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Fecal indicator concentrations of surface runoff in rural watersheds, Korea

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ABSTRACT

To evaluate fecal contamination discharged from diffuse sources, flow rates and fecal indicator microorganism concentrations of rainfall runoff draining three rural watersheds were monitored. Land uses of the study watersheds were mainly unpolluted forestry and crop field with area of 14–70 ha. Monitored fecal indicators were total coliform (TC), fecal coliform (FC), *Escherichia coli* (EC), and fecal streptococcus (FS). Membrane filtration technique was adopted to measure all fecal indicators. Event mean concentrations of each fecal indicators were; TC was 2.32×10^2 to 3.68×10^5 CFU/100 ml; FC was 2.29×10^2 to 1.66×10^5 CFU/100 ml; EC was 1.76×10^2 to 1.21×10^2 CFU/100 ml; and FS was 1.42×10^2 to 8.48×10^4 CFU/100ml.

Keywords: Coliform; Diffuse sources; Event mean concentration; Fecal contamination; Rainfall runoff; Water quality

1. Introduction

As recreational purpose of surface water is more emphasized, many concerns have been raised recently about the personal hygiene and waterborne pathogens. Pathogens are considered to be representative of those associated with waterborne disease include enteric viruses derived from human fecal contamination, bacterial pathogens, represented by *Escherichia coli* O157:H7, and the protozoan pathogens *Cryptosporidium* and *Giardia* [1, 2].

Pathogen levels in the water can be estimated by measuring the pathogen indicator microorganisms. Pathogen indicator organisms, often called indicator organisms, refer to pathogen associated microorganisms, typically chosen for easier isolation and identification of contamination [3, 4]. Total coliform, fecal coliform and *E. coli* (EC) are most commonly used indicator microorganisms. Enterococci and streptococci are also used in several precedent researched [5–7].

Forestry and agricultural land uses constitute 65% and 20% of land use in Korea. Even though most agricultural activities are practiced at lower reaches of river basins, paddy fields in the form of terraced farming are also common in mountainous areas. Rainfall runoff from agricultural-forestry watershed are discharged into streams flow through cities. Hence, characteristics of rainfall runoff from agricultural-forestry watershed are important for the proper management of surface water quality of an urban stream. Therefore, the main objectives of this study were to estimate the concentrations and loadings of fecal indicators from forestry and agricultural land uses.

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2. Methods

2.1. Studied watersheds

Three rural watersheds with areas ranging from 14.0 to 69.3 ha were selected for the monitoring study (Table 1). Unpolluted forestry mainly constitutes the watersheds while agricultural land uses were practiced near the mouth of the watersheds. Table 1 is a summary of watershed characteristics and Fig. 1 is descriptive shapes of the study watersheds. The first watershed Sutong, which is clean mountainous areas containing forestry only, is a representative of typical land use in Korea and was used as the base-line condition for water quality analysis. The other watersheds consist of different mixtures of forestry and agricultural areas. Average annual precipitation depth of the basin is 1,290 mm based on precipitation data of 1969–2001 acquired from the Korea Water Company.

Table 1
Schematic description of the study watersheds.

Watershed	Name	Area A(ha)	Land use (%)
1	Sutong	23.3	Forest 99.0, road 1.0
2	Sungjeon	14.0	Rice paddy 8.2, forest 91.8
3	Jinjam	69.3	Rice paddy 33.0, residential 4.0, forest 63.0

2.2. Monitoring program

Sampling was carried out three times at each monitoring station during dry weather. Ten rainfall events were monitored at each study watershed, mostly during March–September 2006. Rainfall events to monitor were selected among several rainfall events among forecasted precipitation depth exceeding 10 mm. Meteorological information was obtained from the regional office of the Korean

