Research article

Influences of Land and Water Use on the Water Quality of Canals through Agricultural Areas

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Abstract Shinotsu Canal passes through an agricultural area that contains a high pollutant load from catchments. This pollutant load influences the Ishikari River water quality, which consequently affects downstream aquatic biota. This study was conducted to evaluate the influences of agricultural land and water use activities on Shinotsu Canal water quality. The Shinotsu Canal is 25 km long and contains a 10,864 hectare catchment area, which is divided into 10 sub-catchment areas. The proportions of major land uses such as paddy fields, uplands, and forests were categorized by the supervised classification method using satellite data for each sub-catchment area. Water samples were collected manually from 11 points (P1~P11) upstream to downstream from May 2006 to April 2009. The suspended sediment (SS) concentration was analyzed by suction filtration; nitrate nitrogen (NO_3-N) was measured by ion-chromatography; and total nitrogen (TN), total phosphorus (TP) were measured by UV-spectrophotometry. The SS, TN, and TP concentrations were highest during the puddling period (PP), whereas the highest NO_3-N concentration occurred during the snow melting period (SMP). There was a positive significant relationship between accumulated paddy field area (APA) and SS ($r = 0.94$) and between the accumulated upland area (AUA) and SS ($r = 0.96$) at <0.001significance level during the PP. The TP concentration was also significant during the SS. TN was highly correlated with APA ($r = 0.94$, $P < 0.001$) and AUA ($r = 0.98$, $P < 0.001$) during the SMP. The SS, TN, and TP concentrations were higher downstream (P11) than upstream (P1) at all periods except for TN during the normal irrigation period. We conclude that land and water use for agriculture, seasonal meteorological characteristics, and fertilizer management affect Shinotsu Canal water quality.

Keywords land and water use, water quality, agricultural area, Hokkaido

INTRODUCTION

Shinotsu Canal in the Shinotsu district is 25 km long with both inlet and outlet on the Ishikari River, Hokkaido, Japan. The canal basin is covered by paddy fields, upland fields, and forests. Agriculture is the main land use activity in this district. It is well known that agricultural non-point source pollution from watersheds is a major cause of water quality degradation. Intensive agriculture emits significant amounts of nutrients, particularly nitrogen, phosphorus, and sediment (Monaghan and Smith, 2004). The water quality of streams, rivers, and lakes is highly related to land use in the catchments, which can affect the quantity and quality of runoff during and after precipitation. Tong and Chen (2002) examined the hydrologic effects of land use in Ohio and discovered a significant relationship between land use and stream water quality, especially with respect to nitrogen and phosphorus contamination. Tachibana et al. (2001) reported that non-point pollution greatly influences the water quality of the Ishikari River. Reuse water may contain higher levels of pollutants from surface runoff, i.e., sediments, pesticides, and nutrients, than natural streams. Water reuse is one of the most important factors for water quality degradation downstream of the Shinotsu Canal. Polluted water also affects the downstream agricultural watersheds and aquatic biota of the Shinotsu Canal. However, some natural and agro-environmental problems associated with water use and quality, land use, and management of the Shinotsu Canal still remain to be solved. The objective of this study was to evaluate the influences of agricultural land and water use activities on the water quality of the Shinotsu Canal.

MATERIALS AND METHODS

The investigation was conducted on the Shinotsu Canal in the Shinotsu district of the southern part of the Ishikari River basin in the west-central part of Hokkaido, northern Japan (Fig. 1). Its agricultural catchment area (CA) is 10,864 ha, and the main crops are rice, wheat, maize, onion, vegetables, etc.

