

Storm runoff quality and pollutant loading from commercial, residential, and industrial catchments in the tropic

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Abstract Information on the pollution level and the influence of hydrologic regime on the stormwater pollutant loading in tropical urban areas are still scarce. More local data are still required because rainfall and runoff generation processes in tropical environment are very different from the temperate regions. This study investigated the extent of urban runoff pollution in residential, commercial, and industrial catchments in the south of Peninsular Malaysia. Stormwater samples and flow rate data were collected from 51 storm events. Samples were analyzed for total suspended solids, 5-day biochemical oxygen demand, chemical oxygen demand, oil and grease (O&G), nitrate nitrogen ($\text{NO}_3\text{-N}$), nitrite nitrogen, ammonia nitrogen, soluble reactive phosphorus, total phosphorus (TP), and zinc (Zn). It was found that the event mean concentrations (EMCs) of pollutants varied greatly between storm characteristics and land uses. The results revealed that site EMCs for residential catchment were lower than the published

data but higher for the commercial and industrial catchments. All rainfall variables were negatively correlated with EMCs of most pollutants except for antecedent dry days (ADD). This study reinforced the earlier findings on the importance of ADD for causing greater EMC values with exceptions for O&G, $\text{NO}_3\text{-N}$, TP, and Zn. In contrast, the pollutant loadings are influenced primarily by rainfall depth, mean intensity, and max 5-min intensity in all the three catchments. Overall, ADD is an important variable in multiple linear regression models for predicting the EMC values in the tropical urban catchments.

Keywords Event mean concentration · Multiple linear regression · Stormwater · Tropical environment · Urban runoff

Introduction

Two phenomena of urbanization and industrialization are quickly taking place in many developing countries and have significantly influenced the quality of runoff and water bodies (Du et al. 2010). Anthropogenic and transportation activities have been identified to generate considerable amount of solids, organic matters, nutrients, and heavy metals on the catchment surfaces (Miguntanna et al. 2010; Mahbub et al. 2011; Gunawardana et al. 2012). Recently, varying magnitudes of water quality impairment associated with urban runoff have been reported in different countries, for example in Kuwait (Al-Jaralla and Al-Fares 2009), China (Qin et al. 2010), France (Zgheib et al. 2011), India (Jamwal et al. 2011),

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and Hawaii (Lapointe and Bedford 2011). Hence, there is a need to characterize and examine the stormwater runoff quality of water quality monitoring and management in urban catchments.

Goonetilleke et al. (2005) found significant differences in stormwater constituents for different land-use categories. Some other researchers have established the relationships between land-use types and storm runoff pollution characteristics for various catchment land use that include residential, commercial, industrial, highway, parking lot, bridge, elevated roadway structure, street, and roof (Sansalone et al. 2005; McLeod et al. 2006; Kim et al. 2007; Kayhanian et al. 2007; Ballo et al. 2009; Davis and Birch 2010; He et al. 2010; Francey et al. 2010; Lee et al. 2011; Tiefenthaler et al. 2011). Assessment of stormwater quality from urban catchment is usually estimated by using event mean concentration (EMC) (Charbeneau and Barrett 1998). Since EMC values tend to vary greatly depending on the storm and site characteristics (Kim et al. 2005; Luo et al. 2009), an intensive rainfall–runoff event sampling program is necessary to better estimate pollutant loadings into the receiving streams. This issue is particularly important in tropical environments because the rainfall and runoff generation processes are different from the temperate regions where most of the studies on non-point source (NPS) pollution have been carried out. Due to the limited number of studies conducted in tropical environments, the mechanism of NPS pollutant transport and the influence of hydrologic regime on the pollutant loading in the tropics are still unclear. Understanding these interactions is useful for improving design criteria and strategies for controlling stormwater pollution in urban areas. Thus, this study aims to achieve the following three objectives: (1) to characterize urban storm runoff quality using EMCs, (2) to establish relationships between pollutant loadings and EMCs, and (3) to develop predictive equations for estimating EMC values for major urban land uses.

