

ESTIMATION OF MONTHLY POTENTIAL NITROGEN LOAD FROM AGRICULTURAL AND FOREST WATERSHEDS USING QUICKBIRD REMOTE SENSING IMAGERY

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ABSTRACT:

Eutrophication of coastal oceans as a result of the delivery of excess nutrients by rivers is a critical environmental issue on local, regional, and global scale. Japanese agriculture has created high nitrogen surpluses in agricultural lands due to the increasing rate of chemical fertilizer application and the increase of livestock. In this study, to estimate the nitrogen load exported to Koise River, a major river in Lake Kasumigaura, from its catchment area, extensive field survey and water quality experiments have been conducted from 2007 to 2008. Remote sensing data of QuickBird imagery was applied to the dataset on water quality during two years (Year 2007 for model calibration and Year 2008 for model validation) at 11 streams. Water quality indicator of total nitrogen (TN) were examined and an efficient approach, which estimates monthly pollutant loads directly from satellite imagery and ground observed hydrological data, was investigated. Then the pollutant loads of TN were estimated and prediction results show that the proposed simulation technique can be used to predict the monthly TN pollutant loads of river basins in Japan. Seasonal variation of pollutant loads from 2007 to 2008 were also analysed from different sources according to land covers. This study presents usefulness of remote sensing technique for evaluation and interpretation of water quality datasets and apportionment of pollution sources with a view to get better information about the water quality for more effective management of water resources in river basins.

1. INTRODUCTION

1.1 General Information

Export of excess nutrients from land surface to coastal ocean through river is a critical environmental issue on local, regional, and global scales (Smith et al., 2005; Seitzinger and Kroeze, 1998; Turner and Rabalais, 2003). Investigators increasingly recognize that human action at the landscape scale is a principal threat to the ecological integrity of river ecosystems, impacting habitat, water quality, and the biota via numerous and complex pathways (Strayer et al., 2003). Major changes associated with increased urban land area include increases in the amounts and variety of pollutants in runoff, increased water temperatures owing to loss of riparian vegetation and warming of surface runoff on exposed surfaces (Paul and Meyer, 2001; Carpenter et al., 1998). In recent decades, land cover changes around river basins have caused serious environmental degradation in global surface water areas, in which the direct monitoring is inherently difficult since it requires spatial and temporal measurement tools for land cover changes in the river basin and water qualities, and also it requires models relating them (Oki and Yasuoka, 1997; Omasa et al., 2006; Rhodes et al., 2001). Prediction of pollutant loads is therefore crucial to river environmental management under impact of climate change and intensified human activities. Furthermore, it is necessary to identify the pollution sources and their quantitative

contributions to total pollution load for effective pollution control and water resource management.

As for the water quality in Japan, it has been improved remarkably during the past decades. For example, in the Yodo River, which is the principal river in Osaka Prefecture on Honshu, the average annual concentration of BOD is 3.4 mg/l, 2.5 mg/l, 2.3 mg/l, and 1.5 mg/l for year 1985, 1990, 1995, and 2004, respectively. As for one of the three biggest rivers in Japan, Tone River, the average annual concentration of BOD is 2.6 mg/l, 2.3 mg/l, 1.9 mg/l, and 1.4 mg/l for year 1985, 1990, 1995, and 2004, respectively, which also shows a decreasing trend. However, Japanese agriculture has created high nitrogen surpluses in agricultural lands due to the increasing rate of chemical fertilizer application and the increase of livestock (Mishima, 2001; Kimura, 2005; Kimura and Hatano, 2007). Therefore, the water quality is a still big concern among water related issues in Japan.

1.2 Objective of this study

For estimating the daily influent TN load to rivers, He et al. (2009a) proposed an integrated approach to assess daily nitrogen loads from anthropogenic and natural sources in Japan by a process based modelling frame and detailed database. In the case that only long term (for example: yearly) pollutant load is focused on and the spatial distribution of pollutant in each point of river basins is not emphasized, some simple empirical

methods are applicable. As for annual TN loads, a method has been proposed to successfully calculate the potential annual TN in river basins of entire Japan (Oki and Yasuoka, 1997, 2008; He et al., 2009b). The objective of this study is to examine the capability of this empirical method to estimate monthly potential annual loads of TN in Japanese river basins with the aid of very high resolution QuickBird remote sensing imagery. In addition, this study will focus more on the estimation of monthly TN load from agricultural and forest watershed.

