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Short communication

Influence of rainfall characteristics on pollutant wash-off for road catchments in urban Shanghai

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ABSTRACT

The influence of different rainfall characteristics on pollutant wash-off was investigated in stormwater runoff from three road surfaces in a highly urbanized area of Shanghai, China. The relationships between rainfall characteristics and pollutant wash-off were analyzed using sectional analysis, an innovative concept of using sector parameters to investigate the relationship between the pollutant wash-off process and different sectors of the runoff hydrograph and rainfall hyetograph. Results indicated that the rainfall intensity of the initial phase of a rainfall event was critical to the magnitude of the first flush. Rainfall duration and the antecedent dry period also influenced pollutant load washed-off during intermediate and final phases of a rainfall event. No influence of rainfall depth on first flush was observed. Several rainfall characteristics played important roles in pollutant wash-off processes. These findings are critical for designing and implementing low impact development practices.

1. Introduction

Urban stormwater quality evaluation has become a fundamental step in the evaluation of receiving water bodies (Collins et al., 2010). The water quality characteristics of runoff from different catchment types have been widely investigated and evaluated worldwide (e.g., Deletic and Maksimovic, 1998; Dierberg and DeBusk, 2008). Such evaluations and their associated discussions have used the event-based water quality parameters and event-based rainfall characteristics, such as event mean concentration for pollutants, rainfall depth and rainfall intensity as rainfall characteristics. However, the event-based parameters appear to be insufficient to describe, and may even overshadow the relationships between pollutant wash-off and rainfall characteristics, as described in Liu et al. (2012).

First flush is an important phenomenon in urban stormwater management, and has been proposed for nearly three decades (Geiger, 1987). As several deficiencies and problems existed in traditional assessment methods, a new method that redefined stormwater first flush phenomenon was proposed by Bach et al. (2010). One of the highlights of this method is that the wash-off process is divided into several slices, and each slice is analyzed separately. This is a novel idea, useful to pollutant wash-off analysis. Sectional analysis of the pollutant wash-off based on the runoff hydrograph was first introduced by Alias et al., (2014a,b). This analysis method was similar to that proposed by Bach et al. (2010), but incorporated a dimensionless philosophy that was highly innovative. Given the specific characteristics of the experimental site and the randomness of the rainfall events in previous work, it is unclear whether such results can be generalized to other catchments with different rainfall conditions.

In this study, sectional analysis of the pollutant wash-off was employed for three road catchments located in a highly urbanized area of Shanghai, China. The study objectives were: (1) to evaluate variation in the sectional analysis of pollutant wash-off based on the runoff hydrograph for different road catchments with different rainfall conditions; and (2) to determine the factors influencing the pollutant wash-off process for these road catchments.

2. Materials and methods

2.1. Experimental sites

Three road catchments located in a highly urbanized area of Shanghai were selected for study. Each catchment area was 210 m^2, but slope varied from 0.015 to 0.020. The impervious fractions for these catchments were close to 100%. The volumetric runoff coefficients calculated for rainfall events had a mean value of 0.89. The three road catchments: Catchment A, B and C, were located close to each other, and had a rain gauge installed to monitor rainfall. We selected small-scale catchments to study pollutant wash-off processes, without the influence of pollutant

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transportation and sewer sediment wash-off in the sewer system. In small-scale catchments, the first flush is generally regarded as more significant than for large scale catchments (Deletic and Maksimovic, 1998; Lee and Bang, 2000).

2.2. Field sampling and testing

Runoff from three road catchments was sampled manually from April to September 2012, according to protocols outlined in Burton and Pitt (2002). A total of 27 rainfall events were monitored over this period. The characteristics of each rainfall event are provided in Appendix A (Supplementary data). The return period of rainfall events varied from 0.1 to 3 year. We regard these data as representative of average rainfall conditions for the region. Runoff samples were tested for total suspended solids (TSS), chemical oxygen demand (COD), total nitrogen (TN), and total phosphorus (TP) using standard methods (APHA, 2012). The detailed sampling and water quality analysis procedures also are provided in Supplementary data.

2.3. Sectional analysis method

Sectional analysis was used to investigate the relationship between the pollutant wash-off and different sectors of the runoff hydrograph and rainfall hyetograph, as outlined in Alias et al., (2014a,b). Sections for the wash-off parameter are determined using the increments of pollutant load percentage washed-off for a given percentage of runoff volume. More detailed information is available in Appendix A (Supplementary data). Sectional parameters for rainfall characteristics are represented by the rainfall characteristics during a certain increment of effective rainfall. For example, AvgI1020 represents the average rainfall intensity for 10% to 20% of the effective rainfall depth.