Methodology

Study area

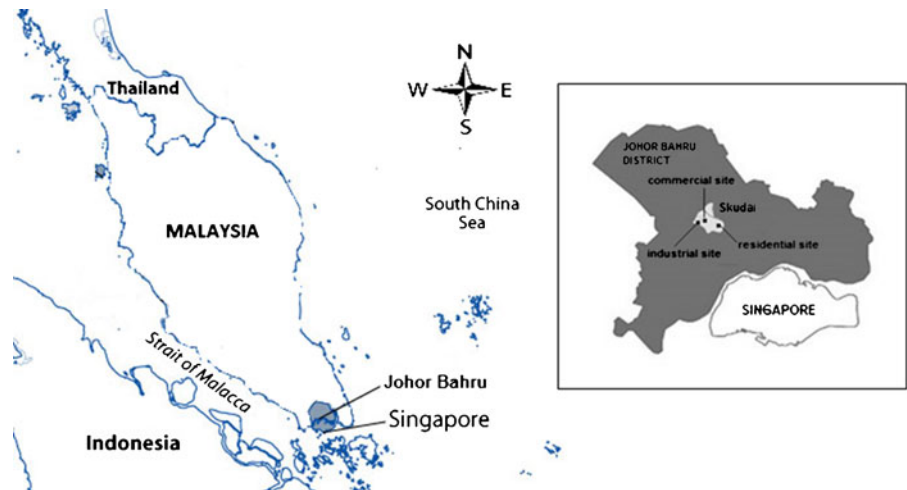
This study was carried out in Skudai, a rapidly expanding suburb of Johor Bahru, Malaysia (Fig. 1). Three catchments of different land use

(commercial, residential, and industrial) were selected (Table 1). The commercial and industrial catchments are serviced by separated open channel stormwater systems while the residential catchment utilizes separated underground stormwater system as specified in the Stormwater Management Manual for Malaysia (DID 2000). None of these catchments has wastewater treatment plant within it so that the effect of land use could be more easily singled out.

Collection of samples and analysis

Rainfall data were collected using 0.2-mm tipping bucket rain gauges installed within each study catchment. The flow level was measured using stage gauge which was fixed at the wall of the trunk storm sewer. The flow velocity for different depths was measured using current meter (Swoffer model, 2100) for several storm events. Then, a stage–discharge rating curve was developed for each catchment to convert the recorded flow depth to volumetric flow rate and subsequently generate hydrograph for each runoff event. Total runoff volume was determined from the hydrograph as the product of flow rate and runoff duration. At each site, stormwater samples were manually grabbed. Since the sampling sites were not far off the Universiti Teknologi Malaysia (UTM), sampling team members could reach and standby in the sites before rainfall started. One-liter stormwater sample was collected using glass bottle for every time interval. The sampling intervals were between 1 and 10 min on the rising limb of the hydrograph and 10 and 20 min on the falling limb. More intense sampling on the rising limb of the hydrograph is crucial for assessing first flush occurrence. Depending on the storm size, the number of samples per storm event varies from 8 to 15. This sampling protocol followed the procedure outlined by Caltrans (2000) which recommends at least six samples per storm. Although laborious, this technique is more reliable for a small urban catchment, compared to an automatic water sampler, due to the very rapid rise in water level once the storm has started. In addition, grab sampling could minimize the possibility of oil and grease being stucked to the inner surfaces of the tubing and containers in the automatic sampler.

Fig. 1 Location of study area



Dry weather based flow samples were also collected manually over 24 h during one working day and weekend (Wednesday, Saturday, and Sunday). Dry weather is defined as days without rain for 24 h before sampling. A total of 72 samples were collected from each site to establish an average baseflow concentration of the various water quality constituents. In addition, three rainfall samples from different storm events were collected for rainwater quality analysis. All stormwater samples were brought to Environmental Laboratory in UTM and analyzed for total suspended solids (TSS, APHA 2540D), biochemical oxygen demand (BOD₅, APHA 5210B), chemical oxygen demand (COD, APHA 5220B), oil and grease (O&G, APHA 5520B), nitrate nitrogen (NO₃-N, APHA 4500.B), nitrite nitrogen (NO₂-N, APHA 4500.B), ammonical nitrogen (NH₃-N, APHA 4500.F), soluble reactive phosphorus (SRP, APHA 4500P.E), total phosphorus (TP, APHA 4500P.B), and zinc (Zn, APHA 3120.B). All chemical analyses were performed based upon the Standard Method for Water and Wastewater (APHA 2005).

