

Pollutant Loads of Urban Runoff from a Mixed Residential-Commercial Catchment

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Abstract—Urban runoff quality for a mixed residential-commercial land use catchment in Miri, Sarawak was investigated for three storm events in 2011. Samples from the three storm events were tested for five water quality parameters, namely, TSS, COD, BOD₅, TP, and Pb. Concentration of the pollutants were found to vary significantly between storms, but were generally influenced by the length of antecedent dry period and the strength of rainfall intensities. Runoff from the study site showed a significant level of pollution for all the parameters investigated. Based on the National Water Quality Standards for Malaysia (NWQS), stormwater quality from the study site was polluted and exceeded class III water for TSS and BOD₅, with maximum EMCs of 177 and 24 mg/L, respectively. Design pollutant load based on a design storm of 3-month average recurrence interval (ARI) for TSS, COD, BOD₅, TP, and Pb were estimated to be 40, 9.4, 5.4, 1.7, and 0.06 kg/ha, respectively. The design pollutant load for the pollutants can be used to estimate loadings from similar catchments within Miri City.

Keywords—Mixedland-use, urban runoff, pollutant load.

I. INTRODUCTION

DEVELOPING countries such as Malaysia is characterized by rapid urbanization, which alters natural vegetation, and the physical characteristics of the landscape. This results in lower infiltration capacity of the soil and an increase in runoff volume [1], [2]. Increase in impervious area follows development, and this typically produces hydrographs with earlier and higher peaks. Higher runoff volume and peak flow can cause flooding, watercourse and habitat destruction [3].

Urban surface runoff has been found to account significantly for water quality degradation observed in rivers, lakes and other receiving waters downstream or within urban areas [4], [5]. During a storm event, the resulting runoff accumulates pollutants from the air, road and soil surfaces, as well as storm drains, eventually discharging into receiving waters. This leads to water contamination and pollution of the receiving water bodies [6]. In Canada, urban runoff has been identified as a threat to drinking water supplies and the health of aquatic ecosystems [7].

In many cities in the tropics, urban runoff is a major contributor to river pollution [8], [9]. In Malaysia, according to the Environmental Quality Report by the Department of Environment (DOE) for the year 2011, a total of 39 rivers in Malaysia were found to be polluted. The number of clean

rivers has also dropped significantly, when measured in terms of Biochemical Oxygen Demand (BOD) pollution, from 104 to 44 compared to the previous year. As for the Suspended Solids (SS), the number of clean rivers had also decreased from 334 rivers in 2010, to 293 rivers in 2011 [10].

Urban runoff pollution has been found to have a significant relationship to the degree of urbanization and land use classifications. Urban runoff quality results show high variability with different land use, such as residential, industrial, agricultural, or land for recreational purposes. In order to establish standard values for stormwater runoff quality guidelines, and to determine best management practices, land use based models are widely used to estimate stormwater runoff pollutant loads [11]. To effectively calibrate the land use based models, hydrologic monitoring data, including stormwater runoff quality data, is an essential requirement.

Miri is a rapidly developing city, characterized by expanding road networks, infrastructure developments and development of new townships. Sungai Adong River classified as polluted, and Sungai Miri River as slightly polluted, as reported by the Department of Environment Malaysia [10]. However, the contribution of urban runoff from Miri City to the river water quality is still largely unknown.

In order to formulate a water quality management plan for urban streams, it is necessary to study the characteristics of urban runoff and to develop urban runoff pollution load factors. However, one of the significant issue faced by urban planners and environmental regulatory agencies, is the lack of recent urban runoff data. In Malaysia, very few studies can be found on urban hydrology and stormwater pollution. Data on urban runoff and its associated pollutants are very limited for Miri. Thus, this can impede formulation of effective management strategies to control urban runoff.

In this study, runoff from a mixed residential-commercial catchment in Miri, Malaysia is monitored for several critical water quality parameters. The aim of the study is to quantify the pollutant loadings from the study catchment, which can be used to aid planning, evaluation and management of urban runoff pollutants.

II. METHODS

A. Study Site

The study site is located within the Desa Senadin Development in Miri, Sarawak. The study catchment covers an area of 3 hectares, with a flat terrain. It has a mixed residential-commercial land use, consisting of 102 units of link houses and 10 units of commercial shop lots.

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The climate in Miri is warm and humid throughout the year, characteristic of a tropical climate, with daily air temperature between 23 to 32°C. Annual rainfall ranges between 2800 to 3200mm. Miri experiences two monsoon seasons throughout the year, one where it brings about drier months from April to September, and the other, a wet season from October to March.

