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Water Quality from a Mixed Land-Use Catchment in Miri, Sarawak

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***Abstract*—**Urbanization has been found to impact stormwater runoff quantity and quality. A study catchment with mixed land use, residential and industrial were investigated and the water quality discharged from the catchment were sampled and tested for four basic water quality parameters; BOD_5, NH_3-N, NO_3-N and P. One dry weather flow and several stormwater runoff were sampled. Results were compared to the USEPA stormwater quality benchmark values and the Interim National Water Quality Standards for Malaysia (INWQS). The concentration of the parameters was found to vary significantly between storms and the pollutant of concern was found to be NO_3-N.

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

I. Introduction

In urban areas, due to concentrated human activities, land use changes and developments affect stormwater runoff quantity and quality. The urbanization process causes changes in the physical characteristics of the catchment such as an increase in the imperviousness of the area and it also alters natural vegetation and drainage patterns. Consequently, runoff volume increases and the time during which runoff occurs decreases [7], [16]. Urban stormwater runoff has also been identified as a prime contributor to surface water pollution [18]. Precipitation falling upon a catchment accumulates pollutants from the air, roadway, ground surfaces, and storm drains, including suspended desiments, heavy metals, hydrocarbons, nutrients, and pathogens, which contributes to water contamination and river pollution [1], [4], [15]. In many cities in the tropics, urban stormwater runoff is a major contributor to river pollution [16], [19].

Urban pollutants can be classified as point source (PS) and non-point source pollutants (NPS). Point source pollutants can be readily identified, such as effluent from a wastewater treatment plant or industrial sites. Non-point source pollutants are generated on and discharged from land surfaces as a result of rainfall and transported via surface runoff. Non-point source pollutants are transported in a diffuse manner and the source is not readily identified. Non-point source pollutants include fertilizers and pesticides from lawns and gardens, animal and bird feces, oil drippings and street dirt, and direct discharges into the drainage system [17]. The pollutants deposited in a catchment are subject to wash off and transported from the source areas primarily during storms [16], [19].Depending on the type of land use and the activities carried out on the land, the volume of runoff and the amount and types of pollutants carried with it will vary. In addition, the intensity and duration of rainfall and the time since the last storm event will also affect the quantity and transport of pollutants generated [21]. Joshi and Balasubramanian reported total concentration of heavy metals in runoff generated from an industrial site to be seven times higher than the total concentration from a residential area [12]. Runoff from impervious pavements and street surfaces were found to contain high level of contaminants such as motor oil, grease, trace metals, and halogenated phenol [2], [5], [11]. In Wuhan City Zoo in China, a study conducted by Zhao et al. revealed that nitrogen and phosphorus constituted an average of 61% and 78% respectively of the pollutant loads from the surface runoff [20].

Trace metals such as Lead, Cadmium, Copper and Zinc have been identified as the most common metals that contaminate urban runoff and are typically taken as representative examples of pollutants of concern in urban waterways [3]. Chromium has been found to be the dominant trace metal in residential runoff in a study conducted by Joshi and Balasubramanian [12]. On the other hand, zinc was identified as the leading contaminant at a residential district situated in central Paris, mainly due to roof sheet erosion [10]. Studies of urban runoff have shown that the characteristic of urban runoff quality is highly localized and depends on the catchment properties and typically governed by the particular land use nature [9].

In Malaysia, developing stormwater management to minimize, control, and remediate the impact of land-use changes on a watershed is still in its infancy. In the Urban Stormwater Management Manual for Malaysia, guidelines are presented on runoff quantity and quality control through various Best Management Practices (BMPs) [6]. However, the implementation of the BMPs is sporadic as there are no regulatory requirements for control of stormwater discharge quality for developments. BMPs are usually required to mitigate non-point source pollutants, and they include management practices and engineering methods to control pollutants in stormwater runoff [12].

