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Stormwater runoff monitoring in a deciduous and coniferous forest

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ABSTRACT

Fifteen storm events were monitored from April to October 2008 to investigate the stormwater runoff pollutant concentrations on a deciduous and coniferous forest in Korea. Based on the initial monitoring assessment, the average pollutant concentrations of stormwater runoff from the two forest sites were minor and not very significant in comparison to urban areas in Korea. In addition, the levels of pollutants from the forest sites were lower than the average stream water quality and could be considered as background concentration of forest sites. The results indicated that the pollutant event mean concentrations (EMCs) from the deciduous forest were significantly greater than the coniferous forest ($p < 0.02$) for all the measured pollutant parameters that include BOD, COD, DOC, SS, TN and TP; hence, not significantly different for TN ($p = 0.16$) and TP ($p = 0.17$). No correlations were identified between the pollutant EMCs and rainfall variables. The pollutant and flow patterns were used to provide guidance to a more appropriate sampling method, i.e., collection of optimum number of samples at optimum time interval. Based on the concentration data and rainfall, the sampling time interval could be selected and used in the subsequent monitoring.

Keywords: Coniferous; Deciduous; Event mean concentration; Forest; Nonpoint source; Runoff

1. Introduction

Nonpoint source (NPS) pollutants enter waterways as stormwater runoff from diffuse distributed sources across the landscape. Since Korea is a heavily forested country, with 65% (6.39 million ha) of its total area covered with forest, associated forest landuse activities are considered potential sources for NPS in addition to urban landscapes. The common pollutants and pollution that may originate from forest lands are sediment, elevated water temperatures, nutrients, organic debris, and pathogens [1]. Even though many of these constituents occur naturally in most water bodies, excessive levels of these constituents might result from stormwater runoff during rainy seasons which can impair or cause the loss of beneficial uses in these water bodies. Moreover, without adequate controls, forestry operations may degrade several water quality characteristics in water bodies receiving drainage from forest lands. For example, sediment concentrations can increase due to accelerated erosion; water temperatures can increase due to removal of over story riparian shade; slash and other organic debris can accumulate in waterbodies, depleting dissolved oxygen; and organic and inorganic chemical concentrations can increase due to harvesting and fertilizer and pesticide applications. Turbid waters tend to have higher temperatures and lower dissolved oxygen concentrations, increasing biological oxygen demand levels and accelerating chemical processes [2–4]. These potential increases in water quality

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contaminants are usually proportional to the severity of site disturbance [5]. Hence, NPS pollution impacts depend on site characteristics, climatic conditions, and the forest practices employed.

In Korea, the identification of NPS pollutant levels from forest landuse is still under research. Based on the study of Yur and Kim (2005) on the characteristics of NPS pollution in urban, agricultural and forested watersheds, the results revealed that the event mean concentration (EMC), which was used to quantify the average pollutant load washed off during a storm event with respect to the event runoff volume, from forested watershed were relatively small and in the range of 0.1 to 37 mg/l for suspended solids (SS), 2.1 to 16.5 mg/l for chemical oxygen demand (COD), 0.3 to 2.2 mg/l for total nitrogen (TN), and 0.1 to 0.5 mg/l for total phosphorus (TP) which were 5 to 63 times lower compare to agricultural watersheds [6]. In Luxembourg, Salvia-Castellvi et al. (2005) reported that 0.4 kg/ha-y of TN load was exported from forested area (extent of forest cover between 20 and 93%) smaller compare to agricultural (2733 kg-N/ha-y) and mixed landuse areas (17–22 kg-N/ha-y) [7].

This research was conducted to determine the extent of NPS pollutants in two different forest landuse types a deciduous and coniferous forest, by measuring the average pollutant concentration of stormwater runoff during storm events. The data will be used to provide guidance to the appropriate scheme at which sampling should be conducted (i.e., representing the rainfall amount and duration with least amount of samples to be collected). A standard sampling method for stormwater runoff in forest landuses is thus needed to properly identify the concentration differences for each storm event. The long term monitoring will be continued in the succeeding years to gather adequate data and eventually specify the target levels of pollutants to meet the total maximum daily load (TMDL) as well as to establish other water quality regulations by the Ministry of Environment (MOE) in Korea.