Data analysis

Pollutant loadings were estimated using EMC which is defined as the total constituent mass *M* discharged during an event divided by the total runoff volume *V* during the event (Huber 1993), expressed as:

$$EMC = \bar{C} = \frac{M}{V} = \frac{\int_0^t Q(t)C(t)dt}{\int_0^t Q(t)dt} \tag{1}$$

where *M* is total mass of pollutant during the entire runoff (kilograms), *V* is total volume of runoff (cubic meters), *C(t)* is time varying pollutant concentration (milligrams per liter); *Q(t)* is time variable flow (liters per second); and *t* is total duration of runoff (seconds).

The estimation of annual discharged loads for evaluating long-term impacts of urban wet weather discharges requires site mean concentration (SMC). The SMC value is calculated as the average of EMC values for a particular catchment. Correlation analysis was carried out to determine the relationships between EMCs and loading against storm characteristics, i.e., rainfall depth (*R_D*), duration (*R_{Dur}*), mean intensity (*I*),

Table 1 Characteristics of study catchments

Site name	Taman Universiti	Taman Impian Emas	Kawasan Perindustrian Taman Universiti
Land use	Commercial	Residential	Industrial
Area (ha)	34.21	32.77	4.38
No. of shops/houses/factories	609	473	25
Impervious area (%)	95	85	93
Average daily traffic (cars/day)	33,286	7,811	3,148

max 5-min intensity ($I_{\max 5}$), and antecedent dry day (ADD). Multiple linear regression analysis was employed to determine the relationship between EMCs values and storm characteristics as in Eq. (2).

$$\text{EMC} = a \pm b(R_D) \pm c(R_{Dur}) \pm d(I) \pm e(I_{\max 5}) \pm f(\text{ADD}) \quad (2)$$

where a is arbitrary constant and b , c , d , and f are coefficients for each rainfall variable.

Results and discussion

Rainfall pattern

To achieve reliable estimates of SMC at each catchment, 17 independent storm events were sampled in each residential, commercial, and industrial catchment in years 2008 and 2009. Based upon the rainfall-runoff data at the study area, a storm event is defined as rainfall depth greater than 0.8 mm which is the amount sufficient to initiate surface runoff. The monitored rainfall depths range from 1.8 to 107.4 mm while the intensities vary from 2.7 to 99.5 mm/h. Most of the storm duration is less than 2 h, and the ADD was between 0.03 and 16.5 days. The intensities of these 51 events are plotted along with intensity–duration–frequency (IDF) curves for Johor Bahru in Fig. 2. The figure shows that the return period for all the sampled storms range from a few days to a few months, and only four storms exceeded the 1-year return period (53 mm/h for a 1-h duration storm). As such, the monitored storm events mostly represent small and frequent storms in Malaysia and other humid tropic cities. The EMCs derived from these storms are important for predicting annual pollutant loading from different urban land uses.

Characteristics of stormwater runoff quality

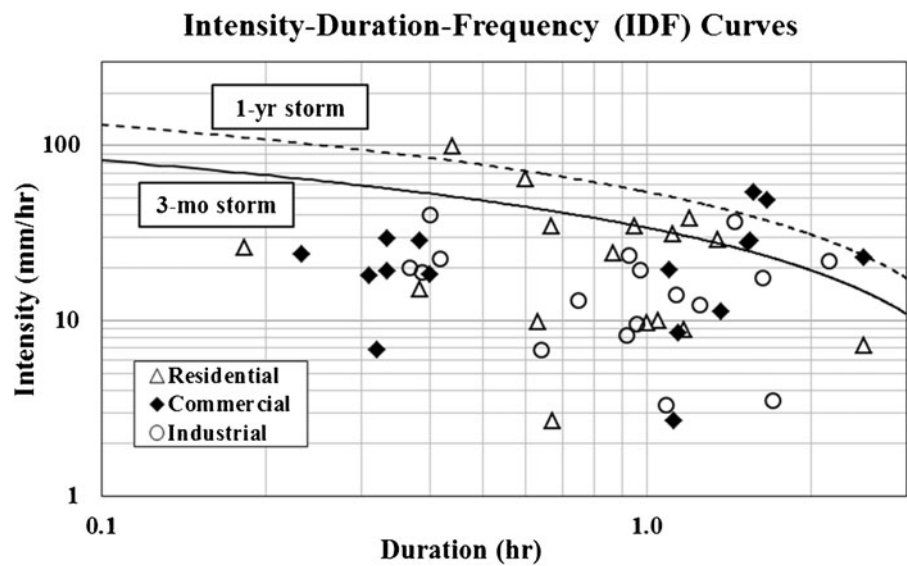
The EMC values derived from each storm are plotted in box plots as shown in Fig. 3. It can be seen that most of the constituent levels in rainwater (as indicated by dotted line) are very low or below the detection limits. Therefore, the rainwater quality is not likely to influence the pollutant contents in the stormwater except possibly for $\text{NO}_3\text{-N}$. This may imply that rainfall is a considerable source of $\text{NO}_3\text{-N}$ in the urban catchment. The base flow mean concentration of various