Catchment boundary for the study site was determined based on as-built drawings for the study area. The drainage network constructed in the study comprises of open rectangular concrete channels which serve as a conveyance system for both stormwater runoff and wastewater effluents from septic tanks. Wash off from the study site also discharges directly into the open channels. Runoff from the study catchment outfalls to a major monsoon drain, flowing south into a detention pond, eventually connects to the Sungai Miri River.

Fig. 1 shows the catchment area under study and the sampling location. The land use distribution within the study site is shown in Fig. 2.

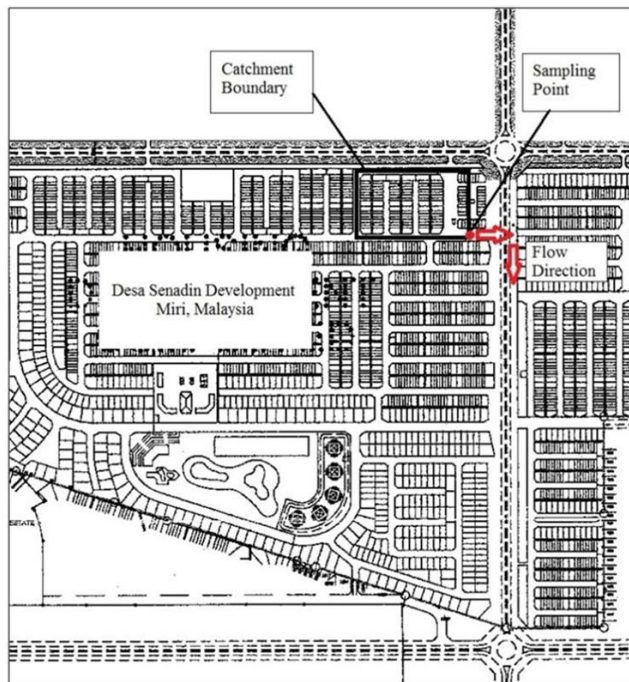


Fig. 1 Study site location within the Desa Senadin Development in Miri

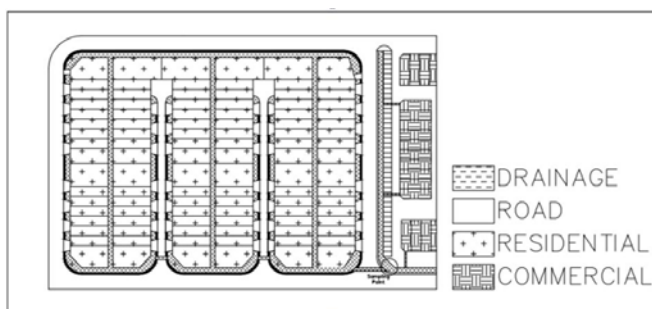


Fig. 2 Land use distribution within the study site

B. Rainfall and Runoff

Rainfall was monitored continuously using a tipping bucket rain gauge (HACH) with a data logger. Rainfall depth was recorded every 2 minutes. Runoff flow was determined by velocity-area method. A flow velocity meter was used to measure flow velocity at the sampling location. Flow was calculated as the product of the flow velocities and the drain's cross section at various water levels during sampling.

C. Water Quality Sampling and Testing

Stormwater runoff samples were collected for three rainfall events from November 2011 to March 2012, during the period of time when the study site was experiencing more frequent rainfall events. Thus, sampling was only done for rainfall events that had a minimum of 1 day antecedent dry weather period. Samples were manually collected at the outlet of the study catchment. A total of 8 samples were collected for each event, distributed over the rising and falling limb of the hydrograph. Samples collected were tested within 24 hours according to Standard Methods. Five water quality parameters were tested, including total suspended solids (TSS), chemical oxygen demand (COD), biochemical oxygen demand (BOD₅), total phosphorus (TP), and lead (Pb).

The characteristics of the three rainfall events monitored are presented in Table I. The three rainfall events monitored have distinct characteristics. Of the three, event 1 had the highest maximum rainfall depth and the highest average intensity at 42 mm/h. It was characteristic of a tropical thunderstorm, with high intensity and short duration. Event 2 was a moderate shower, with rainfall intensity of 17 mm/h, but had the longest antecedent dry period of 3 days. Event 3 had the lowest rainfall intensity at 7.3 mm/h, but with antecedent dry period similar to event 1 at 1.3 days. Rainfall intensity is an important characteristic that contributes to particle transport and antecedent dry period allows for accumulation of pollutants during the dry weather period.

