Urban Runoff Characteristics in Tehran, Iran

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ABSTRACT

This paper presents the general and first flush characteristics of 14 wet weather runoff qualities in Tehran, Iran during 2008-2011. Flow and runoff samples were collected from different surface types that include rusted and galvanized iron roofs, asphalt street, urban streams and storm channel collection systems. The results showed that Event Mean Concentration (EMC) of dissolved pollutants such as nitrate (NO_3-N) and phosphate (PO_4) were higher in streams with base flow whereas dissolved metals such as Zn were about 30 times higher in galvanized roof and asphalt surface runoffs. Large EMC variability in total suspended solids (TSS) were observed in measured samples ranging from 80 to 1720 mg/L. Stronger and frequent first flush was observed for TSS as well as dissolved pollutants in smaller drainage areas compared with larger drainage areas.

KEYWORDS

Urban Runoff, Pollution, Event Mean Concentration, First Flush, Tehran.

1 INTRODUCTION

Increased impervious surfaces in urban areas due to land development can adversely impact the storm water runoff management from two main reasons: firstly, the increased impervious surfaces will increase the overall and peak runoff volume during the rain events and secondly, the impervious surfaces will act as a catalyst for particle and pollution build up that can be washed off during rain events. Several aspects of urban runoff pollution including their source and quality as well as impact on receiving waters have been investigated by different researchers around the world. Some example studies include: Barret et al., 1998; Lee et al., 2000; Lee et al., 2004; Han et al., 2006; Flint and Davis, 2007; Francey et al., 2011; Barco et al., 2008; Gromaire et al., 2001; MacKay et al., 2011; Thomson et al., 1997; Eriksson et al., 2007; Thomson et al., 1997; Stenstrom and Kayhanian, 2005. However, the urban runoff pollution characteristic in Tehran is not known that is the focus of this study.

Tehran is located in the south of Alborz Mountains with an average annual rainfall of 230 mm. Currently in Tehran, streams and storm water channels with aid of curbs and gutters convey runoff from 1280 km^2 drainage area toward storm sewers. Base flows of urban streams which act as part of storm sewer systems originate from mountains or Qantas. These streams occasionally receive illicit discharge of wastewater at different locations. Studies performed by Khakriz Ab Corporation (1997) revealed that quality of Tehran's urban streams is continuously in decline trend as the water travel from north to south (Khakriz Ab, 1997). Beside from illicit activities and pollution discharged during dry period, additional quantity of pollutants are also washed off and discharged to these streams during rain events from high density urbanized areas. The untreated water from these streams is used to irrigate crop land in southern Tehran. The consumption of fruit and vegetables produced from these untreated waters can pose health risk. The untreated waters can also impact the environment and aquatic life. To alleviate the problem, a master plan has been developed to systematically manage and control stormwater related pollution in Tehran (Mahab Qodds and Pöiry, 2010). The master plan recommends monitoring of stormwater quality in both runoff and stream flow which is the focus of this study.

At present only limited information about the quality of stormwater runoff and stream flow in Tehran is available. One previous highway runoff characteristics in Tehran (Nouri and Naghipour, 2002) is compared with several other relevant urban runoff qualities in Riyadh (Ishaq, 1992), Esfahan (Taebi and Droste, 2004), Calgary (He et al., 2010) Austin (Barret et al., 1998), Minnesota/ Minneapolis (Thomson et al., 1997) and California/Los Angeles (Stenstrom and Kayhanian, 2005) (see Table 1). As shown, only total suspended solid (TSS) was measured and that minimum TSS concentration in Tehran was higher than other cities. Since Tehran is located in arid/semiarid region build-up of these suspended particles and any related particle-bound pollutants during the long dry season can especially pose air quality problem. The large wash off of pollution mass during storm events can also impose additional problems as discussed above. This study was specifically undertaken to evaluate the characteristics of stormwater runoff in Tehran from different surface type and stream flow during multiple storm events and wet weather seasons from 2008 to 2011.

Table 1.Comparison of runoff quality in Tehran with other comparable urban cities.