In Sarawak, to prevent developed sites from excess runoff, comprehensive design of infrastructures such as roof gutters, swales, drains, and channels collect, convey and discharge surface runoff to rivers, lakes, and other water bodies as quickly as possible. This drainage system designed based on conventional method of conveyance not only increases the magnitude of discharge, and reduces the travel time to the nearest water body, it also does not aid in pollutant removal. Best Management Practices that aims to control urban runoff and improve water quality from runoff are rarely practiced in Sarawak and such measures are typically funded and implemented by government agencies such as the Department of Irrigation and Drainage (DID) Malaysia/Sarawak. In

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addition, 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. In this study, runoff from a catchment with a mix of residential and industrial land use 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 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 area under study is just north of the residential estate, covering an area of 41 ha, with a fairly flat terrain, and with a mix of residential and industrial land use. The site comprises of low density, single storey residential housing and a low density industrial site. The industrial site is not completely developed even though the existing development has been established for more than five years. There are several parcels of land that are still not developed and left as open space with grass. Runoff from the study site discharges to an existing retention pond, which flows out to the Lutong River, and eventually enters the South China Sea.

The drainage network constructed in the study area serves as a drainage for both wastewater effluent and stormwater runoff for the residential and industrial site. Stormwater runoff with accumulated pollutants is conveyed to the retention pond through open rectangular concrete channels. Sewage treatment in the form of septic tanks is utilized for both residential households and the industrial site. Effluent from the septic tank discharges to the same drainage network. Greywater from the residential households and any washoff from the industrial site also discharge directly into the open drains.

The catchment boundary was determined based on as-built drawings of the study site. Approximately 60% of the mixed land use catchment is impervious, with 40% covered by pervious surfaces such as open space and lawns. The catchment area under study and the existing retention pond is shown in Fig. 1. The main drain is a rectangular concrete channel with a longitudinal slope of 0.5%.

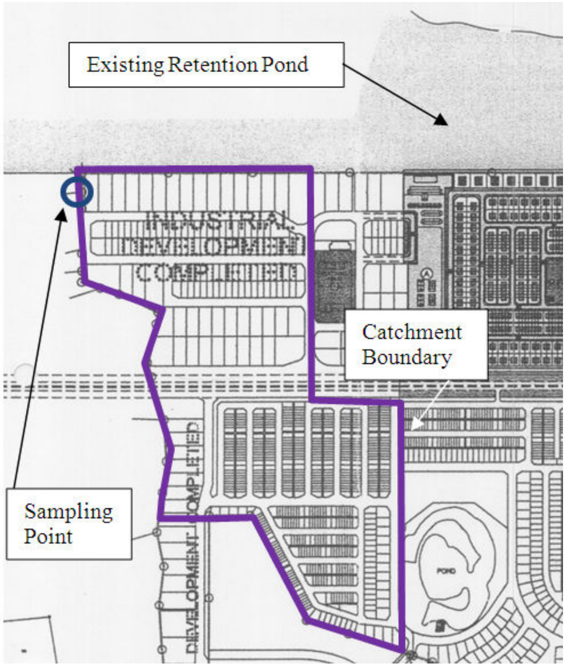

Fig. 1 Study catchment and sampling point

B. Sampling Runoff Quality

Water from the drainage network was grab-sampled manually. Samples were collected for a dry weather flow and also after several storm events of different depths. Runoff from one storm event was sampled at a time interval of 10 minutes up to an hour. Table I describes the sampling events. Samples were tested for phosphorus (P), ammonia nitrogen (NH_3-N), nitrate nitrogen (NO_3-N), and the 5-days biochemical oxygen demand (BOD_5).

TABLE I
Description of Sampling Events

Date	Rainfall	Description
01-Sep-10	-	Sample collected for dry weather flow, with 9 days of dry period preceding sampling day.
09-Sep-10	67 mm	Sample collected after storm event, 3-15 mm rainfall recorded in the days preceding sampling day
15-Sep-10	4 mm	Sample collected after storm event, with 5 days of dry period preceding sampling day
08-Oct-10	9 mm	Six samples collected at an interval of 10 minutes after the start of the storm. 2 days of 40 mm rainfall preceded the sampling day

