Research article

Nonpoint Source Water Pollution in Rural Areas in the Upper Ayase River Basin of Saitama Prefecture in Japan

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Abstract Nonpoint source pollution of water is an important environmental issue in Japan. In this study, water samples were collected from 12 selected sites and 4 different periods at the upper stretch of the Ayase River Basin located in Saitatma prefecture, and analyzed. The results revealed that the water in the study area was in eutrophic condition and the extent of pollution varied in different ranges depending on the sites' ambient conditions. Moreover, the growing to harvesting period of crops (mainly mid-September to late-October) showed peak-values for nitrogen/phosphorus levels in water samples. The study recommends that either a strict policy needs to be incorporated or much more care should be taken to control pollution from agricultural runoffs.

Keywords water quality, nonpoint source pollution, agricultural water, Ayase River Basin

INTRODUCTION

While agriculture is the single largest user of global freshwater resources, surface water quality detriment in agricultural watersheds is a major environmental concern in many parts of the world. In Japan, efforts over the recent decades to address point source pollution from industrial and municipal sources have greatly improved the water quality. However, problems related to nonpoint sources of pollution, e.g. agricultural sources still remain to be solved (Inoue, 2003; Roy, 2007, Takeda et al., 2009). Depending on the land uses and management practices, different types of nutrients, pesticides, fecal coliforms and sediments from agricultural activities are acknowledged to be among the main causes of these problems (Kawashima, 1996; Takeuchi et at., 2005; Matsuno et al., 2007; Kawamura and Ebise, 2014).

The Ayase River, which flows through the Saitama prefecture and Tokyo's metropolitan city, has been ranked as one of the country's most polluted rivers while domestic and industrial effluences were detected as the prime causes for its pollution. The central government (Ministry of Land, Infrastructure and Transport; MLIT) with the cooperation of local authorities/communities adopted different measures to stop the inflows of domestic and industrial wastewater into the rivers which resulted in the satisfactory recovery of the water quality in the Ayase River (MLIT, 2015). Also the government policy (adopted in 1987) facilitated to control such point source pollution activities. However, for nonpoint sources, although some monitoring guidelines and activities have been launched in recent years by the central government and local authorities, there is no established national regulation/act or policy to stop the pollution caused mainly from agricultural effluents. Therefore, individual consciousness and activities of farmers remain as the most dominating factors to maintain the water quality in the public water bodies such as lakes, ponds, and rivers of a locality in Japan. It is noted here that the amount of nitrogen/phosphorus input and pesticides per hectare of agricultural lands in Japan is remarkably high compared to other developed countries in the world (Parris, 2011). Therefore, even the central government and the local authorities maintain the water quality of the public waterbodies, such as sampling and monitoring works in the Ayase River are carried out periodically by the respective bureaus; it could be difficult to determine the short-periodic (daily and weekly) load from every individual farmland and settlement to the river. However, to reduce the non-point source pollution, it is important to regular monitor the water quality at a micro level in public waterbodies that reside next to agricultural settlements.

This study focuses on the upper reach of the Ayase River Basin, which lies in the Saitama prefecture and is a highly-dense and famous agricultural suburb. Along with other tributaries of the Ayase River in the upper basin, the Minumadai irrigation canal, excavated in 1728, functions as the trunk waterway to irrigate more than 12,000 hectares of farmland (Shibata, 1985). In short, the upper Ayase River Basin is a rural suburb characterized by a dense intermixtures of farmlands and farmers' residences, and this study analyzed the spatial (site-specific) and temporal (seasonal) status of water quality linked to agricultural activities in the area. Accordingly, water samples from the mainstream and tributaries of the Ayase River as well as primary, secondary, and tertiary canals of the Minumadai irrigation canal were collected periodically as the water passed through different agricultural settlements, and analyzed.

The objective of this study is to evaluate the spatial and temporal variations in the water quality of the streams and canals in the upper Ayase River Basin as well as to identify different variation patterns associated with either seasonal variations or pollution sources in the area.