City	Year	Annual rainfall (mm)	Drainage area (ha)	Land use	TSS (mg/L)	TP (mg/L)	TN (mg/L)
Riyadh*	1984-89	95	300-900*	Street/ Parking lot	276-1458	0.33-0.37	4.12-4.38**
Tehran	2001	240-500	ND	Highway	820-1179	ND	ND
Esfahan	1999-2001	118	360	Residential/ commercial	230-3177	0.27	1.2-22.4
Calgary	2006-2007	320	150	Residential	20-342	ND	ND
Austin	1993-95	825	0.053-10.5	Highway	19-129	0.1-0.33	0.37-1.07***
Minnesota/ Minneapolis	1981-88	719	8.5	Highway	118	0.56	2.39
California/ Los Angeles	1999-2002	410-510	0.4-17	Freeway	68	0.9	9.7**

ND =No Data; *drainage area and pollutant concentration is based on the average of 2 sites in Ryiadh; **TKN; *** NO_3-N

2 METHODOLOGY

Different impervious surfaces including rusted and galvanized iron roofs, mosaic roof, asphalt street, urban streams and storm channel collection systems were monitored during 14 rain events from 2008 to 2011. Selective characteristics of rain events and impervious surfaces are presented in Table 2. Flowrate was measured by different techniques depending on the surface type and stream flow. Flow from asphalt street was quantified by a simple v-notch weir on curb along the street using the volume method. Runoff from roofs was determined by recording the volume of water discharged through rainspout with time. Urban stream flow was determined by measuring the depth of water on a drop just downstream of sampling point. Approximately 500 ml of sub-samples were collected at different time interval (~15 min at the start of rain event up to one hour and on an hourly basis during the remainder of the event) during the rainfall events. All sub-samples were delivered to the Environmental Lab at Sharif University of Technology as soon as the rain events ended. Each sub-sample was chemically analysed separately for selective constituents such as: TSS, TP, PO_4, NH_4-N, NO_3-N, Fe, Zn, Cu and Pb. These chemical constituents were selected due to their importance compared with current water quality criteria in Tehran. The measurement of TSS and chemical constituents were performed by spectrophotometer and atomic absorption specified by Standard Method (APHA, 1998). Event mean concentration (EMC) of TSS and chemical constituents was computed by using the individual sample concentration and the record of flow rate measurement.

Table 2. Selective description of rain events and monitoring sites.

Site ID	Dates	Location	Surface type	Drainage area (m^2)	Land use
A1	3 Nov 2009	Khashayar basin	Urban stream	8,350,000	Residential
B1	20 Feb 2010	SUT[*], hydraulic lab	Rusted iron roof	600	Roof top, 30% slope
C1	20 Feb 2010	SUT[*], central store	Galvanized iron roof	110	Roof top, 40% slope
B2	22 Feb 2010	SUT[*], hydraulic lab	Rusted iron roof	600	Roof top, 30% slope
C2	22 Feb 2010	SUT[*], central store	Galvanized iron roof	110	Roof top, 40% slope
B3	26 Feb 2010	SUT[*], hydraulic lab	Rusted iron roof	600	Roof top, 30% slope
C3	26 Feb 2010	SUT[*], central store	Galvanized iron roof	110	Roof top, 40% slope
D1	26 Feb 2010	SUT[*] campus	Asphalt street	2,200	Educational
D2	8 Apr 2010	SUT[*] campus	Asphalt street	2,200	Educational
E1	24 Apr 2010	SUT[*], Civil Eng. Building	Mosaic roof	100	Roof top, 2% slope
A2	2 May 2010	Khashayar basin	Urban stream	8,350,000	Residential
F1	13 Dec 2010	Nyavaran, Moghadasi	Storm channel	9,600	Residential
A3	27 Oct 2011	Khashayar basin	Urban stream	8,350,000	Residential
A4	16 Nov 2011	Khashayar basin	Urban stream	8,350,000	Residential

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3 RESULTS AND DISCUSSION

Table 3 shows the average flow rate and EMC of different pollutants measured during 14 storm events. Some highlights of these results are worth noting; especially with respect to existing allowable effluent water quality. For instance, TSS under this study varied between 80-1720 mg/L; indicating that the minimum value is 10 folds lower than the highway runoff TSS reported in Table1. However, the average TSS EMC is about 600 mg/L which is 15 times higher than allowable limit (less than 40 mg/L) for discharge requirement to natural streams. EMC of total phosphorous for all storm events were less than allowable discharge limit (less than 3-5 mg/L) to receiving waters except in 27 Oct 2011 which was one of the most intensive storm events in the study duration period. In general, the results obtained from this study confirmed that, compared with the current water quality standard for discharge of treated wastewater to surface receiving waters in Iran, most dry and wet weather flow need to be treated before discharging into streams (Mahab Qodds and Pöry, 2010).

