Influence of Rainfall Characteristics on First Flush Behaviour

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Abstract. Urban stormwater with impervious surface often produces runoff with a variety of contaminants. This paper discusses an investigation into the influence of rainfall characteristics toward the first flush behaviour. This study involved field investigations, sampling of urban stormwater runoff, laboratory testing and data analysis. 15 stormwater samples were collected and executed manually in a small catchment, which represents the higher institution area in Skudai, Johor. Data collections were carried out on 9 November 2017. Correlation of pollutants such as total suspended solids (TSS), total dissolved solids (TDS), biological oxygen demand (BOD), chemical oxygen demand (COD) and zinc with runoff were derived within the evaluation of hyetograph, hydrographs and pollutographs. The concentration varied at different stages of the same rainfall event. The higher strength of first flush was seen in case of TSS, BOD and zinc compared to TDS and COD. The finding shows that high rainfall intensity in the beginning of the event had contributed to the high wash off of some pollutants such as TSS, BOD and zinc. The concept of the first flush cannot be used alone to establish a reliable methodology to design treatment facilities. Additional knowledge and information are necessary.

1. Introduction

Non-point source (NPS) pollution is the main contributor to urban water quality deterioration, and most NPS pollutants enter urban water systems by rainfall-runoff [1]. Urban stormwater runoff mobilizes a variety of contaminants to waterbody, affecting the water quality [2]. These contaminants originate from different land uses such as residential, commercial, and industrial. The concentrations and types of contaminants increased due to the increasing of a development and changes of land use activities. Yoon et al. [3] illustrated that urban NPS pollution is significantly influenced by many factors, among which are rainfall characteristics (rainfall intensity, rainfall duration, and rainfall depth), land use, number and distribution of dry days, and street cleaning methods. The wash-off of surface pollutants depends on rainfall intensity, the dilution of pollutants depends on rainfall depth, and the timing of the pollutant wash-off process and of pollutant transport depends on rainfall distribution [4].

The occurrence of a first flush effect has been observed for suspended solids, nutrients, and trace metals in urban, transportation, and agricultural drainages [5-7]. Several physical mechanisms control

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the stormwater quality in critical source areas including pollutant buildup and wash-off [8, 9]. Studies of rainfall timing, including antecedent dry period, can lead to the build-up of pollutants until they reach a maximum accumulation rate [10]. Rainfall intensity and duration are considered to be important hydrological factors in particle wash-off based on the outcomes of Sartor and Boyd (1972) [11].

Previous studies have successfully investigated the effect of rainfall characteristics on first flush behavior, Taebi and Droste (2004) [12] was observed that only long duration rainfall with largest runoff volume will result in a first flush event. In addition, antecedent dry period (ADP) was found as one of the most important rainfall parameters influencing the first flush concentration of suspended solids [13-15]. Similarly to study conducted in a residential area in Johor, Malaysia found that the first flush magnitude increased with the increasing length of the dry period [16]. However, Li et al. (2007) [13] observed that there was no correlation between rainfall-runoff characteristics and first flush indicator except for maximum rainfall intensity. Therefore, this study was design to investigate the role of rainfall characteristics on the first flush phenomenon.

2. Study Area

The study area is located at School of Civil Engineering, Universiti Teknologi Malaysia, Johor Malaysia. Stormwater runoff samples were collected at one of the M50 buildings of university campus; Faculty of Civil Engineering, Universiti Teknologi Malaysia. The location of the study area was selected as it is accessible and the researcher can be at the location immediately after the rainfall has started as it is in walking distance from the researcher accommodation. Figure 1 illustrates the size of study area. The study area is 0.6 ha with 1150 m long drain. Figure 2 shows the location of car park in the catchment area. The slope ranges from 1.2% to 9%. The catchment drainage system separates stormwater system from the sewer system. Data collections were carried out on 9 November 2017.

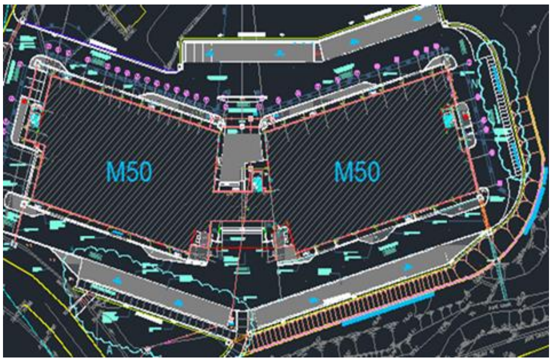

Figure 1. The catchment areas

Figure 2. Location of car park in the catchment area

3. Flow measurement and stormwater sampling

15 of stormwater samples were collected to assess the water quality on both rising and falling limbs of the hydrograph. All the samples were collected manually using 1 L polyethylene bottles. The discharges of stormwater runoff were calculated as the product of the flow velocities and the drain cross section area for various water levels. The channel water level-discharge rating curve was developed at the end of the conduit to convert the water level into discharge. Flow rate was measured using velocity and water depth recorded. For each sample taken, the level of stormwater runoff in the drain and sampling time were recorded; the bottles were labelled with date, sample number and time. The stormwater runoff samples were collected from the beginning to the end of the storm event.

