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Water quality of runoff from agricultural-forestry watersheds in the Geum River Basin, Korea

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Abstract Forestry and agricultural land uses constitute 85% of Korea and these land uses are typically mixed in many watersheds. Land cover is one of the most important factors affecting diffuse pollution and water quality. The aim of this study is to estimate the pollutant concentrations in runoff from four study watersheds consisting of a mix of forestry and agricultural land uses at different ratios in the Geum River Basin. The effect of topographical variables was also considered. The ratio of agricultural land use to the total area of study watersheds was in the range of 0.01–0.36. Flow rate and water quality (suspended solids, organics and nutrients) of runoff from 40 rainfall events were monitored at the study watersheds. Descriptive statistics showed higher nutrients and organic concentrations in runoff from watershed with higher agricultural activities. Event Mean Concentration (EMC) of individual runoff event was calculated for each water quality constituent based on the flow rate and concentration data of runoff discharge, and arranged on a cumulative probability scale according to runoff occurrence. From the correlation analysis between EMC data and affecting variables, the ratio of agricultural land use to the total area was identified as the parameter that most affected the magnitude of EMC.

Keywords Agriculture · Forestry · Event mean concentration · Land use · Topography · Rainfall runoff · Water quality

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Introduction

Surface water quality has not improved significantly in many countries including Korea, despite efforts to reduce pollutant loading from point sources (Park et al. 1998; UNEP 2004). Diffuse pollution has raised more concerns for many years, which has been identified as an important cause of surface water quality degradation (Novotny 1999). Diffuse pollution from agriculture or forestry has not received much attention in Korea as much as urban diffuse pollution because it was generally believed that the concentration of diffuse pollutants from rural area is relatively low and non-toxic. Due to the large area of forestry and agricultural land uses, however, contaminant loading from rural areas may significantly impact the receiving water body (Novotny and Olem 1994; Withers and Lord 2002). Eutrophication is one of the serious problems caused by high concentration of nutrients discharged from agricultural areas. Kim et al. (2004) also reported significant amounts of non-biodegradable organics originating from forestry near water sources.

Rainfall runoff discharge from agricultural-forestry land use has very complicated processes. Land management, vegetative changes, groundwater withdrawals, and reservoir management can impact water quantity and water quality of runoff responses (Arnold and Allen 1996). More diffuse pollution may result from the increased release rate of contaminants from farm buildings and livestock holding buildings at remote area, atmospheric deposition, and soil, where excessive fertilizers is used. Because pollution in an agricultural area originates from various sources, the water quality in flooded agricultural fields can vary greatly (Maul and Cooper 2000). The estimated analysis of N input in a watershed revealed the importance contribution of wet and dry atmospheric deposition of NO_3 and NH_4 (Mosello and Marchetto 1996). Significant quantities of dissolved nutrient from fertilizer application are present in a river during wet weather (Jain 2002). Topography and soil type of a watershed can also significantly impact runoff quality (Fisher et al. 2000; Thierfelder 1999; Tong and Chen 2002; Withers and Lord 2002); erosion and herbicide losses can be higher in a sloping areas (Gardi 2001).

Forestry and agricultural land uses constitute 65 and 20% of land use in the Republic of Korea, respectively. 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. The runoff discharge data are difficult to interpret because of mixed land use and mountainous terrain in a watershed.

Therefore, the main objectives of this study are to estimate the pollutant concentrations and loads of runoff from different (forestry and agricultural) land uses and to analyze pollutant loading data to understand the effects of mixed land use and topography on water quality.

Materials and methods

Description of watersheds

Four watersheds which areas ranging from 2.85 and 27.37 km^2 were selected for this study. The first watershed, 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. Study watersheds are located in the Geum River basin, one of the four major river basins in the Republic of Korea. The length of the river is 401 km, and the river basin covers 988 km^2. Average annual precipitation depth of the basin is 1,290 mm based on precipitation data of 1969–2001 acquired from the Korea Water Company.

