FIRST FLUSH LOADING OF POLLUTANTS FROM URBAN STORM RUNOFF IN SKUDAI JOHOR

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Abstract

Runoff of eight storm events from residential (3.34 ha) and six events from commercial (0.75 ha) catchments were sampled to investigate the first flush phenomenon. The first flush was analysed by plotting the cumulative loading ratio against cumulative runoff ratio. The degree of flushing was higher in the commercial catchment as reflected by more points fall above the bisector line. Results indicated that the first flush phenomenon was greater in the smaller catchment. For the commercial catchment, the first 20 - 30% of the flow evacuated between 20-70% COD, 22-74% SS, 24-68% NO_3-N, 7-69% NH_3-N and 22-87% P. For the residential catchment, the first 20 - 30% of the discharges evacuated between 15-69% COD, 15-78% SS, 14-49% NO_3-N, 23-53% NH_3-N and 23-43% P. For both catchments, no correlation was found between the pollutant concentration and the antecedent dry weather period.

Keywords: Commercial catchment, first flush, residential catchment, stormwater runoff

1.0 Introduction

Urban stormwater discharge is a major contributor to the pollution of receiving waters. It is also well known that constituents transported in storm runoff are more concentrated at the beginning of a storm event than at the end of the same event (Sansalone and Cristina, 2004). This phenomenon is known as 'the first flush of storm runoff'. For the past several years, many studies have been carried out to analyse the existing of the first flush, but in Malaysia it is still very rare. There are many factors that affect the occurrence and impact of a first-flush event, such as the size and drainage characteristics of the catchment area, the imperviousness of the basin, rainfall intensity, antecedent dry weather period, and the mobility and property of the pollutants. However, some of these studies (e.g. Gupta and Saul, 1996; Lee et al., 2002) found no correlation between the first flush and the antecedent dry weather period. The existence of first flush of pollutants provides an opportunity for stormwater managers and engineers to control water pollution in an economic and efficient way. If most of the urban-surface pollutant load were transported during the initial phase of a storm, then a small volume of runoff storage would be needed to treat and remove the bulk of urban-surface pollutants. Controlling the first flush has become the most practiced criterion for the design of stormwater treatment facilities (Deng, 2005).The first flush phenomenon could be defined or evaluated using several methods. In this study, the analysis was done by plotting the cumulative loading ratio curve against cumulative runoff ratio. Besides, the relationship between the antecedent dry days and concentrations were also examined.

2.0 Methods

2.1 Study site

The study site is located in Skudai, Johor, Malaysia. The residential catchment is 3.34 ha and the commercial catchment is 0.75 ha (Figure 1). The development in the residential catchment is mainly single storey houses with 147 houses. The catchment represents a typical high density low cost residential area. It was estimated that about 15% of the catchment is still pervious while the rest are roofs, pavement and road surfaces. Open spaces are located at the outlet of the catchment. For the commercial catchment, about 20% of the catchment is still pervious mainly covered by grass land while the rest are roofs, pavement and road surfaces.

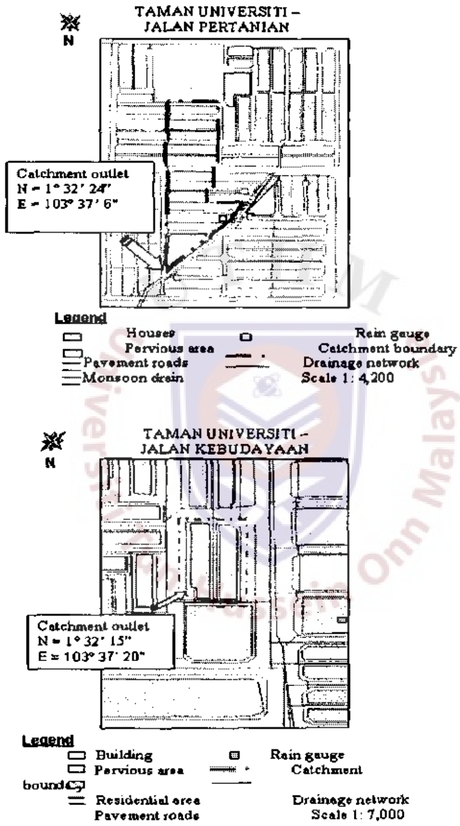

Figure 1: Residential and Commercial Catchments

2.2 Runoff water quality sampling and analysis

Samples are collected manually instead of using automatic water samplers. This is due to safety reasons as the site is very open to public. Although quite laborious, manual sampling could provide opportunities to collect more samples at preferred time intervals. All bottles used for collecting samples were washed with dilute acid (sulfuric or hydrochloric) and thoroughly rinsed with deionized distilled water. It is very important to keep these bottles clean to ensure they were free of any contamination.