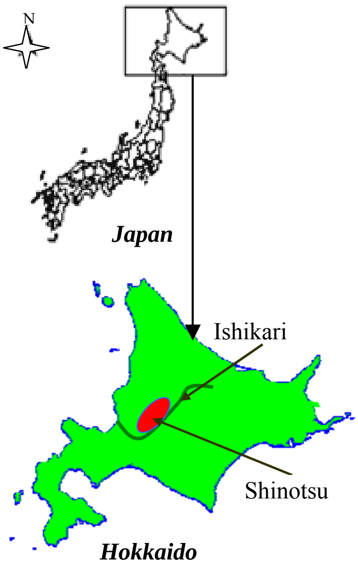

Fig. 1 Location map of study

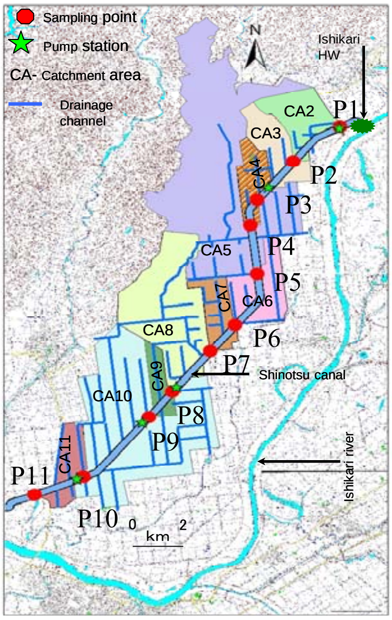

Fig. 2 Investigated area of Shinotsu

The annual average precipitation is 1024 mm and most of it falls as rain from June to September. The annual snowfall is 9500 mm and occurs from mid November to April. Maximum snowfall occurs in January. The annual temperature ranges from a minimum of −7.4°C in January to a maximum of 23°C in August. The study area is within the temperate zone, so there are four seasons. However, we divided the study year into five periods: puddling (PP; May), normal irrigation (NIP; June~August), post irrigation (PIP; September~mid November), snow covered (SCP; mid November~mid March), and snow melting (SMP; mid March~April). Water samples were collected manually from May 2006 to April 2009 from upstream to downstream at 11 points along the Shinotsu Canal. Sampling points are indicated by P1~P11 in Fig. 2. Samples were collected 10 times during the PP, 11 times during the NIP, 11 times during the PIP, 9 times during the SCP, and 8 times during the SMP. In the laboratory, a portion of each sample was filtered through pre-rinsed 0.2-µm filter paper, and the nitrate nitrogen (NO_3-N) concentration was determined using ion chromatography.

Water samples were analyzed according to the Japanese Industrial Standard (JIS). SS was determined gravimetrically by suction filtration, and total nitrogen (TN) and total phosphorus (TP) were determined by UV spectrophotometry. The investigated area was determined using ArcGIS 9.2 modeling software. The total catchment area was divided into 10 sub-catchment areas, represented as CA2~CA11 (Fig. 2). The catchment area for the P2~P11 sampling points was also represented by CA2~CA11. The catchment and sub-catchment areas were delineated on 1:25,000 scale digital topographic maps, and land use was categorized by the supervised classification method (Satellite Pourl Observation deta Terra (SPOT) of June 4, 2006, and Advance Land Observing Satellite (ALOS) data of July 28 and Aug 9, 2006). Simple linear regression was applied to evaluate the relationships of the paddy and upland fields with SS, TN, and TP for each period.

RESULTS AND DISCUSSION

There was a significant difference in nutrient concentrations among the sampling points. The SS concentration showed its highest average value of 81 mg/L during the PP at P10 and the lowest value of 1 mg/L during the SCP at P1 (Fig. 3). During this period, maximum water is irrigated and there is excess used water runoff through the drains into the canal, which carries a high SS load.