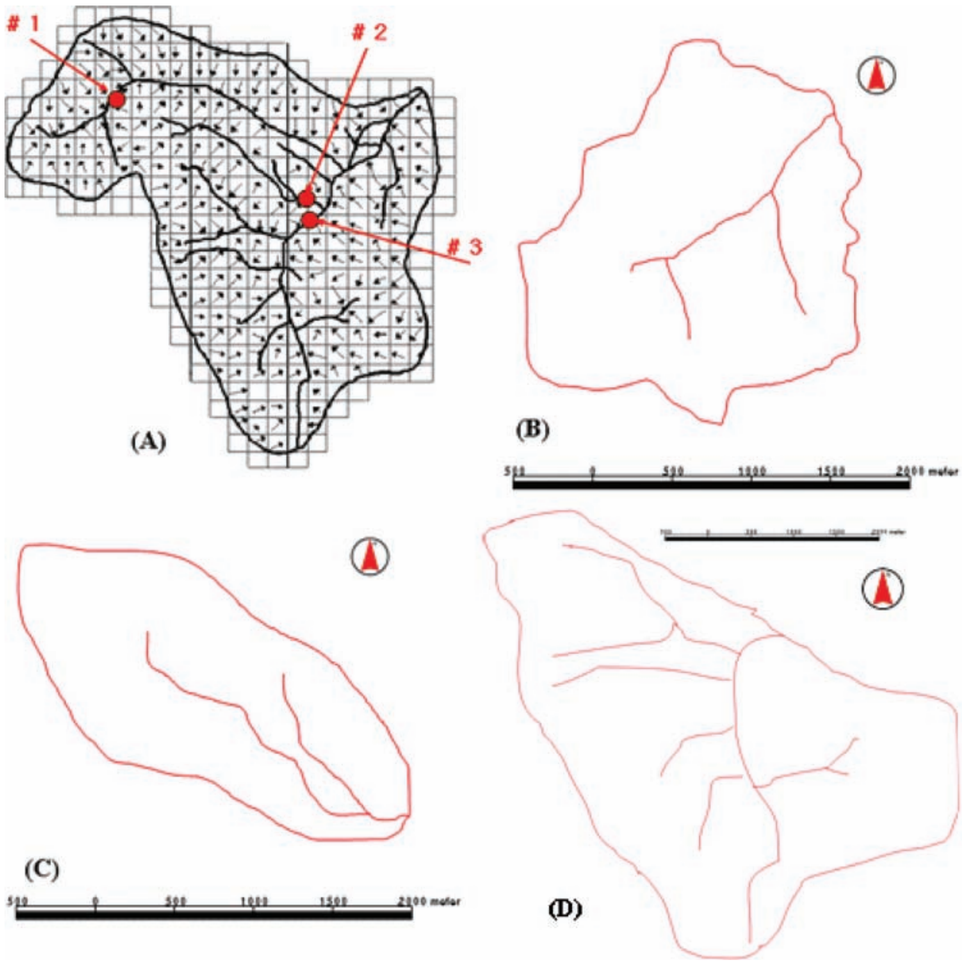

Fig. 1. Schematic representation of study watersheds: (A) location of the monitoring points; (B) Sutong watershed; (C) Sungjeon watershed; (D) study watershed 3 (name: Jinjam).

Meteorological Administration. Runoff volumes were measured using a velocity meter probe, Global Water® FP-101 of PlanoMolding Company, USA. Cross-section at each monitoring points was surveyed prior to each rainfall event. Flow velocities were measured at 1/3, 1/2, and 2/3 width at 1/3 depth of the monitoring points and averaged.

2.3. Analysis of samples

Analysis for COD_{cr}, SS, and fecal indicators were made in accordance to Standard Methods [8]. Total coliform (TC) was measured by Standard Methods 9222B. M-Endo medium was used and incubated for 24 h at 35°C. Fecal coliform (FC) was measured using Standard Methods 9222D. M-FC medium was used and incubated 24 h at 44.5°C. EC was measured using Standard Method 9230C. Nutrient agar-MUG was used and incubated 24 h at 35°C. Fecal streptococci (FS) was measured by Standard Methods mE method (9230C), and incubated 48 h at 35°C.