Stormwater was grab-sampled using a 1-litre polyethylene bottle. Samples were taken when there was noticeable change in the water level. For every sample taken, the sampling time and water level were recorded. About 10 to 15 samples were collected during each storm on both the rising and the falling limbs of the hydrograph. In the small catchment, more samples were collected on the rising limb than on the falling limb. This is important to get a better description of the first flush phenomenon.

Water samples were sent for analysis within 24 hours after sampling. The parameters analysed were Chemical Oxygen Demand (COD), Suspended Solids (SS) and Nutrients (NO_3-N, NH_3-N and P). The laboratory analysis followed the Standard Methods for the examination of water and wastewater (APHA *et al.,* 1995). The analysis of phosphorus was carried out using Inductively Coupled Plasma-Mass Spectrometry (ICP –MS).

2.3 Characteristics of rainfall events

Characteristics of and runoff data collected from November 2003 to December 2004 are summarised in Table 1. Eight storm events for the residential and six events for the commercial catchments were sampled and analysed. During the monitoring periods, observed antecedent dry period ranged from 21 to 120 hours and the rainfall size ranged from 1.52 to 65 mm. The storm depth and intensity are important for the transport of particulates whereas the length of dry periods indicate the amount of accumulated pollutant since the preceding event (Lee *et al.*, 2004).

Table 1: Rainfall characteristics of monitored storms

Site	Event measured	Rain-fall (mm)	Inten-sity (mm/hr)	Days since last storm (hr)
Resi-	11-Jan-04	1.52	3.5	120
dential	2-Mar-04	1.52	2.5	23
catch	4-Mar-04	18.8	16	45
ment	6-Mar-04	2.8	9.3	46.4
	12-July-04	19	16	24
	8-Sept-04	6.8	8.8	50
	4-Nov-04	65	27	21
	27-Dec-04	8	9.6	-
Com-			8	
mer-			21	
cial			15	
catch	11-Mar-04	20.1	10	24
ment	16-Mar-04	31.3	11	25
	18-Mar-04	3	7	47.7
	19-Mar-04	7		23.8
	14-Apr-04	11		48
	10-Sept-04	4.9		49

3.0 Results and Discussion

3.1 Event mean concentration (EMC)

Due to high variability in pollutant concentrations throughout a given rainfall – runoff event, a single parameter known as Event Mean Concentration (EMC) is often used. EMC of contaminants can be represented by the total constituent mass discharged, during an event, divided by the total runoff volume of the event as follows (Adam and Papa, 2000);

$$EMC=\frac{M}{V} = \Sigma Q_i C_i \Delta t / \Sigma Q_i \Delta t \quad (1)$$

M is the total mass of pollutant over the entire event duration (*g*), V is the total volume of flow over the entire event duration (m^3), t is time (*min*), $Q_i\ (t)$ is the time-variable flow (m^3/min), C_i is the time-variable concentration (*mg/l*) and Δt is the discrete time interval (*min*) measured during the runoff event.

The loadings were than obtained by multiplying the concentration (EMC) from the flow-weighted composite sample by the total runoff volume for the event (Lee *et al.*, 2004).

3.2 First Flush Analysis

For a given catchment the pollutographs and hydrographs vary from one storm event to another depending on the rainfall intensity, the antecedent dry weather period, the condition of the sewer system, the dry deposits and the accumulation of pollutants.

To resolve this discrepancy, Saget *et. al.* (1996) proposed a dimensionless representation of cumulative loading ratio curve against cumulative runoff ratio or *M(V)* curve. Equations (2) and (3) represent the first flush phenomenon;

$$L = m(t) / M \quad (2)$$

$$F = v(t) / V \quad (3)$$

where L is dimensionless cumulative pollutant mass; $m(t)$ is pollutant mass transport up to time t (g); M is total mass of pollutant over the entire event duration (g); F is dimensionless cumulative runoff volume; $v(t)$ is flow volume up to time t (m^3) and V is total volume of flow over the entire event duration (m^3). The diagonal line represents the loading of a hypothetical pollutant with constant concentration. The loadings for COD, SS, NO_3-N, NH_3-N and P are plotted in Figure 2.