pollutants generally exceeded the mean and median values of stormwater's EMC for all land uses except for TSS and O&G from the commercial and industrial catchments. This may imply that TSS and O&G were temporarily deposited in the channel or drain's wall until the next storm with sufficiently large energy to transport these pollutants once more (Chow et al. 2011). Francey et al. (2010) also found higher TSS concentration in storm flow than in base flow but vice versa for nitrogen. The practical implication of their study is that the runoff generated by small storms and base flow cannot be bypassed but must be treated.

The commercial catchment exhibits the highest medians EMC for BOD, COD, TSS, $\text{NH}_3\text{-N}$, and TP, followed by the industrial and residential catchments. The main sources of producing organic matters during storm events were restaurants and food stalls especially in the commercial catchment. In contrast, the industrial catchment shows the highest medians EMC for O&G, $\text{NO}_3\text{-N}$, and Zn. The SMC for Zn at the industrial catchment was far greater than the residential and commercial catchments. The source of Zn could be from roof, factories, and vehicle wear and tear in the industrial catchment. The large storm to storm variations of EMC as well as the diverse type of land use in urban catchment necessitate a long-term monitoring program in order to better estimate SMC.

The SMC value for every constituent was determined in all catchments. Table 2 compares the present SMCs with values from literature. Our SMCs of TSS for the residential catchment is at least three times lower than the other studies. Earlier, Nazahiyah et al. (2007) recorded high SMC of TSS ($\text{EMC} = 364 \text{ mg/L}$) from a residential catchment that has bare area near the catchment outlet. It is possible that these sections contribute TSS through erosion processes. In her study in a smaller commercial catchment close to the present site, Nazahiyah (2005) found higher SMCs for all pollutants. The storm sizes studied by Nazahiyah (2005) were generally smaller (3.0 to 31.3 mm) compared with 2.0 to 107.4 mm in the current study. Therefore, it can be declared that a larger storm with higher runoff volume tends to dilute pollutants more rapidly. This was also examined in Minnesota, USA by Brezonik and Stadelmann (2002) who found larger EMCs in a smaller suburban residential catchment compared to a larger one. Almost all the residential SMCs for various constituents in this study are lower than the results in Singapore, Canada, and Australia

Fig. 2 IDF curves for monitored storm events



(Table 2). In contrast, our SMCs for all constituents at the commercial catchment are higher than elsewhere. Variations in the EMC and SMC values for different locations may reflect different levels of management and maintenance regimes. Qin et al. (2010) stated that high population density, lack of environmental consciousness, and poor litter management in urban areas are the common reasons for poor stormwater quality.

Correlation between hydrological parameters with EMC and loading

The relationship between EMCs and loading of various constituents with storm characteristics was analyzed using Pearson correlation analysis (Table 3). The storm characteristics analyzed included rainfall depth (R_D), rainfall duration (R_{Dur}), mean intensity (I), max 5-min intensity (I_{max5}), and ADD. Only significant correlations ($p < 0.05$) are presented in Table 3. Most of the storm variables showed negative correlation with EMC. The strongest correlations were found for ADD with TSS, BOD, NH_3-N , and SRP in the industrial catchment. Strong correlations were also observed between COD and NH_3-N at the residential catchment and TSS and NO_2-N in the commercial catchment. This finding shows that pollutant build-up tended to increase with the length of ADD periods. Elsewhere, the ADD was also found to be positively correlated with EMCs of TSS (Chui 1997; Brezonik and Stadelmann 2002; Kim et al. 2007; Gan et al. 2008). Surprisingly, the relationship between TSS and ADD at the residential catchment was

not significant. Similar observation was obtained by Deletic and Maksimovic (1998) in Lund, Sweden, Charbeneau and Barrett (1998) in Texas, USA, and He et al. (2010) in Calgary, Alberta. Gnecco et al. (2006) in Italy suggested that the build-up process seems to be more affected by the site-specific activities rather than ADD.

