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Storm Runoff Pollution from a Residential Catchment in Miri, Sarawak

Ho, C. L. I.[1]* and Choo, B. Q.[2]

[1]*School of Engineering and Science, Curtin University Sarawak Campus, Miri, Sarawak, Malaysia*

[2]*Frasers Centrepoint Limited Management Services Pte Ltd., Singapore*

ABSTRACT

In this paper, stormwater runoff from a residential catchment located in Miri, Sarawak, was characterized to determine the pollutant concentrations and loading. The observed average event mean concentrations were 116 mg/L for TSS, 115 mg/L for COD, 1.5 mg/L for NH_3-N, and 0.23 mg/L for Pb. Based on Interim National Water Quality Standards (INWQS) for Malaysia, the average event mean concentration, EMC value for TSS exceeded class II (50 mg/L), exceeded class V (>100 mg/L) for COD, and exceeded class III (0.9 mg/L) for NH_3-N. All four water quality parameters exhibited first flush characteristic but to varying magnitude which was influenced by the storm characteristics.

Keywords: Storm runoff, residential catchment, NPS pollutant

INTRODUCTION

Developing countries such as Malaysia are characterized by rapid urbanization. In an urbanized area, anthropogenic activities and land use highly influence storm runoff volume and quality. The urbanization process results in an increase in imperviousness of the surface area and it also changes natural land covers as well as the drainage network. This results in an increase in runoff volume and produces hydrographs which have higher and earlier peaks (Elliott & Trowsdale, 2007; Gupta & Saul, 1996). Urban storm runoff has also been identified as one of the leading causes of degradation in the quality of receiving waters (USEPA, 2002). Rainfall washes off pollutants from the air and surfaces, carried into the drainage systems, and eventually leading to water contamination and river pollution (McLeod *et al.*, 2006). In many cities in the tropics, urban stormwater runoff is a major contributor to river pollution

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Email addresses:
Ho, C. L. I. (carrie.ho@curtin.edu.my),
Choo, B. Q. (kevincbq@gmail.com)
*Corresponding Author

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(Nazahiyah *et al.*, 2007; Novotny & Olem, 1994). However, studies on urban runoff are still very limited, particularly in Malaysia, and the research is non-existent in Miri, Sarawak.

Urban runoff pollution can be broadly categorised into point source (PS) and non-point source pollution (NPS). Major point source pollution includes effluent from a wastewater treatment plant and industrial discharges. Non-point source pollution is not readily identifiable and the pollutants are transported in a diffuse manner. Typical non-point source pollutants that can be found in urban storm runoff include organic materials, suspended solids and nutrients such as ammonia nitrogen and phosphorus and heavy metals (Tsihrintzis & Hamid, 1997).

In Malaysia, development of preventive strategies to mitigate the impacts of NPS pollution from urban runoff is still in its infancy. An Urban Stormwater Management Manual for Malaysia has been developed and some guidelines are presented for Best Management Practices (BMPs) for control of urban stormwater (DID, 2000). However, formulation of effective management strategies is hampered by the lack of data on the diffuse pollutant loads. In Miri, Sarawak, the contribution of pollutants from urban runoff into the receiving water has not been well understood and limited data are available on urban runoff pollutants.

Miri is a fast developing city, characterized by rapid urbanization in the last decade. Large tracts of land are largely converted into residential developments. Waterways located within the city are heavily polluted, with Miri River, which enters the South China Sea, being one of the most polluted rivers in Sarawak. However, the contribution of NPS pollution to the quality of the surface water is still largely unknown.

The amount and types of pollutants found in storm runoff vary according to the catchment's predominant land use and associated human activities. Rainfall characteristics such as intensity and size will also impact pollutant transport (Zoppou, 2001). The variability of source loadings for urban runoff necessitates the sampling of storm events and analysis of runoff pollutants to estimate pollutant loading to the receiving water courses. The objectives of this study, which was conducted in Miri, Sarawak, were to characterize the storm runoff pollution from a residential area and to analyze the first flush effect of the storm runoff pollution.

