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Trend of storm water runoff pollutants temporal variability from different land use sites in Korea

Sheeraz Memon[a,b], Ma. Cristina Paule[a], Sunghoon Yoo[a], Raja Umer[a], Bum-Yeon Lee[a], Chinzorig Sukhbaatar[a], Chang-Hee Lee[a,*]

[a]*Department of Environmental Engineering and Energy, Myongji University, San 38-2, Namdong, Yongin, Gyeonggi Province, Korea, email: changhee@mju.ac.kr*
[b]*Department of Environmental Engineering, Mehran University of Engineering & Technology, Jamshoro, Sindh, Pakistan*

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ABSTRACT

Pollutants temporal variability during storm water runoff is of great concern due to diffuse pollution source, rainfall change, impervious cover percentage, soil permeability and runoff volumes. This study examines the variations and fluctuations of storm water pollutants during runoff duration from different land use sites in Yongin city, Korea. Samples from urban, agriculture, construction, mix catchment, and stream sites location were collected and analyzed. Concentration profiles, correlations between storm variables and event mean concentration, flow weighted mean concentration (FWMC) levels and pollutant loading curves were calculated to characterize the pattern of storm water temporal variability. It was found that pollutants level varied significantly between the monitoring sites and also differed temporally from individual events within same location. The magnitude of suspended solids (SS), chemical oxygen demand (COD), and total phosphorous (TP) showed high variability in mix catchment, urban and stream sites, whereas, chloride (Cl) showed minimal variability in all sites. Average values of FWMC level were found high in 2 to 4 h or >4 h of runoff duration from mix catchment and construction sites which clearly show the non-existence of first flush effect. These findings can support for the improvement of storm water monitoring projects in Korea.

Keywords: Storm water; Temporal variability; Flow weighted mean concentration; First flush

1. Introduction

Storm water runoff contributes major portion of quality deterioration to the inland waterways of Korea. Although, many monitoring and restoration projects have been initiated to control storm water pollution and to improve quality of natural waters, since the last two decades but it is insufficient due to limited resources and inadequate data sets. Urbanization and Industrialization are the major causes of change in natural land, increase in impervious surfaces and runoff volumes, which ultimately affects water quality and aquatic habitats, and generate higher and early peaks [1,2]. Numerous domestic and abroad studies have reported that urban storm water pollution is a major source for the deterioration of water quality [3–5].

In general, Storm water pollution is difficult to manage and control because it comes from many diffuse sources and can generate high pollutants concentration from an entire watershed toward the sink in a variant and vigorous way. Constituents such as sediments, organic matters, pesticides, nutrients, heavy metals from agriculture, urban, constructions, highways and other areas are transported through runoff or percolation during storm event. Each constituent is considered as dominant according to site specific conditions and affected by soil type, land use pattern and management

* Corresponding author.

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practices within the catchment. In previous studies, it was found that pollutant loads and concentrations of suspended solids, heavy metals, nutrients and organic matters are high in urban areas [6–8]. In case of nutrients, excess use of fertilizers and pesticides in agricultural land cause algal bloom and eutrophication in lakes, rivers, reservoirs and estuaries [9,10], whereas, construction industry can generate 1000 to 2000 times higher sediments than forest site [11]. The magnitude and variability of each constituent depends on rainfall data, runoff amount, land use patterns and man-made activities according to different watershed characteristics, however it is important to identify and understand the behavior of storm water pollutants throughout the rainfall-runoff period from multiple land use sites. Researchers observed that large variability and uncertainty during storm water discharge is associated with runoff loadings, which largely depend on rainfall and runoff [12].

The focus of this research is on temporal analysis of storm water pollutants from different land use sites in which runoff quality, its trend and variability within and in between storm events were investigated according to site specific conditions and hydrological characteristics. High amount of variability during inter-intra storm events or within and between the catchments require more number of samples for the accuracy of sampling strategy and design [13]. The authors reported that time-variables measurements within storm event provide a better understanding of temporal processes that affect pollutant loading [14]. Temporal variations are specified either in pollutograph or Event mean concentration (EMC) form because of the diffuse nature of pollutants [15]. EMCs are used to quantify flow weighted mean concentrations of storm water pollutants throughout the storm duration and depend on hydrological and site specific characteristics. First flush effect is also widely studied and reported because it is important to control and manage the storm water pollution economically, effectively, and efficiently. It is the existence of large amount of pollutants emission in initial portion of storm water event which can provide basics to improve and optimize the best management practices. Many past researchers [16–19] quantified first flush phenomenon and its correlation with rainfall characteristics. The aim of this research was to identify and describe the temporal variations of each pollutant during rainfall period within and between monitoring sites. It was also aimed, to identify the overall behavior of storm water pollutants during rainfall events and to quantify first flush phenomenon. This study can provide a complete scenario for developing storm water pollution abatement programs from different land use sites in Korea.

