Contributions of Dry and Wet Weather Runoffs to Annual Pollutant Loading in Tropical Urban Catchments

Ming Fai Chow and Zulkifli Yusop

Abstract This study compares the relative contributions of potential contaminants discharged in dry weather flow (DWF) and wet weather flow (WWF) from typical type of catchments in Malaysia. A total of 52 storm events were monitored for WWF quality evaluation. Hourly DWF samples were also collected manually during selected weekday (Wednesday) and weekend (Saturday and Sunday). All water samples were analyzed for TSS, COD, BOD, oil and grease (O&G), NO_2–N, NO_3–N, NH_3–N, soluble P, total P and Zinc. The results indicate that TSS, BOD, COD and O&G were mostly transported in WWF than in DWF. More than 70% of the total annual load of TSS and O&G were transported in storm water runoff. Conversely, annual loadings of NH_3–N and soluble P were mainly evacuated by DWF at the commercial and industrial catchments. Storm water runoff contributes greater loadings of N and P in the residential catchment. In general, each pollutant and land use would give different relative contributions to the annual pollutant loadings. In conclusion, this study have recognized the relative pollutant loading contributions by dry and wet weather flows in typical urban catchments in Malaysia. This findings will help the decision makers to develop better target specific pollutant treatment strategies to reduce the urban water pollution.

Keywords Dry weather runoff · Non-point source pollution · Storm water Urban area · Wet weather flow

M. F. Chow (✉)
Center for Sustainable Technology and Environment (CSTEN),
Universiti Tenaga Nasional, 63000 Kajang, Selangor, Malaysia
e-mail: Chowmf@uniten.edu.my

Z. Yusop
Water Research Alliance (Water RA), University of Technology
Malaysia (UTM), Johor Darul Ta'zim, 81310 Johor Bahru, Malaysia

1 Introduction

Rapid urbanization can cause the increased pollutant loading as well as runoff to receiving waters during both wet weather flows (WWF) and dry weather flows (DWF) [1–3]. Urban wet weather flow has long been recognized that contributes significant pollutants and causes the water-quality degradation in the receiving waters. For the past recent years, more concerns were focused on controlling WWF rather than DWF in the urban runoff management. However, the published literature shows that the discharge of dry weather pollutant may consider to have a major effect to the receiving water quality [4–8]. Volume of dry weather flow from storm drains is comprised mostly of nuisance flows (i.e., exfiltration from leaky sanitary sewers, illicit connections from sewerage, permitted discharges from industrial or municipal area [9–14].

Dry weather pollutants for example solids, metals and nutrients can be generated from natural sources and anthropogenic sources [15]. These pollutants may present in dry weather with low concentrations flow but there are certain dangerous pollution that could influence the marine life [16]. Furthermore, DWF can give a significant quantity of the annual elements load for instance, nutrients as well as metals during years through low rainfall volume [17]. McPherson et al. [8] has investigated the long term weather flow and pollutant loading at Ballona Creek watershed. The result showed that between 100 and 500 kg/year of trace metals load discharged annually during dry weather periods.

In order to mitigate adverse impacts from urban watersheds, an understanding of the relative pollutant contributions and characteristics from urban DWF and WWF is essential because management approaches may contrast for these two sources. The prediction of annual pollutant loads is required to formulate and fulfill the planning and management objectives. Evaluations of annual pollutant loads from a watershed to estimate future annual loads are also needed in order to determine the influence of watershed's urbanization process. Data on both concentration and discharge are required to calculate the annual loads and fluxes (e.g., [18]). The data of average annual pollutant concentration (dry and wet condition) can be found by direct measurement or from previous studies. However, there are no previous studies have been found on relative sources of dry weather loading in tropical urban catchments. Necessary data is required by researcher to determine the estimated loads and concentrations throughout dry weather condition and possible sources. Therefore, this study compares the relative contributions of potential contaminants discharged in dry weather flow (DWF) and wet weather flow (WWF) from typical type of urban catchments in Malaysia.

2 Methodology

2.1 Area of Study

This study was conducted in Skudai, Malaysia as shown in Fig. 1. Three typical types of land uses specifically residential, commercial, and industrial were selected within the Skudai river basin for wet and dry weather loading investigation. The annual rainfall in the Sg. Skudai river basin is approximately 2400 mm. Heavy rainfall is normally occurs between November and January [19] and dry and wet weathers could be determined accordingly. The details characteristics of each catchment were summarized in Table 1.