Table 3. Average flow rate and EMC of pollutants during monitored storm events.

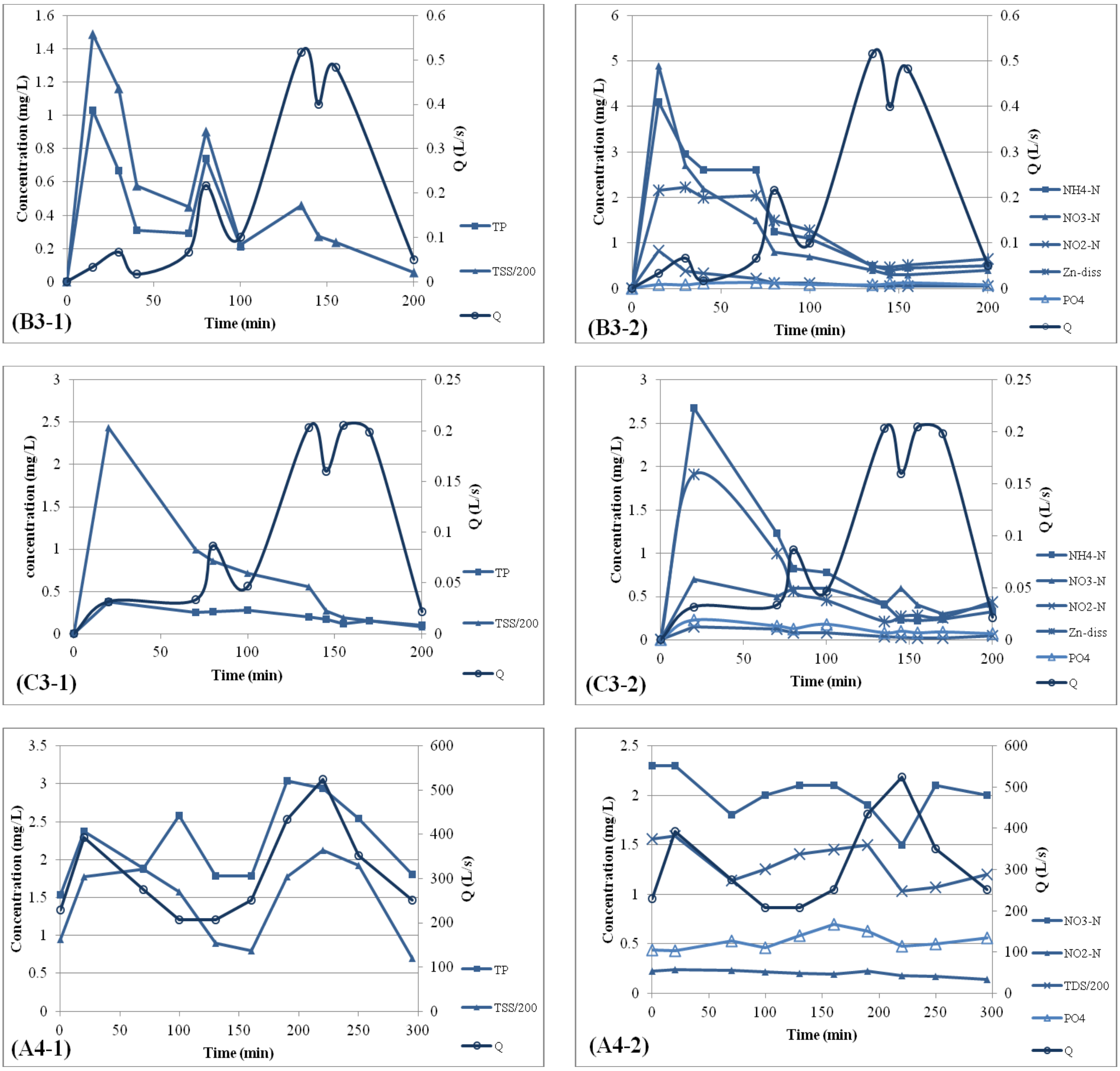
No.	Date	Q_{avg}	TSS	TP	PO_4	NH_4-N	NO_3-N	Fe[a]	Zn[a]	Cu[a]	Pb[a]
		L/s	mg/L					µg/L			
A1	3 Nov 2009	306.67	-	4.96	2.30	4.25	4.89	-	-	-	-
B1	20 Feb 2010	0.20	-	-	0.04	5.09	1.08	142	1456	5	5
C1	20 Feb 2010	0.15	-	-	0.04	4.45	1.40	189	1	5	5
B2	22 Feb 2010	0.05	-	-	-	-	-	160	1995	6	53
C2	22 Feb 2010	0.03	-	-	-	0.56	0.45	152	943	5	13
B3	26 Feb 2010	0.20	80	-	0.11	0.77	0.57	92	765	-	-
C3	26 Feb 2010	0.09	109	0.20	0.11	0.56	0.45	317	431	5	5
D1	26 Feb 2010	0.57	182	1.23	0.10	0.88	1.47	-	-	6	6
D2	8 Apr 2010	0.48	392	1.85	0.06	1.28	2.71	170	837	14	71
E1	24 Apr 2010	0.04	449	1.74	0.18	0.77	2.05	-	-	-	-
A2	2 May 2010	168.47	398	5.02	1.15	3.44	1.49	281	41	22	5
F1	13 Dec 2010	2.83	1720	5.38	0.36	2.50	19.89	163	60	28	-
A3	27 Oct 2011	261.69	1683	18.3	3.25	-	3.06	-	54	18	257
A4	6 Nov 2011	320.83	327	2.40	0.53	-	1.97	-	18	4	8
	Median	0.34	392	2.4	0.14	1.28	1.49	163	431	6	7
	Average	76	593	4.6	0.69	2.23	3.19	185	600	11	43
	Standard Deviation	128	642	5.5	1.05	1.77	5.17	70	671	8	79