2. DATA AND METHODS

2.1 Site description

Lake Kasumigaura, the second largest lake in Japan, is surrounded by many large agricultural lands. It is located in the eastern part of the Kanto Plain, 50 km northeast of Tokyo (Figure 1). The lake basin is smooth and shallow with a surface area of 171 km², a mean depth of 4 m, and a maximum depth of 7.4 m near the mouth of Takahamairi Bay. The lake water surface is only 1.0 meter above sea level. About 20.5% of the watershed is periodically flooded for rice and lotus cultivation mainly spreading in the low-lying areas of land and the predominance of non-point sources such as forest and agricultural lands as well as the higher activity in livestock production are contributing a lot to the pollution of Lake Kasumigaura (Moriizumi et al., 1975).

2.2 Data Collection

We collected the hydrochemical dataset (river discharge - Q, total nitrogen - TP, total phosphorus - TP, total organic carbon - TOC) from 2007 to 2008 in eleven stream's outlets in Koise River (Fig. 1). Among these eleven observation sites, the collected data of site 1 to 8 has long term continuous record and those of site 9, 10 and 11 have some missing record. Therefore, the collected data of site 1 to 8 was used in this study.

2.3 Remote sensing data

Very high resolution satellite images offers a great potential for the extraction of land use and land cover related information for watershed management. The QuickBird imagery (Digital Globe Company) datasets with spatial resolution of 2.4 meter were used to produce a land cover distribution map by using ISODATA (Iterative Self-Organizing Data Analysis Technique) method. The land cover distribution of each river basin was then extracted (Fig. 2). In this study, the QuickBird imagery datasets were classified into six categories (class1: Paddy field; class 2: Evergreen forest; class 3: Deciduous forest; class 4: Crop land; class 5: Urban area; class 6: Bare land). The basin area and land area of each land cover category were then calculated from the land cover distribution map.

2.4 Estimation of annual nutrient load discharged from a river basin

In the above collected dataset, the annual mean total nitrogen concentration, TN [mg/l], and the monthly river flow, Q [m³/mon], which were measured at the mouth of the river in each basin, were used to evaluate the annual total TN load discharged from each basin (Oki and Yasuoka, 2008). The measurement of the river near the mouth allows us to determine the annual total nitrogen load discharged from the whole river basin area. Therefore, the annual total nitrogen load discharged

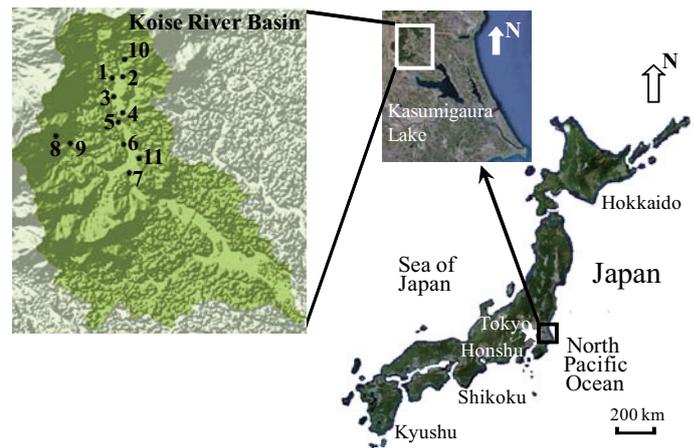


Figure 1 Location of Koise River basin and observation sites for water quality sampling.