2. Materials and methods

2.1. Study area

In this study, Storm water discharge sampling was conducted from the outfalls of 5 different sites such as construction, mix catchment, agriculture, urban and small catchment located in the same region, Yongin city, South Korea for the year 2013. Fig. 1 shows the monitoring sites location map. These representative sites were selected on the basis of drainage pattern, well mixed flow conditions, frequent field visits, and onsite ease in access and approach. Mix catchment site reflects the surrounding urban land use and discharge from construction site. Runoff from respective catchment area drains in a single outlet pipe or open channel toward guem-hak stream with a separate sewer system without any significant treatment. Table 1 shows a summary of site characteristics.

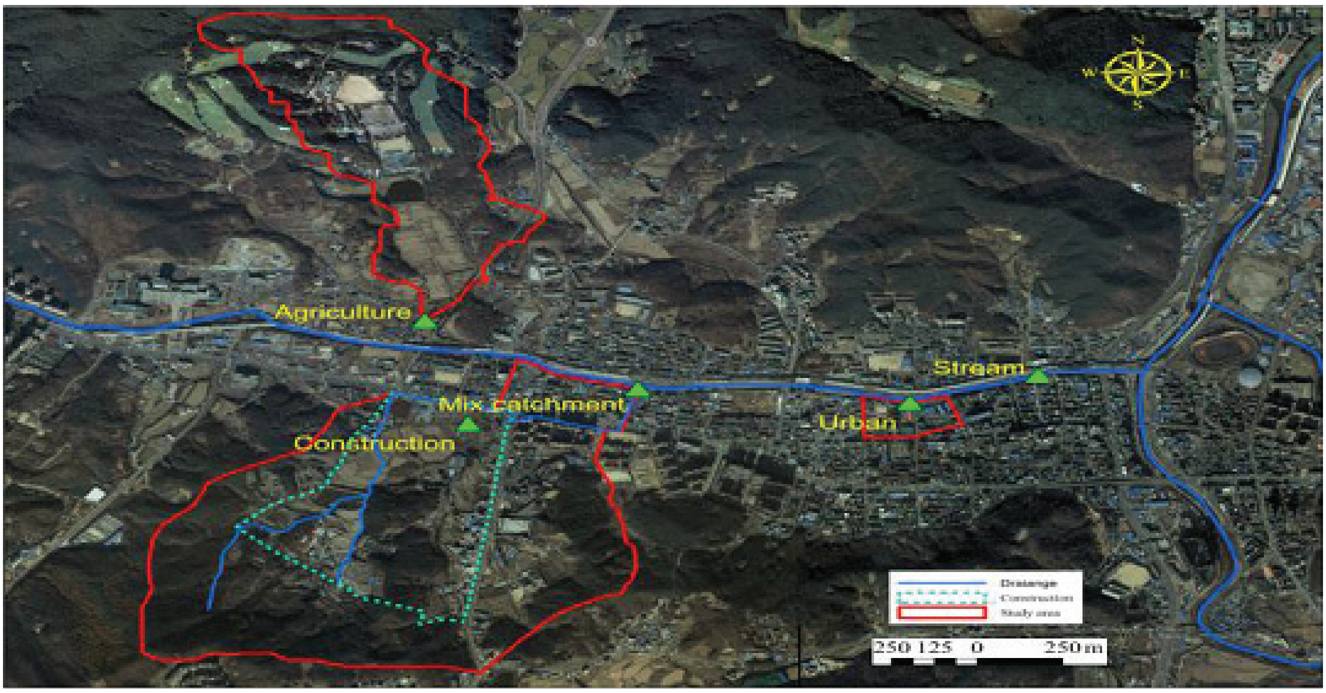

Fig. 1. Monitoring sites location map.

Table 1
Summary of site characteristics

Land use	Catchment outlet	Total catchment area (m^2)	Imperviousness (%)
Construction	Rectangular Channel box	468493	8
Mix catchment	Rectangular Channel box	1451500	20
Agriculture	Open channel	577100	8
Urban	Circular pipe	41200	100
Stream	Open channel	14407232	46

2.2. Sample collection

Samples were taken manually from number of storm water events during the period of May 2013 to November 2013 and were collected using 2 L polyethylene bottles according to time-spaced and flow weighted intervals before discharge into the stream. Sampling was started when runoff was generated or a flow above baseline conditions was observed during a rainfall event. Small sampling intervals (5 to 30 min) were followed in the initial period (first 2 h) and during peak flow of storm water event, whereas, large sampling intervals (1 to 2 h) were followed in the remaining storm water event (after initial 2 h except peak flow rate time) when change in flow and concentration was found little.