[a] Reported EMCs are for dissolved fraction, except for A4 and A5 events which are for total EMC.

- = Not analyzed.

The variability of pollutant concentration and flow rate over time for 3 events are depicted in Fig.1. As shown, first flush of particulate pollutant concentration (Fig. 1a) for some pollutants and events can be observed. The presence of first flush can be defined by a pollutograph when a higher pollutant concentration at the beginning of storm event is usually observed compared with the rest of the storm event. It is also worth to note that particulate pollutant first flush is closely correlated with TSS pollutograph (Fig.1 B3-1, C3-1, and A4-1). Occasionally, a second flush can be observed in particulate pollutants and that can largely be dependent on the presence and availability of additional concentration of TSS. For example on 26 Feb 2010 event for rusted roof (Fig.1 B3-1), a second peak can be observed which is stronger than the first one and closely related to the observed TSS pollutograph. However, the same second flush could not be observed for galvanized roof (Fig.1 C3-1) since majority of the suspended particles were most probably washed off during the first peak flow rate and hence no additional particles were added during the remainder of the storm events. This finding can be confirmed with study of He et al. (2010) that investigated urban storm water runoff in semiarid region of Calgary and showed a good correlation between TSS EMC and flow rate as long as a sufficient build up of suspended particles on impervious surfaces occur.