TABLE I
 RAINFALL CHARACTERISTICS OF THE MONITORED RUNOFF

Characteristics	Event 1 24-Nov	Event 2 22-Dec	Event 3 3-Jan
Max. rainfall depth (mm)	4.6	2.5	1.0
Avg. rainfall intensity (mm/h)	42	17	7.3
Rainfall duration (h)	0.5	1	1
Antecedent dry period (d)	1.5	3	1.3

III. RESULTS AND DISCUSSION

A. Characteristics of Runoff Water Quality

The maximum pollutant concentrations recorded for the three monitored events are shown in Table II. Samples collected from event 2 showed an overall high concentration of pollutants, which can be attributed to the longer antecedent dry period compared to the other two events. It is most discernible for total suspended solids (TSS) concentration, which typically shows a high correlation with the length of antecedent dry period. For event 2, the maximum TSS concentration was 802 mg/L, which was much higher

compared to the peak TSS value for event 1 and event 3. Similarly, concentration of chemical oxygen demand (COD) was also significantly influenced by the length of antecedent dry weather period, with event 2 recording a maximum of 70 mg/L, which was much higher compared to the peak COD value for event 1 and event 3.

Despite the fact that antecedent dry weather period for event 1 and event 3 were similar (~1.5 days), samples collected for event 1 showed an overall higher pollutant concentrations compared to event 3. This could be attributed to the rainfall intensity for event 1, which was much higher at 42 mm/h compared to event 3 with 7.3 mm/h. High rainfall intensity can result in a strong wash off effect, which could lead to higher pollutant concentrations in the surface runoff.

Based on the maximum pollutant concentrations for the three storm events, TSS exceeded class V (300 mg/L) of the National Water Quality Standards for Malaysia (NWQS), for event 1 and event 2. For all three events, the biochemical oxygen demand (BOD₅) concentration also exceeded class V (12 mg/L) of the NWQS. This indicates that the storm runoff was polluted in terms of TSS and BOD. Concentrations of chemical oxygen demand (COD), total phosphorus (TP), and lead (Pb) in the samples tested were also significant. This suggests that the runoff from the study site had a significant level of pollution.

TABLE II

MAXIMUM POLLUTANT CONCENTRATION FOR MONITORED RUNOFF			
Pollutant (mg/L)	Event 1 24-Nov	Event 2 22-Dec	Event 3 3-Jan
TSS	385	802	46
COD	28	70	13
BOD ₅	35	67	73
TP	6.2	10.1	-
Pb	0.43	0.46	0.30

B. Event Mean Concentration (EMC)

Concentrations of runoff pollutants can vary several times in magnitude during a storm event, so a flow weighted mean concentration of the pollutant, known as the event mean concentration (EMC) are often used to characterize the pollutant. The EMC is defined as the total pollutant mass discharged during an event, divided by the total runoff volume [12], expressed as:

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

where C is the time-variable concentration and Q is instantaneous discharge.

Table III presents the EMC values for event 1 and event 2, as both events produced critical levels of pollutants. Pollutant concentrations vary for both storms, but in general, significantly higher EMC for the pollutants were observed for event 2, which had a longer antecedent dry weather period compared to event 1.

The highest EMC for each pollutant was selected to represent the runoff quality from the study site. Based on the National Water Quality Standards for Malaysia (NWQS), the

stormwater runoff from the study site can be classified as slightly polluted, exceeding class III water quality, especially in terms of TSS and BOD₅, with maximum EMCs of 177 and 24 mg/L, respectively.

TABLE III
 EVENT MEAN CONCENTRATIONS OF POLLUTANTS INVESTIGATED

Event Mean Concentration (mg/L)	Event 1 24-Nov	Event 2 22-Dec
TSS	128	177
COD	9.7	17.4
BOD ₅	7.8	24.2
TP	1.1	3.8
Pb	0.26	0.20

C. Event Based Pollutant Loadings

Event based loadings were obtained from the product of the event mean concentration and the total runoff volume for each event monitored. Table IV summarized the total load for each pollutant for the study site in kg/ha for event 1 and event 2, as both events were large storms and had high levels of pollutant concentrations. Large storms typically results in high pollutant loadings due to the large runoff volume produce.