Total of 12 to 15 samples were collected from high impervious sites (Urban, Mix catchment, and Stream), whereas, minimum 8 samples were collected from permeable cover sites (agriculture and construction) per storm event. Overall, the intervals at each site were different due to change in impervious area, increase or decrease in percolation rate and other site characteristics. This setup of intervals was based on last 2 years data of storm water events. More samples were collected in initial rainfall-runoff period compared to middle and later period to capture first flush effect. The samples were brought into laboratories and were stored in the refrigerator for the water quality analysis. Total of nine storm water events were monitored which differs in number of samples collected. Samples were analyzed within 6 h of collection for BOD_5, and turbidity, whereas SS, COD, TOC, Cl and nutrients were analyzed within three days in the laboratory using Korean Standard Methods.

2.3. Equipment installation and data analysis

Rainfall depth and its duration was measured by installing Casella standard tipping bucket rainfall gauge in an open space and was compared to local meteorological data. The annual precipitation was recorded as 1321 mm. Rainfall amounts ranged from 1.5 to 89.4 mm and average rainfall intensity ranged from 0.23 to 15.78 mm/h. Antecedent dry period which is duration between storm event sampled and the last measurable event ranged, was in the range of 3–10 d. Flow rate at each site was measured either manually or automatic throughout the storm event. In construction site, it was not possible to install automatic flow meter due to ongoing activities of excavation, filling, clearing and grading therefore it was measured manually through velocity meter and wetted cross sectional area. Similar methodology was followed for agriculture and stream sites. In case of mix catchment and urban sites, automated flow meter (PCM F Nivus portable flow meter) was installed at the outlets. These flow meters recorded the data at each one minute interval after calculating depth and velocity of water.

2.4. Flow weighted mean concentration (FWMCs)

High variability and fluctuations in pollutants concentration within the storm water event makes it difficult to use mean, median or mode values of the samples collected during storm event. Many studies have suggested a single index value in the form of flow weighted event mean concentration. It can be defined as the total pollutant mass divided by total runoff volume discharged during rainfall event [19–21]. Hydrological and site specific characteristics affect the event mean concentration because it represents the concentration level of the entire storm water event, and also it is difficult to characterize flushing pattern of individual site, therefore in this study, storm event is divided in three different time intervals i.e., 0 to 2 h, 2 to 4 h and >4 h for FWMC analysis. It is the mean concentration at F1, F2 and F3 time intervals per event and calculated as,

$$\text{mean concentration} = \frac{M}{V} = \frac{\int_t^{t=T} Q_t C_t dt}{\int_t^{t=T} Q_t dt}$$

where M is the total mass of the pollutants (g); V is the total volume (m^3), t is the time in minutes, C_t is the pollutant concentration at time t (mg/L) and Q_t is the flow rate at time t, and F1, F2, F3 are flushing intervals at 0 to 2 h, 2 to 4 h and >4 h.

First flush (FF) existence during storm water monitoring is of great importance due to difference in flushing intensity within the storm event according to rainfall and site specific characteristics. It is described as the high pollutants concentration in the initial storm water runoff compared to later event [22].

3. Results and discussion

3.1. Storm water pollutants variability

Fig. 2 shows temporal variations of runoff quality from different land use sites for 2 representative storm events of June 18 and July 22, 2013. During both events hydrological and climatic conditions such as antecedent dry period, rainfall depth, average rainfall intensity, and runoff volume varied significantly from 2.8 to 3 d, 45.6 to 89.4 mm, 3.6 to 9.5 mm/h, and 11000 to 50000 m^3 but the pollutants concentration behavior was found similar. In urban site, peak concentrations for TOC, DOC, Cl, TN and TP were observed within 1 h of runoff due to high impervious cover and then sharply decreased, whereas SS and turbidity levels increased with flow rate change in later period. Similar results were found in previous studies [23]. Agriculture site showed fluctuations in concentration level for all water quality parameters.