Table 2
Description of rainfall events monitored in this research.

	1st event (14 June 2006)	2nd event (21 June 2006)
Rainfall depth (mm)	48.0	40.5
Rainfall intensity (mm/h)	3.2	3.7
Maximum rainfall intensity (mm/h)	11.5	20.0
Rainfall duration time (h)	15.0	11.0
Antecedent dry days (day)	3	5

3. Results and discussion

3.1. Discharge characteristics of diffuse pollutants

Table 2 is the precipitation depth, rainfall duration time, and dry days since the last rainfall event that was monitored in this study. Precipitation depth of the first rainfall was 48.0 mm while that of the second rainfall was 40.5 mm. Maximum rainfall intensity and the antecedent dry days of the second rainfall event were bigger than those of the first rainfall event.

Figure 2–4 show the precipitation, flow rate, and water quality variation of rainfall runoff for each watershed. Time series variation of SS, organics and fecal indicator concentrations were plotted with a hydrograph and

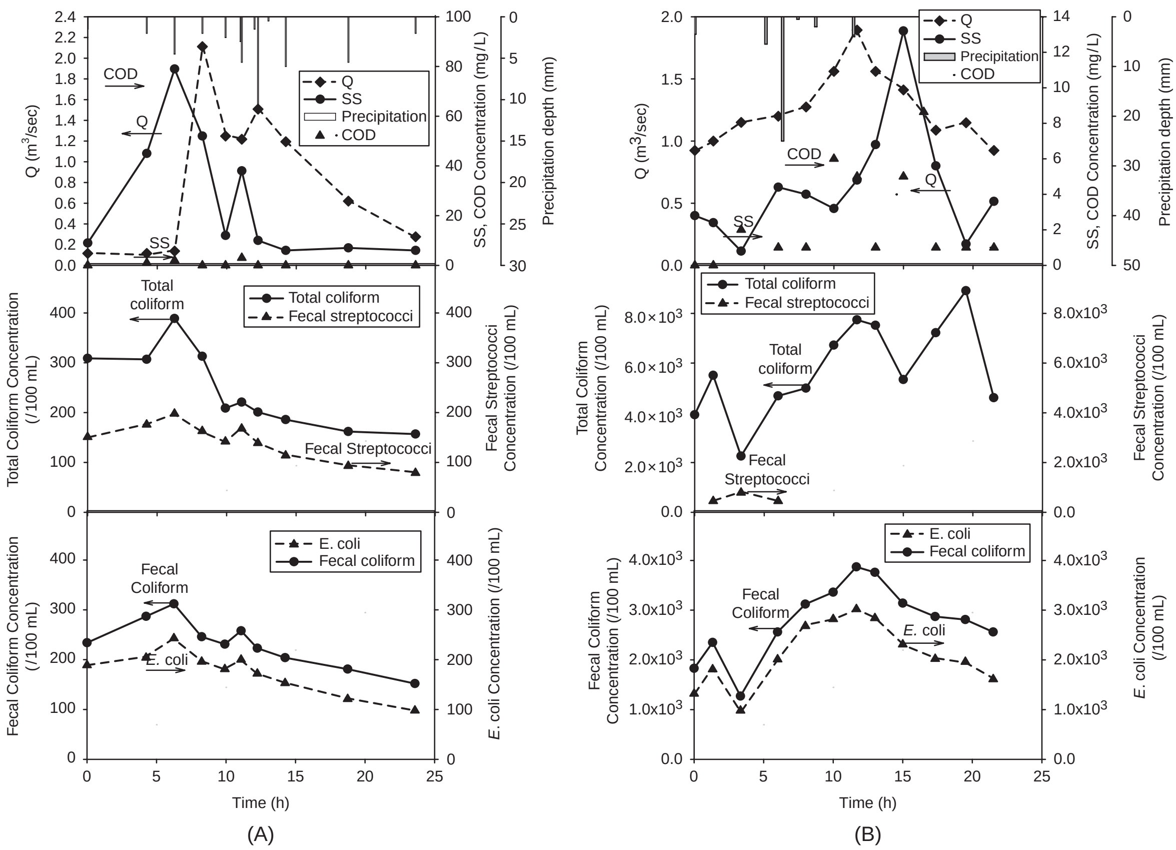

Fig. 2. Precipitation, flow rate (Q), suspended solid (SS), and chemical oxygen demand (COD) (top), total coliform and fecal streptococci (middle), *E. coli* and fecal coliform (bottom) for Sutong study watershed (A) 1st rainfall event; (B) 2nd rainfall event.