MATERIALS AND METHODS

Study Area

The study site is located in Miri, Sarawak. The climate is tropical, with an annual precipitation ranging between 2800 and 3200 mm. The residential catchment is 9.8 ha in size, with no significant slope in the terrain. The residential houses are single storey terraced houses, high in density, which results in low perviousness of about 13%. Impervious areas include paved roads, concrete pavements, and roofs.

As-built drainage drawings were used to delineate the catchment boundary, according to the direction of flow. The drainage channels are open, rectangular in shape and constructed using concrete, which is typical for Sarawak. The drainage system conveys both stormwater runoff and wastewater effluents from individual septic tanks from the houses. Any washoff from the surface, as a result of human activities such as from car wash and paved surface cleanings also discharges into the drainage channels. Runoff from the catchment under study outfalls into an existing retention pond, located north of the study area. Fig.1 shows the catchment boundary and the location of the retention pond.

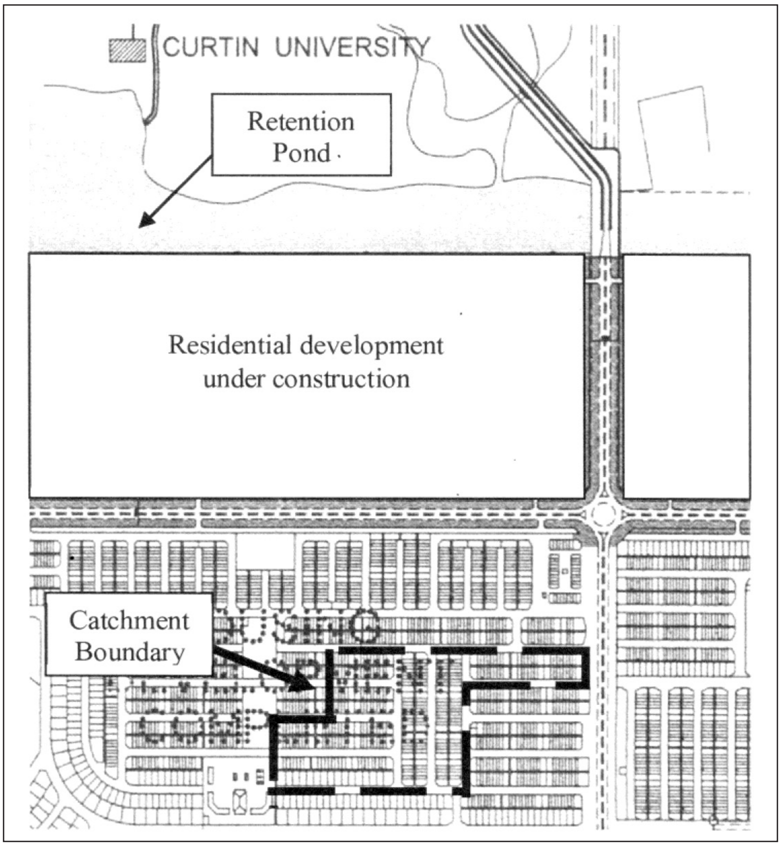

Fig.1: Study catchment in Miri, Sarawak

Rainfall and Runoff

Rainfall was monitored continuously using a tipping bucket rain gauge (HACH) with a data logger. Rainfall is recorded every two minutes. Runoff discharge and volume was determined using the velocity-area method. During sampling, a velocity meter was used to measure the velocity of the flow at the catchment outlet. The runoff discharge was calculated as the product of the flow velocities and the cross section area of the drainage channel at various water levels measured.

Sampling and Analysis

The samples were collected from 3 rainfall events from August to December 2011. The samples were collected at the outlet of the catchment. A total of 10 samples were collected for each of the rainfall events monitored at various intervals throughout the hydrograph. Descriptions of the events sampled are summarized in Table 1. Water quality parameters tested for in this study include total suspended solids (TSS), chemical oxygen demand (COD), ammonia nitrogen (NH_3-N), and lead (Pb).