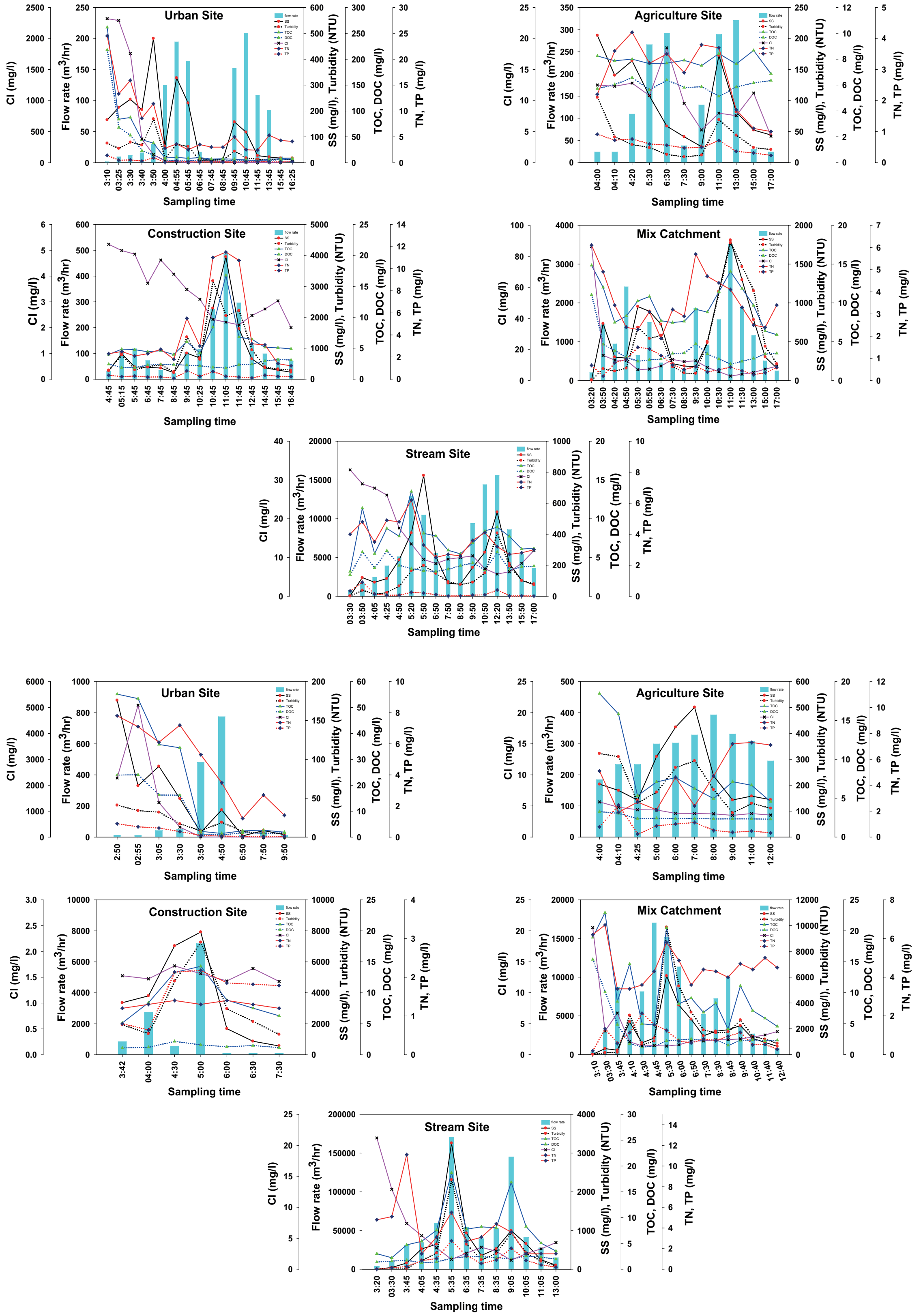

Fig. 2. Pollutants trend graph during June 18 and July 22, 2013 events.

Peak pollutant concentrations appeared in different runoff time intervals but were not followed or correlated by peak flow rate. In general, SS-turbidity-TP followed similar trend of increase or decrease in concentration levels. Peak concentrations of SS, Turbidity, TOC, TN were observed at the same time of peak flow rate in the later period of storm event, whereas, TN, DOC showed steady values in construction site area. In case of chloride concentration, multiple peaks were observed against the increase in flow rate. From mix catchment site, pollutants concentration was high in the beginning of runoff due to surrounding urban areas and decreased gradually with the time. But these levels increased in the middle and last portion due to construction site runoff impact except for chloride, TP and DOC. Stream site showed various peaks for all pollutants concentration and no correlation was observed with increase or decrease in flow rate. Overall SS and turbidity, TOC and DOC followed similar patterns throughout storm event.

Concentration levels of SS, COD, TP and Cl varied significantly throughout the storm water event in all monitoring sites as shown in Fig. 3. Results illustrated that SS levels fluctuated high in mix catchment and urban sites, whereas, COD showed irregular patterns for all monitoring sites except urban site in some storm water events. In case of TP, gradual decrease was observed in urban site after 1 h of runoff but other monitoring sites showed multiple peaks of TP. Overall Cl concentration showed early wash off characteristic in initial period of event and then gradual decrease was observed in all monitoring sites.