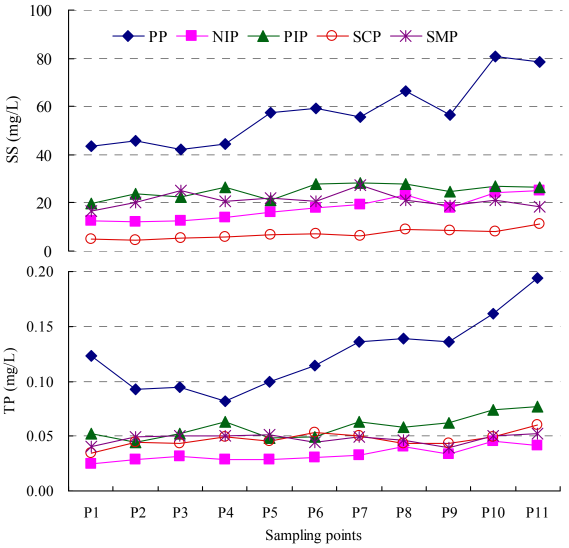

Fig. 3 Periodic variations in SS and TP

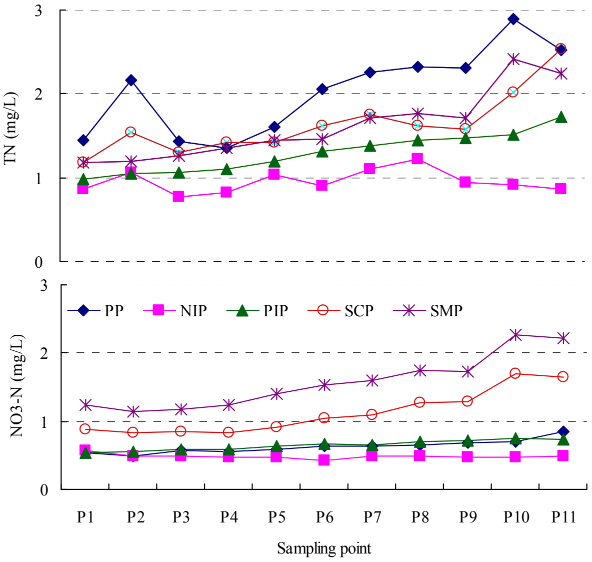

Fig. 4 Periodic variations in TN and NO_3-N

Russell et al. (2001) found that farm fields in agricultural watersheds are the major sediment sources and determined the rate of soil loss from fields in response to various agricultural practices. The lowest SS value occurred during the SCP, because the land surface is covered by snow, and there are no land use activities. We found an increasing trend in the SS concentration in the order of SCP < NIP < SMP < PIP < PP. The TN and TP concentrations are higher during the PP (Fig. 3, 4), because chemical fertilizers are applied during transplanting, resulting in an increase in dissolved nutrient concentrations in the drain water and discharge of the nutrients via surface drainage water into the Canal. It has been reported that the nitrogen and phosphorous concentrations in drainage water increase during the PP, transplanting, and when fertilizer is applied (Takeda et al., 1991; Feng et al., 2004). Hiroaki et al. (2009) also suggested that TN and TP are high during the puddling and transplanting periods in Shimane Prefecture, Japan. During the NIP, the average TN and TP concentrations were lower than those during others periods, which might have been due to the retention time of water in the paddy fields during the growing season for plants with high nutrient uptake. Tomas et al. (2003) and Braskerud (2002) reported that the retention of water in paddy fields during the growing season induces purification mechanisms, such as denitrification, plant uptake, or sedimentation, similar to those present in natural and artificial wetlands. The average SS, TN, and TP concentrations during the PIP, SCP, and SMP were relatively higher than those during the NIP. Because no agricultural activities are conducted in this area during the PIP, SCP, and SMP, it is believed that residual soil nutrients are leached by rain and snowmelt water, which subsequently flow into the Canal. The NO_3-N concentration at P10 during the SMP was 2.26 mg/L (Fig. 4). During this period, snow melt continuously percolates into the soil, and nitrogen fertilizer decomposes to NH_4+ through nitrification, which oxidizes to NO_3- under aerobic conditions. Nitrate is water soluble and is lost through leaching in melting water and increased drainage discharge though the Shinotsu Canal, which had high NO_3-N concentrations during the SMP. A significantly higher NO_3-N concentration is found in agricultural streams and rivers during high flow conditions (Castillo et al., 2000). A recent study indicated that the large loading of nutrients into rivers occurs during the early stage of the snowmelt period in Hokkaido (Hayakawa et al., 2003).