2. Materials and methods

2.1. Site characteristics

The monitoring sites were located at Gongju city in the South Chungcheong Province and Jinan County in the North Jeolla Province, Korea which belong to the tributaries of Geum River (Fig. 1). A 30-y old natural deciduous forest in low altitude zone (S1-G) and a 30-y old artificial coniferous forest in high altitude zone (S2-J) were selected by the MOE as representative sampling locations. In Korea, coniferous forest make up nearly 42% (2.70 million ha) of the total forest cover while the broadleaved (deciduous) forest cover 26% (1.66 million ha). The two sites selected for this research were classified as 'permanent protection' forest, wherein operations were restricted only for the development of national parks, environment conservation, research, and other forest land enhancement activities. The Korea Forest Service (KFS) has been managing all types of forests according to their purposes. However, forest conversion in both permanent and non-permanent forests has been happening. So as to prevent indiscreet forest conversion and reduce impact on forests, KFS enacted and enforced Forest Land Management Act in 2002. The Act

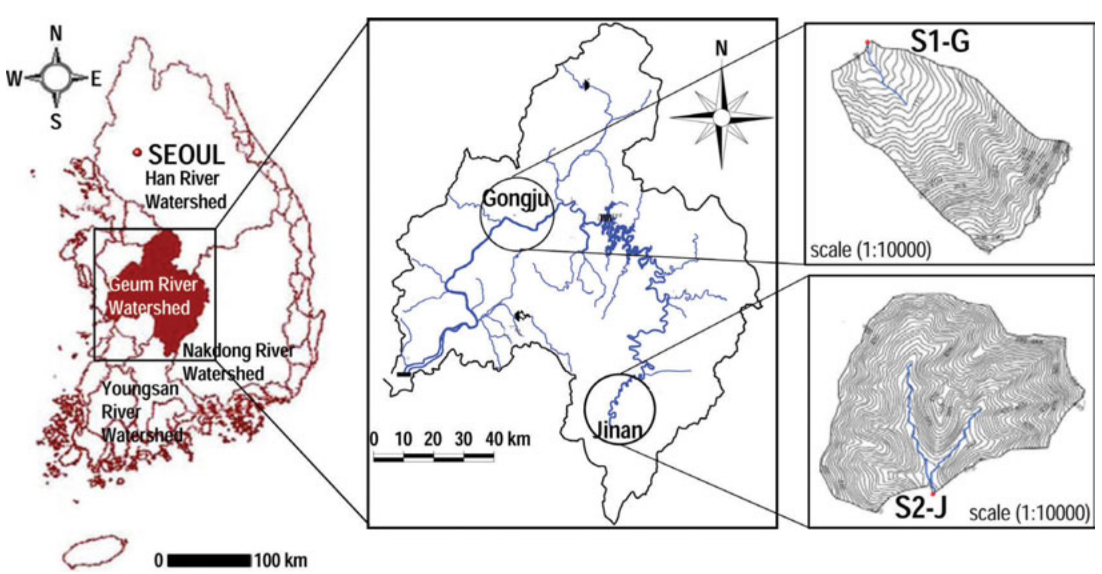

Fig. 1. Location of the monitoring sites.

Table 1
Description of the monitoring sites

Site	Forest type	Area (m^2)	Elevation (m)	Slope	Soil type/Origin	Soil texture
S1-G	Deciduous (broadleaf)	2,90,000	40–310	5–36°	Granite, gneiss	Silty-sand
S2-J	Coniferous (needleleaf)	5,30,000	340–550	15–40°	Sandstone, shale	Silty-sand

prescribes strict regulations on land-use change, mining, quarrying, and other activities. It also provides for restoration and post-management activities on converted forest areas.

The details of the monitoring sites are given in Table 1. Soil origin was sedentary soils derived from granite, gneisses, and shale with predominantly fine grained texture capable of absorbing water slowly and retaining for longer time.