EMC values at the residential catchment are moderately correlated with rainfall and runoff variables. Negative correlation was observed only between SRP vs R_D , TP vs R_{Dur} and SRP vs I_{max5} . Rainfall depth and duration are negatively correlated with TSS, BOD, NH_3-N , SRP, and TP at the commercial catchment. Meanwhile, rainfall duration at the industrial catchment shows negative correlation with O&G but was positively correlated with NO_3-N . Kim (2002) found negative correlations between EMCs of various pollutants against total rainfall, storm duration, average rainfall intensity, and total runoff volume. Larger storms tend to produce lower EMCs due to dilution effects or exhaustion of pollutant sources (Yusop et al. 2005; Gan et al. 2008). Similarly, Brezonik and Stadelmann (2002) in Minnesota, USA, found negative correlations between precipitation amount and EMCs of dissolved P (DP), COD, and NO_3-N plus NO_2-N . In their studies, Brezonik and Stadelmann (2002) and He et al. (2010) showed that constituents such as TSS, TP, and COD have negative correlation with rainfall duration. They explained that prolonged storms tend to produce more runoff volume that dilutes the concentrations of these constituents. Their

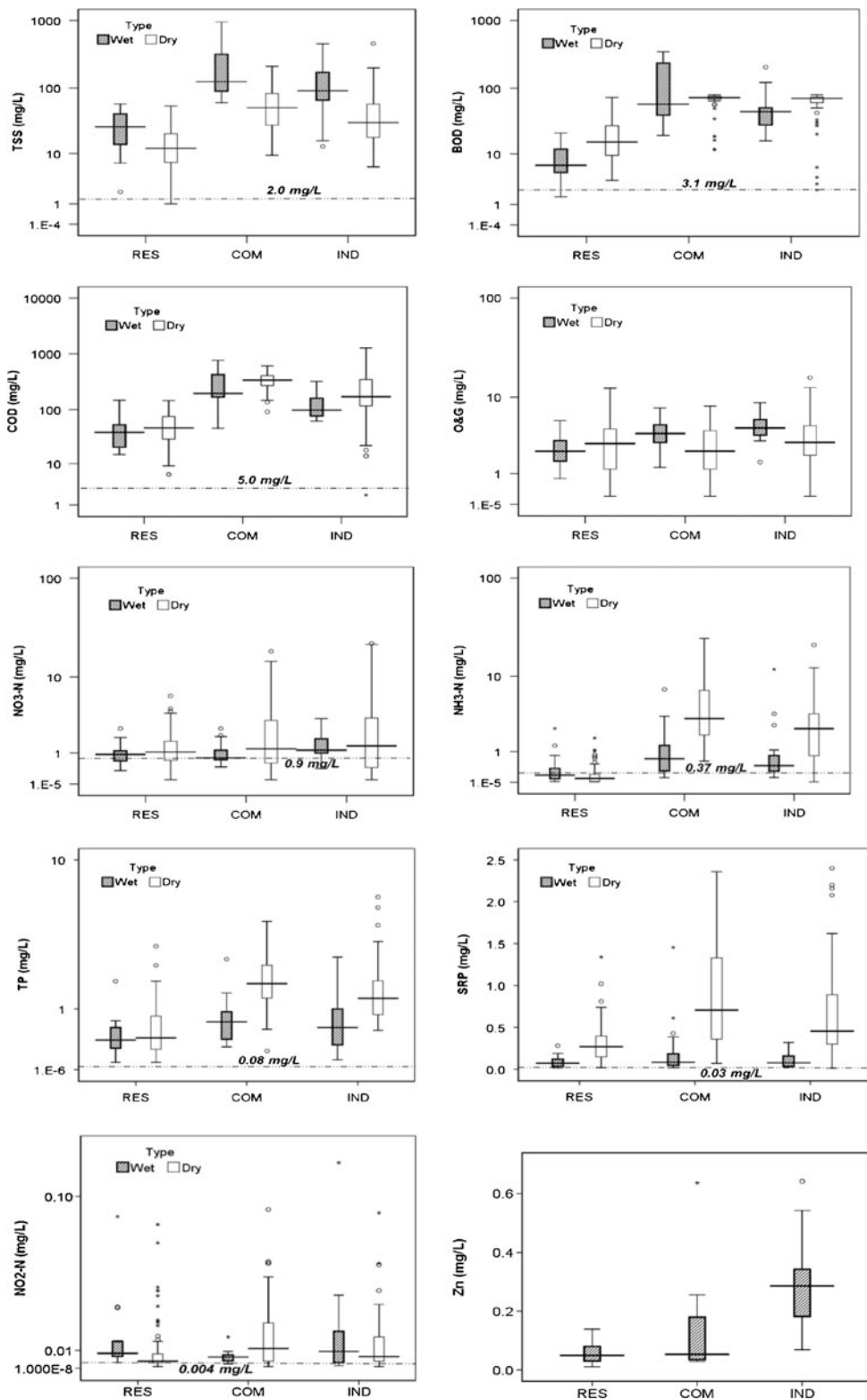


Fig. 3 Box plots of event mean concentration and dry weather concentration for residential (*RES*), commercial (*COM*), and industrial (*IND*) catchments

Table 2 Comparison of SMCs with urban runoff SMC’s reported in the literature

Site	Area	%Imp	Constituent										
				TSS	O&G	BOD	COD	NO ₃ -N	NO ₂ -N	NH ₃ -N	TP	SRP	Zn
This study	Residential	32.77	85	21	2.32	6.5	36	0.90	0.011	0.19	0.38	0.07	0.04
Malaysia ^a	Old residential	3.34	94	364	-	95.0	311	2.4	0.10	3.50	-	3.0	-
Australia ^b	High density residential	89.1	74	101.8	-	-	-	-	-	-	0.35	-	1.24
Canada ^c	Old residential	616	-	190	-	-	100	-	-	-	0.53	-	-