TABLE 1
Rainfall events monitored in this study

	1st Event	2nd Event	3rd Event
	28th Aug	20th Sept	28th Dec
Rainfall depth (mm)	8	103	2.8
Rainfall intensity (mm/h)	6.3	41	21
Max. rainfall intensity (mm/h)	30	145	38
Rainfall duration (h)	0.63	2.5	0.13
Antecedent dry period (h)	167	82	19

RESULTS AND DISCUSSION

Temporal Variation of Pollutants

A set of hydrograph and pollutograph for each of the water quality parameters tested can be produced based on the runoff monitored. Fig.2 and Fig.3 show the precipitation and the development of the flow and concentrations of TSS, COD and Pb during the 1st and 2nd storm events monitored in this study. Event 1 was a short but intense rainfall, characteristics of a tropical thunderstorm. Event 2 was a heavy storm, totalling 103 mm, with maximum rainfall intensity of 145 mm/h. Event 1 was high intensity at the start of the event, and event 2 was high intensity at the later period of the event.

In both events, pollutant concentration peaked before maximum flow occurred. Pollutant concentration rapidly decreased after the peak. It can be observed that event 2, which had a much higher rainfall intensity and duration than event 1, resulted in high TSS being sustained over the first half period of the event, whereas for event 1, TSS rapidly reduced from the initial high concentration. This finding indicates that the characteristic of the rainfall events greatly influences the pollutant generation pattern.

Pollutant Load Distribution

Concentration of pollutants found in storm runoff can be highly variable over the duration of the storm. Thus, an event mean concentration (EMC) is often used to evaluate the impacts of stormwater runoff on receiving waters. An EMC represents a flow-weighted average concentration of runoff computed as the total storm pollutant load divided by the total runoff volume, expressed by Equation 1.

$$EMC = \frac{\sum_{i=1}^{n} C_i Q_i}{\sum_{i=1}^{n} Q_i} \quad [1]$$

C (unit is mg/L) is the time-variable concentration of the pollutant and Q (unit is m^3/s) is instantaneous discharge.