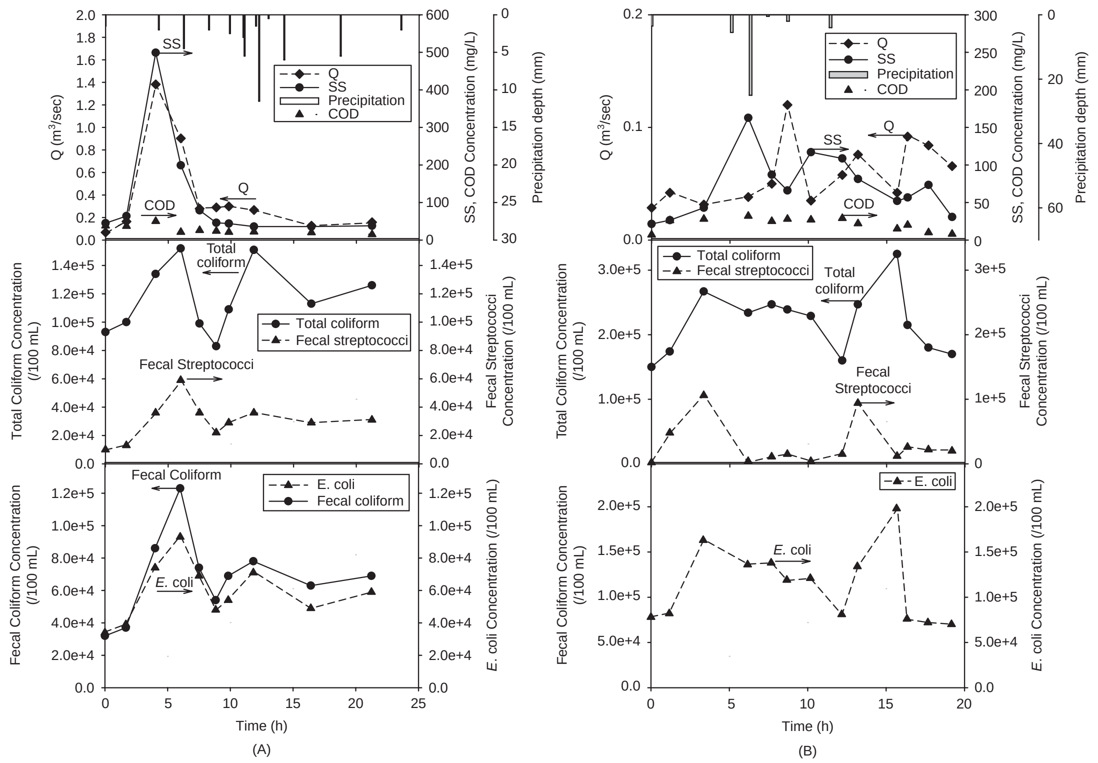

Fig. 3. Precipitation, flow rate (Q), suspended solid (SS), and chemical oxygen demand (COD) (top), total coliform and fecal streptococci (middle), *E. coli* and fecal coliform (bottom) for Sungjeon watershed (A) 1st rainfall event; (B) 2nd rainfall event.