2.2. Climatic condition

Approximately 85% of Korean forests are identified as cool temperate forests. Annual rainfall is about 1200 mm in the forest region. More than half of the total rainfall amount is concentrated in the summer months of June, July and August; while rainfall of winter from December to February is less than 10% of the total annual rainfall. The variation of annual mean temperature ranges from 6 to 13°C [8]. The climatic condition for the two forest sites are presented in Table 2. Slight differences in the mean rainfall and temperature values were observed between the forest sites.

2.3. Sampling and analytical methods

A total of 202 samples were obtained from the 15 monitored storm events conducted on both sites during the first year monitoring period from April to October 2008. Each site was equipped with ISCO 6712FR fiberglass refrigerated sampler unit and an automatic flow meter. The standard sampling method for NPS monitoring at forest sites is yet undetermined thus runoff during storm events was analyzed to establish an appropriate sampling approach to be incorporated for the succeeding monitoring period. In the first few monitoring months, several samples were collected at various time intervals during each storm event. Sampling interval was adjusted depending on the rainfall quantity and duration thus, sampling intervals varied during a monitoring event. Shorter sampling time intervals were typically selected in the beginning hours (e.g., 15 or 30 min) to give account to small storm events while longer sampling intervals (e.g., 2, 4 or 8 h) after several hours elapsed. This method was selected on the assumption that more pollutants will be washed-off during the early hours of storm (typical NPS monitoring). Hydrologic data including flow rate, depth of water level, rainfall, etc., were consistently measured throughout each storm event. Analytical analyses for typical water quality parameters such as TSS, BOD, COD, DOC, TN and TP were performed based on Standard Method for the Examination of Water and Wastewater [9]. The EMCs and stormwater runoff patterns were calculated and evaluated. All variables were tested with the Shapiro–Wilk test for normal distribution before statistical analyses. The comparisons of means, variations, and correlations were performed and all hypotheses were tested at 5% significance level by either a student t-test or a one way ANOVA using OriginPro 7.5 SRO v7.5714 (B714) (© OriginLab Corporation 1991–2003) software package.

Table 2
Climatic condition on the two forest sites*

Parameter	Gongju city (S1-G) Mean (Min/Max)	Jinan County (S2-J) Mean (Min/Max)
Rainfall (mm)		
Annual	1188 (794/1581)	1207 (821/1443)
Event	14.0 (0.5/141)	12.5 (0.5/219)
Temperature (°C)		
Spring (Mar–May)	14.1 (1.9/23.5)	12.3 (−0.4/22.4)
Summer (Jun–Aug)	24.6 (15.6/30.2)	22.9 (15.9/29)
Autumn (Sep–Nov)	13.6 (−3.3/24.1)	12.1 (−3.4/23.9)
Winter (Dec–Feb)	−0.5 (−12.4/12.3)	−1.2 (−12.1/12.8)

*Data is based on a 5-y period (2004–2008) provided by the Korea meteorological administration (KMA).

3. Results and discussion

3.1. Monitored storm events

Table 3 provides the summary of the 15 storm events for the year 2008 monitoring period. The maximum antecedent dry day (ADD) was 12 d for both sites and typically less than a week before sampling was conducted. Mean event rainfall was 11.4 and 19 mm for S1-G and S2-J, respectively. The artificial coniferous forest (S2-J) received greater rainfall because it is located in higher altitude zone. Likewise, the average rainfall intensity in S2-J was greater ranging from 0.2 to 4.9 mm/h.

Table 3
Summary of fifteen monitored storm events for the year 2008

Site code	Basic statistics	Antecedent dry day (d)	Total rainfall (mm)	Runoff duration (h)	Average rainfall intensity (mm/h)
S1-G	Mean ± S.D.	6.3 ± 4.1	11.4 ±8	15.3 ± 8.2	1.1 ± 0.8
	Min/Max	1/12	2/22	5.6/29.2	0.2/2.7
S2-J	Mean ± S.D.	6 ± 3	19 ± 23.7	8.9 ± 6.6	1.9 ± 1.9
	Min/Max	3/12	1/65.5	1.8/19	0.6/4.9

S.D. = standard deviation.