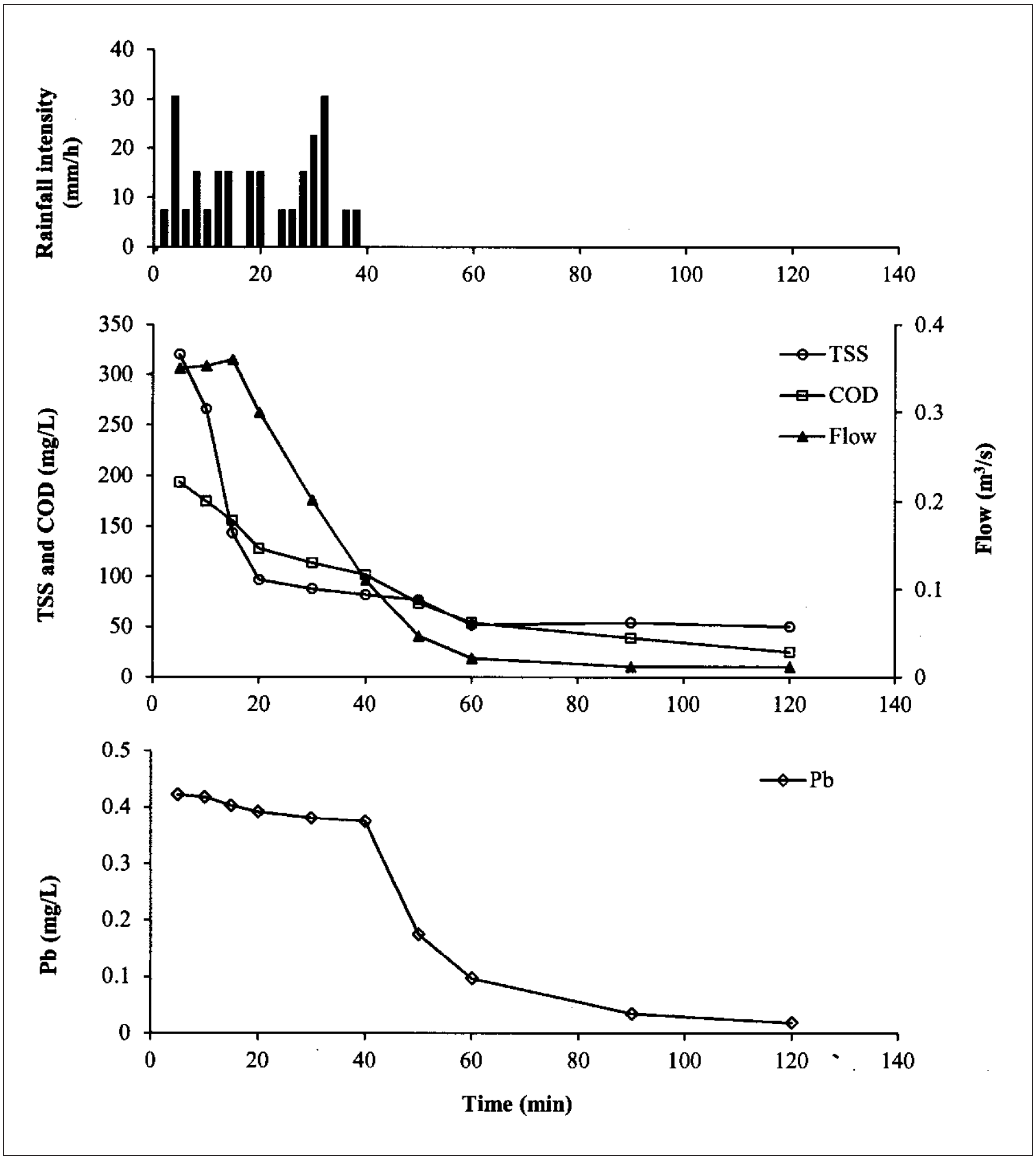

Fig.2: Flow and concentration of TSS, COD, and Pb for Event 1

Table 2 presents EMCs and loads from the three events monitored. Average EMC values were 116 mg/L for TSS, 115 mg/L for COD, 1.5 mg/L for NH_3-N, and 0.23 mg/L for Pb. It can be seen that the EMC values for the pollutants vary depending on the characteristics of the rainfall. Meanwhile, the EMC values for TSS and NH_3-N increased with the length of the antecedent dry period. Event 1 had the longest antecedent dry period of 7 days, followed by event 2 with 3.5 days, and event 3 with <1 day. The EMC values for the pollutant COD, however, showed correlation with the size of the rainfall, with event 2 having the lowest EMC value for COD, but the largest rainfall at 103 mm. The large rainfall event would have diluted