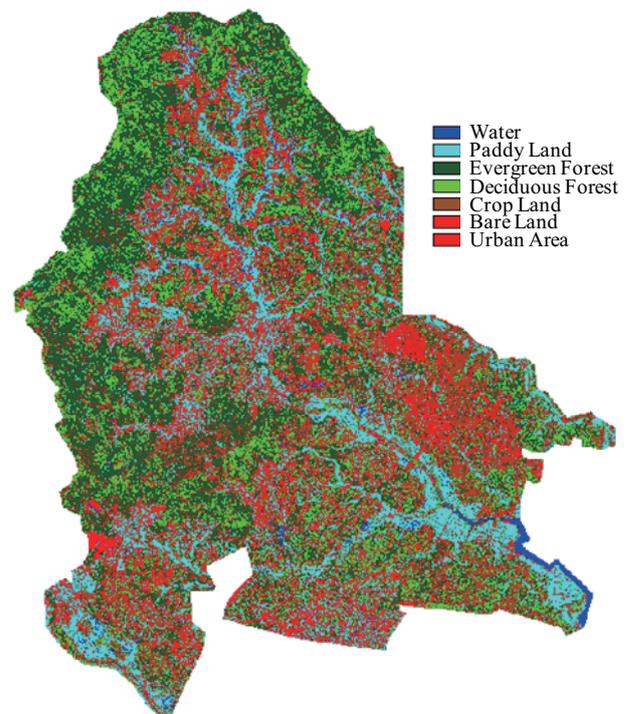


Figure 2 Land cover map generated by Quick Bird remote sensing imagery.

from each river basin i can be presented as follows:

$$\frac{L_i}{A_i} = k \cdot \left(\frac{Q_i}{A_i} \right)^n \cdot \left(\frac{S_i}{A_i} \right) \quad (1)$$

Where

L_i (kg/mon) = the total monthly pollutant load exported from the river basin i

A_i (km²) = the area of the river basin i

Q_i (m³/mon) = the monthly river discharge in the river outlet of the river basin i

S_i (kg/mon) = the monthly runoff load accumulated from different land covers in the river basin i

k, n = empirical coefficients.