2.2 Water Quantity and Quality Measurements

Storm water runoff was measured and sampled at the main outlet of studied catchment. The flow depth in the storm drain was determined by using a stage gauge manually. A stage–discharge curve was established to convert the flow depth
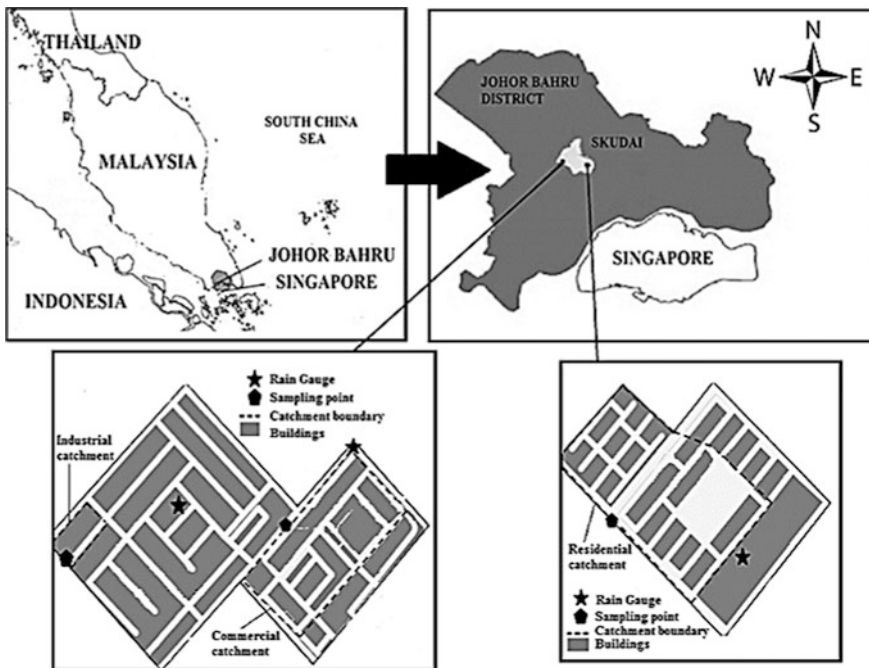

Fig. 1 Selected sampling location for this study

Table 1 Catchments characteristic in this study

Characteristics	Taman Impian Emas	Taman Universiti	Taman Perindustrian Universiti
Land use	Residential	Commercial	Industrial
Area	32.77	34.21	4.38
No. of shops/houses/factories	473	597	25
Impervious area (%)	85	95	93
Average daily traffics (cars/day)	7811	33286	3148

data to volumetric flow rate. After that, hydrograph was generated for individual storm runoff event. The area under the hydrograph was determined as the runoff volume that discharged during the storm event. Storm water samples were taken manually throughout the storm events. Although this method was considered more laborious than automatic water sampler, but it is suitable for small urban catchment that subjected to rapid increasing of water level in short period when the storm runoff has begun. Furthermore, grab sampling is able to reduce the risk of oil and grease from attaching to the container and the internal surfaces of the sampling tube in the automatic sampler. The total number of samples collected for each storm event differs from 8 up to 15 based on the storm size. The sampling protocol was followed the procedure outlined by Caltrans [20]. The intervals for each sampling were set between 10 and 20 min during the falling limb of the hydrograph. Meanwhile, 1–10 min was determined as the sampling interval during the rising limb of hydrograph. More acute sampling on the rising limb of the hydrograph is required in order to evaluate the first flush effect. Approximately 1 L of runoff volume was collected for each sample. In addition, hourly dry weather samples were collected manually for 24 hours during one day of weekdays (Wednesday) and the weekend (Saturday and Sunday). From each site, a total of 72 samples were collected in order to determine the standard dry weather concentration of selected water-quality parameters. Flow rate for every sample was measured in order to calculate the dry weather's pollutant loading. Rain samples were taken manually at an open arena in order to determine the quality of rainwater at study area. Three rainwater samples were taken from each storm event and analyzed for the average pollutant concentration. The standard method for the examination of water and wastewater [21] have been used as guidelines to conduct the stormwater quality analysis for every sample. The analytical number used are as follow: BOD (5210B), COD (5220B), TSS (2540D), oil and grease (O&G) (5520B), NO_2–N (4500-NO2 B), NO_3–N (4500-NO3 B), NH_3–N (4500-NH_3 F), total P (4500-P B), soluble P (4500-P E), and Zinc (3120 B).