Figure 1 shows the shapes, size, land use, and flow channel of the studied watersheds. The shape of a watershed can be described using shape factor, mean slope, and drainage density. The shape factor is a dimensionless variable defined as the drainage area divided by the square of the main channel length (USGS 1998). Mean slope is often called the main channel slope and defined as the difference in elevations at points 10 and 85% of the distance along the main channel divided by the distance between points (dimensionless) (USGS 1998). Drainage density defined as the channel length divided by watershed area (Marani et al. 2003). Watershed 1 (Fig. 1a) had an area of 3.38 km^2, mainly composed of forestry of coniferous trees with no fertilizers added on. Watershed 1 was located near the Shindang Reservoir, which was designated as the head water of the Geum River. The sampling station was located at the mouth of the watershed. Watershed 2 (Fig. 1b) covered 2.85 km^2, and the land cover was forestry except for limited terrace farming near the mouth of the catchment where the sampling station was located (Fig. 1b). Because seeding and transplantation are practiced during March to May in the area, aqueous fertilizers could leak into the water body during wet weather. Watershed 3 (Fig. 1c) covered 4.97 km^2. Even though agricultural land use was limited in the area, active plant cultivation was observed near the base of the mountain where a monitoring station was located. Almost no management was practiced to minimize the fertilizer

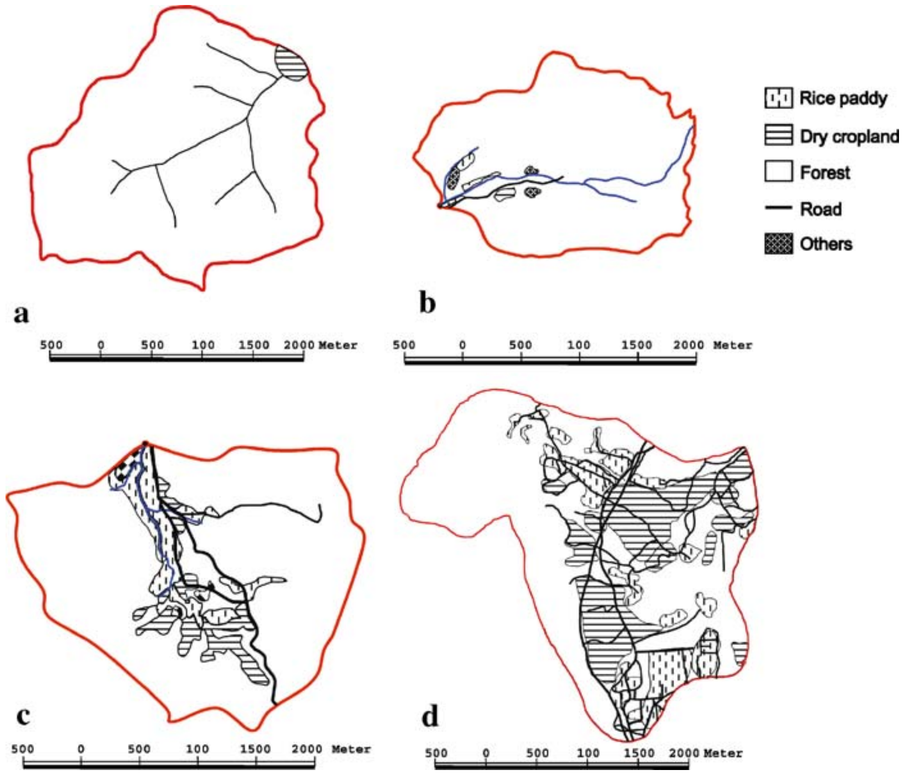

Fig. 1 Shape, land use, size, and flow channel of study watersheds: **a** study watershed 1, **b** study watershed 2, **c** study watershed 3, **d** study watershed 4

runoff during wet weather. Watersheds 2 and 3 drained to an agricultural reservoir, which flowed to a regional river located downstream. Watershed 4 (Fig. 1d) covered 27.37 km^2. Its land was mainly comprised of 35.9% of rice paddy and 44.8% of forestry.

The ratios of agricultural use area to the total land of the watersheds studied were arranged in an increasing order in Table 1. Study watersheds 1 through 4 in Table 1 were arranged such that the ratios of area for agricultural land use to the total watershed area increased. Study watersheds 1 and 4 were closely located and while study watersheds 3 and 4 were located nearby. It was assumed that the precipitation characteristics including depth and

Table 1 Topography and land use description of the study watersheds

Watershed	Name	Area A (Km^2)	Length[a] L (Km)	Mean width A/L (Km)	Shape factor A/L^2(Km)	Density L/A (Km^{-1})	Mean slope (%)	$RAIN_{ave}$[b] (mm)	Land use (%)
1	Sutong	3.38	2.875	1.176	0.409	0.851	62.61	1,356.7	forest 99.5, road 0.1, others 0.4
2	Sansuchon	2.85	1.575	1.810	1.149	0.553	22.64	1,252.1	rice paddy 1.8, cropland 0.7, forest 94.2, road 0.7, others 2.6
3	Daegokchon	4.97	1.649	3.014	1.828	0.332	41.17	1,252.1	rice paddy 8.4, cropland 6.4, forest 82.3, road 1.4
4	Sinheung	27.37	6.173	4.434	0.718	0.226	5.97	1,356.7	rice paddy 35.9, forest 44.8, road 4.7,residential 13.3, others 1.3

[a] channel length.