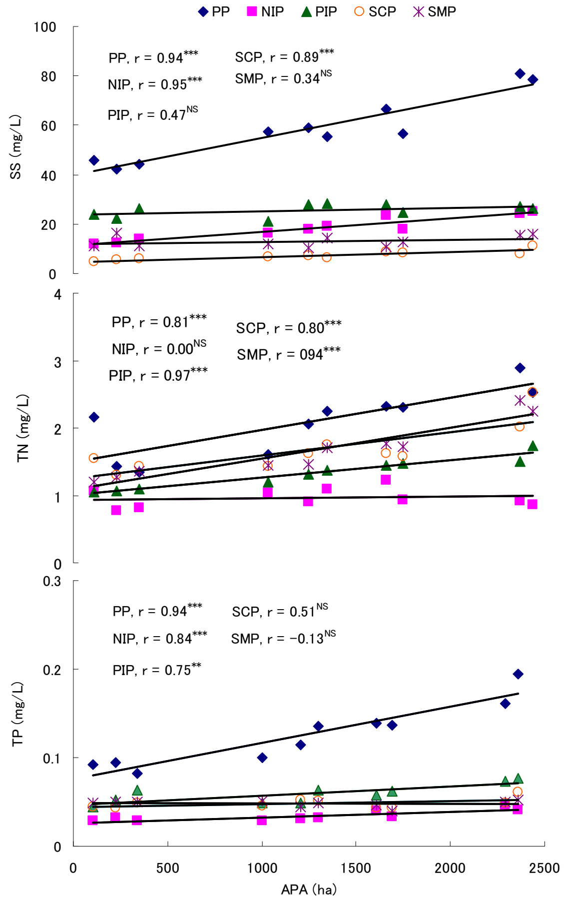

Fig. 5 Relationship between APA and nutrients

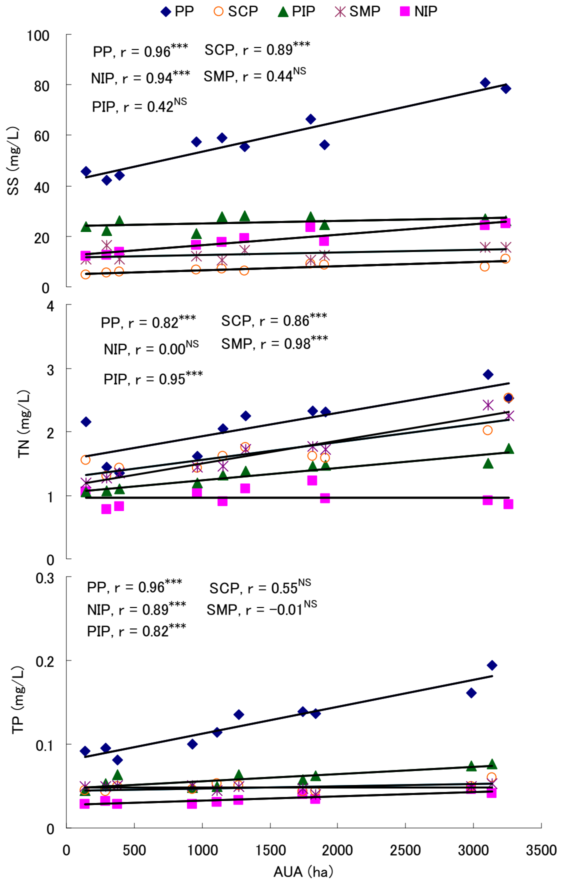

Fig. 6 Relationship between AUA and nutrients

There was a relationship between water quality parameters (SS, TN, and TP) and the accumulated paddy field area (APA) and accumulated upland area (AUA) during the PP, NIP, PIP, SCP, and SMP. APA is calculated as in Eq. (1)

$$APA\ i = \sum\nolimits^{i}_{2} PAi = PA2 + PA3 + \cdots + PAi, \tag{1}$$

where (i = 2~11). AUA is calculated in the same manner. Linear regression results showed a highly significant correlation between APA and SS during the PP (r = 0.94), NIP (r = 0.95), and SCP (r = 0.89) ($P < 0.001$; Fig. 5), as well as between AUA and SS during the PP (r = 0.96), NIP (r = 0.94), and SCP (r = 0.89) ($P < 0.001$; Fig. 6) due to intensive agricultural activities during the PP and NIP. There were no such relationships during the PIP and SMP, because agricultural activities were absent. Hamill and McBride (2003) reported that lowland stream sediments were highly associated with intensive agricultural land use in Southland, a New Zealand province. TP showed a similar trend of correlations with both APA and AUA as SS did, but not during the SCP. It has been reported that the concentration of phosphorus is more transport limited because phosphorus adsorbs on sediments and is therefore lost through runoff and erosion (Heathwaite et al., 2000).