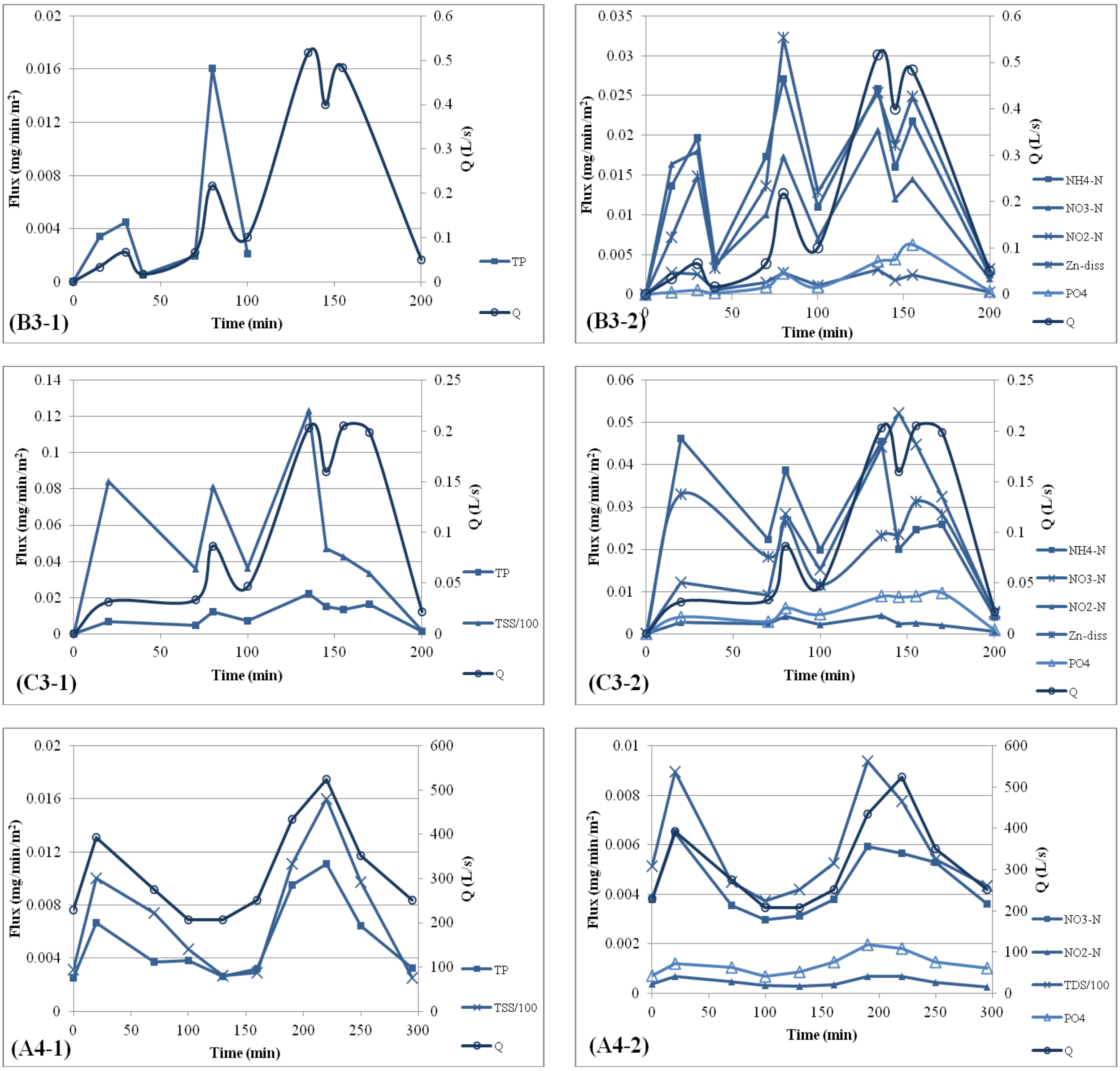
The concentration first flush for dissolved pollutants is more often observed for most events on smaller drainage area (Fig.1 B3-2, C3-2). Other researchers have shown comparable concentration first flush results (Han et al., 2006 and Lau et al., 2009). The concentration first flush of dissolved pollutants for larger watershed is less pronounced (Fig.1 A4-2). This finding is consistent with most other paved surface first flush investigation showing that generally lower first flush occurrence can be observed with larger watershed and a higher time of concentration (Kang et al., 2006 and Kang et al., 2008).



(a) Particulate constituents (b) Dissolved constituents

Figure1. Time series of pollutants EMC and flow rate for B3, C3, and A4 events: (a) particulate constituents and (b) dissolved constituents.

The time series results of flux for total and dissolved constituents for storm events B3, C3 and A4 is shown in Figure 2. Flux is defined as pollutant loading rate per unit drainage area expressed mathematically as (Q×C)/A. In this expression, Q is flow rate (L/min), C is pollutant concentration (mg/L) and A is the drainage area (m^2). As can be seen, the flux of particulate pollutants (i.e., TSS and TP) show more correspondence with discharge flow rate than the flux associated with dissolved pollutants (i.e., NH_4-N or dissolved Zn).



(a) Total constituents

(b) dissolved constituents

Figure2. Time series flux of total and dissolved constituents for B3, C3, and A4 events: (a) total constituents, (b) dissolved constituents.

The result of mass first flush for TP, TSS, NH_4-N and NO_3-N for different storm events is shown in Figure 3. As shown, stronger mass first flush for TSS and TP was observed for galvanised and rusted roofs and much weaker mass first flush was observed during other storm events and surface types. In general, mass first flush was observed for dissolved constituents for most events and surface types. While large part of our first flush findings were consistent with other studies, however, some inconsistencies were also reported in the literature. For example, mass first flush ratio for 20 percent of normalized volume (MFF_{20}) computed from our study was comparable to the values reported by Han et al. (2006). Whereas, Taebi and Droste (2004) reported stronger first flush for TSS than pollutants such as TN in plain of Esfahan and two other researchers observed stronger first flush for TDS than TSS (He et al., 2010; Flint and Davis, 2007).