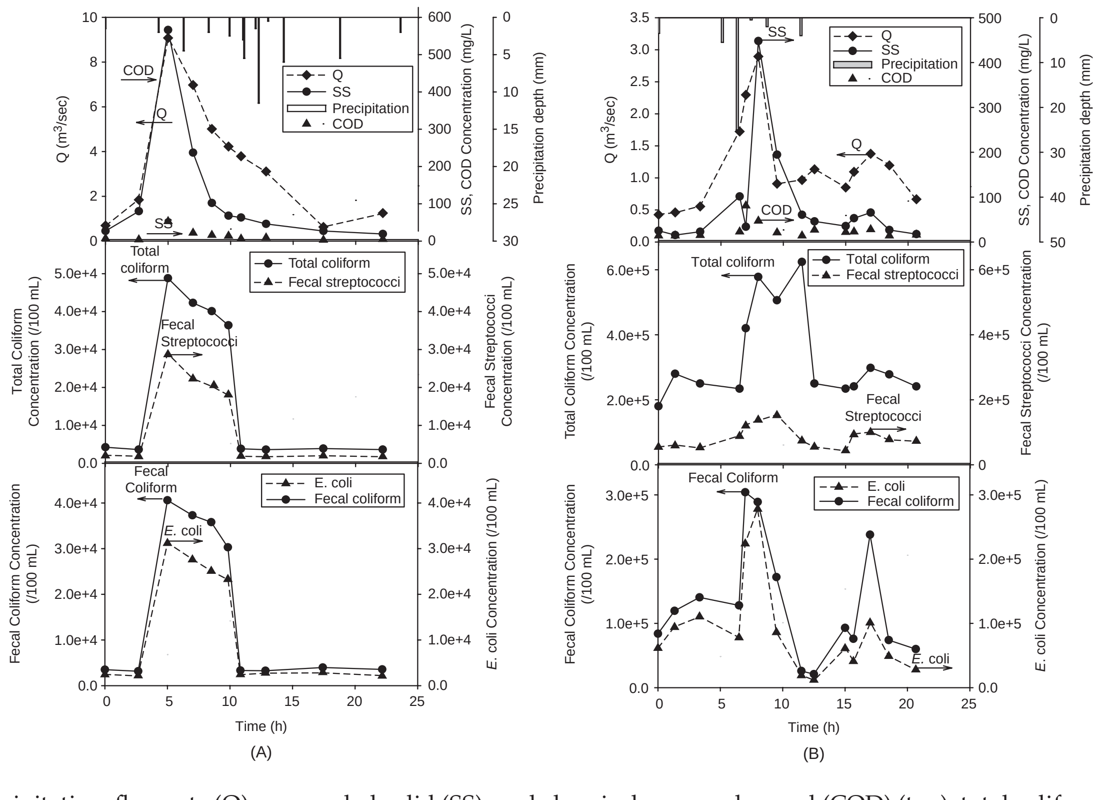

Fig. 4. Precipitation, flow rate (Q), suspended solid (SS), and chemical oxygen demand (COD) (top), total coliform and fecal streptococci (middle), *E. coli* and fecal coliform (bottom) for Jinjam watershed (A) 1st rainfall event; (B) 2nd rainfall event.

Table 3
Concentration variation during dry weather and wet weather and event mean concentrations (EMCs) for the first study watershed.