Data points above the diagonal line represent a higher loading and associated with pollutants that exhibit a seasonal first flush (Lee *et al.*, 2004). Bertrand *et al.* (1998) defined first flush by the fact that at least 80% of the pollutant mass is transported in the first 30% of the volume. Meanwhile, Wanielista and Yousef (1993) proposed that 50% of the pollutant mass is transported in the first 25% of the volume. In this study, for both catchments, most data points within the initial 30% of the runoff volume fall above the diagonal line. Table 2 shows averages cumulative pollutant loadings that fall in the 20-30% range of runoff volume. The mean values ranged from 0.38 to 0.55, with a maximum of 0.87. Since the average cumulative pollutant load that fall in the 20-30% range of runoff volume are considered, there is no first flush exist if the mean values was 0.25. It can be concluded that all contaminants exhibited strong first flush.

Table 2: Cumulative load at 20-30% of the runoff volume in the commercial catchments

	Commercial				
	COD	SS	NO_3-N	NH_3-N	P
Minimum	0.25	0.22	0.24	0.07	0.22
Maximum	0.82	0.74	0.68	0.69	0.87
Mean	0.54	0.48	0.46	0.38	0.55

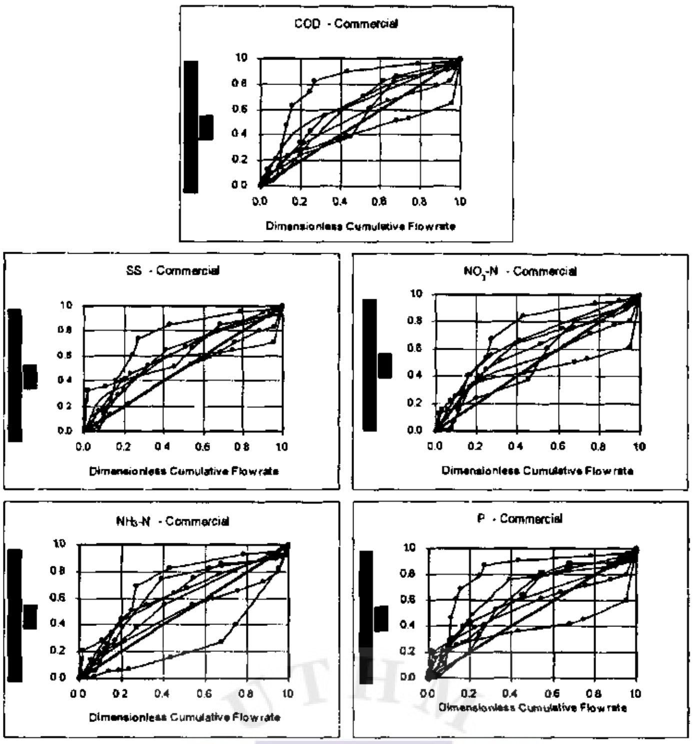

Figure 2: Mass Volume, *M (V)* ratios of COD, SS, NO_3-N, NH_3-N and P in the commercial catchment

For the residential catchment, the mean values ranged from 0.17 to 0.47 as shown in Table 3. SS showed the strongest first flush with mean mass to volume ratio of 0.47.

Table 3: Cumulative load at 20-30% of the runoff volume in the residential catchment

	Residential				
	COD	SS	NO_3-N	NH_3-N	P
Min	0.15	0.15	0.14	0.23	0.23
Max	0.69	0.78	0.49	0.53	0.43
Mean	0.42	0.47	0.3	0.38	0.33