Sampling was preferably conducted for heavy rainfall with long duration allowing adequate sample collection. On the other hand, rainfall duration in the natural deciduous forest (site S1-G) was longer than the S2-J site. On average rainfall duration was about 9 to 15 h for each storm event. Overall, no statistically significant differences between the two sites were detected for all rainfall variables.

3.2. Pollutant concentrations (EMCs) at forest sites

The EMCs were calculated to represent the concentration of each pollutant. EMC is defined as the pollutant mass washed off by a storm divided by the event runoff volume [10]. During a storm, the soil particles in the forest lands will be washed-off by surface stormwater runoff which can potentially affect the concentration levels of pollutants in the downstream regions. Fig. 2 shows the box and whisker plots of EMCs for the two

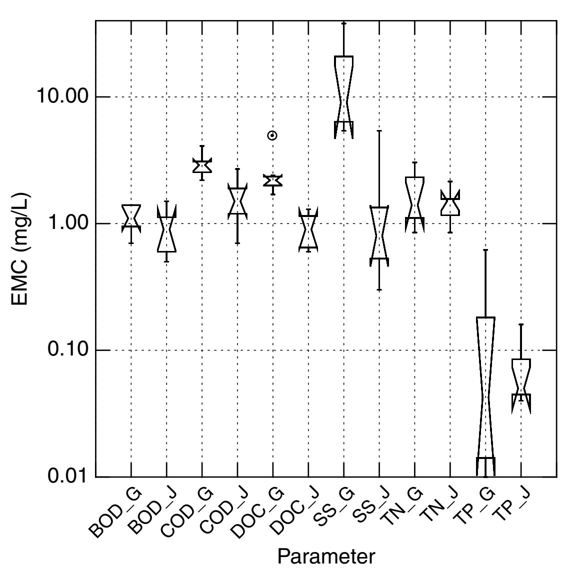

Fig. 2. Comparison of forest EMC of pollutants in the two sites ('G' represents the natural deciduous forest and 'J' represents the artificial coniferous forest).

forest sites. It can be observed that pollutant EMCs in the deciduous forest (S1-G) were greater than the coniferous forest (S2-J) for all the measured pollutant parameters. Mean ± standard deviation BOD EMCs are 1.1 ± 0.26 and 0.9 ± 0.4 mg/l for S1-G and S2-J, respectively. COD and DOC EMCs are 2.9 ± 0.58 mg/l and 2.5 ± 1 mg/l for S1-G; and 1.6 ± 0.65 mg/l and 0.9 ± 0.3 mg/l for S2-J. In addition, S1-G EMCs for SS, BOD, COD, and DOC were significantly greater than S2-J site ($p < 0.02$). Nutrient EMCs were also higher in the deciduous forest (S1-G) than in coniferous forest (S2-J). TN and TP EMCs are 1.7 ± 0.86 mg/l and 0.15 ± 0.22 mg/l (S1-G); and 1.4 ± 0.42 mg/l and 0.07 ± 0.04 mg/l (S2-J). Hence, were not significantly different for TN ($p = 0.16$) and TP ($p = 0.17$). Apparently, the biggest difference can be seen in the SS EMC ($p = 0.0088$) which appeared to be greater in the natural deciduous forest (14.8 ± 12.2 mg/l) than in the artificial coniferous forest (1.5 ± 1.8 mg/l). It is speculated that most of the sediments (especially clay and silt) are eroded and detached in the S1-G site that is a deciduous type natural forest having lower altitude and moderately in a coniferous type artificial forest (S1-J). It is also reflected in the turbidity of the collected water samples. The findings showed that greater particulates and natural organic detritus were washed off by stormwater runoff at S1-G site during storm events than S2-J site. Consequently, it could be stated that one of the possible reasons was due to the nature of leaves. It was known that a coniferous forest has trees that never lose their leaves and that are always green all year-round. On the other hand, leaves on the trees of a deciduous forest do turn colors and eventually fall especially during the autumn and winter seasons. Eventually, the fallen leaves will undergo decomposition in the soil and other microbial processes through time [11,12]. A study of Hesselsøe et al. (2001) concluded that leaf-associated soil supports the development of a generally higher level of potential nitrification activity during degradation of leaves [13]. The growth, activity and population size of bacteria in soil are strongly influenced by the major physiochemical factors controlling microbial activity (e.g., temperature and moisture) [14].