[b] average annual precipitation depth.

duration for watersheds that are located nearby were identical during the study period. Thus, same rain gauge data were used for watersheds 1 and 4, and 2 and 3, respectively.

Sampling and experiments

Ten rainfall events were monitored at each study watershed, mostly during March to September, 2002. 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 Meteorological Administration. Runoff volumes were measured using a velocity meter probe, Global Water® FP-101 of Plano Molding 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.

Water samples were taken manually and some by automatic samplers to minimize sampling errors. All samples were collected at 10 cm depth from water surface and stored in 1.0 l clean narrow-mouth plastic polyethylene bottles with Teflon®-lined screw caps. The number of samples taken during each rainfall event was adjusted to 12–18 as the water level at the site was observed to adequately depict the shapes of hydrographs. Samples were taken more frequently during high flow rate conditions. About 150 samples of the concentration data were obtained for each study watershed, and approximately, 15 samples were taken for each rainfall event. Quantity and quality of the low flow were monitored two times a week at each site as well.

Samples were stored in ice immediately following collection and during transport to the laboratory. All samples were analyzed within 8 h after collection. Suspended solid (SS), total chemical oxygen demand (TCOD), soluble chemical oxygen demand (SCOD), total nitrogen (TN), ammonia nitrogen (NH_3-N), nitrate nitrogen (NO_3-N), total phosphorus (TP), and phosphate (PO_4-P) concentrations were measured by using the Standard Methods 20th ed (APHA, AWWA, WEF, WPCF 1998).

Statistical analysis

Effects of land use and topography variables on water quality were examined by using the Pearson correlation analysis between affecting variables and contaminant loadings using SPSS ver. 10. Skewed data were transformed into logarithmic data for further analysis. Because flow rate and loadings are all measurable continuous variables, parametric analysis was more suited to this purpose instead of non-parametric analysis. Rainfall runoff was analyzed similarly by Brezonik and Stadelmann (2002).

Table 2 Description of rainfall events monitored in this study

Event no.	1[a]			2			3			4		
	Rain[b]	T[c]	Dryday[d]	Rain	T	Dryday	Rain	T	Dryday	Rain	T	Dryday
1	18.5	67.5	5	1.0	9.8	3	1.0	9.8	3	18.5	67.5	5
2	66.5	60.7	12	16.5	8.2	5	16.5	8.2	5	66.5	60.7	12
3	14.4	26.5	3	42.2	39.3	2	22.0	20.6	5	14.4	26.5	3
4	43.5	36.0	2	129.0	46.0	2	42.2	39.3	2	43.5	36.0	2
5	44.5	47.6	1	24.0	36.2	7	129.0	46.0	2	44.5	47.6	1
6	259.8	123.8	11	0.1	17.0	1	24.0	36.2	7	259.8	123.8	11
7	35.0	41.3	1	19.5	31.0	10	0.1	17.0	1	35.0	41.3	1
8	4.5	22.3	4	89.5	52.0	2	19.5	31.0	10	4.5	22.3	4
9	37.0	30.0	3	12.0	24.0	7	89.5	52.0	2	37.0	30.0	3
10	135.0	60.0	2	118.0	252.0	2	12.0	24.0	7	135.0	60.0	2

[a] watershed.

[b] precipitation depth (mm).

[c] rainfall duration time (h).

[d] dry days since last rainfall event (day).

Results and discussion

Table 2 is the precipitation depth, rainfall duration time, and dry days since the last rainfall event that was monitored in this study. Sum of precipitation depths monitored in this study was 48.6% of the annual precipitation depth for watersheds1 and 4, and 28.4% for watersheds 2 and 3. Figure 2 is the comparison of

