ESTIMATION OF ORGANIC POLLUTANT AND NUTRIENT LOADINGS IN A RURAL RIVER

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ABSTRACT

The runoff loadings of organic pollutants and nutrients from paddy fields are higher during the rice-transplanting period because the farmer puddles the paddy fields and adds large quantities of fertilizers to the fields at that time. From 1992 to 1994, water samples were collected at five stations on a rural river during rice-transplanting period. In addition, rain event observations were conducted. Particulate organic pollutant and phosphorus concentrations were higher than dissolved forms, and the particulate nitrogen concentration was lower than the dissolved concentration. In addition, the concentrations of particulate forms increased with increases in the concentration of suspended solids and with increases in flow, although the concentrations of dissolved forms did not change. We evaluated the runoff loadings per watershed area during the rice-transplanting period for each of three years. In 1992, the specific flow and nitrogen levels were about three times higher than they were in the other observation years. However, the ratios of organic pollutant- and phosphorus-specific loadings in 1992 to those in the other two years were greater than that of specific flow, because the increasing amounts of particulate forms were higher than those of flow and dissolved forms.

KEYWORDS: Paddy field, particulate, pesticide, river, runoff

INTRODUCTION

In Japan, organic pollutant and nutrient loadings from point pollution sources decreased due to the establishment of standards for emission and fundamental policy related to the reduction of the pollutant load. However, loadings from non-point pollution sources, especially cultivated areas, remain an important problem regarding the improvement of surface water quality (Inoue *et al*., 1983, Yamamoto *et al*., 2000, Umemoto *et al*., 2001). As about 55% of Japan's cultivated ground is used as rice paddies, pollutant loadings from paddy fields create eutrophication problems in downstream areas (Ebise *et al*., 1993).

The runoff loadings of organic pollutants and nutrients from paddy fields are higher during the rice-transplanting period because the farmer puddles the paddy fields and adds large quantities of fertilizers to the fields at that time. Although the irrigation water for paddy fields in Japan is generally managed artificially, a portion of the fertilizers applied to the fields is discharged into rivers by inundation water released for rice transplanting and drainage during rain events.

The purpose of our study was to determine the runoff loadings of organic pollutants and nutrients from non-point sources. This paper focuses on cultivated areas, especially paddy fields, and concentrations and loading changes during the down-flow.

OBSERVATION AREA AND MATERIALS

River water samples were collected from between 1992 to 1994 at 5 stations on tributaries and on the main stream of the Koise River (catchment area, 218.6 km^2), shown in Figure 1, which flows into Lake Kasumigaura, the second largest lake in Japan. The largest portion of the Koise river watershed is mountainous. The ratio of paddy fields to the catchment area varies from 3.1 to 12.2%, and paddy fields constitute about half of the cultivated area (Table 1). The constitution ratio of cultivated areas in the Koise River watershed is the normal in Japan's rural area.

Most of the farmers puddle the paddy fields and apply fertilizer during late April, and after a few days transplant the rice seedlings. Afterward the farmers apply fertilizer several times during the primary growth period. Therefore the investigation period extended from late April to June, with observations made daily during the rice-transplanting period and weekly at the end of the investigation period. Numbers of investigation were 22 at 1992, 33 at 1993, and 34 at 1994. In addition, rain event observations were conducted at Site 2 throughout the study. When river water samples were taken, pH, electric conductivity, and river flow were measured.

The water samples were filtered through a GF/C filter (Whatman). After filtration, the filter was dried and the concentrations of suspended solids were measured, and afterwards particulate carbon (POC) and particulate nitrogen (P-N) were measured using a CHN Corder (MT-5, Yanaco Analytical Instrument). Unfiltrated samples were measured for biochemical oxygen demand (BOD), total chemical oxygen demand (T-COD_{Mn}), total phosphorus (T-P), and total nitrogen (T-N). Filtrated samples were measured for dissolved chemical oxygen demand (D-COD_{Mn}), dissolved organic carbon (DOC), dissolved phosphorus (D-P), and dissolved nitrogen (D-N). Particulate COD_{Mn} (P-COD_{Mn}) and particulate phosphorus (P-P) were calculated by subtracting dissolved material from total material. Total organic carbon (TOC) was the sum of DOC and POC. P and N were analyzed using an AutoAnalyzer (Bran+Luebbe) after digestion by potassium persulfate. BOD and COD_{Mn} were measured by means of the titration method, and DOC was analyzed using a TOC

Analyzer (TOC-500, Shimadzu Corporation). COD_{Mn} was oxidized using the potassium permanganate, and the value of COD_{Mn} was lower than that of COD_{Cr} using potassium dichromate, due to the weakness of the oxidative activity of potassium permanganate. The concentration of P-N measured using the CHN Corder was almost same as the difference of T-N and D-N (r=0.93, n=89, St.6).