METHODOLOGY

Study Area and Sampling

The length of the Ayase River is 47.6 km with a total basin area of 176 km^2. In fact, agricultural effluent is the main water source of the Ayase River, and the basin is characterized by a level to undulating topography. Average annual precipitation in the vicinity swings from 1100 to 1800 mm. While most of the lands in the upper basin (present study area) are occupied mainly with paddy fields, uplands, and farmers' residences, the middle and the lower basins are full of residences, office-buildings and small- to medium-sized factories. The sampling sites were selected based on preliminary surveys and information collected from the local government authorities. As seen in Fig. 1, the study area (in the upper Ayase River Basin) overlaps the borders of three neighbor wards, namely the Minuma ward, Midori ward, and Iwaki ward, all of which incorporate agricultural fields with numerous surface inlets and outlets of the Ayase River and its tributaries as well as the Minumadai irrigation canal and its diversions. Also in the study area, the lower reach of the Fukasaku River joins the upstream of the Ayase River from the north (Fig. 1). Sampling of surface water from these waterways was carried out from July 2014 to December 2014. The average monthly precipitation was 143 mm in July, 100.5 mm in August, 71 mm in September, 300.5 mm in October, 74 mm in November and 45.5 mm in December (Japan Meteorological Agency). Within this period, water samples were collected in daytime from 12 locations (waterways) at 4 different intervals: July 23 (1st sampling); September 19 (2nd sampling); October 26 (3rd sampling): and December 3 (4th sampling) in 2014. While the 1st sampling covered seeding, sowing, and transplanting activities of paddy and upland crops and was labeled the "summer-irrigation" period, the 2nd sampling represented the peak-time of growing and fertilizer use and was labeled the "fall-growth" period. Also, the 3rd sampling time was labeled the "fall-harvest" period, and the 4th sampling time was labeled the "winter-fallow" period.

Samples of surface water were collected in polyethylene bottles, brought back to the laboratory, and preserved and processed for major physico-chemical analyses while *in-situ* measurements were carried out for several parameters. Specifically, the position of each sampling site was recorded with a Global Positioning System receiver (Poke-Navi Map 21EX; Empex Instruments Inc., Japan), the Dissolved Oxygen (DO: mg L-1) was measured at each site by using a portable DO meter (YK-22DO; Lutron Co. Ltd.), and air and water temperatures (°C) were measured by using a mercury thermometer (0-100°C). Table 1 summarizes the sampling details of the survey.

Measurement and Analysis

The pH and Electrical Conductivity (EC: mS cm^{-1}) of the water samples were measured with a pH meter (Twin pH B-212; Horiba, Japan) and an EC meter (B-173; Horiba, Japan), respectively. The

Chemical Oxygen Demand (COD) of the water samples was measured by using a compact COD analyzer (TNP-10 coupled with a TNP-HT heater; TOA-DKK Co., Japan). Moreover, the concentrations of the major water-polluting ions (NO_3^- , NO_2^- , NH_4^+, PO_4^- , SO_4^{2-} , Cl^- , Na^+, K^+, Mg^{2+}, and Ca^{2+}) were measured with the ion-chromatography method (833 Basic IC plus ion-chromatograph, 863 Compact Autosampler; Metrohm).

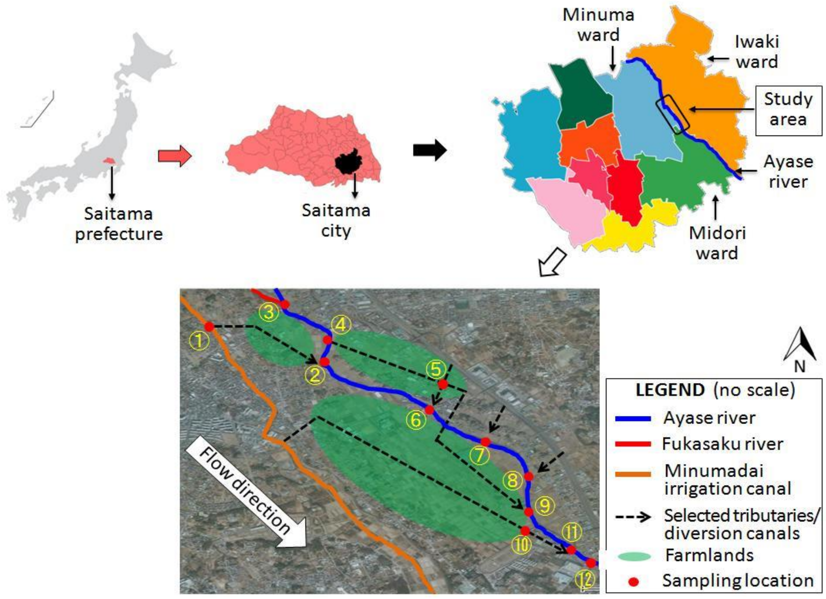

Fig. 1 Study area (the upper Ayase River Basin) showing the sampling sites of agricultural water