III. Results and Discussion

The results for the sample collected for the dry weather flow and the samples collected after the storm events is shown in Table II. Sample 1 was the dry weather flow which was collected during a long dry spell, with 9 dry days preceding the sampling day. Thus the sample recorded the highest concentration of BOD_5 at 31 mg/L, P at 6.70 mg/L, and NH_3-

N at 2.50 mg/L compared to the other samples. Sample 2 was collected after a heavy storm, with the days preceding the sampling recording storms of depths varying from 3-15 mm. This significantly diluted the concentration of P and NH_3-N in the runoff to 0.30 mg/L and 0.55 mg/L respectively. The concentration of P and NH_3-N in sample 3 showed a slightly higher concentration than sample 2. This is likely due to the 5 days of dry period preceding the sampling day, which allowed the buildup of the pollutants that were subsequently washed off in the 4 mm storm event. The samples showed BOD_5 values were not influenced by the storm size. Even though sample 2 was collected after a large storm event compared to sample 3, it recorded a significantly higher value compared to sample 3. As for NO_3-N, storm size did not seem to affect the concentration values. Six samples were collected at a 10 minutes interval for a 9 mm storm event. The samples were tested for phosphorus (P), ammonia nitrogen (NH_3-N), and the 5-days biochemical oxygen demand (BOD_5). Fig. 2 and Fig. 3 show the pollutographs resulting from the storm event for P and NH_3-N, respectively. The pollutographs exhibit the gradual decrease in the concentration of the pollutants as the storm progresses. The characteristic rapid increase in the pattern of the pollutographs is not evident here, most likely due to the fact that the catchment's response to rainfall peaked in a very short time (less than 10 minutes, in this case). The flashy characteristic of a small urban catchment, with a short time to peak has been observed by others [14], [16], [19]. From Fig. 4, a clear gradual decrease in the pollutograph pattern for BOD_5 was not evident, but the samples showed a general decreasing BOD_5 concentration as the storm progresses. The concentrations of $P \leq 0.5$ mg/L, $NH_3\text{-N} < 2$ mg/L, and $BOD_5 \leq 12$ mg/L in the samples collected for this storm event were significantly lower compared to the dry weather flow. This can be attributed to the fact that the catchment experienced rainfall with depths of 40 mm in both days preceding the sampling day. This would have resulted in significant wash off of the pollutants prior to the sampling day.

TABLE II
CONCENTRATION OF WATER QUALITY PARAMETERS

Sample	Date	BOD_5 (mg/L)	P (mg/L)	NH_3-N (mg/L)	NO_3-N (mg/L)
1	01-Sep-10	31	6.70	2.50	4.0
2	09-Sep-10	27	0.30	0.55	6.0
3	15-Sep-10	10	0.63	1.90	6.0

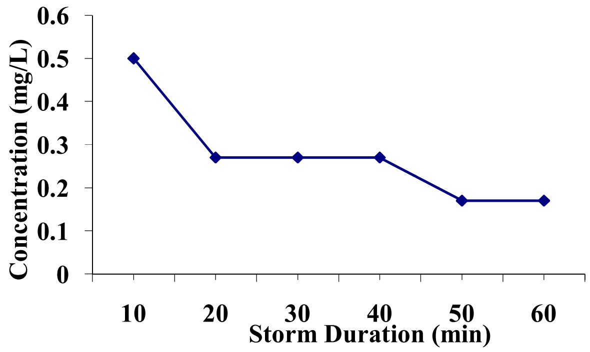

Fig. 2 Pollutograph for Phosphorus (P)

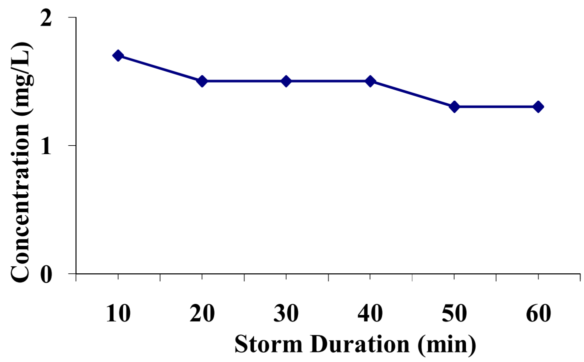

Fig. 3 Pollutograph for Ammonia Nitrogen (NH_3-N)