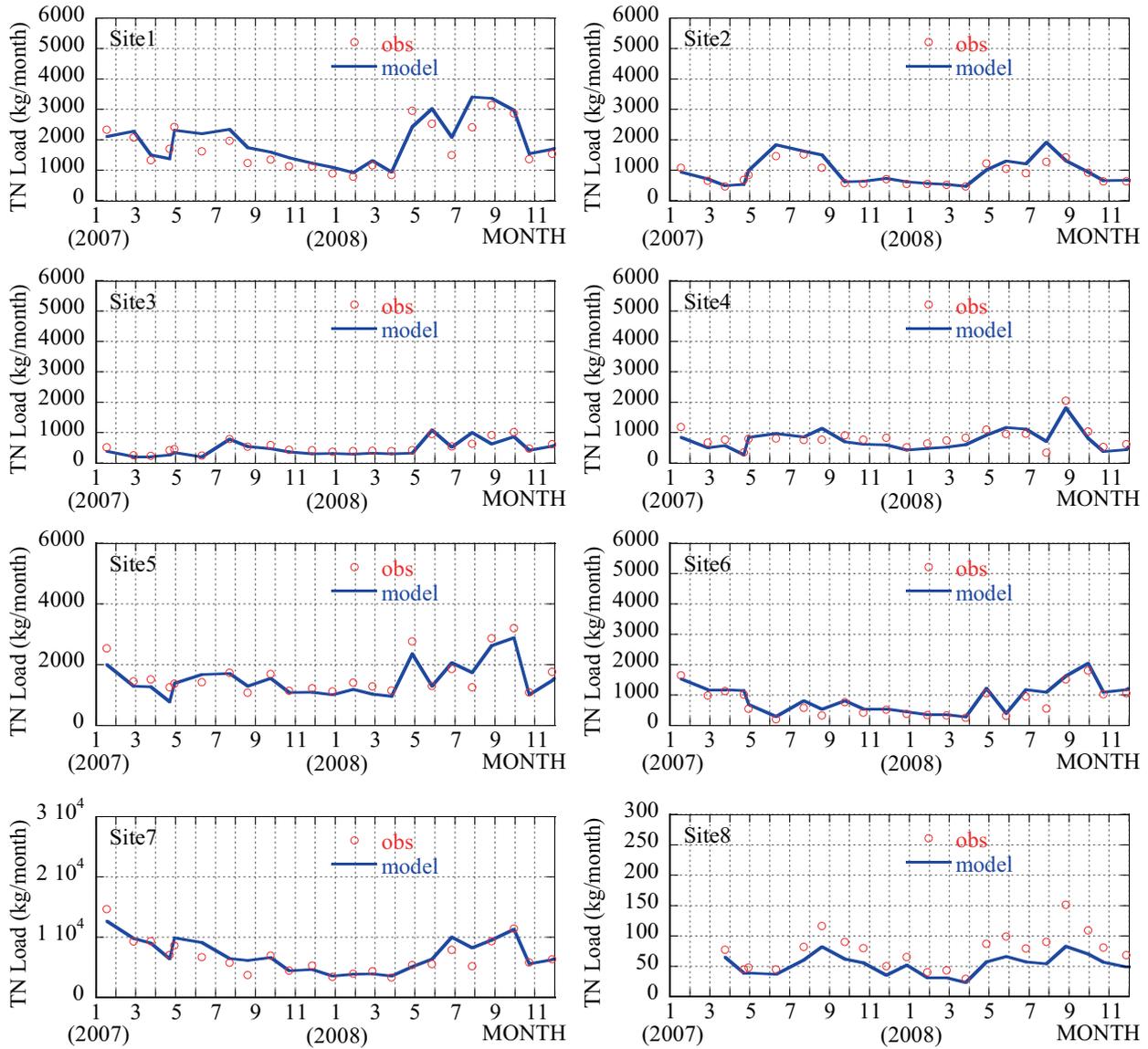


Figure 3 Comparison between simulated and observed total load for eight tributaries of Koise River.

In the above equations, the effect of basin area on pollutant load is removed with the division by basin area.

The monthly runoff load accumulated from different land cover in the river basin i , i.e. S_i is expressed by:

$$S_i = \sum_j^{LC} (U_j \cdot A'_{ij}) \quad (2)$$

Where

j (=1 to LC) = each land use category

LC = the total number of land cover category

U_j (kg/km²/mon) = the coefficient named as runoff load factor of each land cover category j

A'_{ij} = the area of each land cover category j .

3. RESULTS AND DISCUSSION

3.1 Estimation of TN load in Koise River basin

The aim of this study is to estimate the TN load in Koise River basin. The model described in Section 3 was then applied to each watershed in Koise River basin. Here, the collected dataset in Year 2007 was used for model calibration and that of Year 2008 was used for model validation. The comparison of observed and simulated TN load (including calibration and validation datasets) in each month was illustrated in Fig. 3. Site 1 to 8 stand for the river mouth for eight tributary catchments (accordingly named as Koi-1 to Koi-8), respectively. The actual TN loads were calculated for 2007 and 2008 when the field water quality monitoring data is available. They are shown as red circles in Fig. 3. From it, we can find that the simulated seasonal variation of TN load corresponded very well to the observed ones from Year 2007 to year 2008. As for the amount of TN load, the value is the smallest for the forest watershed

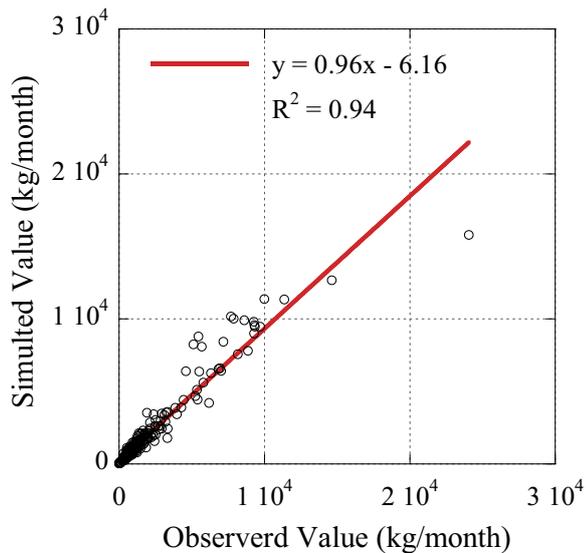


Figure 4 Scatter plot of simulated and observed total nitrogen (TN) loads.

Koi-8 which has an area of about 1 km² and largest for the watershed Koi-7 which has the largest area of about 33.3 km². The biggest amount of TN load from Koi-1 to Koi-6 ranges from 1000 kg/month to 3000 kg/month, with the area ranging from 6.5 km² to 17.0 km². Figure 4 shows the scatter plot of the observed and simulated TN load (including calibration and validation datasets). It was shown to be closely related with a significant correlation coefficient: $r^2 = 0.94$, and with slopes of the regression line being nearly 1.0 (0.96). It demonstrated the good agreement between the observed and simulated TN load. The above estimation results shows the ability of the proposed model to estimate TN load in monthly time scale.