Table 1 Detail of survey showing sampling period and positions in different sites of the study area, 2014

Sampling location	Characteristics of the sampling site	Sampling position	
		Latitude	Longitude
1	Water intake point of the MIC*	35° 41' 18.78" N	139° 45' 24.37" E
2	MIC* water discharge outlet to the Ayase River	35° 56' 5.27" N	139° 40' 55.62" E
3	Joining point of the Fukasaku River	35° 56' 23.03" N	139° 40' 47.49" E
4	Upper reach of the Ayase River/OSG* irrigation canal	35° 56' 30.89" N	139° 40' 56.13" E
5	OSG* drainage canal outlet	35° 56' 57.20" N	139° 41' 34.15" E
6	Drainage outlet of OSG and others to the Ayase River **	35° 55' 47.20" N	139° 41' 31.44" E
7	Drainage outlet to the Ayase River (mainly uplands)	35° 55' 32.24" N	139° 41' 57.06" E
8	Drainage outlet to the Ayase River (near a factory)	35° 55' 11.7" N	139° 42' 1.42" E
9	OSG* drainage canal final outlet	35° 55' 10.4" N	139° 41' 58.89" E
10	Drainage outlet to the Ayase River (paddy fields)	35° 54' 55.5" N	139° 42' 8.15" E
11	Lower reach of the Ayase River	35° 54' 59.42" N	139° 42' 6.75" E
12	Discharges mixed from locations (sampling sites) 10 and 11	35° 54' 42.89" N	139° 42' 22.54" E

Notes: * *MIC indicates the Minumadai Irrigation Canal, and OSG the Ohashi Sluice Gate.*
*** In this sampling site, discharges from other outlets mixed with the discharges from the Ohashi Sluice Gate drainage canal.*

RESULTS AND DISCUSSION

Spatio-temporal Variation in Water Quality

The average values of the parameters measured at the 12 selected sampling sites in the upper Ayase River Basin are summarized in Fig. 2 (2.1 to 2.15). The temperature of water samples in all the measured periods showed no extreme variation from the average value at the time of collection, which decreased with the seasonal ambient temperature. However, the pH value at sites 1, 4, and 9 (Fig. 2.2 and Table 1) showed little variation (alkaline) in the fall-growth and fall-harvest periods. For EC, sampling site 7 (upland outlet; Fig. 2.3) particularly showed larger values (26 to 81 mS cm^{-1}) in all sampling periods while sampling site 1 (Minumadai Irrigation Canal: MIC intake) showed extreme temporal fluctuation compared to the other sites (0.18 to 73 mS cm^{-1}). Fig. 2.4 shows that the DO values in the sites increased gradually from the summer-irrigation to winter-fallow period. Since DO is inversely dependent on temperature, the tendency is natural. With different ranges of spatio-temporal fluctuations, the water in most of the sampled sites showed increased DO levels. The samplings were carried out in daytime and under eutrophic conditions; DO greatly increases during the day, but is greatly reduced after dark. The tendency of elevated COD (above 10 mg L^{-1}) at several sites, particularly at site 7 (upland outlet) and site 8 (factory outlet) in the fall-harvest period, site 10 (paddy field outlet) and site 11 (lower reach of the Ayase) in the summer- irrigation period indicated the water bodies had suffered some kind of deterioration due to the discharges of effluents (see Fig. 2.5). Figs. 2.6, 2.7 and 2.8 show the forms of nitrogen (NO_3^- , NO_2^- , and NH_4^+)-effects to the water quality, all of which were caused by runoffs from fertilized lands.