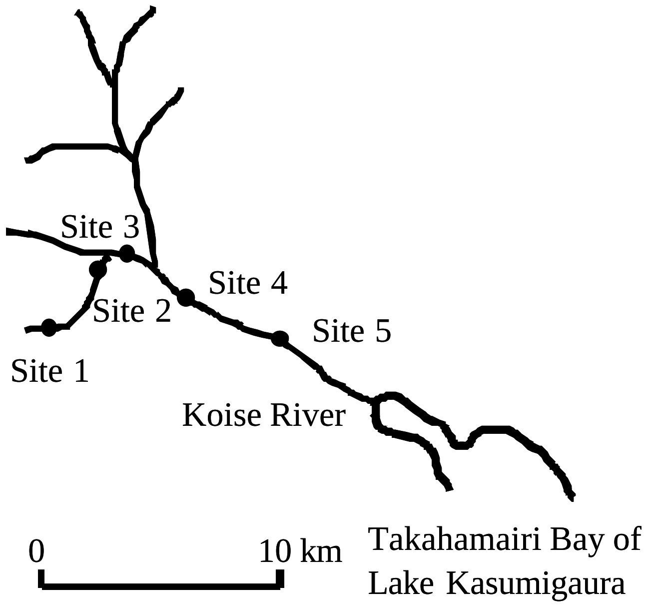

Figure 1 *Location of sampling point*

Table 1 Classified area by land use in observation basin

		Site 1	Site 2	Site 3	Site4	Site 5
Catchment area	(km^2)	9.4	18.2	39.8	127.5	147.4
Cultivated area	(km^2)	0.52	2.93	8.23	31.8	37.0
Cultivated area	(%)	(5.5)	(16.1)	(20.7)	(24.9)	(25.1)
Paddy field area	(km^2)	0.29	1.66	4.19	15.6	19.1
Paddy field area	(%)	(3.1)	(9.1)	(10.5)	(12.2)	(12.9)
Field area	(km^2)	0.07	0.46	1.61	8.7	10.1
Orchard area	(km^2)	0.05	0.46	1.63	4.3	5.5
Other	(km^2)	0.11	0.35	0.80	3.2	2.3

RESULTS AND DISCUSSION

Concentration change during rice transplanting period

In three years of observation, the concentration changes in organic pollutants and nutrients were showed the same pattern. As an example, Figure 2 shows the concentration and flow changes during the investigation period at Site 2 in 1992. POC (TOC - DOC), P-COD_{Mn} (T-COD_{Mn} - D-COD_{Mn}), and P-P (T-P - D-P) concentrations were higher than dissolved forms, and the P-N (T-N - D-N) concentration was lower than D-N. In addition, the concentrations of particulate forms increased with increases in the concentration of suspended solids and with increases in flow, although the concentrations of dissolved forms did not change.

On the 5th of May, suspended solids and particulate form concentrations were higher without increases in flow. On this day, many paddy fields in the chatchment area were in the midst of rice transplanting. Before rice transplanting, the farmers decreased the water level of paddy fields in order to allow the rice transplanter greater mobility. Therefore, inundation water containing a high level of suspended solids was discharged from the paddy fields, and thus concentrations of particulate forms were higher. D-N concentrations from late April to mid-May were higher compared with those after mid-May. This high concentration was caused by discharge from paddy fields.

Concentration change during rain event

Figure 3 shows the concentration and flow changes during rain event at Site 2 in 1994. When the flow increased, suspended solids and particulate form concentrations increased. The maximum concentrations of TOC, T-COD_{Mn}, and BOD were 48, 39, and 11 mg/L, respectively. These concentrations were 12.6, 7.2, and 3.1 times the concentrations before the flow increases, and these increases were caused by increases in particulate forms. This TOC ratio was highest, and that of BOD was lowest. This result suggests that the particulate organic pollutant whose level increased during rain event underwent a low degradation rate by microorganism, although particulate BOD was not analyzed.