After sampling work, the samples were transferred to the Environmental Laboratory at Universiti Teknologi Malaysia for laboratory analysis. Analysis methods were performed based on Standard Methods for the Examination of Water and Wastewater [17]. The pollutants analysed in laboratory analyses were TSS, TDS, COD, BOD and zinc. The hydrologic (rainfall and runoff) data and water quality data were collected during rainfall event. The rainfall depth varied from 0.25 mm to 16 mm and ADD is 24 hrs. Rainfall duration measured is 92 min, and intensity calculated ranged from 1.5 to 96 mm/h. Figure 3 shows how the runoff velocity is measured.

Figure 3. Measurement of runoff velocity

4. Rainfall measurement

Tipping bucket rain gauge (ISCO) with volume resolution 0.01 inch/tip rainfall was used continuously to measure rainfall intensity, the unit was then converted to mm/hr. The rain gauge was installed on a levelled platform on a roof at M50 building to keep sufficient exposure and avoid obstruction from the tree canopy. The gauge is connected to the central data acquisition system (data logger).

5. Results and discussion

Figure 4 summarizes runoff hydrograph, hyetograph and pollutograph of TSS, TDS, COD, BOD and Zinc pollutants for rainfall event. From the observation of pollutographs, concentration of pollutant vary even in the same rainfall events and watersheds. The initial concentrations of the event are compared to the later concentrations in order to evaluate first flush occurrence [18, 19]. Similar concentration patterns were obtained for TSS, BOD and zinc with relatively high and quickly decreasing concentrations in the initial phase of runoff. This observation signifies the wash away by the initial part of runoff toward the pollutant buildup during dry days.

The length of dry days in between the two rainfall events could play a significant role. It is observed that ADP for the event was 24 hours. The pollutants get accumulated during dry days and are washed away during the runoff event. Therefore, longer durations of dry days provide a greater chance for pollutants get accumulated.

Furthermore, the finding shows high rainfall intensity in the beginning of the event had contributed to the high wash off of some pollutants such as TSS, BOD and zinc. The highest peak concentration was found in TSS pollutant, which is 430 mg/L, while the lowest peak concentration was found in zinc pollutant, which is 0.2 mg/L. Furthermore, the characteristics of the wash off process with regard to five pollutants showed some differences, even at the same rainfall intensity condition. This means that the variability of the pollutants’ wash-off characteristics were significantly influenced by the behavior of the pollutants transport [20]. As such, particles of different densities and sizes would behave differently during build up and wash off process [22, 22].

In addition, peak concentration of all pollutants occurred and increasing within the first 0 to 18 minutes and decreasing after 23 minutes. It can be concluded that the result of this study is in agreement with Lee et al., (2011) [23], which stated that typical first flush effect normally occurred within 20 minutes after runoff started. Qin et al. (2016) [24] also stated that the first flush phenomenon occurs when the peak concentration of the pollutants preceded the discharge peak. For this study, peak concentration of TSS, BOD and zinc pollutants occurred before the peak discharge, indicating that

