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Runoff Quality and Pollution Loading from a Residential Catchment in Miri, Sarawak

Carrie Ho, and Choo Bo Quan

***Abstract*—**Urban non-point source (NPS) pollution for a residential catchment in Miri, Sarawak was investigated for two storm events in 2011. Runoff from two storm events were sampled and tested for water quality parameters including TSS, BOD_5, COD, NH_3-N, NO_3-N, NO_2-N, P and Pb. Concentration of the water quality parameters was found to vary significantly between storms and the pollutant of concern was found to be NO_3-N, TSS, COD and Pb. Results were compared to the Interim National Water Quality Standards for Malaysia (INWQS),and the stormwater runoff from the study can be classified as polluted, exceeding class III water quality, especially in terms of TSS, COD, and NH_3-N with maximum EMCs of 158, 135, and 2.17 mg/L, respectively.

***Keywords*—**Residential land-use, urban runoff, water quality.

I. Introduction

In many countries, development is marked by rapid urbanization, which results in changes to surface hydrology of the catchment. The urbanization process alters the hydrology of the catchment, among them, decreasing infiltration rate, and runoff retention time. Consequently, runoff volume increases and the time during which runoff occurs decreases [1], [2]. Urban runoff is also widely recognized as a major contributor of non-point source pollutants (NPS), and a significant cause of degradation of urban water bodies [3]. Non-point source pollutants are pollutants whereby the source is not readily identified, and are transported is a diffuse manner, primarily during storms via surface runoff. Non-point source pollutants include street dirt, accumulation and wash off of atmospheric dust, fertilizers and pesticides from lawns, and direct discharges of pollutants into storm sewers [2], [4]. In many cities in the tropics, urban runoff is a major contributor to river pollution [4], [5].

The quality of urban runoff in terms of the amount and types of pollutants generated and transported will vary depending on land usage and the activities carried out on the land. Urban runoff quality and pollution loading has been shown to have a high variability among different land use such residential, industrial, agricultural, and land for recreational purposes. In a study conducted by Joshi and Balasubramanian, concentration of heavy metals in stormwater runoff was found to be several times higher at industrial sites compared to residential areas [6]. In a study conducted in Western Australia, it was found that runoff from an industrial catchment had five times the amount of suspended solids compared to the commercial catchment, and the residential catchment had very low ammonia and phosphate concentrations [7]. In comparing residential catchments to industrial catchments, Lee and Bang found that average loading rate of pollutants such as BOD_5, COD and SS were higher in residential catchments [3]. In a study of urban runoff from the City of Saskatoon, Canada, runoff from commercial land use was found to have significantly higher unit area pollutant load than residential catchments [8]. The characteristic of urban runoff quality is highly localized and has been shown to be typically governed by land use nature. As such, land use based models are widely used to estimate stormwater pollutant loads [9].

In Malaysia, urban runoff pollution has only started to gain attention in the last decade. In the 2000 Annual Report by the Department of Environment (DOE) of Malaysia, 52 river basins were found to be polluted with suspended solids due to urban development without appropriate management [10]. The deterioration of urban river quality necessitates the development of stormwater management to minimize, control, and remediate the impact of land-use changes on a watershed. To improve surface water quality, non-point source pollutants in urban runoff have to be mitigated through a combination of management practices and engineering methods. However, runoff management practices require monitoring and analysis of pollutants entering the system in order to design and implement preventive practices. In Malaysia, very limited data is available with regards to urban runoff and its associated pollutants.

Miri is one of the growing cities in Sarawak and characterized by rapid urbanization. Large tracts of land are converted to residential, commercial and industrial developments. The need for urban runoff control measure is critical as the waterways located near the city is heavily polluted, with Miri River which enters the South China Sea at the centre of Miri Town being one of the most polluted river in Sarawak. However, urban runoff quality studies are scarce in Miri, thus contribution of NPS pollution to surface water is still largely unknown. In this study, runoff from a residential catchment in Miri is monitored for several water quality parameters. The aim of the study is to obtain baseline data of the water quality discharged into the drainage network, which can be used to aid planning, evaluation and management of stormwater drainage and control measures.

II. Methods

A. Study Site

The study site is located in Desa Senadin estate, situated approximately 15km northeast from Miri City. The catchment

C. Ho is with Curtin University Sarawak Campus, Miri, Sarawak 98009 Malaysia (phone: 608-544-3832; fax: 608-544-3837; e-mail: carrie.ho@curtin.edu.my).

B. Q. Choo is with BBR Holdings Limited, 486126 Singapore (phone: 65-91424495; e-mail: kevincbq@gmail.com).

area under study is within the residential estate, covering an area of 9.8 ha, with a fairly flat terrain. The site consists of high density, single storey link houses. It is estimated that the catchment comprises 19% paved roads, 68% residential houses, and 13% grass and lawns. Imperviousness of the catchment area is about 77%.