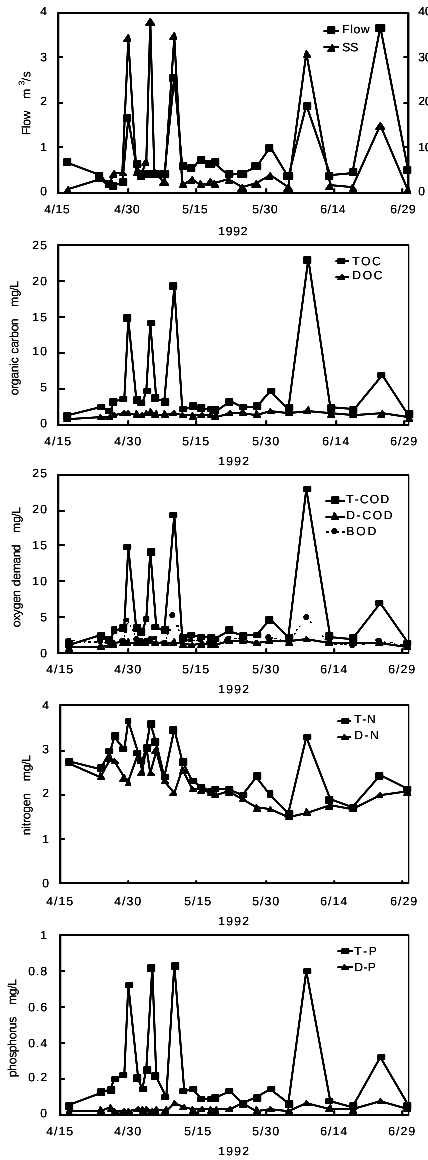

Figure 2 *Concentration changes in flow and organic pollutant and nutrients during rice transplanting period at Site 2 in 1992*

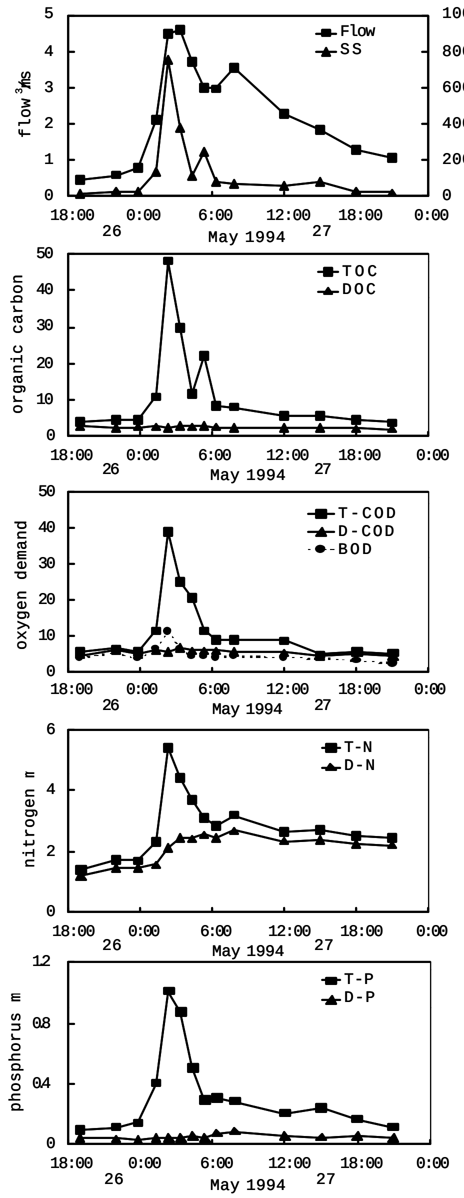

Figure 3 *Concentration changes in flow and organic pollutant and nutrients during rice transplanting period at Site 2 in 1994*

The maximum concentrations of P-N and P-P were 3.3 and 0.97 mg/L, and were 20 and 18 times those before the flow increases. The T-N/T-P ratio was lowest when T-P concentration was highest, but the P-N/P-P ratio did not nearly as extensive as change during rain event. It is considered that particulate nutrients were discharged from the same sources unrelated to flow change. The runoff characteristics of particulate nutrients were different from those of dissolved nutrients. Therefore not only total nutrients were analyzed but separation analyzes of particulate forms and dissolved forms were performed in order to necessary to elucidate the source of the nutrients.

As the organic pollutant and nutrients concentrations were higher during rain events, the amounts of their runoff loadings were higher, too. Therefore the evaluation of runoff loadings during rain events was very important in determining the exact runoff loadings from non-point pollutant sources.

Specific organic pollutant and nutrients loadings

We evaluated the runoff loadings per watershed area during the rice-transplanting period for each of three years; the results are shown in Table 2. The specific rainfall of the three years during this period was 5.41, 4.28, and 4.10 $10^3 m^3/km^2/day$; specific rainfall in 1992 was higher than that in other two years. Although the 1992/1993 rainfall ratio was 1.3, that of specific flow ranged from 1.7 at Site 6 to 3.1 at Site 3. As paddy fields used large amounts of irrigation water from the river, when clear weather continued, most of the river water was distributed over the paddy fields, and river flow was very low.