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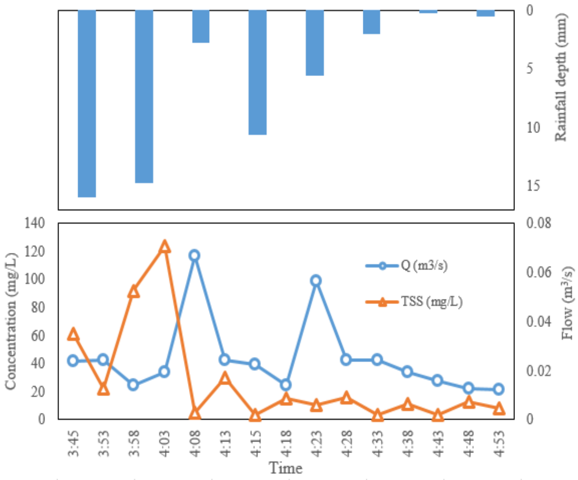
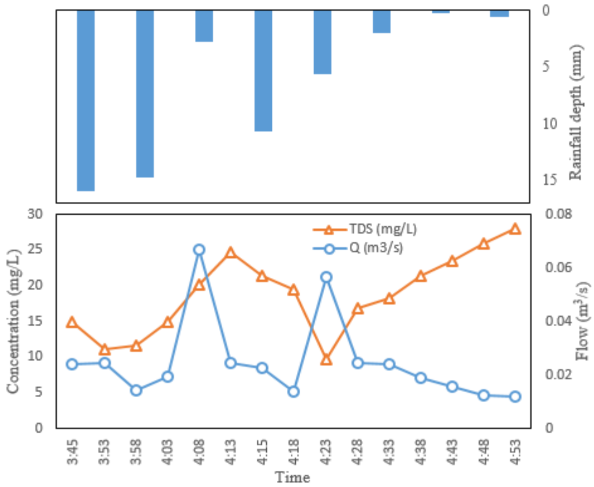
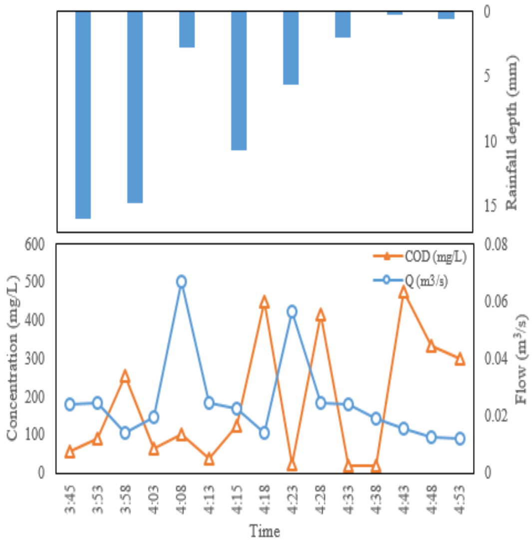
first flush effect was apparent for those pollutants [25]. It was caused by the early runoff, flushing the accumulated pollutants from the streets and sewers before the major runoff flow arrived at the outfall.



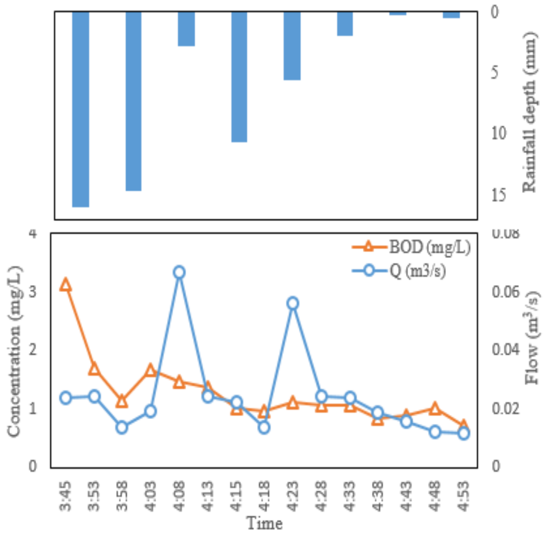
(a) Total Suspended Solid



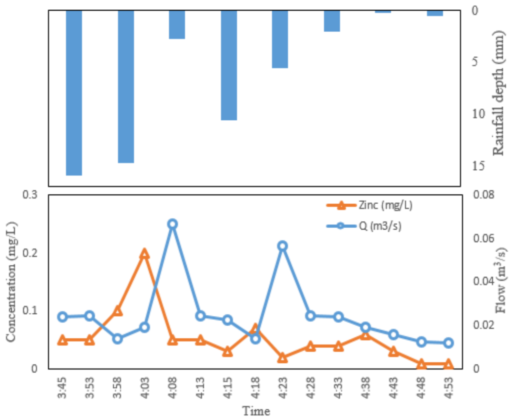
(b) Total Disolved Solid



(c) Chemical Oxygen Demand



(d) Biological Oxygen Demand



(e) Zinc

Figure 4. Hyetograph, hydrograph and pollutograph for the event.

6. Summary and conclusion

Each figure should have a brief caption describing it and, if necessary, a key to interpret the various lines. The study was carried out to identify the occurrence of first flush based on concentration of the pollutant and its relationship with rainfall characteristics. Rainfall characteristics were found as the important factors influencing the first flush of pollutants. The concentration varied at different stages of the same rainfall event. The higher strength of first flush was seen in case of TSS, BOD and zinc compared to TDS and COD.

It can be concluded that pollutants are removed from surfaces by the washing action of rainfall and runoff. All waterbodies contain those pollutants due to natural processes, but anthropogenic activity results in elevated concentration of pollutants. Thus, monitoring of pollutants concentration is a very good predictor of water quality. Bilotta and Brazier (2008) [26] found that elevated concentrations of pollutants is also due to an alteration of the physical, chemical and biological properties of a waterbody. Numerous factors might influence the relationship between rainfall characteristics toward first flush behavior. Therefore, further analysis on this phenomenon should be discussed in detail.

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