Singapore ^d	High density	199	68	66	-	-	-	0.70	-	-	0.08	-	-
This study	Commercial	34.21	95	167	3.66	81.1	225	0.93	0.006	0.71	0.69	0.11	0.08
Malaysia ^a	Commercial	0.75	98	195	-	135	487	2.8	0.43	3.80	-	-	-
Australia ^b	Commercial	28.2	80	71.4	-	-	-	-	-	-	0.15	-	-
Canada ^c	Commercial	74.6	-	210	-	-	75	-	-	-	0.45	-	-
This study	Light industrial	4.68	93	91	4.47	42.6	117	1.20	0.009	0.58	0.59	0.08	0.24
Canada ^c	Light industrial	420	-	3.0	-	-	41.8	-	-	-	0.13	-	-
USA ^e	Industrial	-	-	231	-	-	-	0.46	-	0.25	0.27	-	-

- no data

^aNazahiyah (2005)

^bFrancey et al. (2010)

^cMcLeod et al. (2006)

^dChua et al. (2009)

^eLine et al. (2002)

findings reinforced NURP results that EMCs are not linearly correlated with runoff volume (USEPA 1983). I_{max5} and mean intensity at the commercial catchment were negatively correlated with NO₃-N, NH₃-N, SRP, and NO₃-N. Both I_{max5} and mean rainfall intensity at the industrial catchment were negatively correlated with NH₃-N, TP, and SRP. There was no positive correlation between rainfall intensity and EMC of constituents in all the studied catchments. Although some researchers found that rainfall intensity is an important parameter for washing off suspended solids (Chui 1997; Deletic and Maksimovic 1998; Vaze and Chiew 2003; Li et al. 2005; Chua et al. 2009; He et al. 2010), this was not observed by Gnecco et al. (2006), Kim et al. (2007), and Gan et al. (2008). Such differences emphasize the need for local studies when evaluating the behavior of EMC with rainfall and flow.

Based upon the Pearson correlation analysis (Table 3), the most important parameters that influence the loading of various pollutants are R_D , I , and I_{max5} . Mean intensity only correlates positively with TSS, O&G, NO₃-N, NO₂-N, TP, and Zn in the residential catchment. Similar findings were observed by Chui (1997), Brezonik and Stadelmann (2002), Chua et al. (2009), and Francey et