3.2 Contribution of different land to TN load

For understanding the contribution of different lands to TN load, the TN load from different land sources was calculated and shown in Figure 5. Since the QuickBird imagery datasets were classified into six categories (class 1: Paddy field; class 2: Evergreen forest; class 3: Deciduous forest; class 4: Crop land; class 5: Urban area; class 6: Bare land), the TN loads from these six categories were accordingly calculated by using Equation (1) and (2). As results, except Koi-8, in which the TN load are almost generated from evergreen forest, most of the TN load origins from crop land and little part of TN load comes from evergreen forest. The contribution of urban area is quite small comparing with that from crop land. The variation of TN load from evergreen forest is very stable in non-irrigation period in both 2007 and 2008 comparing with that from crop land. The TN load from evergreen forest in irrigation period is found to be larger than that in non-irrigation period. The reason is that the rainfall and river discharge in irrigation period are generally larger than that in non-irrigation period from the observed hydrological data records.

From Fig. 5, it can be found that the TN load from urban area is large in July, August and September for most of the subwatersheds since the river discharge is also high in these months. In the whole year of 2007 and 2008, the TN load from evergreen forest is much larger than that from deciduous forest. In subwatershed Koi- 4, 5, 6, and 7, the TN load in January

2007 is also high since the river discharge is high as 0.13 m³/s, 0.33 m³/s, 0.23 m³/s and 1.70 m³/s, respectively. Their river discharges are all higher than that in February, March, and April. Moreover, the peaks of TN load from crop land were mostly found in irrigation period. As for the biggest subwatershed Koi-7, the TN load from crop land in irrigation period is smaller than that in non-irrigation period in 2007, but vice versa in 2008. The reason is considered to the impact of irrigation activities and river discharge on the dilution process of TN in crop land.

3.3 Discussion

The “pollutant load unit” (PLU) method was popularly applied in catchment scale to estimate and evaluate the effect of agricultural and human activities on water quality and to develop pollutant-control plans (Harasawa, 1990). However, those load units are usually determined using only outflow data independently of the amounts of TN input on the soil surface, the PLU method does not answer the questions of how much TN derived from nonpoint sources enters the water (Nakanishi and Ukita, 1985; Ogawa and Sakai, 1984). It also does not provide the monthly and seasonal change of TN load. Therefore, this study proposed a simple way to estimate the TN load from high resolution remote sensing imagery with monthly and seasonal description of TN load for each land cover category.

The present method in this study was successfully able to capture the seasonal changes in TN load generated from different land cover in the tributary catchments of Koise River basin. From the above analysis, the TN loads from both agricultural land and forest are greatly contributing to the non-point source TN load for Koise River basin through the whole year. It is found that the variations of TN load in forest land and crop land are caused by the hydrometeorological condition and agricultural water use in irrigation period. In Koise River basin, agricultural land especially rice paddy soil was supposed to remove nitrogen during the rice growing season through denitrification and plant uptake. As the adaption policy for the non-point source TN load in Koise River basin, it is better to analyze these seasonal changes of TN load from forest land and crop land considering both climate change and human activities.

In addition, another advantage of the proposed method in this study should be emphasized and that is utilizing very limited hydrological data and land cover data, which are very easily available throughout Japan. Moreover, it can be employed to estimate the TN load in un-gauged catchment if river discharge and land cover data is available. Provided the future scenarios of land cover change and river discharge change, it is also possible to predict the impact of climate change and land cover change on the water quality in rivers.

4. CONCLUSIONS

This study analyzed the water quality characteristics in several tributaries of Koise River basin and estimated the nitrogen load exported to Koise River by using remote sensing data of Quick Bird imagery and the observed dataset on water quality during two years (2007–2008). The prediction results of the pollutant TN loads show that the proposed estimation technique can be used to predict the monthly pollutant loads of river basins. Seasonal variation of pollutant loads from 2007 to 2008 were also estimated from different sources according to land covers. It presents usefulness of remote sensing technique for