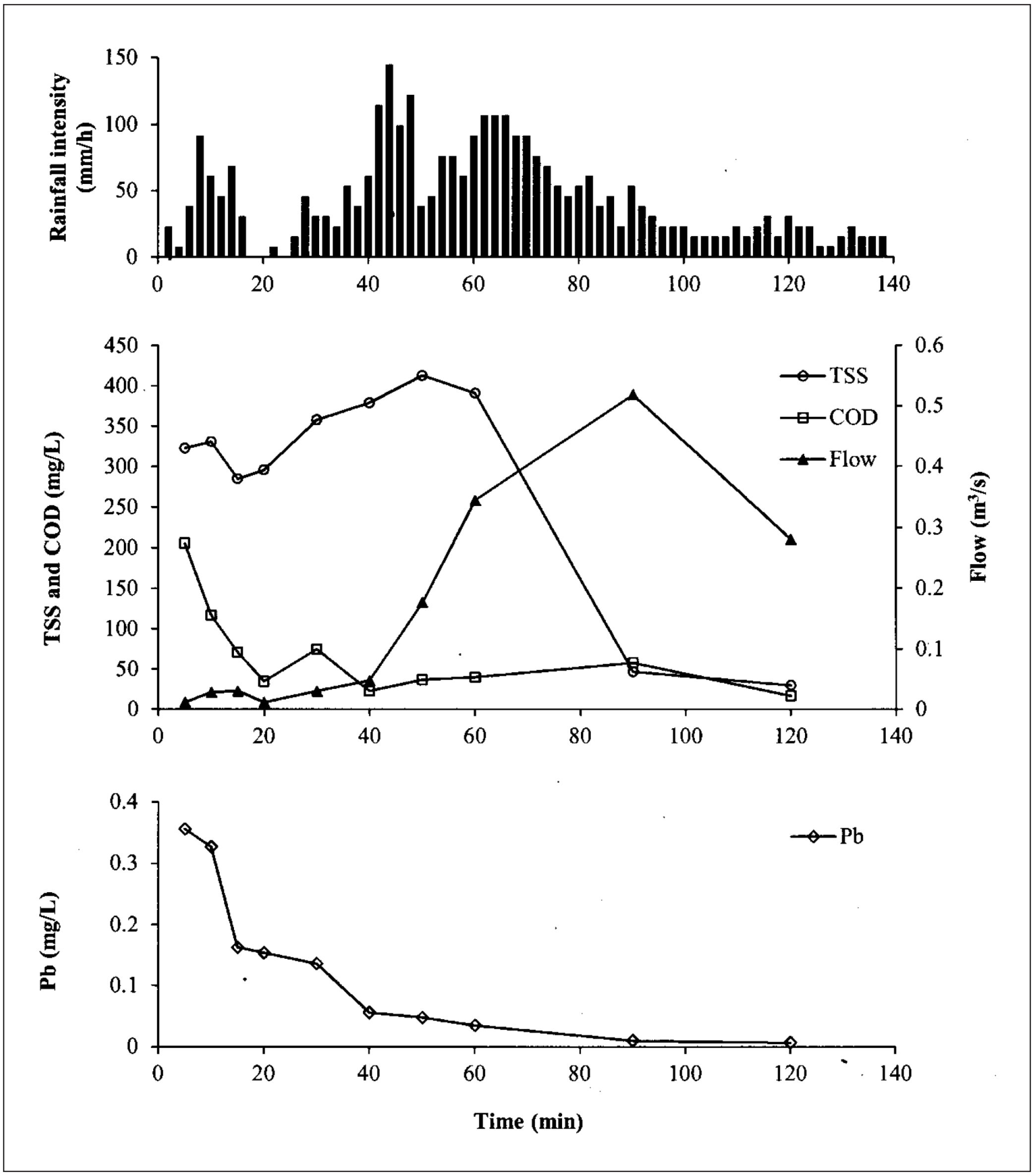

Fig.3: Flow and concentration of TSS, COD, and Pb for Event 2

the strength of the pollutant. The average EMC value for COD exceeded class V (>100 mg/L) of the Interim National Water Quality Standards for Malaysia (INWQS). The average EMC value for TSS exceeded class II (50 mg/L) and the average EMC value for NH_3-N exceeded class III (0.9 mg/L) of the Malaysian INWQS. This shows that the quality of the runoff from the study site is slightly polluted. However, it does result in significant contaminant loading to the receiving water.

TABLE 2
EMCs and total discharged loads for monitored runoff

Pollutants	1st Event		2nd Event		3rd Event	
	EMC (mg/L)	Load (kg)	EMC (mg/L)	Load (kg)	EMC (mg/L)	Load (kg)
TSS	158	107	115	209	76	3
COD	135	92	44	79	167	7
NH_3-N	2.17	1.5	0.89	1.6	-	-
Pb	0.36	0.25	0.02	0.04	0.31	0.01

In urban runoff, pollutant load delivery is typically not proportional to the amount of runoff volume. Pollutant load is often significantly higher during the early portion of the storm runoff and this characteristic is known as the first flush phenomenon. One widely used method to identify first flush is by plotting a dimensionless curve of cumulative discharge volume against cumulative discharge mass (Bedient *et al.*, 1980). A 45^o bisector line is also drawn and first flush is considered present when the initial slopes of the dimensionless curves are greater than the 45^o bisector.

From Fig.4, the plot of the distribution of pollutant load with volume showed that all the pollutants exhibit the first flush phenomenon, but to varying degrees. The dimensionless curves of all four water quality parameters studied were largely above the bisector line for all three events. This suggests that large fractions of the pollutant load were transported by the initial portion of the runoff. The difference between the curves and the bisector line can be used to indicate the magnitude of the first flush. TSS showed a strong first flush characteristic for all three storm events, whereas COD exhibited a weak first flush characteristic. NH_3N and Pb both exhibited a strong first flush characteristic for one storm event only.