Nevertheless, there was no clear relationship between the pollutant EMCs and rainfall variables. Then again, it is possible that with heavy rainfall and longer rainfall duration, EMC is relatively small due to dilution effect exemplified in certain events with total rainfall exceeding 20 mm lasting for more than 10 h. An analysis made by Kim et al. (2003) on agricultural-forestry watershed concluded that correlations between pollutant EMCs and stormwater runoff variables were low and not significant [15].

Evidently, the pollutant EMCs in forest landuse were extremely lower in comparison to paved areas ($p < 0.0001$). A study on the pollutant unit loads of various transportation landuses in Korea [16] reveals that on average, SS EMC is about 93.3 mg/l that is 6 to 20 times greater than the average forest SS EMC (4.13–14.8 mg/l); forest COD EMC is 30 to 60 times smaller than in paved areas (COD EMC = 91.2 mg/l). On the other hand, TN and TP EMCs although small in transportation landuses are in magnitude of 2 and 4 to 7 times more than forest TN and TP values.

Fig. 3 shows the comparison of the average forest EMCs from S1-G and S2-J sites with the average concentration of pollutants in the corresponding nearby streams located at Ungjindong, Gongju City and Gamakri, Jinan County. The data used for the stream concentration was based from January 2004 to July 2009 average monthly pollutant concentrations provided by the National Institute of Environmental Research (NIER). As demonstrated in the figure, the degree of pollutant levels in the forest landuses was definitely lower in comparison to stream conditions although not significant (S1-G, p = 0.55; S2-J, p = 0.21). SS concentration in the forest was 1.3 to 6.2 times smaller than the stream SS concentration which signifies that soils were being deposited and carried downstream during storms. The concentrations of BOD and COD were increased by 27 to 65% in the stream and TN in stream was 2.1 to 2.5 greater than the forest TN concentration. On the other hand, the TP concentration differs for both sites. In the deciduous forest site (S1-G), forest TP is 23% less than the stream TP; however, in

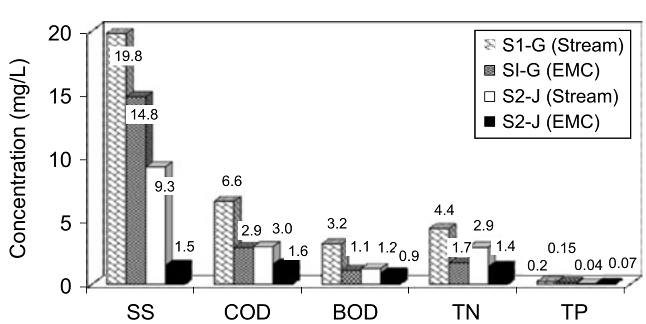

Fig. 3. Comparison of forest EMC and stream concentration of pollutants in the two sites.

the coniferous forest site (S2-J), forest TP was decreased by 94% in the stream. These indirect comparisons were merely done as a basis to assess the pollutant levels in forest sites in relation to average concentrations in the stream. Nonetheless, concentrations in streams were influenced by several factors/sources and forest stormwater runoff is only one of those. For instance, the pollutants (e.g., organics and nutrients) from forested and agricultural watersheds could be transported by either leaching to the groundwater or carried through surface stormwater runoff. Soluble compounds tend to enter the soil and are transported (leached) via subsurface flow. Compounds that absorb to soil particles are typically transported during storm events, both ways pollutants will still enter the receiving water [17]. Ultimately, it implies that sources of water pollution are diverse and it is extremely important to know the contributing levels of pollutants for each specific landuse to be able to determine the limit of pollutant concentration and to establish policies and management measures in the future.