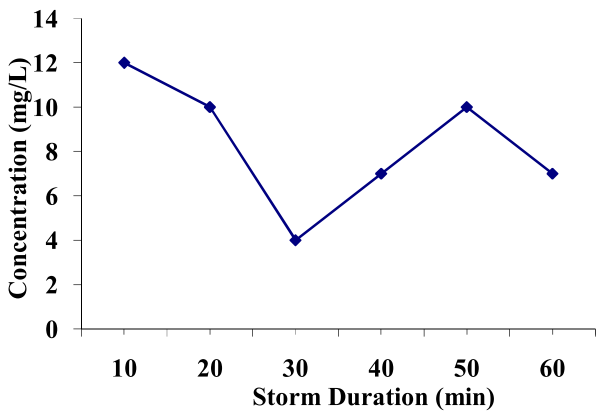

Fig. 4 Pollutograph for BOD_5

Based on the Interim National Water Quality Standards for Malaysia (INWQS), the stormwater runoff from the study site can be classified as polluted, especially in terms of BOD and NH3-N. The stormwater quality falls within class IV water, whereby the water is polluted and can be used for irrigation only. However, the dry weather flow would be considered class V water, whereby the water is extremely polluted and cannot be used for any purpose.Benchmark limits that serve as 'levels of concern' for stormwater sampling, devised by the U.S. Environmental Protection Agency (USEPA) is presented in Table III for the water quality parameters tested in this study. The benchmarks are intended to provide comparison values for sampling whereby pollutant concentration exceeding the benchmark value could potentially impair or contribute to impairment of water quality as well as affect public health [8]. As there are no specific regulations for urban runoff quality discharged to surface waters in Malaysia currently, the USEPA surface water discharge criteria are used as a benchmark for comparison with the results obtained from sampling in this study.

Comparing results obtained from the water samples in this study, it can be seen that the concentration of NO_3-N in the samples were consistently much higher than the USEPA benchmark value. The P concentration exceeded the benchmark value for the dry weather flow, but the concentrations were much lower than the benchmark value for stormwater runoff sampled from various rainfall depths. This indicates that phosphorus in the drainage flow was most likely contributed by effluent discharged from households and the industrial site rather than from overland flow. Greywater discharged untreated from the households and industrial site typically contain detergents and washing liquids that contributes to the high phosphorus concentration in the discharged water. Both BOD_5 and NH_3-N concentrations were within the benchmark values. From this study, NO_3-N was found to be the critical pollutant of concern for the study catchment.

TABLE III
STORMWATER SAMPLING PARAMETER BENCHMARK VALUES

Parameter Name	Benchmark Level
Biochemical Oxygen Demand (5-days)	30 mg/L
Nitrate + Nitrite Nitrogen	0.68 mg/L
Total Phosphorus	2.0 mg/L
Ammonia	19 mg/L

Results from the study indicates that as the drainage network constructed in Miri serve both as a conveyance system for wastewater discharge from households/industrial sites and also for stormwater runoff, lower water quality discharges into the retention pond during dry periods compared to the runoff from storm events. However, as samples were collected following heavy storms, the impact of dilution could have been a major factor in the relatively low concentrations of P, NH_3-N, and BOD_5. A more intensive stormwater monitoring program would have to be carried out for various storm sizes in order to gain a better understanding of the pollutant loading from the study catchment.

IV. CONCLUSION

Information derived from this study is useful as a basis for improving ambient water quality in urban areas. The study catchment presents a complex stormwater management problem, as the conveyance system is an open channel and subject to direct discharges from the development area. Based on the Interim National Water Quality Standards for Malaysia (INWQS), the stormwater quality from the mixed land use catchment was polluted and fall in class IV water. However, a long term monitoring program would have to be implemented to investigate the influence of dry weather periods and rainfall intensity on the water quality of the stormwater runoff. 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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