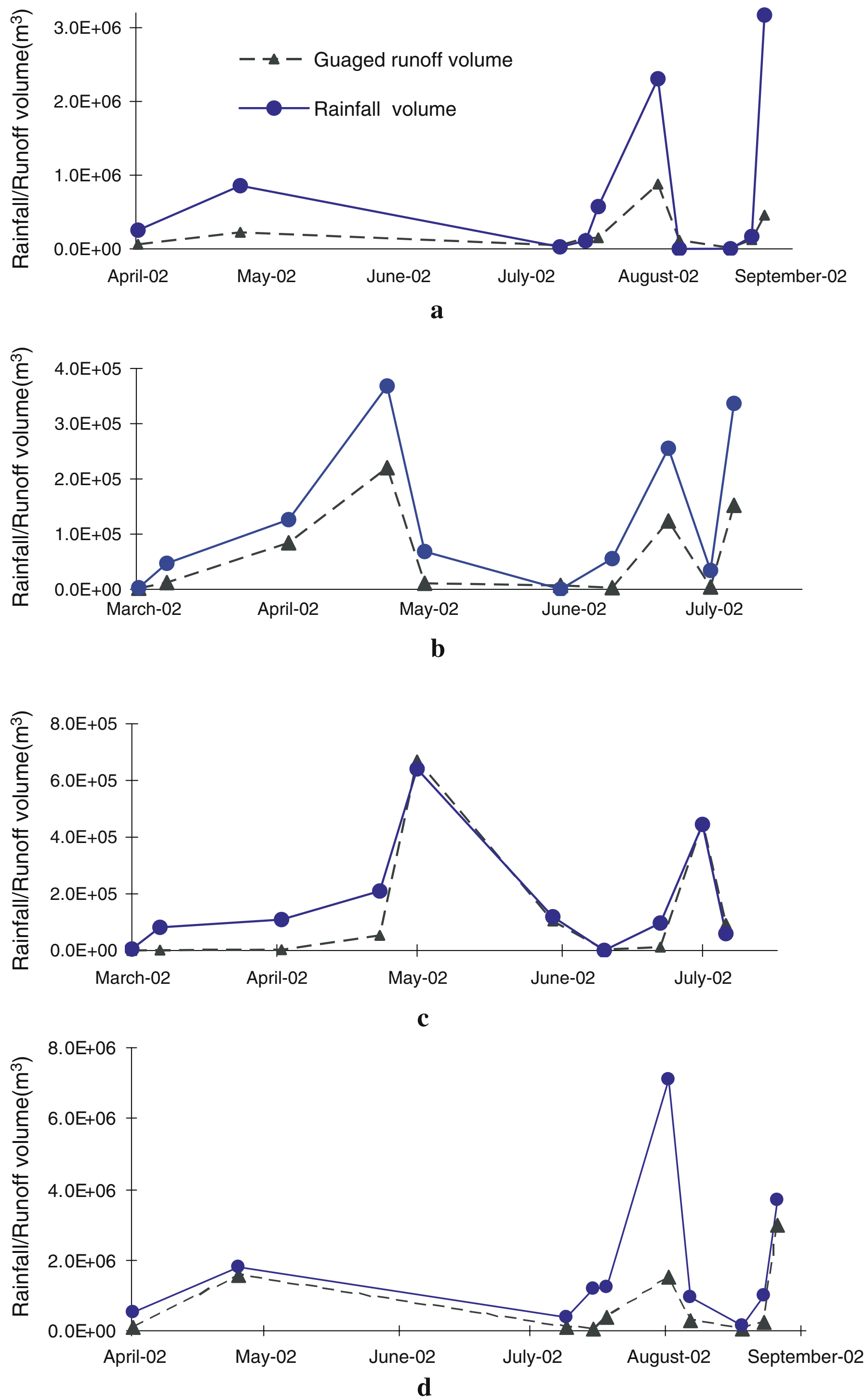

Fig. 2 Rainfall volume versus the gauged runoff volume for study watersheds: **a** Watershed 1, **b** Watershed 2, **c** Watershed 3, **d** Watershed 4