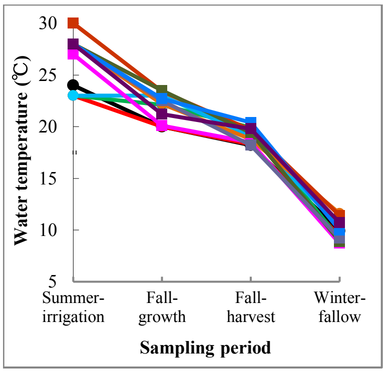

Fig. 2.1 Periodic variation in temperature

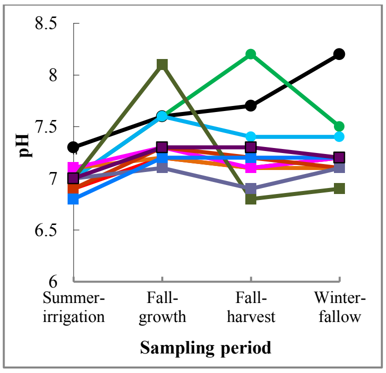

Fig. 2.2 Periodic variation in pH

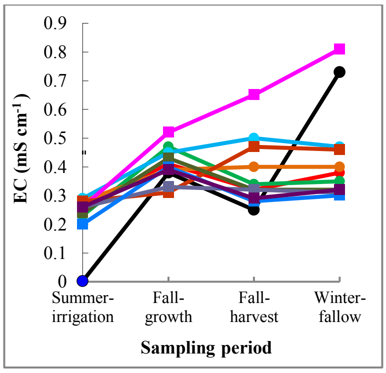

Fig. 2.3 Periodic variation in EC

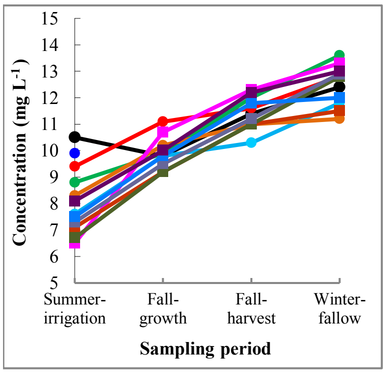

Fig. 2.4 Periodic variation in DO

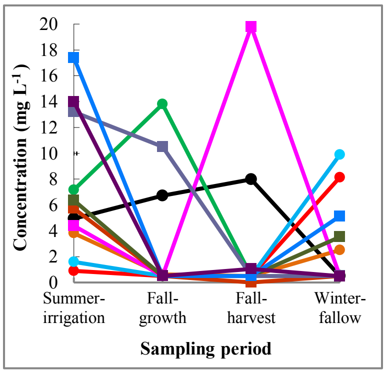

Fig. 2.5 Periodic variation in COD

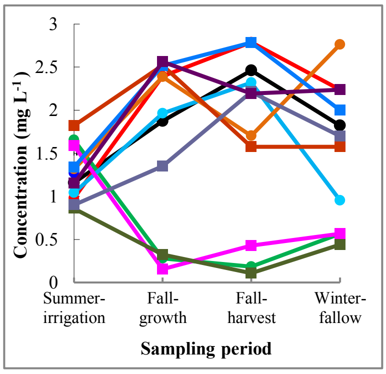

Fig. 2.6 Periodic variation in NO_3^-

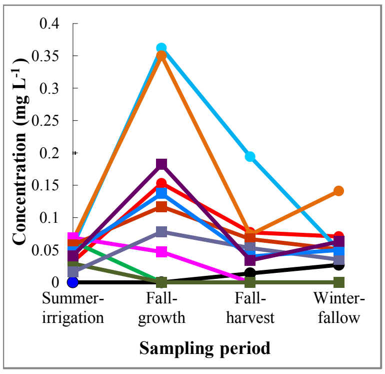

Fig. 2.7 Periodic variation in NO_2^-

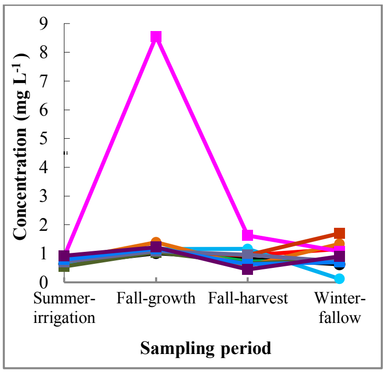

Fig. 2.8 Periodic variation in NH_4^+

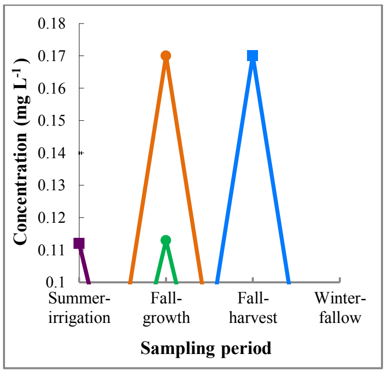

Fig. 2.9 Periodic variation in PO_4^-