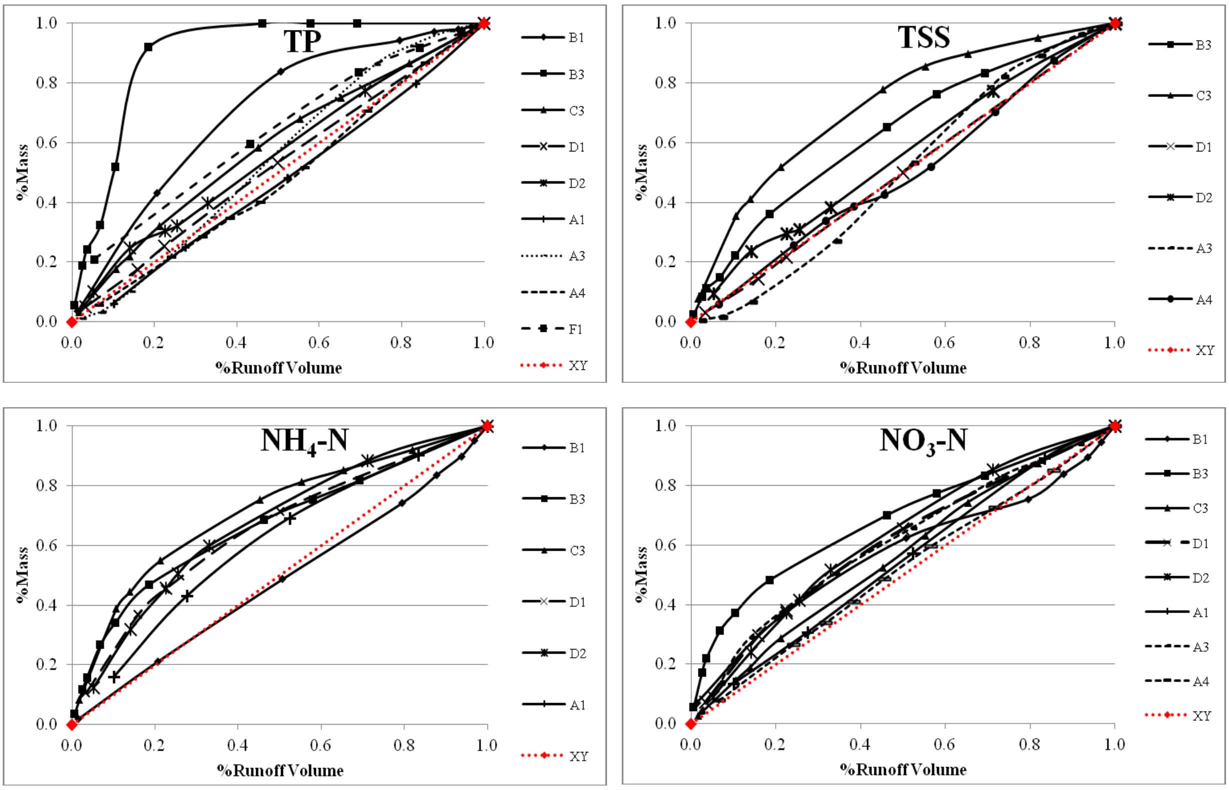


Figure3. Mass first flush of TP, TSS, NH_4-N, and NO_3-N for different storm events.

4 CONCLUSIONS

Average EMC of TSS, TP, PO_4, NH_4-N, NO_3-N for all monitored events were 593, 4.6, 0.69, 2.23, 3.19 mg/L and 185, 600, 11 and 43 µg/L for Fe, Zn, Cu and Pb respectively. These runoff monitoring results showed that, in general, the concentration of TSS, TP and most heavy metals exceed the required effluent water quality standard for stream discharge in Iran.

Mixed results for concentration and mass first flush were observed for both total and dissolved constituents. In general, more frequent and stronger mass first flush was observed for dissolved pollutants and when the drainage area was smaller. Direct corresponding of pollutant first flush in stream flow was less evident since the pollutant wash off is always lagging behind due to higher time of concentration and also for dilution effect. Relatively good correlation was also obtained between flux of pollutants and discharge flow rate. The findings in this study is a good testament for proof of using appropriate low impact development (LID) or other BMP strategies in Tehran to improve the discharged runoff quality.

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