It was found that peak concentration occurred at any time in construction, site but gradual decrease was not followed due to ongoing development activities such as digging, transportation and filling of soil, removal of vegetation cover, construction of buildings, roads and streets, and others. Mix catchment site showed high variability for SS, COD and TP. It can be explained, as the sampling site is the outlet of surrounding urban areas and runoff from construction site, therefore fluctuations in concentration levels were obvious and hence no clear pattern was observed. In case of Cl, it showed increasing trend in the initial part due to surrounding urban land use impact, but decreased in later period of storm water event. Steady values of Cl were observed in agriculture for most rainfall events regardless of the flow pattern, whereas SS, COD and TP showed temporal changes during runoff duration. Initial runoff in urban site was polluted and resulted in peak concentration levels, but gradual decrease was observed in middle and later period, except for the high rainfall intensity storm water events. Amongst all pollutant parameters, Cl showed a clear pattern of early wash off and then gradual decrease was observed. All of the curves in stream site showed multiple peaks of SS, COD and TP for all events.

It is also important to calculate correlation coefficients of storm variables such as flow rate (FR in m^3/h), total rainfall

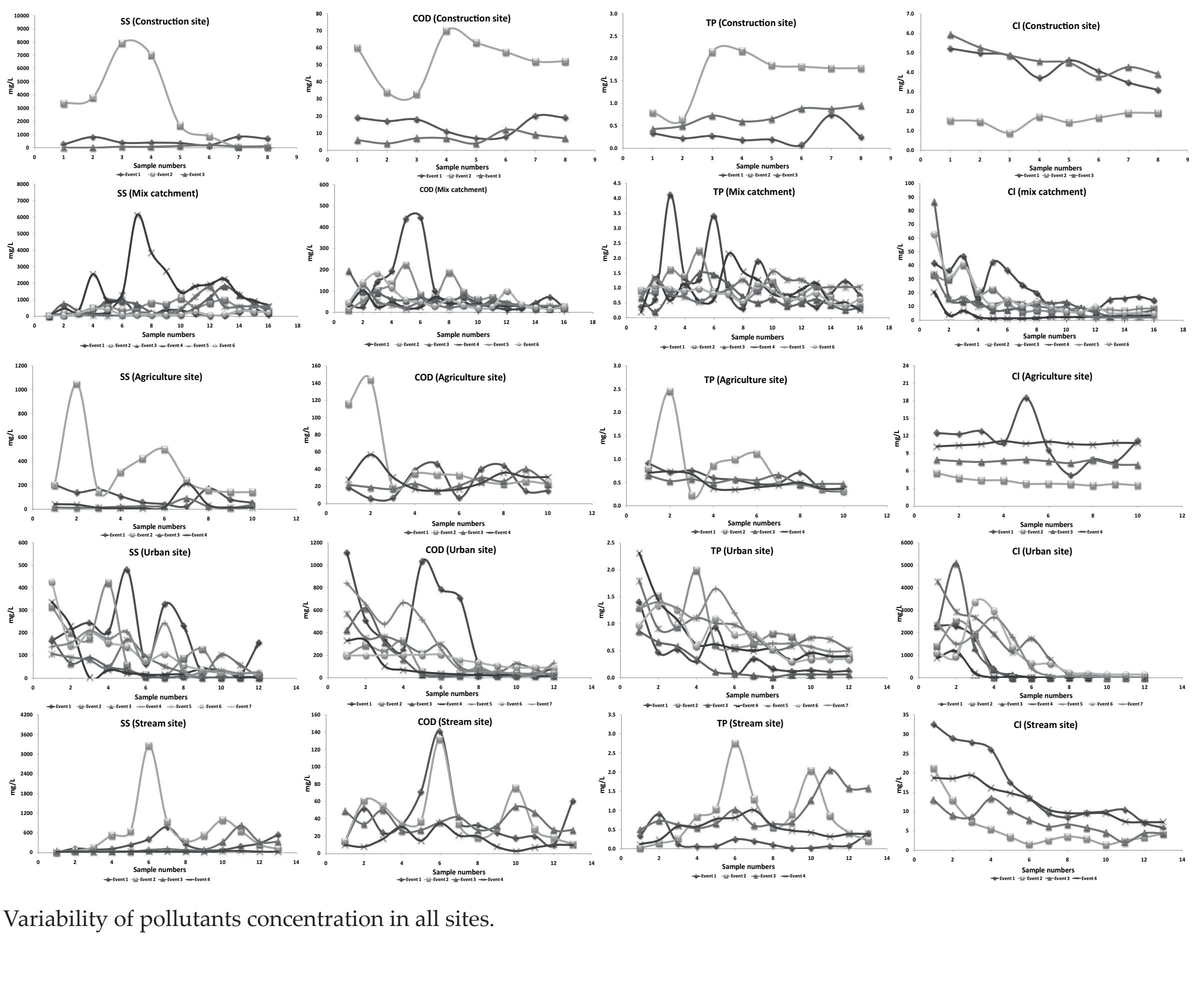

Fig. 3. Variability of pollutants concentration in all sites.