3.3. Modifications in sampling collection scheme

An attempt has been made to characterize the pollutant concentration patterns over the duration of the each storm event. Multiple hydro and polluto-graphs were generated for all the storm events. Fig. 4 illustrates an example of event hydro and polluto-graph for each site. In Fig. 4(a), the flow rate was almost constant but the BOD concentration peaked at after almost four hours since the start of the storm event. SS concentration on the other hand shows comparable pattern to BOD which also fluctuates during the entire storm period. In instances depicted in Fig. 4(b) where the flow rate was almost twice the flow rate in Fig. 4(a) during the beginning hours and increased rapidly then decreased afterwards, concentration presents a different trend. Although the flow rate did not peaked during the beginning hours, the high flow rates instigated sufficient scouring of soil surface resulting to an increased in pollutant concentrations of SS and BOD. It is therefore necessary to calculate EMC to better represent the concentration of a specific pollutant.

The data gathered during the monitoring period were used to suggest an appropriate method for sample collection. Based on the hydro- and polluto-graphs generated, the rainfall and pollutant trends were observed and classified into distinct types as follows: Type a and/or b (increase); Type c (wash-out); and Type d (random) as demonstrated in Fig. 5. It was apparent that increasing pollutant concentration for S1-G dominates while mostly random and increasing in S2-J. Wash-out type was rare in the case of organics and nutrients which suggest that pollutant concentration over stormwater

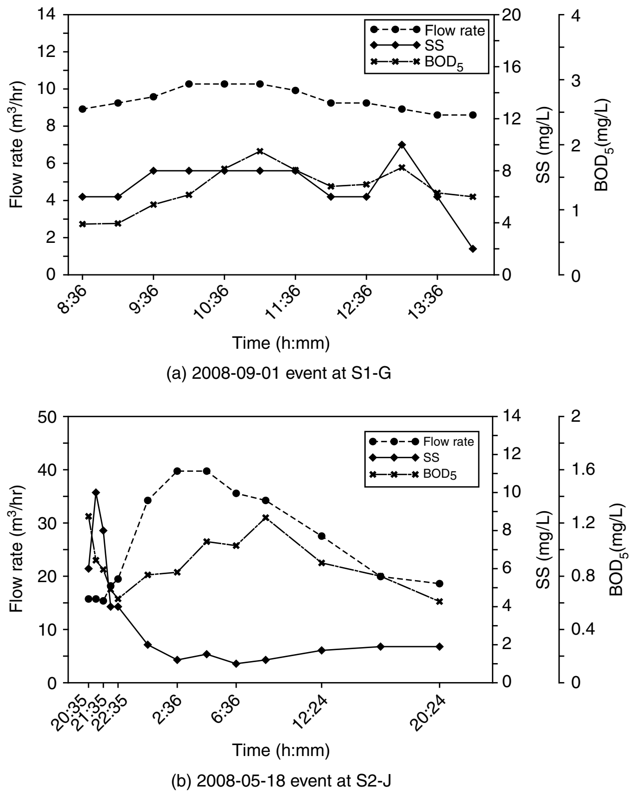

Fig. 4. Hydro- and polluto-graphs of two selected events for each site.

runoff duration in forest landuse was unlikely similar to impervious landuses wherein the first flush phenomenon was typically exhibited. Overall, the likelihood that pollutant concentrations peaked was observed either during the earlier period of the storm event or perhaps in the middle which was also dependent on the intensity of flow rates. Nonetheless, there was no general trend that can be concluded based on the storm events. It was certain that concentration peaks were close for most parameters except SS while nutrient concentration were normally constant for most of events. Hence, the difficulty of describing the pollutant concentration patterns was attributed to limited samples collected and random sampling interval. Therefore, following the investigations carried out over the monitored events, a more appropriate sampling scheme was suggested as follows: from the start of stormwater runoff, one sample should be collected (0 min), 5 samples at the next 15 min interval, 6 samples at the next 30 min interval, 5 samples at the next 60 min interval and if the duration of stormwater runoff is long, 6 additional samples at the next 120 min interval. Typically, the auto-sampler collects a maximum of 24 samples. Depending on the amount of rainfall, the sampling could be adjusted. The suggested sampling scheme is being used in the monitoring up until recently.