Table 3 Descriptive statistics of runoff concentrations for study watersheds

Constituent	Watershed	n[a]	Average[b]	SD[d]	SE[e]	Minimum	Maximum
SS	1	147	2.1	10.0	0.8	nd[f]	112.3
	2	150	60.8	180.4	14.7	0.3	1,425.0
	3	149	116.4	398.1	32.6	0.3	3,510.0
	4	143	86.2	294.0	24.6	2.5	2,612.0
		Average[c]	66.4	266.1	11.0		
TCOD	1	147	4.92	4.97	0.41	nd	28.60
	2	150	17.05	54.15	4.42	0.7	442.00
	3	149	12.65	16.53	1.35	1.1	141.80
	4	143	19.78	38.29	3.20	nd	423.40
		Average	13.57	34.69	1.43		
SCOD	1	147	2.74	3.85	0.32	nd	18.80
	2	150	3.10	3.55	0.29	0.4	23.10
	3	149	3.17	2.19	0.18	0.2	11.80
	4	143	6.93	7.06	0.59	nd	35.30
		Average	3.96	4.80	0.20		
TN	1	123	1.08	0.84	0.08	nd	3.10
	2	150	1.08	0.88	0.07	0.22	5.90
	3	149	2.00	0.78	0.06	0.58	4.06
	4	143	4.38	2.06	0.17	1.16	17.00
		Average	2.16	1.85	0.08		
NH_3-N	1	126	0.04	0.06	0.01	nd	0.38
	2	150	0.12	0.14	0.01	0.01	0.79
	3	149	0.18	0.18	0.01	0.01	1.26
	4	143	1.39	0.99	0.08	nd	5.20
		Average	0.44	0.75	0.03		
NO_3-N	1	147	0.72	0.42	0.03	0.26	2.80
	2	150	0.52	0.19	0.02	0.03	0.99
	3	149	1.39	0.35	0.03	0.1	2.20
	4	143	2.48	2.13	0.18	0.3	8.10
		Average	1.26	1.33	0.05		
TP	1	147	0.28	0.15	0.01	0.06	0.81
	2	150	0.20	0.21	0.02	nd	1.62
	3	149	0.52	0.57	0.05	0.04	3.48
	4	142	1.18	0.82	0.07	0.39	6.80
		Average	0.54	0.64	0.03		
PO_4-P	1	147	0.09	0.06	nd	0.01	0.35
	2	150	0.08	0.21	0.02	nd	1.06
	3	149	0.03	0.02	0.00	nd	0.18
	4	143	0.42	0.17	0.01	0.12	0.89
		Average	0.15	0.21	0.01		

[a] number of samples taken at the designated watershed.

[b] average of the designated watershed.

[c] average of all four study watershed.

[d] standard deviation.

[e] standard error.

[f] not detected.

rainfall volume versus gauged runoff volume for the study watersheds.

Table 3 is the descriptive statistics of the runoff qualities monitored at the study watersheds. Average concentration, standard deviation, standard error (standard deviation of the sampling distribution of that statistic), minimum and maximum values of concentrations are summarized in the table for each monitored concentration at each study watershed.

The maximum average SS value of 116.4 mg/l was given by watershed 3, followed by watersheds 4, 2, and 1. The magnitude of standard deviation and standard error were in the same order. In Table 1, watershed 4 showed the highest ratio of agricultural land use to total area and the lowest mean slope among the four watersheds. Maul and Cooper (2000) reported that runoff quality varied greatly within agricultural sites, indicating that the responses of some agricultural fields are different from those of others in terms of SS, and maybe related to watershed characteristics other than land uses. As SS can be removed from water by settling, channel length and flow velocity may affect SS concentration.

Agricultural activity of watershed 3 was lower than that of watershed 4 while the mean slope and shape factor were much higher than those of watershed 4, findings which imply that the flow channel is steep and shorter in watershed 3 than watershed 4. It can be seen from here that both land use and morphological properties affect SS runoff discharge.

The maximum SCOD concentration was 6.93 mg/l in watershed 4, followed by watersheds 3, 2 and 1. Land use of the watershed seemed to have affected the SCOD concentration. For TCOD, however, this order is not applied. The average value of TCOD for watershed 2 was high, even though 94.2% of land use was forestry. The standard deviation value was the highest. This result implies significant variation of the runoff concentration from a forestry watershed. Kim et al. (2004) indicated that organics discharged from forestry contribute the water quality level in the receiving water body. The average concentrations of some constituents such as TN and NH_3-N tended to increase as the ratio of agricultural area to the total watershed area increased. However, the concentrations of NO_3-N, TP, and PO_4-P of watershed 1 were higher than those of watersheds 2 and 3.

Flow rate and concentration change of runoff were monitored based on the chemical analyses results of samples from 40 rainfall events. EMC of each analyzed constituent was calculated using Eq. 1.

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

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. The EMC concept can be used to concisely summarize the highly variable data and compare the results from different events at different sites. Because EMCs are calculated as one value based on the monitored flow rate and concentration data, they are significantly affected by the flow rate. This means that the local water budget affects the magnitude of EMCs.

Table 4 is the descriptive statistical analysis results of EMCs monitored in this study. In general, the average values of EMC for watershed 4 were the highest, followed by watersheds 3, 2, and 1. In Table 1, ratio of agricultural area to the total watershed area for watershed 4 was highest, followed by watersheds 3, 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. In the concentration data in Table 3, SS value of watershed 4 was larger than that of watershed 3 even though the difference may not be significant. It can be found that other rainfall characteristics and/or flow rate characteristics have greater effect on SS concentration of discharge. The larger area for watershed 1 compared to watershed 2 may have affected the magnitude of EMC. The standard deviations of watershed 4 was the highest, followed by those of watersheds 3, 2, and 1. This result indicates that the magnitude and variability of the SS EMC are related with agricultural activities in the area. Even though land use and topography variables simultaneously affected the runoff qualities, their relative contribution is not clear in this data set. Higher standard deviation and standard error in Table 4 means that flow rate variations contributed to the magnitude of EMCs.