(TR in mm), average rainfall intensity (AVI in mm/h), runoff volume (RV in m^3) and antecedent dray period (ADP in days) with pollutants event mean concentration (mg/L) to determine the impact on storm water quality. These variables were selected on the basis of monitoring frequency and availability of data. Table 2 represents the numbers of Pearson correlation coefficients '*R*' and their significance level less than 0.05. Mix catchment and stream sites showed strong relation between SS and storm variables at significance level $P < 0.05$ as shown in bold text. Overall urban site was negatively correlated with all variables except ADP. Stream site showed strong and positive correlation of hydrological variables on storm water quality except Cl. High and positive correlations of FR, TR, AVI and RV were recorded for SS, TP and TOC from mix catchment, stream and construction sites. ADP was observed as a poor predictor for all pollutants except COD and Cl in mix catchment, TP in stream, TP and TOC in construction, TOC and Cl in agriculture, and TP in urban. Previous study also revealed similar results of weak correlation of ADP with all pollutants EMCS [24]. Concentrations of Cl were poorly described and showed strong negative correlation with all variables. In most of the sites, relationships between FR-SS, TR-SS, ARI SS, and RV-SS were high as compared to other pollutants Pearson coefficient numbers.

3.2. Flow weighted mean concentration (FWMC)

The graph for average values of FWMC is presented in Fig. 4. Urban site showed highest mean concentration levels for all water quality parameters in initial 2 h of runoff period, which clearly shows the early flushing characteristics due to high imperviousness, small catchment size and surrounding urban activities such as residential and commercial areas, local downtown market. Overall SS and turbidity levels from mix catchment site were found high in 2–4 h or >4 h of runoff period but none of the event observed high levels in 1st part except with low rainfall intensities. It was expected due to construction site impact in the middle or later period of storm water event. It means that in this type of monitoring site, flushing characteristics throughout the event is important to monitor and capture. Other pollutants such as COD, TOC, and Cl were high in 1st part. Stream site showed high levels in 0–2 h of runoff for all pollutants but the exponential decrease in concentration levels was not observed in 2–4 h or >4 h of runoff. It may be due to the fact that initial runoff impact was runoff from surrounding impervious areas and later from permeable pavements resulted in high levels. In agriculture site, mean concentration levels were not reduced much in any part of runoff event for most of the pollutant parameters.

Table 2
Pearson correlation coefficient between storm variables and EMC

Monitoring Sites	Pollutants EMC	Correlations				
		FR	TR	AVI	RV	ADP
Mix Catchment	COD	–0.174	–0.168	–0.187	–0.182	**0.822**
	SS	**0.984**	**0.939**	**0.982**	**0.985**	–0.378
	TP	0.433	0.359	0.512	0.414	0.133
	TOC	0.652	**0.667**	**0.719**	**0.672**	–0.520
	Cl	–0.550	**–0.677**	**–0.71**	–0.563	0.439
Stream	COD	0.752	0.815	0.866	0.749	0.123
	SS	**0.97**	**0.948**	**0.999**	**0.965**	–0.170
	TP	0.427	0.290	0.523	0.386	0.627
	TOC	0.774	0.785	0.856	0.766	–0.044
	Cl	–0.779	–0.820	–0.858	–0.777	–0.165
Construction	COD	0.769	0.742	0.834	0.719	0.209
	SS	**0.772**	0.669	0.845	0.724	0.260
	TP	0.580	0.377	0.669	0.535	0.423
	TOC	0.215	0.130	0.334	0.142	0.792
	Cl	–0.526	–0.494	–0.620	–0.461	–0.505
Agriculture	COD	0.217	0.721	0.511	0.037	0.180
	SS	–0.131	**0.942**	0.869	–0.236	–0.345
	TP	0.285	0.833	0.682	0.124	0.035
	TOC	–0.483	–0.159	–0.412	–0.624	0.551
	Cl	–0.411	–0.516	–0.576	–0.544	0.783
Urban	COD	–0.448	–0.481	–0.516	–0.478	0.214
	SS	–0.305	–0.219	–0.293	–0.300	0.199
	TP	–0.402	–0.435	–0.415	–0.432	0.488
	TOC	–0.292	–0.564	–0.462	–0.387	0.064
	Cl	–0.343	–0.650	–0.538	–0.439	0.208