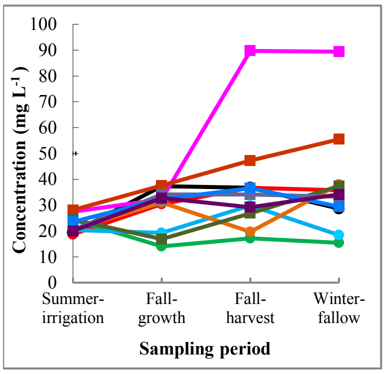

Fig. 2.10 Periodic variation in SO_4^{2-}

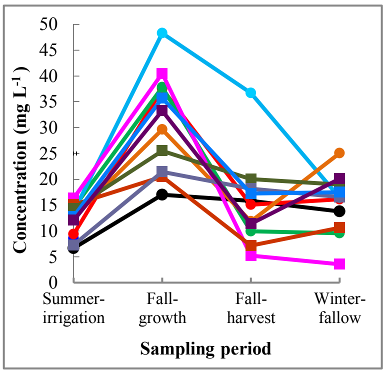

Fig. 2.11 Periodic variation in Cl^-

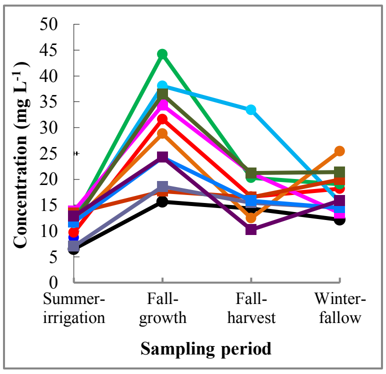

Fig. 2.12 Periodic variation in Na^+

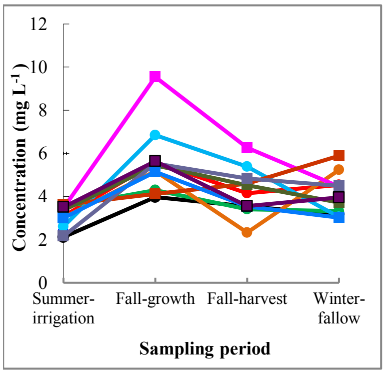

Fig. 2.13 Periodic variation in K^+

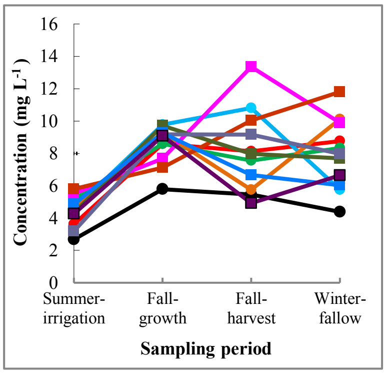

Fig. 2.14 Periodic variation in Mg^{2+}

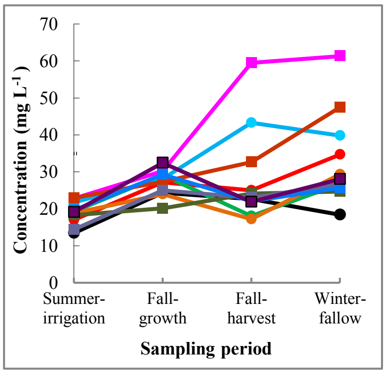

Fig. 2.15 Periodic variation in Ca^{2+}

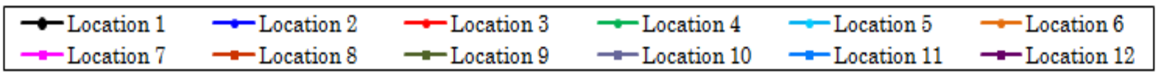

Fig. 2 (2.1 to 2.15) Periodic variation in physico-chemical parameters of water at 12 selected sampling locations(sites) in the upper reach of the Ayase River Basin in Saitama prefecture, Japan (2014)