Figure 3 is the cumulative probability distribution of EMCs for the study watersheds. Eight constituents chemically analyzed in this study are shown in the

Table 4 Descriptive statistics of EMCs by study watersheds

Constituent	Watershed	n[a]	Average[b]	SD[d]	SE[e]	Minimum	Maximum
SS	1	10	5.00	11.00	4.00	0.00	37.00
	2	10	62.00	67.00	21.00	3.00	195.00
	3	10	227.00	370.00	117.00	6.00	1,170.00
	4	10	237.00	439.00	139.00	8.00	1,336.00
		Average	133.00	296.00	47.00		
TCOD	1	10	6.00	5.00	1.00	2.00	17.00
	2	10	7.00	3.00	1.00	3.00	11.00
	3	10	17.00	14.00	5.00	3.00	50.00
	4	10	41.00	65.00	21.00	5.00	223.00
		Average	18.00	35.00	6.00		
SCOD	1	10	2.84	2.53	0.80	0.50	8.80
	2	10	2.70	1.56	0.49	0.90	6.30
	3	10	3.62	1.26	0.40	2.00	5.90
	4	10	7.86	6.68	2.11	1.40	23.70
		Average	4.26	4.16	0.66		
TN	1	10	0.85	0.77	0.24	0.00	2.21
	2	10	0.94	0.25	0.08	0.57	1.31
	3	10	2.08	0.51	0.16	1.27	2.61
	4	10	4.92	2.33	0.74	2.00	10.62
		Average	2.20	2.06	0.33		
NH_3-N	1	10	0.03	0.04	0.01	0.00	0.10
	2	10	0.10	0.09	0.03	0.02	0.26
	3	10	0.17	0.10	0.03	0.02	0.31
	4	10	1.20	0.54	0.17	0.30	2.10
		Average	0.37	0.56	0.09		
NO_3-N	1	10	0.76	0.39	0.12	0.27	1.40
	2	10	0.60	0.15	0.05	0.39	0.86
	3	10	1.37	0.28	0.09	0.84	1.87
	4	10	2.52	2.05	0.65	0.60	6.16
		Average	1.31	1.27	0.20		
TP	1	10	0.28	0.14	0.04	0.10	0.52
	2	10	0.16	0.07	0.02	0.03	0.28
	3	10	0.62	0.52	0.17	0.09	1.77
	4	10	1.36	0.55	0.17	0.55	2.26
		Average	0.61	0.60	0.10		
PO_4-P	1	10	0.09	0.04	0.01	0.05	0.2
	2	10	0.02	0.01	0.00	0.00	0.04
	3	10	0.03	0.01	0.00	0.01	0.05
	4	10	0.42	0.14	0.04	0.23	0.70
		Average	0.14	0.18	0.03		

[a] number of samples taken at the designated watershed.

[b] average of the designated watershed.

[c] average of all four study watershed.

[d] standard deviation.

[e] standard error.