Constituents	Site	Concentration dry weather	Runoff concentration		EMC	
			1st event	2nd event	1st event	2nd event
Suspended solid (mg/L)	1	2.6	26	4.4	25.3	4.6
	2	122	108	71	241	70
	3	35.8	123	82	223	126
Chemical oxygen demand (mg/L)	1	7.1	0.6	2.0	0.5	2.3
	2	14.8	27	21	32	21
	3	27.03	14	26	23	33.6
Total coliform (CFU/100 mL)	1	12.85×10^3	2.45×10^2	5.78×10^3	2.32×10^2	50.4×10^2
	2	1.69×10^5	1.16×10^5	2.18×10^5	12.80×10^4	21.73×10^4
	3	4.480×10^5	1.90×10^4	3.30×10^5	3.10×10^4	3.68×10^5
Fecal coliform (CFU/100 mL)	1	1.15×10^3	2.33×10^2	2.79×10^3	2.29×10^2	25.7×10^2
	2	1.15×10^5	6.85×10^4	–	8.50×10^4	–
	3	2.99×10^5	1.65×10^4	1.30×10^5	2.66×10^4	1.66×10^5
E. Coli (CFU/100 mL)	1	5.00×10^2	1.76×10^2	2.12×10^3	1.76×10^2	20.0×10^2
	2	7.16×10^4	5.90×10^4	1.13×10^5	7.08×10^4	10.78×10^4
	3	2.31×10^5	1.22×10^4	8.88×10^4	1.98×10^4	1.21×10^5
Fecal streptococci (CFU/100 mL)	1	2.50×10^2	1.42×10^2	5.63×10^2	1.42×10^2	4.28×10^2
	2	2.65×10^4	3.01×10^3	2.92×10^4	3.79×10^4	2.90×10^4
	3	3.45×10^5	1.01×10^4	8.44×10^4	1.68×10^4	8.48×10^4

precipitation intensities. In general, the concentrations rose sharply at the early phase of the hydrograph for all water quality constituents. Indicator microorganism concentration variations showed similar tendencies with those of suspended solids. Many precedent researches indicated that microorganisms are discharged in association with suspended particles in surface water [9]. All monitored fecal indicators show similar tendencies while TC concentrations were higher than remains. TC can be induced by several indigenous microorganisms other than fecals.

Event mean concentration (EMC) is appropriate for evaluating the effects of stormwater runoff on receiving waters. An EMC represents a flow-weighted average concentration of runoff computed as the total pollutant mass divided by the total runoff volume for a rainfall event. Hydrographs and pollutographs were prepared based on the chemical analysis results of the samples taken during the monitored rainfall events to estimate the EMC of each analyzed constituent employing the following equation:

$$\mathrm{EMC}_i = \frac{\sum Q_i C_i}{\sum Q_i} \tag{1}$$

where EMC_i, event mean concentration of contaminant constituent i (mg/L); Q_i, discrete flow coordinated on the event hydrograph at time i (m^3); C_i, corresponding concentration on the pollutographs at time i (mg/L); h, high flow; and l, low flow.

Table 3 is a summary of concentration variations during dry weather and wet weather and EMC values for the study watershed. In general, the average values of EMC for watershed 3 were the highest, followed by watersheds 2, and 1. In Table 1, ratio of agricultural area to the total watershed area for watershed 3 was highest, followed by watersheds 2, and 1. As the magnitude of EMCs and ratio of agricultural area to the total watershed area showed same order, it can be understood that agricultural activity in the watershed affects EMCs significantly.

4. Conclusions

To estimate microbial contaminant loading discharged from diffuse sources, rainfall runoff of six rainfall events were monitored at three study watersheds of forestry and agricultural land use. Monitored indicator microorganism constituents were total TC, fecal coliform (FC), *Escherichia coli* (EC), and fecal streptococcus (FS). Soil loss during elevated flow rate caused higher suspended solid concentrations.

Indicator microorganism concentrations were closely related with flow rate. TC event mean concentration (EMC) from unpolluted forestry was 52.72×10^2

CFU/100 ml, FC EMC was 13.99×10^2 CFU/100 ml, EC EMC was 10.98×10^2 CFU/100 ml CFU/100 ml, and FS EMC was 2.85×10^2 CFU/100 ml. From a watershed with agricultural-forestry land use, TC EMC was 17.27×10^4 CFU/100 ml, FC EMC was 8.50×10^4 CFU/100 ml, EC EMC was 8.93×10^4 CFU/100 ml, and FS EMC was 3.35×10^4 CFU/100 ml. Mixed land use of agricultural-forestry with bigger area, TC EMC was 19.95×10^4 CFU/100 ml, FC EMC was 9.63×10^4 CFU/100 ml, EC EMC was 7.04×10^4 CFU/100 ml, and FS EMC was 5.08×10^4 CFU/100 ml.

Acknowledgement

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