Among these items, nitrates (NO_3^-), which have an attraction for soil particles, dissolve in water more readily than phosphates (PO_4^-) and are a better indicator of possible non-point pollution of water while the oxidized/temporary ammonium (NH_4^+) and nitrite (NO_2^-) forms are considerably more toxic. All sites except 4, 7, and 9 showed elevated amounts of nitrates in water throughout the samplings (Fig. 2.6). In addition, the fall-growth season showed elevated amounts of nitrites in water samples at site 5 (Ohashi Sluice Gate: OSG outlet) and site 6 (outlet of OSG and others) while site 7 (upland outlet) showed elevated amounts of ammonium. Fig. 2.9 shows the traceable amount of orthophosphate (the detection limit of phosphate is 0.1 mg L^{-1} of the ion-chromatograph used in the measurement) produced by runoffs at sites 3, 4, 6, 11 and 12 from the summer-irrigation to fall-harvest period. Fig. 2.10 presents the distribution of sulfate (SO_4^{2-}) at different sites where site 7 (upland outlet) and site 8 (factory outlet) showed elevated amounts in the fall-harvest and winter-fallow periods. Sulfate is an inorganic anionic substance that forms salts with sodium, potassium, magnesium and other cations. Both sites 7 and 9 along with site 5 (OSG outlet) showed elevated amounts of cations (Na^+, K^+, Mg^{2+}, and Ca^{2+}) between the fall-growth and winter-fallow periods (see Fig. 2.12 to 2.15). Increases in chloride (Cl^-) loads from the summer-irrigation period to the fall growth period (Fig. 2.11) might be related to variety of factors such as fertilizers and agricultural chemicals in irrigation water used in different fields. In particular, site 5 (OSG outlet) showed elevated amount of chloride during the fall-growth period.

Analysis from the Existing Water Quality Standard Perspective

The sampling sites included multiple inflows and outflows of the Ayase River, and some of these inflows and outflows were used as irrigation water sources. Lately, the irrigated water has been discharged to the mainstream directly or through other diversion canals. In Japan, since there is no regulatory act such as the Total Maximum Daily Load (TMDL) in USA, the status of agricultural water quality in the studied area can only be judged from the country's existing standards for irrigation water quality in paddy fields (MAFF, 2009). On that basis, pH values at sites 1, 4 and 9 in different sampling periods exceeded the recommended limit (6.0 to 7.5). Regarding EC, the values in most of the sites exceeded the limit (below 0.3 mS cm^{-1}) from the fall-growth to winter-fallow period. DO with a spatio-temporal average value of 10.4 mg L^{-1} was much higher than the prescribed limit (above 5 mg L^{-1}), and COD values in several sites and periods exceeded the recommended value (below 6 m L^{-1}). For paddy field water, the recommended amount for total nitrogen (T-N) is less than 1 mg L^{-1}; however, only the nitrate-part in most of the samples exceeded the limit. The measured values clearly indicated that the water flowing through the canals and streams in the study area were oversupplied with nutrients, which is called eutrophication.

At the same time, the country has a strict regulation for the environmental water quality in a river, and therefore, the water quality in a river is usually judged based on the country's environmental standard (MOE, 2015). Both standards share some common items such as pH, EC, DO, COD, T-N and several heavy metal constituents (As, Zn and Cu). However, the latter standard is stricter and is similar to other global standards of developed countries. For example, in Japan, public waterbodies such as lakes, ponds, and rivers are classified into several groups, and the health-hazard parameters (Cd, Pb, As, PCBs, Hg etc.) are monitored regularly by responsible authorities. However, the status of agricultural water is dependent completely upon the farmers' personal attitudes and practices. Since many agricultural canals are directly or indirectly connected with public rivers, keeping the agricultural waterbodies healthy is a prerequisite of maintaining the environmental health of rivers and seas.

CONCLUSION

The upper reach of the Ayase River Basin is a typical agriculture-dominated suburb and the Ayase River itself is an agricultural effluent-based stream. In this study, multiple sites were selected on major waterways for more complete characterization and to allow examination of possible impacts related to various land use practices. Results of this study reveal that, in general, mainstream water quality (the Ayase River) as well as the discharge canals (upper stretch of the Ayase basin) is linked to the ambient land-use practices, and agricultural land flushes more water-polluting agents into the canals and streams between the growing and harvesting seasons, which is early September to late October in the study area.

The control of water pollution from agriculture clearly needs to occur within broader integrated water resource management frameworks that ensure linked land water use together with re-use management. In addition, sustained regulation and water quality monitoring activities at all scales are essential. The findings of this paper provides baseline information and existing status of a rural suburb with agriculture-derived water-pollution, which could be valuable to the design of future participatory (individual and community-based) and policy-making strategies to stop nonpoint source pollution in waterbodies.

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