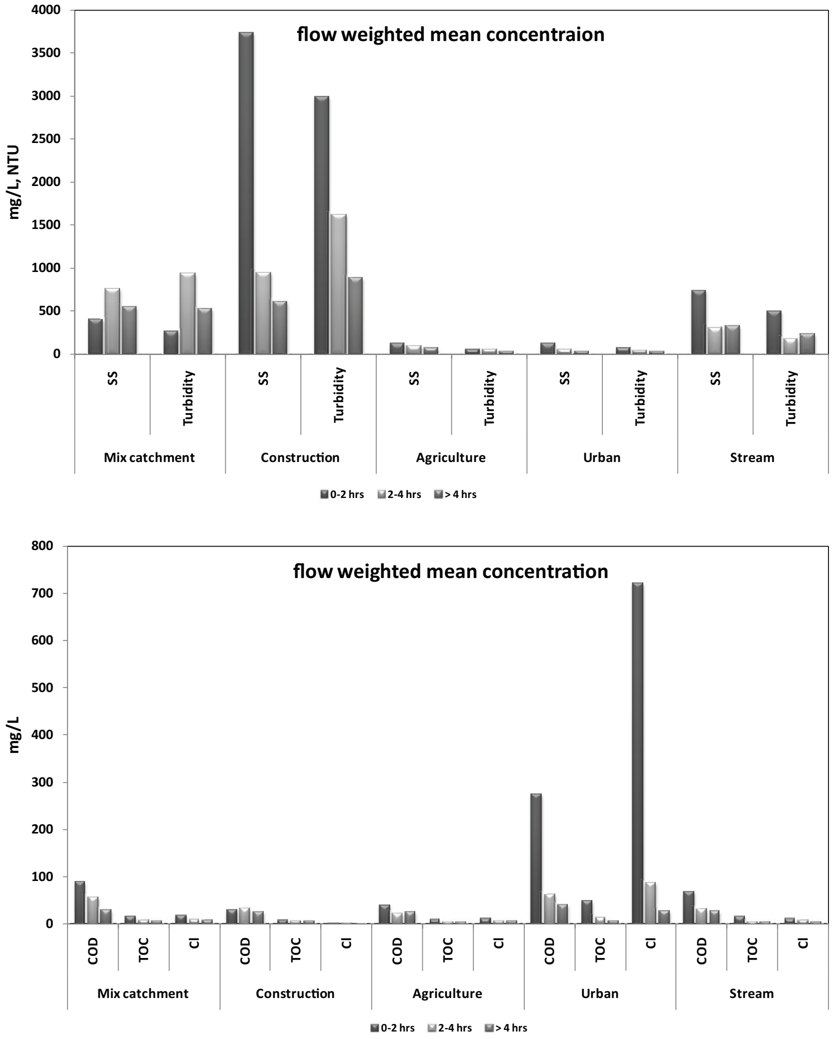

Fig. 4. Flow weighted mean concentration levels.

First flush phenomenon was conducted by plotting cumulative runoff volume against the cumulative pollutant load for two stormwater events of June 18, and July 22, 2013 as shown in Fig. 5. It was found that construction site exhibited weak, mix catchment showed slightly strong, agriculture and stream sites were moderately strong and urban site showed clearly strong FF effect for majority of the constituents regardless of the intra event hydrological variability. It can be seen from the plot that all pollutants were below the bisector line (45°), which reflected poor FF effect from construction site. The curve in mix catchment site indicated deviation of pollutant mass above and below the bisector line due to site specific characteristics. In agriculture and stream sites, FF strength was strongly observed for SS, TP and COD, whereas FF was not found for TOC and Cl. In urban site, the curve was significantly above the bisector line which reflects the positive correlation of FF with impervious cover as was described in previous studies [1,16]. Overall urban site showed higher tendency of pollutants washoff in the initial period of stormwater event as compared to other monitoring sites.