The TN concentration showed a strong and significant relationship with AUA during the SMP (r = 0.98) and PIP (r = 0.95) (P <0.001; Fig. 6). Similarly, APA and TN during the SMP (r = 0.94) and PIP (r = 0.97) were significantly correlated (P < 0.001; Fig. 5). There was also a highly significant correlation between TN and AUA during the PP (r = 0.81) and SCP (r = 0.80) and between TN and APA during the PP (r = 0.82) and SCP (r = 0.86) (P < 0.001). However, there was no relationship during the NIP for either APA or AUA. There was a stronger relationship with TN during the SMP than during other periods because melting water percolates into the soil and the surplus nitrogen is discharged with melted water. Osborne and Wiley (1988) examined an east Illinois watershed and found that median nitrate concentrations are correlated with agricultural practices during the high-flow spring period and are correlated with urban land use during the low-flow summer and autumn. Turner et al. (2001) reported that nitrogen concentrations in streams, rivers, and lakes are highly related to landscape characteristics and land use.

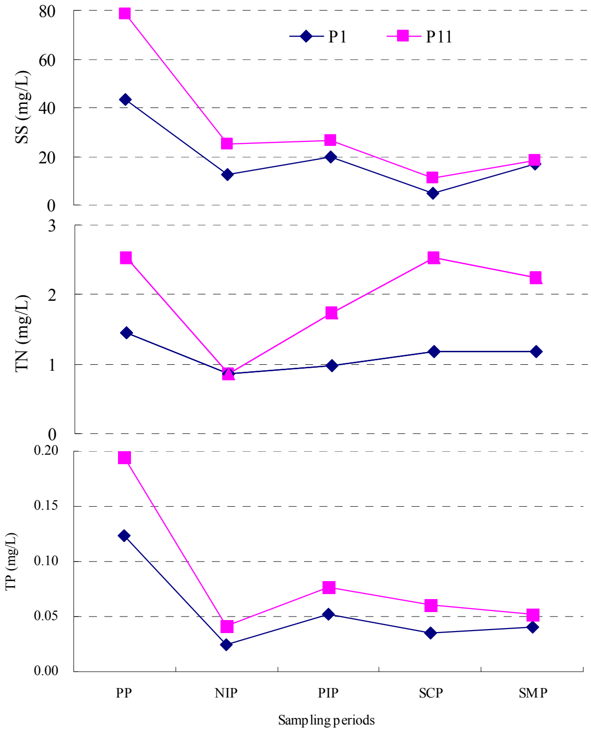

Fig. 7 Comparisons of P1 and P11 streams nutrients in each period

The inlet (P1) of the Shinotsu Canal is at the Ishikari River, which flows downward, and the outlet is at the lower reach (P11) of the Ishikari River. Therefore, P1 is the upstream point and P11 is the downstream point. Thus, P1 represents the Ishikari River water quality and P11 represents the Shinotsu Canal water quality. The SS and nutrient concentrations, except TN, were higher downstream than upstream during every period (Fig. 7). The TN concentration had its lowest value during the NIP, because during that period, paddy plants are in the growing stage and higher amounts of nutrients are discharged than during other periods (Fig. 7). Especially during the PP, the SS and nutrient concentrations were higher downstream than upstream due to puddling activities in the paddy field and the frequent re-use of drainage water as irrigation water at the lower-stream agricultural area of the Shinotsu Canal. Water reuse and land use activities affect water flow from upstream to downstream, so SS and nutrient concentrations increase downstream and degrade water quality of the Shinotsu Canal and the lower reaches of the Ishikari River.

CONCLUSION

This study has shown that there are periodic stream nutrient fluctuations in the Shinotsu Canal. The SS, TN, and TP concentrations were highest during the PP and lowest during the SCP, except for TN during the NIP. NO_3-N concentration was highest during the SMP and lowest during the NIP. APA and AUA were significantly correlated with stream SS during the PP, NIP, and SCP, whereas no relationship existed during the PIP and SMP. The TN concentration was highly associated with APA and AUA during the entire study period, except during the NIP. The concentration of TP had no relationship with APA and AUA during the SCP and SMP, but a strong relationship was found during the PP, NIP, and PIP. It was also found that nutrient concentrations were higher at P11 than at P1 during every period, except for TN during the NIP. Though P11 showed higher values of concentrations during almost every period, there must be an impact of land use and water management on the agricultural area of the Shinotsu Canal. Therefore, it can be concluded that land and water use for agriculture, the seasonal characteristics of meteorology, and fertilizer management reduced the water quality of Shinotsu Canal and ultimately of the Ishikari River.

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