2.3 Analysis of Data

Event Mean Concentration (EMC) has been used to determine the average pollutant concentration, which is defined as the total constituent mass M discharged during an event divided by the total runoff volume, V during the event [22], expressed as

$$\text{EMC} = \bar{C} = \frac{M}{V} = \frac{\int Q(t)C(t)\mathrm{d}t}{\int Q(t)\mathrm{d}t}, \tag{1}$$

where M is total mass of pollutant during the entire runoff (kg); V is total volume of runoff (m^3); $C(t)$ is time varying pollutant concentration (mg/L); $Q(t)$ is time variable flow (L/s); and t is total duration of runoff (s).

Generally, Site Mean Concentration (SMC) is required to estimate the annual discharge of urban wet weather's pollutant loading. The SMC value is calculated based on the average of EMC values for each catchment. In this study, annual pollutant loadings were calculated by using the method defined by Schueler [23] as

$$L = P \cdot P_j \cdot R_v \cdot C, \tag{2}$$

where, L is the normalized annual pollutant load (kg/ha/year), P is the annual precipitation (mm/year), P_j is the dimensionless correction factor that adjusts for storms without runoff, R_v is the dimensionless average runoff coefficient, C is the flow-weighted average concentration (mg/L).

The annual rainfall depth, P was determined from rainfall records collected at the study catchments. A mean annual rainfall of 2523 mm was recorded at the studied catchments and this value was used for the annual precipitation (P). A rainfall correction factor (P_j) of 0.9 was used as recommended by Schueler [23]. This value is supported by rainfall-runoff analysis for all catchments whereby runoff makes up about 90% of the annual rainfall. The runoff coefficient, R_v, was calculated using the equation as below

$$R_v = 0.05 + 0.009(\text{I}), \tag{3}$$

where R_v is runoff coefficient; and I is the imperviousness catchment percentage. The baseflow annual loading of pollutant from each catchment was calculated as follows [6]

$$W = n \times \sum_{j=1}^{n} C_m \times Q_j, \tag{4}$$

where, W is the total load during the sampling period, n, C_m (mg/L) is the median concentration, and Q (m^3/s) is the dry weather flow on day j.

3 Results and Discussion

The descriptive statistics of dry weather's pollutant concentration (mg/L) in all catchments is summarized in Table 2. The average concentrations of pollutants are highest for the commercial catchment except for O&G which is the lowest among the three catchments. The industrial catchment is two folds lower than commercial catchment for NH_3–N concentration and the lowest in the residential catchment. Chow and Yusop [24] implied that car-washing station is the potential source of NH_3–N at the commercial catchment. The high standard deviation suggests that the pollutants concentration fluctuates significantly (Table 2). The mean concentrations of various constituents in rainwater and dry weather discharge are shown in Table 3 together with the EMCs at three types of urban catchments. The rainwater quality (first row) suggests that most of the constituents have very low concentrations. As a result, the pollutant contents in the wet weather discharge would not be influenced by rainwater quality except for NO_3–N. It showed that rainfall sample is a key source of NO_3–N at the urban catchment. The EMC of wet weather flow for all studied catchments are generally lower than mean pollutant concentration of dry weather flow, except for O&G and TSS from commercial and industrial catchments. Chow et al. [25] suggested that O&G and TSS were deposited temporarily in the drain and will be transported during the next large storm event. Similar observation found by Francey et al. [26] that TSS concentration in dry weather flow is lower than storm flow while nitrogen concentration is generally lower in storm flow. It is suggested that dry weather flow and small storm event should be treated instead of bypassing.