The characteristic of the rainfall event also influences the magnitude of first flush, as it can be seen that for event 2 (20 September), TSS, NH_3-N, and Pb exhibited a very strong first flush characteristic. Event 2 had an initial high intensity rainfall which washed off the pollutants, followed closely by the maximum intensity which resulted in the peak hydrograph in the later period of the event, and thus resulted in the distinctive first flush for the pollutants tested.

All four water quality pollutants exhibited first flush for event 1 (28 August), which was a short, but high intensity rainfall. The magnitude of the first flush, however, is weak. As for event 3 (28 December), the pollutants exhibited weak or no first flush, as the rainfall event was small and of short duration, at only 2.8 mm over 10 minutes. This indicates that the presence and strength of first flush is dependent on the characteristic of the rainfall.

CONCLUSION

The NPS pollutant load and the distribution of the load with volume are determined in this study. The results derived from this study are useful to estimate the contribution of runoff pollutants from catchments with residential land use to the waterways in and around Miri City. As Miri is a rapidly expanding city with significant land developments planned for residential housing, the potential NPS loadings due to the developments and its potential impact on surface water can

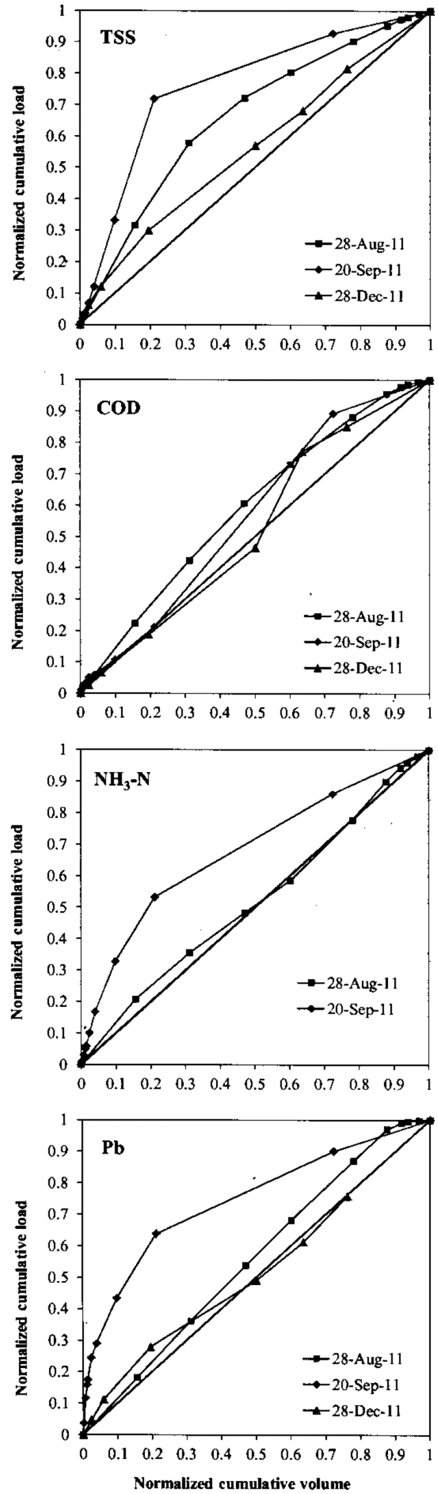

Fig.4: Normalized cumulative curves for TSS, COD, NH3-N, and Pb of the three storm events monitored

be estimated. In this study, observed average EMC values were 116 mg/L for TSS, 115 mg/L for COD, 1.5 mg/L for NH_3-N, and 0.23 mg/L for Pb. All the four water quality parameters exhibited first flush characteristic, but the magnitude of the first flush varied depending on the rainfall characteristic. In conclusion, the study of storm runoff and its associated pollutants is essential to understand the contribution of urban runoff pollutants to the degradation of surface water quality, and an important step in the design of management strategies to address the issue of deterioration of the water quality of rivers in Sarawak.

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