Annual precipitation for Miri ranges between 2800 to 3200 mm and it 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. The climate is warm and humid throughout the year.

Catchment boundary for the study site was determined based on as-built drawings for the estate. The drainage network constructed in the study comprises of open rectangular concrete channels which serve as a conveyance system for both wastewater effluent and stormwater runoff. Wastewater treatment in the form of a septic tank is utilized for the residential households. Effluent from the septic tank discharges to the same drainage network. Greywater from the residential households and any washoff from the site also discharge directly into the open channel. Runoff from the study site discharges into an existing retention pond, north of the study site, which flows out to the Lutong River, and eventually enters the South China Sea.

The catchment area under study and the existing retention pond is shown in Fig. 1. There are two sampling locations or outlet locations for the study site as indicated in Fig. 2.

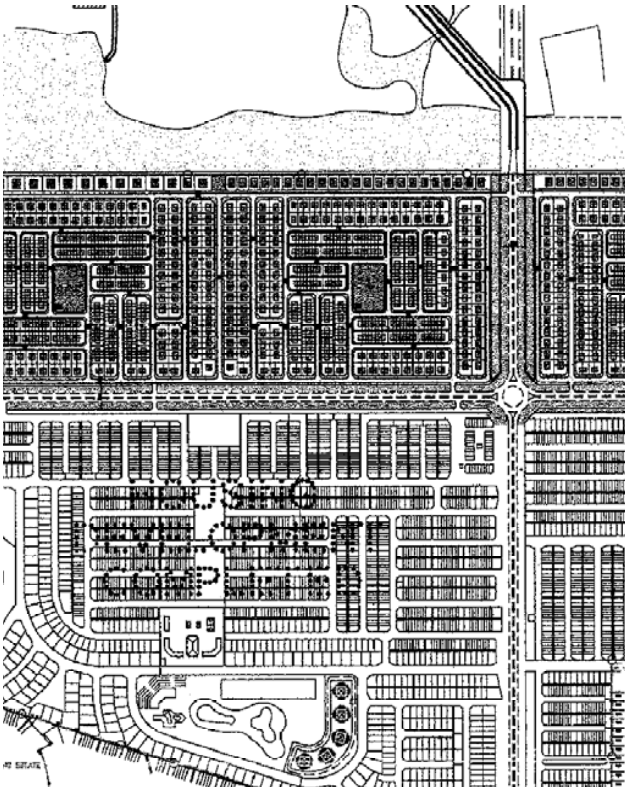

Fig. 1 Study catchment location within the Desa Senadin Estate

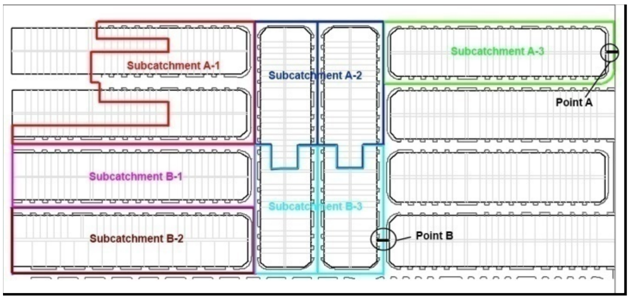

Fig. 2 Sampling/Outlet locations

B. Rainfall and Runoff

Rainfall was monitored continuously using a tipping bucket rain gauge (HACH). Water flow was determined by velocity-area method. A flow velocity meter was used to measure flow velocity at both outlet locations. 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

Water from the drainage network was grab-sampled manually. Two storm events runoff were sampled in August and September 2011, during a period of time whereby the study location was experiencing less rainfall events, and total rainfall recorded for the month were below monthly averages. For each event, 10 samples were collected, through the rising and falling limbs of the hydrograph. The characteristics of the rainfall events whereby the runoff were sampled are summarized in Table I. The two events investigated have distinct characteristics. Observed antecedent dry period for the first event was 7 days and the storm size was 16 mm, with an average rainfall intensity of 5.5 mm/hr. The second event sampled was much larger in size, with rainfall depth totaling 103 mm, and it also had a high rainfall intensity of 20.4 mm/hr. However, the length of antecedent dry period prior to the storm was only 3.5 days.

Samples for the two events were tested for total suspended solids (TSS), the 5-days biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), ammonia nitrogen (NH_3-N), nitrate nitrogen (NO_3-N), nitrite nitrogen (NO_2-N), phosphorus (P), and lead (Pb).