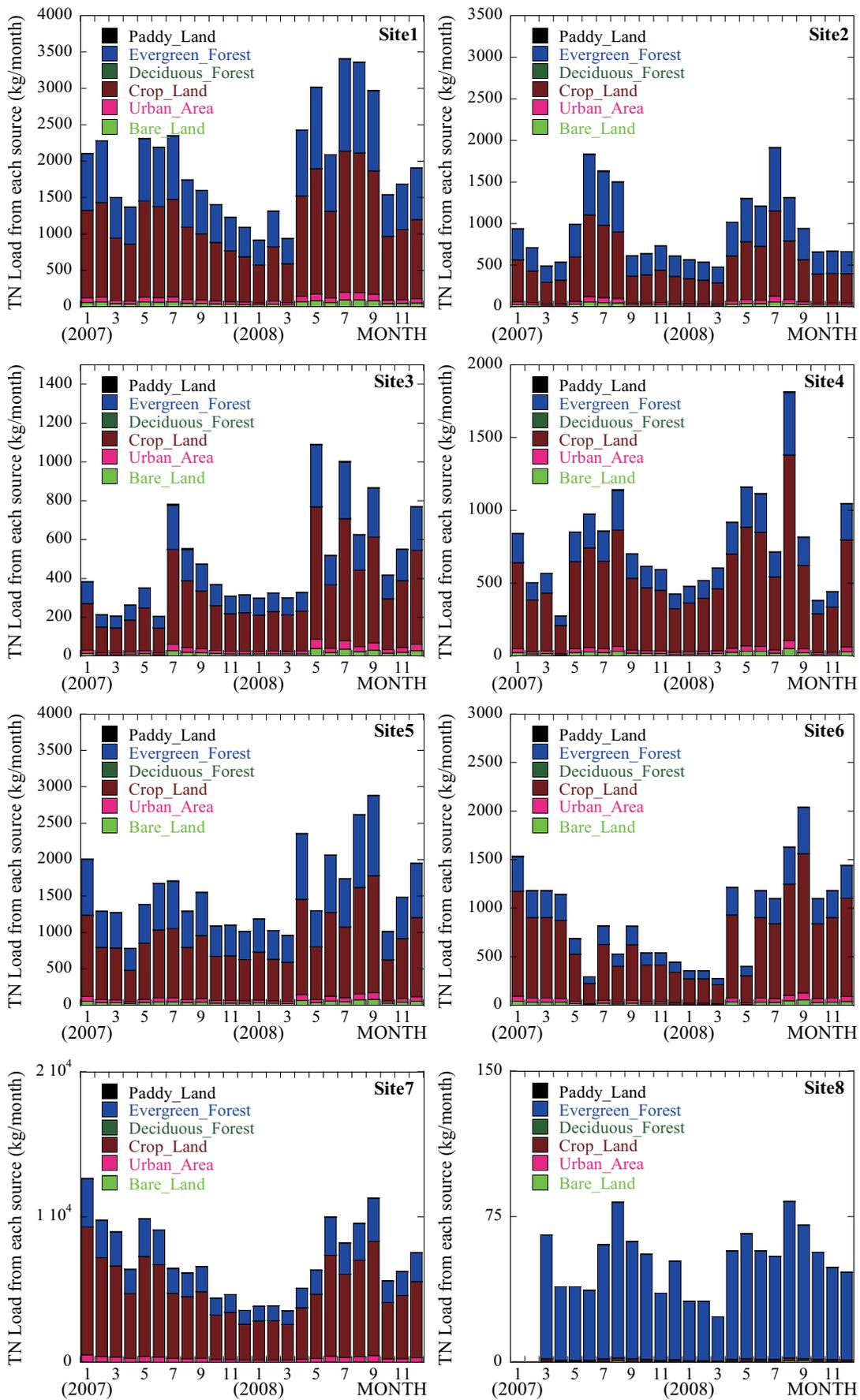


Figure 5 Total nitrogen load from different sources in eight tributaries of the Koise River.

evaluation and interpretation of water quality datasets and apportionment of pollution sources with a view to get better information about the water quality for more effective management of water resources in river basins.

References:

Carpenter SR, Caraco NF, Howarth RW, Sharpley AN, Smith VH. 1998. Nonpoint pollution of surface waters with phosphorus and nitrogen. *Ecol. Appl.* 8:559–68.