Table 2 specific flows and organic pollutant and nutrients loadings at observation stations

				organic carbon			COD_{Mn}			BOD	nitrogen			phosphorus		
	Year	Flow	SS	T	P	D	T	P	D	T	T	P	D	T	P	D
	1992	2.98	226	18.6	15.2	3.4	24.0	18.6	5.4	5.7	5.21	1.37	3.90	0.53	0.35	0.18
Site 1	1993	1.10	27	3.5	2.1	1.4	5.8	2.4	3.4	1.7	1.40	0.23	1.17	0.09	0.07	0.02
	1994	1.12	47	5.5	3.9	1.6	7.1	4.2	2.9	2.5	1.69	0.32	1.37	0.16	0.11	0.05
	1992	4.74	675	41.5	34.4	7.1	47.7	33.9	17.8	11.3	12.1	2.9	9.2	1.43	1.69	0.26
Site 2	1993	1.54	49	6.3	3.1	3.2	11.4	3.2	8.2	3.5	3.03	0.38	2.65	0.21	0.18	0.03
	1994	1.85	66	8.7	4.9	3.8	13.1	5.4	7.7	5.4	4.03	0.30	3.73	0.28	0.19	0.09
	1992	4.95	558	37.5	29.5	8.0	43.0	28.8	14.2	18.4	14.7	3.1	11.6	1.72	1.43	0.29
Site 3	1993	1.99	150	13.8	9.3	4.5	20.7	9.2	11.5	7.7	5.04	0.95	4.09	0.48	0.42	0.06
	1994	2.13	221	18.8	14.2	4.6	26.4	16.0	10.4	9.0	6.04	1.39	4.65	0.73	0.62	0.11
	1992	4.33	559	37.2	29.5	7.7	39.9	27.5	12.4	18.3	11.9	2.8	9.1	1.69	1.44	0.25
Site 4	1993	2.25	162	15.5	10.3	5.2	23.5	10.9	12.6	8.9	5.47	1.25	4.22	0.60	0.53	0.07
	1994	2.34	196	18.0	12.8	5.2	25.3	14.9	10.4	10.0	5.63	1.25	4.38	0.70	0.58	0.12
	1992	3.46	300	23.8	17.5	6.3	29.5	19.2	10.3	12.6	8.89	1.74	7.15	1.02	0.87	0.15
Site 5	1993	2.07	143	13.0	7.8	5.2	21.3	9.1	12.2	7.6	4.83	1.01	3.82	0.50	0.44	0.06
	1994	2.12	141	14.2	9.1	5.1	18.8	7.8	11.0	7.8	5.01	1.04	3.97	0.55	0.45	0.10

unit flow $10^3 m^3/km^2/day$, all other units $kg/km^2/day$

The ratio of cultivated area to watershed area at Site 1 was 5.5% which is lower than the other observation stations, and most of the watershed is mountainous. As the specific loads of organic pollutants and nutrients at Site 1 were lowest, the runoff loadings from forest were lower than those of cultivated areas. Runoff loadings from forest, especially particulate forms, depended on the specific flow, with the 1992/1993 ratio of particulate forms ranging from 5.3 at P-P to 7.8 at P-COD_{Mn}, though the ratio of specific flow was 2.7.

The specific loadings of the dissolved forms were higher downstream; however, the particulate form concentrations were highest at midstream. Downstream, since the slope was gentle and current velocity was low, particles in the river water settled on the riverbed.

The ratio of particulate loading to total loading, especially for phosphorus and TOC, was higher than that of particulate concentration. In 1992, the specific flow and nitrogen levels were about three times higher than they were in the other observation years. However, the ratios of TOC- and phosphorus-specific loadings in 1992 to those in the other two years were greater than that of specific flow, because the increasing amounts of particulate forms were higher than those of flow and dissolved forms.

CONCLUSION

Organic pollutant and nutrient concentrations and loadings were observed in a rural river during the rice-transplanting period. Concentrations of particulate forms increased with increases in suspended solids that occurred during rain events and inundation water was discharged from the paddy fields. Concentrations of dissolved forms were almost constant in the increasing flow. During rain events, when flows and suspended solids increased, particulate forms increased. Runoff loadings from forest and cultivated areas, especially those of particulate forms, depended on the specific flow, because the increased amounts of particulate forms were higher than those of flow and dissolved forms.

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