The dry weather flow concentrations at the residential catchment are relatively lower than those reported by Nazahiyah [27] and Mamun [28] for BOD, COD, TSS, O&G, and NH_3–N (Table 4). The separate underground stormwater drainage system used in this residential catchment could possibly prevent illegal or direct disposal of wastewater into the storm drain and thus reduces the pollutant concentration in the dry weather discharge. Again, the mean concentrations of major pollutants at the commercial catchment are generally lower than results reported by [27] except for NO_3–N and NH_3–N. Comparison was also made with the Effluent Standards A and B recommended by Department of Environment Malaysia [30]. The BOD and COD concentrations in all catchments exceeded the Standard A limits. The dry weather flow qualities at the commercial and industrial catchments are categorized as Class V according to the Interim National Water Quality Standard (INWQS). BOD concentrations are five times above the class V standard whereas the COD concentrations were higher by three orders of magnitude for the commercial and industrial catchments. In addition, NH_3–N concentration from the commercial catchment is approximately two folds greater than the Class V limit. The residential catchment shows relatively lower concentration of TSS when compared to the EQA Standard A. TSS concentration in the commercial catchment, however, exceeds this limit. These results indicate that dry weather flows are significant sources of non-point source pollution in the urban areas. As such,

Table 2 Descriptive statistics of pollutant concentrations (mg/L) for dry weather flows from respective catchments

Catchment		Flow rates (m³/s)	Dry weather flow concentration (mg/L)								
			BOD	COD	TSS	O&G	NO$_3$-N	NO$_2$-N	NH$_3$-N	Soluble P	Total P
Residential	Min	0.0004	3.5	6	1	0.2	0.10	0.001	0.01	0.02	0.09
	Max	0.0040	73.0	146	54	12.4	6.20	0.083	1.72	1.34	3.10
	Mean	0.0020	21.2	55	15	3.1	1.35	0.010	0.19	0.31	0.62
	Median	0.0024	15.5	47	12	2.9	1.05	0.004	0.10	0.27	0.44
	Std. dev	0.0010	15.6	34	11	2.3	1.10	0.016	0.30	0.23	0.53
Commercial	Min	0.0035	11.8	91	9	0.2	0.10	0.001	0.62	0.07	0.24
	Max	0.0091	80.0	608	209	8.0	18.60	0.092	24.80	2.36	4.45
	Mean	0.0053	68.1	342	59	2.7	3.10	0.019	5.22	0.87	1.82
	Median	0.0050	72.5	340	51	2.3	1.20	0.011	3.23	0.71	1.68
	Std. dev	0.0011	16.1	117	40	1.7	4.05	0.020	4.96	0.56	0.84
Industrial	Min	0.0001	2.3	2	6	0.2	0.10	0.001	0.01	0.01	0.57
	Max	0.0075	80.0	1281	457	16.0	22.40	0.090	21.30	2.40	6.19
	Mean	0.0010	62.6	294	49	3.8	2.86	0.013	2.96	0.64	1.55
	Median	0.0005	70.8	172	31	3.0	1.35	0.007	2.37	0.46	1.26
	Std. dev.	0.0014	19.5	303	63	3.0	4.38	0.015	3.36	0.55	1.05

Table 3 Average EMC values of pollutants in rainwater, wet weather and dry weather flows at the study sites

	Concentration (mg/L)									
	BOD	COD	TSS	O&G	NO$_3$–N	NO$_2$–N	NH$_3$–N	Soluble P	Total P	Zinc
Rainwater	3.1	5.0	2.0	ND	0.9	0.004	0.37	0.03	0.08	–
Residential catchment										
Wet weather	6.5	36	21	2.32	0.90	0.011	0.19	0.07	0.38	0.04
Wet weather (median)	6.5	39	26	2.28	0.94	0.008	0.17	0.07	0.41	0.05
Dry weather	21.2	55	15	3.14	1.35	0.010	0.19	0.31	0.62	–
Commercial catchment										
Wet weather	81.1	225	167	3.66	0.93	0.006	0.71	0.11	0.69	0.08
Wet weather (median)	58.1	196	124	3.89	0.80	0.006	0.70	0.08	0.73	0.05
Dry weather	68.1	342	59	2.72	3.10	0.018	5.22	0.87	1.82	–
Industrial catchment										
Wet weather	42.6	117	91	4.47	1.20	0.009	0.58	0.08	0.59	0.24
Wet weather (median)	44.8	97	91	4.52	1.14	0.009	0.46	0.08	0.62	0.29
Dry weather	62.6	294	49	3.78	2.86	0.013	2.96	0.65	1.55	–