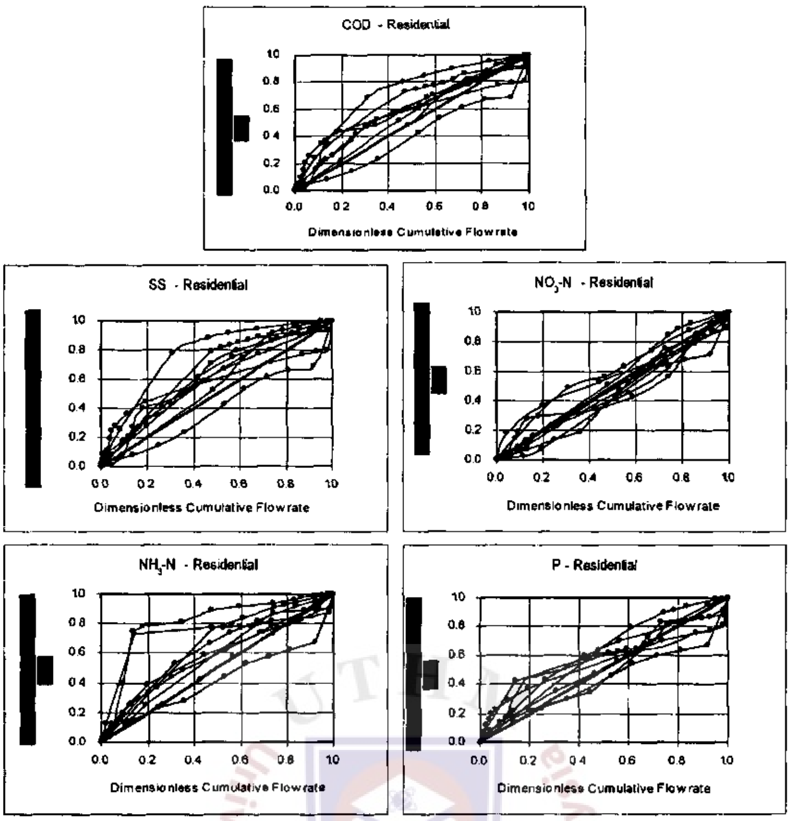

Figure 3: Mass Volume, *M (V)* ratios of COD, SS, NO_3-N, NH_3-N and P in the residential catchment

The degree of flushing, however, was higher in the commercial catchment as reflected by more points fall above the bisector line. The first 20 - 30% of the flow evacuated between 25-82% COD, 22-74% SS, 24-68% NO_3-N, 7-69% NH_3-N and 22-87% P. For the residential catchment, the first 20 - 30% of the discharges evacuated between 15-69% COD, 15-78% SS, 14-49% NO_3-N, 23-53% NH_3-N and 23-43% P. In this study, it was found that the first flush was greater for smaller catchment area.

Concentrations of SS, NO_3-N, NH_3-N and P are plotted against the antecedent dry days (Figure 4). For the commercial catchment, the observed antecedent dry days ranged from 24 to 49 hours and the rainfall size ranged from 3 to 31.3 mm. Interestingly, even with less than 1 dry day period, the event on March 19, 2004 produced the highest SS concentration compared to the other events. Storm size also didn't seem to be a single factor influencing the SS concentration. No correlation was found between the concentration of SS and the antecedent dry day period. COD shows the highest value of median concentration with 49 hours (2.04 days) antecedent dry day. But again there was no correlation between COD and dry day period. The same case was found for the other parameters. For the commercial catchments, there was no correlation between pollutant concentration and the antecedent dry day period. This finding agrees with Gupta and Saul (1996). Since some kitchens in the residential catchments, especially after renovation, directly discharge sullage into drains, the pollutant transport behaviour is less predictable.