al. (2010). Interestingly, rainfall duration is positively and significantly correlated with the loadings of O&G, COD, NO₃-N, NO₂-N, and TP in the commercial catchment. Meanwhile, rainfall depth and runoff volume correlate positively with the loadings of most constituents except for TSS, BOD, and NH₃-N. Rainfall duration correlates with NO₃-N and SRP loadings while mean intensity correlates with O&G, BOD, and COD loadings in industrial catchment. Max 5-min intensity was positively correlated with the loadings of O&G, BOD, COD, NO₃-N, NO₂-N, and Zn. Antecedent dry day correlates well ($p < 0.05$) with TSS, SRP, and NH₃-N loadings in both the commercial and industrial catchments. The ADD showed poor correlation with most of the parameters in all catchments. Although ADD is a significant factor for pollutant build-up in highly urbanized catchments (Brezonik and Stadelmann 2002), in the tropics, the frequent rains means shorten ADD which result in limiting pollutant build-up (Chua et al. 2009). The averages of ADD for the storm events in this study were 2.3, 3.1, and 2.7 days for the residential, commercial, and industrial catchments, respectively. As a result, ADD is not expected to be a significant factor. He et al. (2010) also found that there is no significant correlation between

Table 3 Correlation between EMC with rainfall and flow characteristics for residential, commercial, and industrial catchments

EMC						Loading							
Site	<i>n</i>	R_D	R_{DUR}	<i>I</i>	I_{max5}	ADD	Site	<i>n</i>	R_D	R_{DUR}	<i>I</i>	I_{max5}	ADD
Residential													
TSS	17						TSS	17	0.82		0.80	0.83	
O&G	17						O&G	17	0.83		0.63	0.78	
BOD	17						BOD	17	0.70			0.62	
COD	18					0.77	COD	18	0.71			0.64	
NO ₃ -N	18						NO ₃ -N	18	0.82		0.55	0.72	
NH ₃ -N	18					0.60	NH ₃ -N	18				0.51	
NO ₂ -N	17						NO ₂ -N	17	0.74		0.59	0.75	
SRP	17	-0.52			-0.53		SRP	17	0.69			0.61	
TP	14		-0.65				TP	14	0.65		0.68	0.70	
Zn	12						Zn	12	0.79		0.76	0.83	
Commercial													
TSS	17	-0.50	-0.56			0.62	TSS	17	0.59		0.55	0.70	0.50
O&G	17						O&G	17	0.84	0.74	0.54	0.86	
BOD	16	-0.54	-0.62				BOD	16	0.55		0.64	0.73	
COD	17						COD	17	0.68	0.55	0.57	0.77	
NO ₃ -N	17			-0.49	-0.53		NO ₃ -N	17	0.84	0.75	0.49	0.80	
NH ₃ -N	17	-0.62	-0.54		-0.67		NH ₃ -N	17					
NO ₂ -N	17					0.60	NO ₂ -N	17	0.81	0.72		0.80	
SRP	17	-0.67	-0.69		-0.66		SRP	17					0.59
TP	17	-0.50	-0.55				TP	17	0.76	0.59	0.58	0.79	
Industrial													
TSS	17					0.52	TSS	17					
O&G	16		-0.51				O&G	16	0.78		0.76	0.77	
BOD	13					0.69	BOD	13			0.60	0.58	
COD	15						COD	15	0.85		0.73	0.82	
NO ₃ -N	17		0.50				NO ₃ -N	17	0.90	0.61		0.72	
NH ₃ -N	17				-0.59	0.59	NH ₃ -N	17					0.56
NO ₂ -N	16						NO ₂ -N	16	0.54			0.61	
SRP	16			-0.64		0.55	SRP	16	0.53	0.55			
TP	14				-0.55		TP	14	0.56				
Zn	11						Zn	11	0.70			0.84	

Correlations significant at $p < 0.01$ were expressed in bold

loadings of TSS with rainfall duration and ADD in an urban catchment in Calgary, Alberta.