Harasawa, H. (1990) Supporting system for watersheds managements of lakes. In No. 3 kankyo youryo symposium (*Proc. 3rd symp. on aquatic carrying capacity and its application*), ed. Ebise, S., NIES, Tsukuba, Japan, 1–13 [In Japanese].

He, B., Oki, T., Kanae, S., Mouri, G., Kodama, K., Komori, D., Seto, S. (2009a). Integrated biogeochemical modelling of nitrogen load from anthropogenic and natural sources in Japan. *Ecological Modelling* (220) 2325–2334.

He B, Oki K, Wang Y, Oki T. (2009b). Using remotely sensed imagery to estimate potential annual pollutant loads in river basins. *Water Science and Technology*, doi: 10.2166/wst.2009.596, 60(8) 2009-2015.

Kimura, S.D., Hatano, R. (2007). An eco-balance approach to the evaluation of historical changes in nitrogen loads at a regional scale. *Agricultural Systems* 94, 165-176.

Kimura, S.D. (2005). Creation of an eco-balance model to assess environmental risks caused by nitrogen load in a basin-agroecosystem. PhD thesis, Hokkaido University Graduate School of Agriculture, Japan.

Mishima, S. (2001). Recent trend of nitrogen flow associated with agricultural production in Japan. *Soil Sci Plant Nutr* 47(1),157 -166.

Moriizumi, S., Osaki, K. & Kikkawa, A. (1975) Relation between the amounts of fertilizer on the field and the livestock waste and the water pollution of streams flowing into Lake Kasumigaura. I. On the relation between the amount of application of fertilizers and the specific pollutional loads of nitrogen and phosphorus in main streams flowing into Lake Nishiura. Ibaraki daigaku nogakubu gakujutsu hokoku (Sci. Rep. of the Fac. of Agric. Ibaraki Univ.), 23, 89–99 [In Japanese with English summary].

Nakanishi, H. & Ukita, M. (1985) Calculations of pollutant loads. In No. 2 shizen joka symposium (*Proc. of symp. on self-purification in aquatic environment -Effective use of natural ecosystems for water quality management*). NIES, Tsukuba, Japan, 15–27 [In Japanese].

Ogawa, Y. & Sakai, H. (1984) The fate of nitrate in the rice paddies flowing from upland fields. *Nihon dojo hiryo gaku zasshi (Jpn. J. Soil Sci. Plant Nutr.)*, 55, 533–538 [In Japanese].

Oki, K. and Yasuoka, Y. (1997). Estimation of Annual Total Nitrogen Load to Lake from Basin with Remote Sensing. *Journal of Japanese Remote Sensing Society*, 17(1)22-35.

Oki, K. and Yasuoka, Y. (2008). Mapping the potential annual total nitrogen load in the river basins of Japan with remotely sensed imagery, *Remote Sensing of Environment* 112(6), 3091-3098.

Omasa, K., Oki, K., and Suhama, T. (2006). Remote sensing from satellite and aircraft. In A. Munack (Ed.), *Handbook of agricultural engineering Information Technology*, ASAE, Vol. VI, 231–244.

Paul MJ, Meyer JL. 2001. Streams in the urban landscape. *Annu. Rev. Ecol. Syst.* 32:333–65.

Rhodes AL, Newton RM, Pufall A. 2001. Influences of Land Use on Water Quality of a Diverse New England Watershed. *Environ. Sci. Technol.*, 35(18), 3640-3645

Smith, S.V., Swaney, D.P., Buddemeier, R.W., Scarsbrook, M.R., Weatherhead, M.A., Humborg, C., Eriksson, H., Hannerz, F. (2005). River nutrient loads and catchment size. *Biogeochemistry*, 75, 83-107.

Seitzinger, S.P., Kroeze, C. (1998). Global distribution of nitrous oxide production and N inputs in freshwater and coastal marine ecosystems. *Global Biogeochem. Cycles* 12, 93-113.

Strayer DL, Beighley RE, Thompson LC, Brooks S, Nilsson C. 2003. Effects of land cover on stream ecosystems: roles of empirical models and scaling issues. *Ecosystems* 6:407–423.

Turner, R.E., Rabalais, N.N. (2003). Linking landscape and water quality in the Mississippi River basin for 200 years. *Bioscience* 53, 563-572.

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