TABLE IV
 OBSERVED EVENT BASED POLLUTANT LOADINGS

Pollutant	Pollutant load (kg/ha)	
	Event 1 24-Nov	Event 2 22-Dec
TSS	21	20
COD	1.6	2.0
BOD ₅	1.3	2.7
TP	0.2	0.4
Pb	0.04	0.02

In general, pollutant loads for event 1 and event 2 were similar. The pollutant loadings obtained from this study are much higher in terms of TSS, TP and Pb compared to a study done for a residential catchment in Malaysia [9]. The difference can be attributed to land use, as in this study, commercial land use can result in higher pollutant loads due to activities carried out on the commercial premises. In the study site, the commercial activities carried out include food eateries, hardware shop, and motor cycle repair workshops. Poor housekeeping can result in pollutant wash off during a storm event, and this would increase the pollutant loadings from the catchment.

D. Design Pollutant Load

An estimate of the design pollutant load can be obtained using the highest or critical EMC values computed multiplied by the design runoff volume. A simple method to compute design runoff is using the Volumetric Rational Method:

$$Design\ Runoff = {}^R P_d CA$$

where ${}^R P_d$ is the average depth for rainfall of R -average recurrence interval (ARI) and duration d , C is runoff coefficient and A catchment area. The average rainfall depth, ${}^R P_d$ for the study site can be estimated from intensity-duration-

frequency (IDF) curves developed for Malaysia, expressed as [12]:

$$\ln(RI_t) = a + b \ln(t) + c(\ln(t))^2 + d(\ln(t))^3$$

where $R I_t$ is the average rainfall intensity for R -ARI and duration t , the constants a to d are coefficients that vary depending on the location. For Miri, the coefficients a , b , c , d for rainfall of 2 years ARI are 4.9302, 0.2564, -0.1240, and 0.0038, respectively [12]. However, water quality studies typically requires IDF values for relatively small, frequent storms, as on an annual basis, up to 90% of the total pollutant load is washed off in storms of up to 3 months ARI. As such, the Urban Stormwater Management Manual for Malaysia recommends that water quality design storm be that with a 3-month ARI [12]. The following expressions are used to estimate rainfall intensity for storms of 1, 3, 6-months and 1 year ARI from the rainfall intensity of 2 years ARI [12]:

$$^{0.083}I_t = 0.4^2 I_t \text{ for 1-month ARI}$$

$$^{0.25}I_t = 0.5^2 I_t \text{ for 3-month ARI}$$

$$^{0.5}I_t = 0.6^2 I_t \text{ for 6-month ARI}$$

$$^1I_t = 0.8^2 I_t \text{ for 1 year ARI}$$

Estimate of the design runoff for the study area is calculated using the Volumetric Rational Method based on storms of 1, 3, 6-months and 1 year ARI. The catchment area for the study site is 3 hectares, and runoff coefficient was estimated to be 0.7. Storm duration is equal to 60-minute design rainfall depths. The design pollutant load was computed based on the highest EMC value for the pollutants investigated. Design pollutant loadings for storms of various ARI for the study site are presented in Table V. The magnitudes of the pollutant loads are highly influenced by the runoff volume. It is recommended that pollutant loadings for the 3-month ARI storm be used as the water quality design storm.

TABLE V
 DESIGN POLLUTANT LOADINGS FOR VARIOUS ARI

Pollutant	Design pollutant load (kg/ha)			
	1-month ARI	3-month ARI	6-month ARI	1-year ARI
Design Rainfall Intensity (mm/h)	26	32	39	51
Design Runoff Volume (m ³ /ha)	180	225	270	360
TSS	32	40	48	64
COD	7.5	9.4	11.3	15.0
BOD ₅	4.3	5.4	6.5	8.7
TP	1.4	1.7	2.1	2.8
Pb	0.04	0.06	0.07	0.09

IV. CONCLUSIONS

Information derived from this study is useful in indicating the contribution of stormwater runoff to the degradation of the quality of surface water in Miri. Results of the study showed

that significant levels of pollution were found for TSS, COD, BOD₅, TP and Pb, due to the land use, which included residential and commercial activities. As the waterways within Miri river basin is quite polluted, the data reported here can be used to aid in the formulation of best management strategies to improve the water quality of Sungai Miririver. Design pollutant load for the pollutants can be used to estimate loadings from similar catchments within Miri City.

Based on the National Water Quality Standards for Malaysia (NWQS), stormwater quality from the mixed residential-commercial land use catchment was polluted and exceeded class III water for TSS and BOD₅, with maximum EMCs of 177 and 24 mg/L, respectively. In conclusion, study of runoff quality from developed areas of various land use is a necessary step to understand the extent of the pollution contribution from urbanized catchment in order to address the issue of pollution of receiving water bodies and deterioration of the water quality of rivers in Miri, Sarawak.

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