Multiple linear regression analysis

Table 4 presents the multiple linear regression results for estimating the EMCs. Only pollutants that show significant relationship are listed. The goodness of fit of the models was assessed using the coefficient of

determination (R^2), which describes the overall model fit to the data. Based upon the R^2 values shown, the models fit well, with all results having R^2 above 0.6. The standard error of estimate (SEE) ranges from good (SEE=0.002) to very poor (SEE=157). ADD showed significant relationships with EMCs in all the regression models except for NO₃-N in the commercial catchment. Variables R_D and I were important for NO₃-N, NH₃-N, SRP, and TP models in the

Table 4 Multiple linear regression results for event mean concentration and goodness of fits statistics for residential, commercial, and industrial catchments

	<i>n</i>	<i>a</i>	<i>R_D</i> <i>b</i>	<i>R_{Dur}</i> <i>c</i>	<i>I</i> <i>d</i>	<i>I_{max5}</i> <i>e</i>	ADD <i>f</i>	<i>R</i> ²	<i>p</i>	SEE ^a
Residential										
COD	18	2.46	0.54	11.35	−0.15	−0.13	15.2	0.706	0.017	25
NH ₃ -N	18	−0.365	−0.04	0.26	−0.001	0.01	0.24	0.809	0.002	0.34
Commercial										
TSS	17	631	13.8	−352	−19.7	−1.4	55.9	0.762	0.004	157
NO ₃ -N	17	3.26	0.06	−1.34	−0.09	−0.006	0.005	0.659	0.021	0.40
NH ₃ -N	17	7.0	0.18	−4.27	−0.28	−0.008	0.245	0.648	0.025	1.23
NO ₂ -N	17	0	0	0.004	0	0	0.001	0.725	0.007	0.0022
SRP	17	1.54	0.04	−0.98	−0.06	−0.002	0.05	0.715	0.009	0.23
TP	17	2.82	0.06	−1.55	−0.098	0	0.074	0.662	0.021	0.40
Industrial										
TSS	17	352	4.0	−254	−15	2.9	28	0.685	0.014	90
BOD	13	5.05	−0.43	−1.3	3.44	−0.54	11.7	0.786	0.027	32
NH ₃ -N	17	2.14	0.09	−1.0	0.05	−0.07	0.61	0.71	0.010	1.85
SRP	16	0.2	0.003	−0.08	−0.01	0	0.02	0.671	0.028	0.06
TP	14	1.06	0.02	−0.1	−0.004	−0.01	0.11	0.714	0.041	0.43

^aSEE refers to the standard error of the estimate; significant correlation at *p*<0.05 are shown in bold

commercial catchment, whereas *I_{max5}* was important for SRP in the commercial catchment. For long duration storm, *R_D*, *I*, and *I_{max5}* were mostly negatively correlated with the EMC. Maniquiz et al. (2010) in Korea also suggested that rainfall duration and mean intensity were important parameters in estimating EMC values. However, they did not find significant correlations between pollutant loads and EMC against ADD. The results of this study, however, are different from Brezonik and Stadelmann (2002) and Passeport and Hunt (2009) who found negative relationships between EMCs of TSS, SRP, and TP against ADD.

Conclusions

This study makes significant contributions by answering some key questions especially on the stormwater quality and the influence of hydrological variables on EMC and pollutant loading in residential, commercial, and industrial catchments. These findings are useful as basis for improving design criteria and strategies for controlling stormwater pollution in urban areas. The following conclusions are made from this study:

1. The EMC values for BOD, COD, TSS, NH₃-N, TP, and SRP from the commercial catchment are generally higher than those from industrial and residential catchments. In contrast, the industrial catchment shows the highest EMC for O&G, NO₃-N, and Zn. This finding suggests that the level of stormwater pollutant is strongly governed by the major anthropogenic activities in the catchment. The results of the current study show that site EMCs (SMCs) for residential catchment are lower than the literature while SMCs for commercial and industrial catchments were higher. As expected, the EMC values for stormwater were site specific. Therefore, it is important to carry out local stormwater monitoring program especially in urban areas.
2. A better understanding of hydrological regime affecting the quality and loadings of major pollutants was achieved. Except for antecedent dry days (ADD), all rainfall variables (e.g., rainfall depth, duration, mean intensity, and max 5-min intensity) were negatively correlated with EMCs of most pollutants. This study reinforced the earlier findings on the importance of ADD for causing greater EMC values with exceptions for O&G, NO₃-N,

TP, and Zn. The pollutant loadings are influenced primarily by rainfall depth, mean intensity, and max 5-min intensity. However, ADD seemed to be less important for estimating the pollutant loadings.

- Multiple linear regression models are useful for estimating EMC values of most pollutants. The EMCs of various constituents were mostly influenced by ADD which explains approximately 60–80 % of the variation. However, the findings of this study are not in line with some of the findings in the temperate environment that show negative relationship between EMC and ADD. The discrepancy might reflect site specific management regimes such as intensity of street sweeping.

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