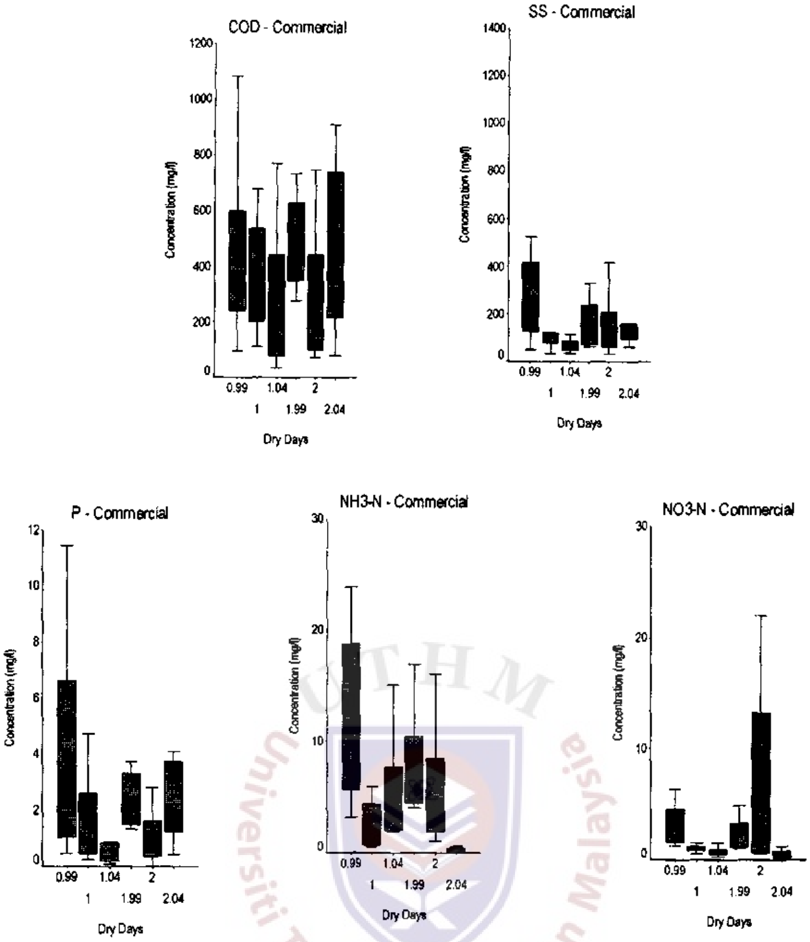

Figure 4: Effects of antecedent dry days on pollutant concentrations

Concentrations of various pollutants of the residential catchments are plotted against the antecedent dry days (Figure 5). The observed antecedent dry days ranged from 21 to 120 hours and the rainfall size ranged from 1.52 to 19 mm. Similar to the commercial catchments, no discernible trend was found between pollutant concentration and the antecedent dry day period

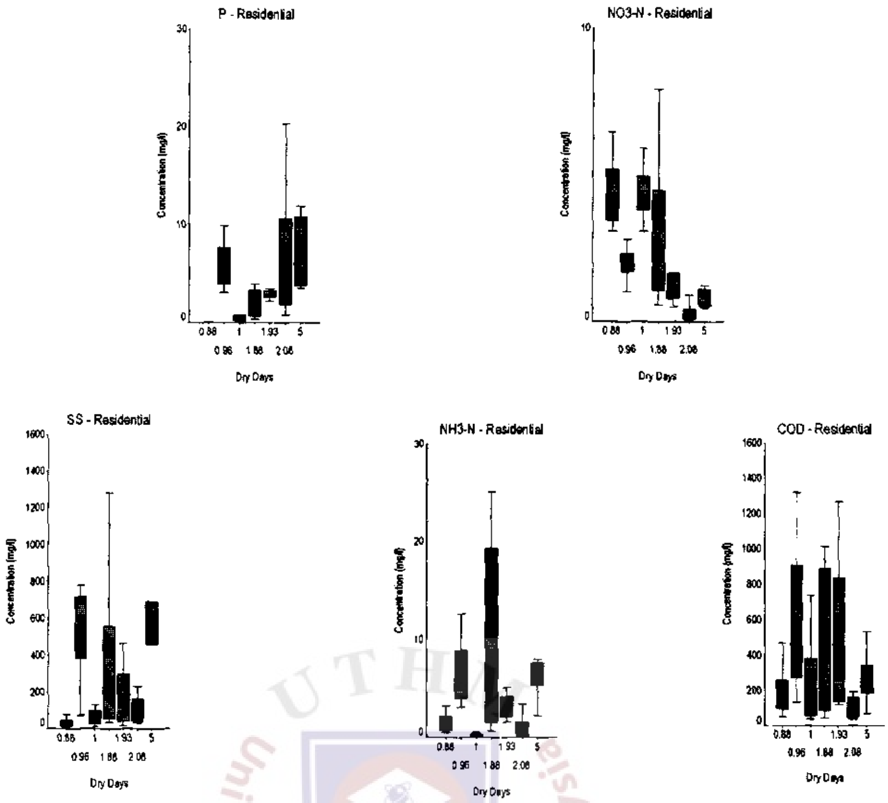

Figure 5: Effects of antecedent dry day on pollutant concentrations

4.0 Conclusion and Recommendations

Despite limited samples, this study provides interesting results on the occurrence of first flush phenomenon of pollutants in typical residential and commercial catchments. First flush loadings were greater in a smaller catchment. For the commercial catchment, the relative strength of the first flush was P> COD>SS> NO_3-N> NH_3-N but slightly different sequence in the residential catchment - SS> COD> NH_3-N> P> NO_3-N. This preliminary finding is useful as basis for designing pollutant control structure. It is more efficient to treat storm runoff during the early part of the storm events before it enters the water bodies.

Future sampling design must include various lengths of dry period and rainfall intensity. Further analysis should be done to estimate the critical amount of runoff volume to treat the early runoff quality.

Acknowledgement

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