3. Results and discussion

3.1. Sectional variation of pollutant wash-off

Preliminary analyses were carried out for TSS, COD, TN and TP to characterize the pollutant wash-off process. Variations in these parameters for 27 rainfall events are shown in a box-and-whisker plot in Fig. 1; the box defines the ±25% limits of the particle population, the horizontal line demarks the median, while the whiskers represent maximum and minimum values, unless there are outliers.

As shown in Fig. 1, the load washed-off by the initial 10% of the runoff hydrograph was higher than for all other sections. The mean values for parameters TSS, COD, TN and TP for this interval (P0010) were 28%, 25%, 21% and 22% respectively. This signifies the occurrence of a first flush for TSS, COD, TN and TP. These mean values for P0010 for parameters TSS, TN and TP were slightly higher than those obtained in a study in Australia by Alias et al. (2014b). This may be the influence of scale on our experimental data, as it is commonly known that small-scale catchments lead to a significant first flush (Deletic and Maksimovic, 1998; Lee and Bang, 2000). Fig. 1 also shows that with increasing increments in runoff, pollutant loads gradually decreased for TSS, COD, TN and TP.

A marked difference in pollutant load for different hydrograph sections was confirmed in this study. This suggests that a sectional analysis of pollutant wash-off is needed to understand the influence of rainfall characteristics on pollutant wash-off processes.

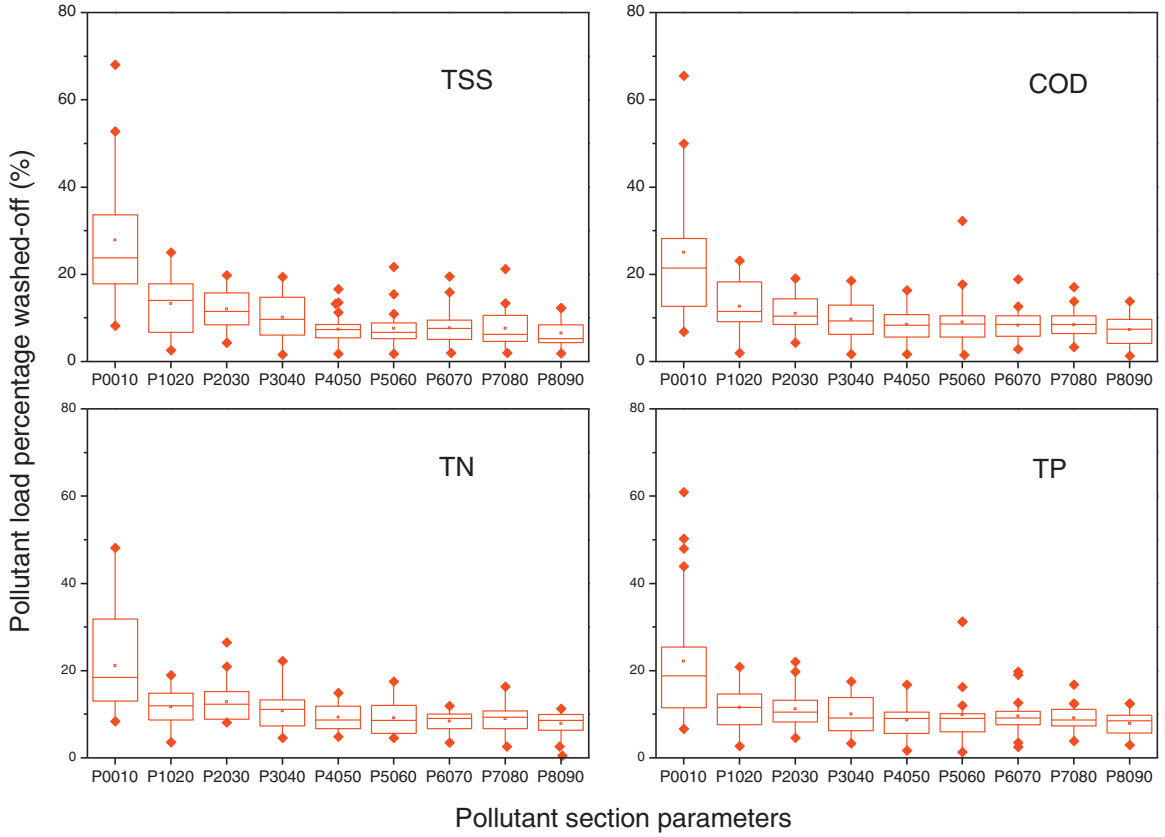

Fig. 1. Pollutant load with respect to percentage washed-off. *P* represents the pollutant load for each percentage sector shown on the *x*-axis; TSS: total suspended solids; COD: chemical oxygen demand; TN: total nitrogen; TP: total phosphorus.