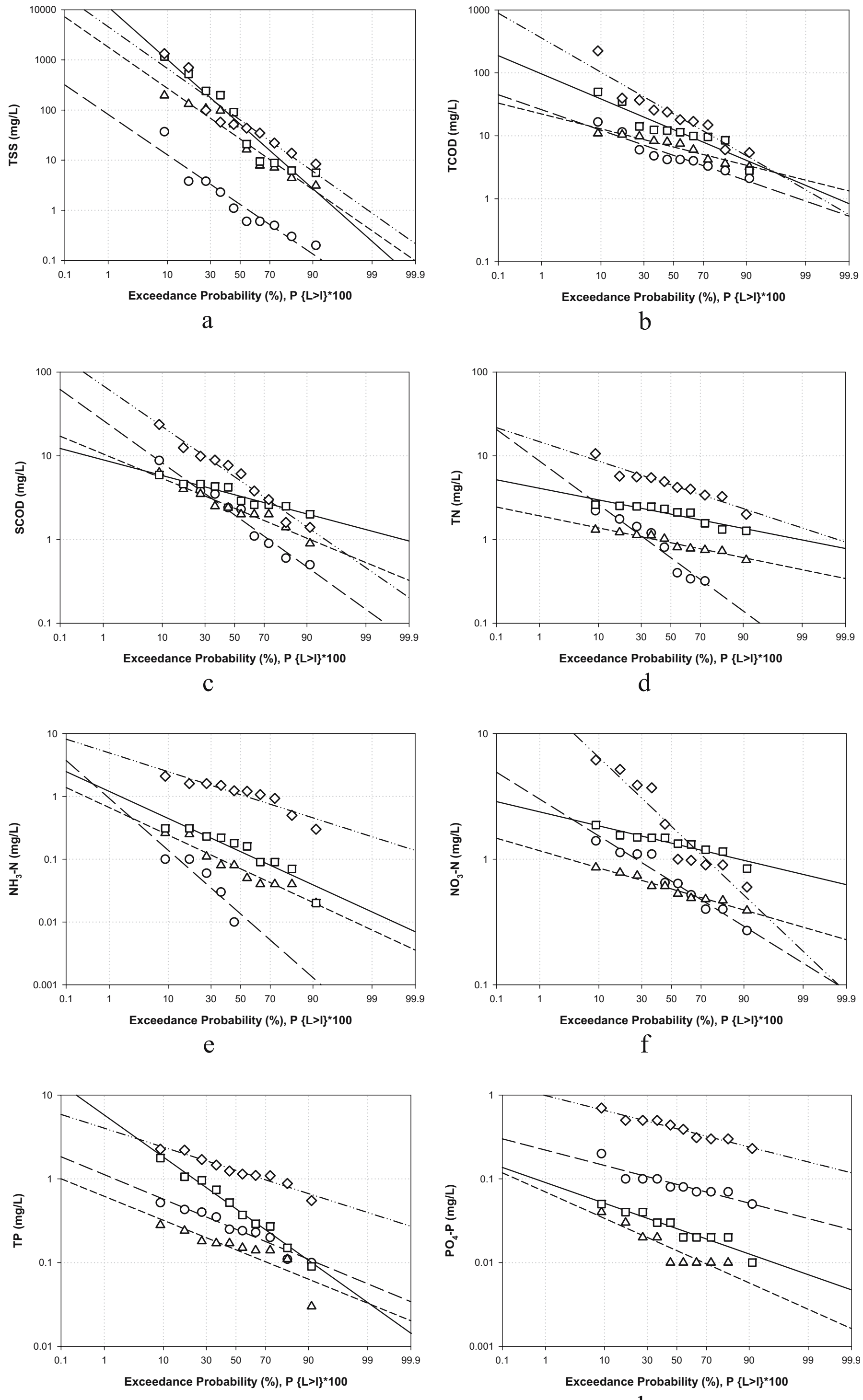

Fig. 3 Cumulative probability distribution of EMCs for various land uses: **a** SS, **b** TCOD, **c** SCOD, **d** TN, **e** NH_3-N, **f** NO_3-N, **g** TP, **h** PO_4-P (*open circle*: first watershed; *open triangle*: second watershed; *open square*: third watershed; *open diamond*: fourth watershed)

figure. The magnitude of EMC for each watershed can be clearly understood from probabilistic occurrences. One can express how often values exceed various magnitudes of interest. This procedure is computationally less extensive than other methods, and assumes that data follow a log normal statistical distribution. Highly site specific data can be qualitatively and quantitatively represented with the probability distribution of EMCs (USEPA 1983). For most constituents, data fitted the log-normal distribution quite well.

In general, watershed 4 included the highest values of EMCs, followed by watersheds 3, 2, and 1. Cumulative probability distributions of suspended solid EMC of watersheds 2, 3, and 4 were similar. SS discharge during the runoff process of the watershed in the agricultural-forestry area is highly related to the agricultural activity of that area.

Cumulative distributions of SCOD, TN, TP, and NO_3-N among the study watersheds intersected because contaminant discharge and hydraulic characteristics affected EMCs. NO_3-N and soluble phosphorus were released from agricultural land use by subsurface runoff (Gardi 2001; Maul and Cooper 2000).

Factors affecting EMC magnitude were analyzed statistically. The relative significance between these factors, which can explain the similarities or dissimilarities between sites, can be investigated by correlation analysis. Table 5 is the Pearson coefficients from the correlation analysis of EMC and affecting factors. Pearson correlation coefficient ranges between −1∼+1. Complete correlation shows+1, and complete inverse correlation shows −1. For variables related with climate, precipitation depth, rainfall duration time, and number of days before rainfall event (variable name: DAY) were considered. All topography variables in Table 1 and agricultural area ratio to the total area (variable name: AGRO) were also considered.