Note – not available

pretreatment are important for controlling the pollution from dry weather discharge into the receiving waters.
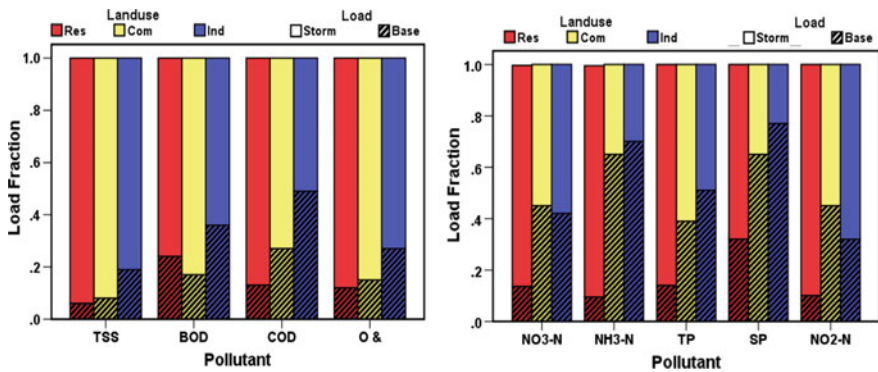
3.1   Annual Pollutant Loading

Figure 2 shows the proportions of annual pollutant loads carried by wet weather and dry weather flows from residential, commercial, and industrial catchments. As noted before, annual pollutant loading of Zn is not discussed here because its dry weather flow concentration was not measured in the study. In overall, a large portion of the annual loading of various pollutants was transported in wet weather flow than in dry weather flow especially for TSS, BOD, COD, and O&G. More

Table 4 Comparison of dry weather flow quality with other studies

Land use/ standard	References	Dry weather flow concentration (mg/L)						
		BOD	COD	TSS	O&G	NO_3–N	NO_2–N	NH_3–N
Residential	Mamun [28]	49.3	120	38	13.0	–	–	4.85
Residential	Nazahiyah [29]	77	470	72	–	0.8	0.02	1.4
Commercial	Nazahiyah [29]	140	710	169	–	0.4	0.07	1.1
Residential	Current study	21.2	55	15	3.1	1.35	0.010	0.19
Commercial	Current study	68.1	342	59	2.7	3.10	0.019	5.22
Industrial	Current study	62.6	294	49	3.8	2.86	0.013	2.96
EQA standard A	DOE [30]	20	50	50	–	–	–	NA
EQA standard B	DOE [30]	50	100	100	10	–	–	NA
INWQS class V	DOE [30]	>12	>100	300	NA	–	–	>2.70

– no data, *NA* not available

Fig. 2 Proportion of annual pollutant loadings carried by storm runoff and baseflow for different catchments

than 70% of the total annual loading of TSS and O&G were transported in storm water runoff. Since the average number of rain days in this area is high (175 days per year), the bulk of annual pollutant loading must have been discharged by more frequent and short duration storms. Conversely, annual loadings of NH_3–N and SP are mainly evacuated by dry weather flow at all studied catchments except for residential catchment. It showed that daily activities in commercial and industrial catchments have generated large amount of NH_3–N and SP. Problems of dry weather discharge from urban land use should be addressed more seriously in order to control the pollution into the receiving waters. Malik [31] showed similar observation that dry weather flow in storm channels are significant sources of ortho-P and NH_3–N. On the other hand, storm water runoff transported greater

loadings of N and P in the residential catchment. This may be associated with fertilizer application on gardens and lawns. Malik [31] also concluded that wet weather flow at residential catchment was the major contributor of nutrients into the receiving waters. Interestingly, the commercial and industrial catchments showed almost equal proportions of annual NO_3–N loading in wet and dry weather flows.

4   Conclusions

This study compares the relative contributions of potential contaminants discharged by dry weather flow (DWF) and wet weather flow (WWF) from typical type of catchments in Malaysia. The results indicate that TSS, BOD, COD, and O&G are mainly transported in stormflow than in dry weather flow. More than 70% of the total annual load of TSS and O&G were transported in storm water runoff. Conversely, annual loadings of NH_3–N and SP are mainly evacuated by dry weather flow at the commercial and industrial catchments. Storm water runoff contributes greater loadings of N and P in the residential catchment. In general, the relative contribution to the annual pollutant loading varied significantly among types of land use and each pollutant. Better target specific pollutant treatment strategies are suggested to be developed in order to reduce the urban water pollution in Malaysia.

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