4. Conclusions

From the results it can be summarized that peak concentration of pollutants was observed in the 1st h of runoff from urban land use site and was not directly related to flow rate in urban site, whereas, other monitoring sites showed dispersed and variable levels according to site specific conditions. High temporal variability and fluctuations in concentration peaks and levels was found in mix catchment site for SS, TP, and COD. The effects of storm variables on event mean concentrations were investigated. It was found that ADP was poorly and negatively correlated with storm water pollutants except Cl in all monitoring sites where as relationship with SS was strong and high for most of the monitoring sites except urban catchment area. The mean flow concentration levels for each event was divided into 3 categories (0–2 h, 2–4 h, and >4 h) and then average of all events values was calculated. Results revealed that urban site showed high flushing characteristics in 1st 2 h of runoff. In case of mix catchment site, SS and turbidity values were

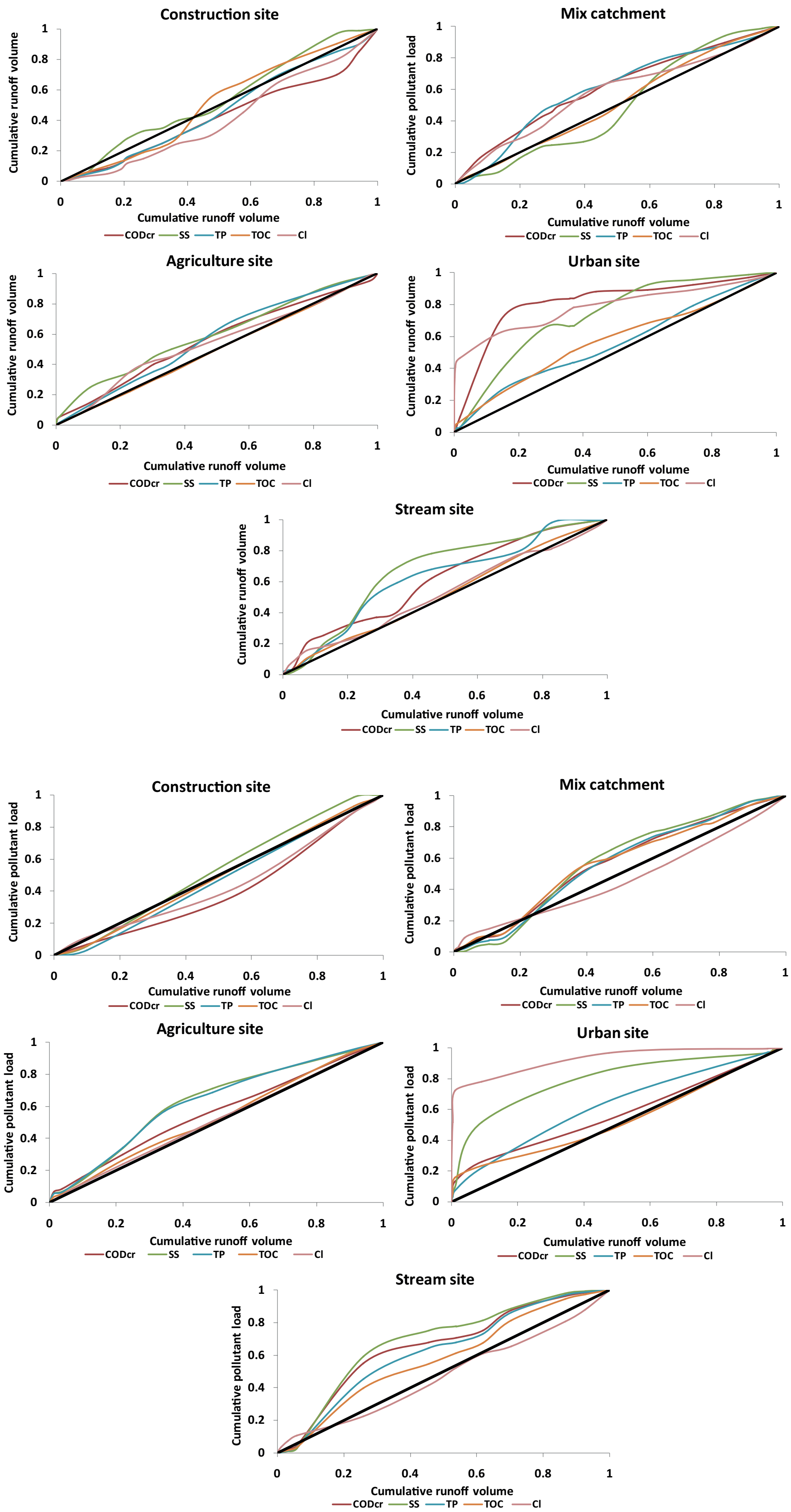

Fig. 5. First flush phenomenon during June 18 and July 22, 2013.

high in 2–4 h or >4 h of runoff and was not found high in 1st part except for the events with low rainfall. A weak first flush was observed at mix catchment and construction sites, whereas urban site showed strong FF effect.

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