The magnitudes of EMCs did not correlated with precipitation depth and rainfall duration time in overall. This result implies that runoff volume and storm water concentration are independent because the total runoff volume is a direct function of the precipitation depth and rainfall duration time. A larger storm event at a watershed, which consists of forestry and agricultural land use, can serve as a better potential water resource than several smaller rainfall events. Low correlations were found between DAY and EMCs. Considering the high correlation between time before precipitation and contaminant loading found by NURP (USEPA 1983), runoff discharge mechanisms at an agriculture-forestry watershed are different from an urban watershed.

Table 5 Results of correlation analysis for EMCs and rainfall runoff variables

EMC	RAIN[a]	*T*[b]	DAY[c]	AREA[d]	LENGTH[e]	MWIDTH[f]	SFACTOR[g]	DENSITY[h]	MSLOPE[i]	AGRO[j]
SS	0.05	0.01	−0.22	0.22	0.15	0.32	0.18	−0.33	−0.21	0.26
TCOD	0.03	−0.02	−0.13	0.40	0.36	0.39	−0.03	−0.33	−0.30	0.40
SCOD	0.16	0.17	−0.18	0.51	0.48	0.47	−0.11	−0.37	−0.37	0.51
TN	0.06	0.06	−0.04	0.77	0.67	0.78	−0.01	−0.68	−0.61	0.79
NH_3N	−0.01	0.05	−0.13	0.88	0.82	0.79	−0.20	−0.63	−0.68	0.87
NO_3N	0.20	0.19	−0.03	0.57	0.52	0.58	−0.03	−0.48	−0.39	0.59
TP	0.15	0.22	−0.26	0.75	0.69	0.75	−0.06	−0.61	−0.50	0.77
PO_4P	0.13	0.20	−0.16	0.90	0.92	0.71	−0.43	−0.48	−0.57	0.86

[a] precipitation depth (mm).

[b] rainfall duration time (h).

[c] number of dry days before rainfall event (day).

[d] watershed area (km^2) (*A*).

[e] channel length (km) (*L*).

[f] mean width (*A/L*).

[g] shape factor (A/L^2).

[h] density (*L/A*).

[i] mean slope (%).

[j] agricultural area ratio to total area (%).

Watershed area and channel length showed low correlations (<0.5) with SS and TCOD, but relatively high correlation (≥0.5) with soluble organics and nutrients. Soluble chemicals correlated with topography variables more than with suspended chemicals, possibly because soluble chemicals are not sinkable. The relative magnitude of nitrate to total nitrogen varied between rainfall events. Depending on the pH and temperature of soils, $NH^{4+}$and NO_3^- ions are produced in a watershed through ammonification and nitrification of organic matter and mobilized into rivers through runoff (Jain 2002).

Among the derived topography variables, mean width showed the highest correlation coefficient, followed by density and mean slope overall. Mean width can be used as an index to represent the topographical characteristics of a watershed, if necessary.

High correlations were found between AGRO and EMCs. In particular, the correlation between nutrients and AGRO was high, so there was a close relationship between agricultural activity in the watershed and nutrient discharge. Comparing absolute values of AGRO with those of mean width, AGRO had more impact on EMCs than mean width did.

It is suggested that Table 5 be analyzed with caution. In many cases, agricultural activities are practiced more in the lower reach of a river basin than anywhere else of a river basin. A watershed dominantly used for agriculture tends to have a lower slope, higher watershed area, and longer channel length. To improve the statistical significances in Table 5, more watersheds and rainfall events should be monitored.

Summary and conclusions

The main objectives of this study were to understand impacts of topography and land use on rainfall runoff water quality in watersheds mainly consisting of forestry and agricultural land use. Forty rainfall events at four study watersheds were monitored for organics and nutrients to understand impacts of land use. The ratio of agricultural land use to the total area of study watersheds were in the range of 0.01–0.36.

From the descriptive statistics of runoff water qualities monitored at study watersheds, both land use and topography variables affected the SS runoff discharge. Land use seemed to affect the rainfall water quality of study watersheds. Organics and nutrient discharge concentration from forestry watershed was higher than those from agriculture-dominant land use at the same time. The effects of mixed land use and topography variables of watersheds on runoff quality were also observed by descriptive analysis of EMCs based on monitored data. By plotting EMCs on a cumulative probability scaled graph for a watershed, discharge characteristics of each contaminant species were obtained. Correlation analysis between EMCs and affecting factors including climate variables, topography variable, and land use variables revealed the followings: (1) EMC values were not correlated with total runoff volume, implying that runoff concentration and runoff volume are independent; (2) times before rainfall events did not affect EMCs; (3) soluble organics and soluble nutrients showed more correlation with topography variables; (4) mean width can be used as an index for topography variables in EMC estimation; and (5) land use impacted EMCs the most, followed by mean width.

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