitrogen load were investigated once a month for a year from 2004 to 2013. Figures 3 (a) and (b) show the correlations between the nitrogen load of the river and the T-N concentrations (Fig. 3 (a)) or the river discharges (Fig. 3 (b)), respectively. From this figure, the nitrogen load had a strong positive correlation with the river discharge (y = 1.73x, *r* = 0.89); i.e. the fluctuation of the nitrogen load was dependent on the fluctuation of the river discharge more than the T-N concentrations. This result suggested that the parameters for calculating the river discharge fluctuation were required to estimate the nitrogen load in the river water.

CONCLUSION

In this paper, we examined the correlations between the T-N concentrations and the proportion of agricultural land, as well as the river discharges and the watershed area based on a decadal investigation in the Tokachi River basin located in the eastern part of Hokkaido, Japan. The decadal mean T-N concentration had a positive correlation with the proportion of agricultural land, and the decadal mean river discharge also had a positive correlation with the watershed area. Also, the nitrogen load of the river, calculated by multiplying the T-N concentration and the river discharge, had a strong correlation with the river discharge. From the basic model formula of nitrogen load and the results as discussed above, the nitrogen load of the Tokachi River basin could be estimated by the agricultural land area of the watershed. However, the parameter could also be set by considering the impact of the river discharge fluctuation because the nitrogen load strongly depends on the river discharge. Also, the results could potentially be used to verify the nitrogen runoff behaviour during flood conditions as a future subject.

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