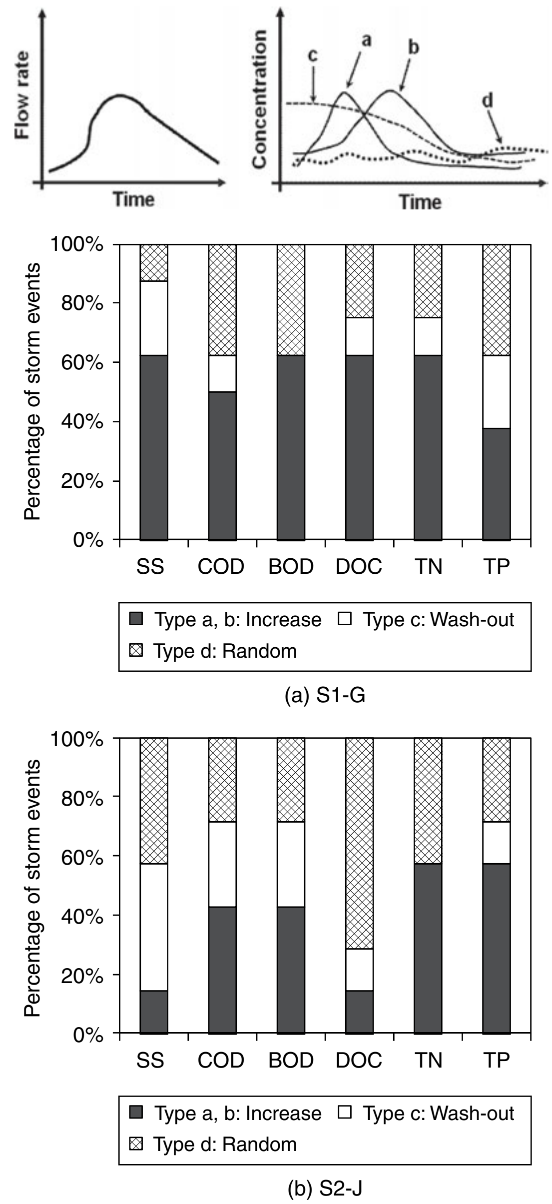

Fig. 5. Percentage of events at each polluto-graph type.

4. Conclusions

This research has been conducted as part of the long term monitoring project on the Geum River watershed financed by the MOE. It is focused on the assessment of NPS pollution in two different forest landuse sites. These forests are classified as 'protection forests' managed by the KFS. Apparently, the average concentrations of stormwater runoff in forest sites were minor and not very significant in comparison to urban areas. However, it is important to recognize the extent of its contribution to the watershed as well as to identify the particular pollutants of concern that would be helpful in meeting the TMDLs.

The findings revealed that the pollutant concentrations were comparatively low (i.e., lower than the stream average concentrations) and the magnitude of the peaks was close for most of the events. The results indicate that the pollutant EMCs in the deciduous forest (S1-G) were greater than the coniferous forest (S2-J) for all the measured pollutant parameters. In addition, S1-G EMCs for organic parameters were significantly greater than S2-J site ($p < 0.02$). Hence, were not significantly different for TN ($p = 0.16$) and TP ($p = 0.17$). Some of the differences were attributable to differing forest types and not on rainfall variables. Greater particulates and natural organic detritus were washed off by stormwater runoff at S1-G site during storm events than S2-J site. Decomposition of the broad leaves present in the deciduous forest seems a factor of the increase in pollutant concentrations. Although similar land use was selected, certain pollutant concentrations were greater than the other but not significant. Organics such as BOD, COD, and DOC concentrations were relatively low while TN and TP were likely comparable to the stream concentration values. This suggests that NPS pollution depends on the meteorological as well as topographic factors.

The data gathered aid in understanding the levels of pollutants in forest landuse which can be considered as background concentration data since the forests were protected from silvicultural activities. In addition, the pollutant and flow patterns were used to provide guidance to a more appropriate sampling method. Based on the concentration data and rainfall, the sampling time interval could be selected and used in the subsequent monitoring. The EMCs obtained from the monitoring and experiments can also facilitate the modeling effort and provide a more vigorous approach for NPS load estimations which will result in water quality response curves in the receiving water bodies. More accurate assessment of NPS pollution from the forest watersheds is needed thus the long term monitoring will be continued in the next couple of years. Ultimately, management measures will be improved and water quality regulations will be established.

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