TABLE I
RAINFALL CHARACTERISTICS OF THE SAMPLED RUNOFF

Date	Rainfall (mm)	Intensity (mm/hr)	Duration since last storm (hr)
28-Aug-11	16	5.5	167
20-Sept-11	103	20.4	82

III. Results and Discussion

A. Characteristics of Runoff Water Quality

The concentration range of the instantaneous samples and the statistical characteristics of the pollutant concentration are shown in Table II. It can be noted that the pollutant concentration is widely variable, as indicated by the high standard deviation, in particular for TSS and COD. Concentration of NH_3-N for majority of the samples collected for the storm of 20 September exceeded class V (2.7 mg/L) of the Interim National Water Quality Standards for Malaysia (INWQS). High concentration of TSS, COD, and Pb were also observed, with maximum concentration of 413, 206, and 0.422 mg/L, recorded respectively. However, BOD_5, NO_3-N and NO_2-N, were present at low concentrations. This suggests that the pollutants of concern for the study area are NH_3-N, TSS, COD, and Pb.

TABLE II
Statistical Summary of Storm Runoff Quality

Pollutant	Range	Mean	Standard Deviation
TSS	30-413	204.2	141.3
BOD_5	6.7-10.3	8.4	1.1
COD	17-206	87.0	59.3
NH_3-N	0.45-3.83	2.40	1.10
NO_3-N	0.10-1.30	0.50	0.28
NO_2-N	0.006-0.128	0.020	0.026
P	0.88-9.67	2.65	2.23
Pb	0.007-0.422	0.200	0.163

B. Event Mean Concentration (EMC)

Concentrations of runoff pollutants often vary several times in magnitude during the 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 computed as the total storm pollutant load divided by the total runoff volume, expressed as [11]:

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

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

Table III presents the EMC values for the runoffs sampled. Pollutant concentrations vary for both storms, but in general, significantly higher concentration for the pollutants were observed for the storm on 28 August, except for BOD_5, NO_3-N, NO_2-N, and P, which did not vary significantly between the two storm events. This is likely due to the longer antecedent dry period of 7 days experienced prior to the storm on 28 August, compared to the storm on 20 September, which had a dry period of 3.5 days prior to the event. This indicates that the length of antecedent dry period is a major factor in determining the amount of accumulated pollutant since the preceding event. In this study, pollutants that were significantly influenced by the length of antecedent dry period include TSS, COD, NH_3-N, and Pb.

Based on the Interim National Water Quality Standards for Malaysia (INWQS), the stormwater runoff from the study can be classified as polluted, exceeding class III water quality, especially in terms of TSS, COD, and NH_3-N with maximum EMCs of 158, 135, and 2.17 mg/L, respectively.

C. Pollutant Loading

An estimate of the event based pollutant loading from storms can be obtained from the product of EMC and the runoff volume. Table IV presents the pollutant loading for the two events sampled in this study. The results showed that loadings are strongly dependent on the runoff volume. Even though the storm on 20 September had lower EMC values for all pollutants except for NO_3-N, it was a much larger storm, totaling 103mm, and therefore produced much higher loadings for all water quality parameters tested.

TABLE IV
Observed Event Based Pollutant Loadings

Constituents	Pollutant load (kg/ha)	
	28-Aug-11	20-Sept-11
TSS	10.98	29.41
BOD_5	0.69	1.86
COD	9.38	25.13
NH_3-N	0.15	0.40
NO_3-N	0.031	0.082
NO_2-N	0.002	0.006
P	0.10	0.27
Pb	0.025	0.067

IV. Conclusion

Information derived from this study is useful as a basis for improving ambient water quality in urban areas, and to determine contribution of NPS pollutants from residential catchments to surface water in Miri. As Miri city is undergoing rapid developments with majority of land conversion dedicated to residential estates, this study can be

TABLE III
EMCs of NPS Pollutants Investigated

Events	TSS (mg/L)	BOD_5 (mg/L)	COD (mg/L)	NH_3-N (mg/L)	NO_3-N (mg/L)	NO_2-N (mg/L)	P (mg/L)	Pb (mg/L)
28-Aug-11	158	10	135	2.17	0.44	0.03	1.43	0.36
20-Sept-11	115	7	44	0.89	0.45	0.01	1.27	0.02

used to estimate potential NPS pollutant loadings from the new residential developments. Results of the study showed that the major NPS pollutants were TSS, COD, NH_3-N, and Pb. Based on the Interim National Water Quality Standards for Malaysia (INWQS), the stormwater quality from the mixed land use catchment was polluted and exceeded class III water, with maximum EMCs of 158, 135, and 2.17 mg/L, respectively. In conclusion, study of runoff quality from developed areas 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 Sarawak.

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