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Characterizing polycyclic aromatic hydrocarbon build-up processes on urban road surfaces☆

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ABSTRACT

Reliable prediction models are essential for modeling pollutant build-up processes on urban road surfaces. Based on successive samplings of road deposited sediments (RDS), this study presents empirical models for mathematical replication of the polycyclic aromatic hydrocarbon (PAH) build-up processes on urban road surfaces. The contaminant build-up behavior was modeled using saturation functions, which are commonly applied in US EPA's Stormwater Management Model (SWMM). Accurate fitting results were achieved in three typical urban land use types, and the applicability of the models was confirmed based on their acceptable relative prediction errors. The fitting results showed high variability in PAH saturation value and build-up rate among different land use types. Results of multivariate data and temporal-based analyses suggested that the quantity and property of RDS significantly influenced PAH build-up. Furthermore, pollution sources, traffic parameters, road surface conditions, and sweeping frequency could synthetically impact the RDS build-up and RDS property change processes. Thus, changes in these parameters could be the main reason for variations in PAH build-up in different urban land use types.

1. Introduction

Polycyclic aromatic hydrocarbon (PAH) are a group of chemical compounds that contain more than two aromatic rings (Dong and Lee, 2009). These compounds are widespread in the environment, and some species are regarded as persistent organic pollutant candidates because of their recalcitrance and carcinogenic potentials (Boström et al., 2002). The main sources of PAH are usually categorized into pyrogenic and petrogenic sources; the former indicates products of the incomplete combustion of fossil fuels (including vehicle exhaust and burning of biomass), and the latter source refers to products of crude oil (including kerosene, gasoline, diesel fuel, lubricating oil, and asphalt) (Tobiszewski and Namieśnik, 2012; Callén et al., 2013). Sixteen types of PAH have been identified by the United States Environmental Protection Agency as priority pollutants; thus, PAH pollution within urban areas has attracted increased research attention. Previous research reported that stormwater runoff could contribute between 14% and 36% of the PAH load to urban aquatic environments (Menzie et al., 2002; DiBlasi et al., 2009), and that PAH concentrations in urban road runoff could rise up to 20 times higher during peak flow than at base flow (Crunkilton and DeVita, 1997). These reports highlight the significant PAH pollution of urban stormwater runoff.

Road deposited sediment (RDS) are generated from a mixture of soil erosion, atmospheric deposition, and traffic-related activities. They could be easily washed off by the stormwater runoff and transported to the receiving water body. Previous research revealed that multiple contaminants such as nutrients, heavy metals, and petroleum hydrocarbons could be absorbed in the RDS and could accumulate on the receiving water body, leading to persistent pollution and threatening the health of ecosystem (Herngren et al., 2006; Rosenkrantz et al., 2008; Bartlett et al., 2012).

To develop effective mitigation strategies for pollutants associated with RDS, an in-depth understanding of their build-up processes is essential. Previous research revealed that pollutants associated with RDS accumulate relatively quickly following a rainfall event, and slow down after several days as a result of

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redistribution induced by anthropogenic activities and natural factors (Shaheen, 1975; Vaze and Chiew, 2002). Numerous studies tried to describe this process using mathematical models (Wicke et al., 2012; Egodawatta et al., 2013). Good fitting results for a few types of pollutants, such as heavy metals, have already been achieved. However, build-up processes of PAH, which has been identified as a specific pollutant of urban road runoff owing to its high content associated with RDS (Wang et al., 2011; Saeedi et al., 2012; Jiang et al., 2014), have received little attention. Moreover, the variation of pollutant species and land use characteristics could seriously influence the pollutant build-up processes (Liu et al., 2012). Thus, specific mathematical models derived from experimental data were essential for characterizing PAH build-up processes on urban road surfaces.

Accordingly, RDS sampled from different land use types with diverse traffic and anthropogenic activities was measured for the PAH pollution level. The research outcomes are expected to establish reliable mathematical models to replicate PAH build-up processes on urban road surfaces, to explain the reason for the variation of PAH build-up processes in different land use types, and to enhance urban road stormwater management strategies that commonly target PAH removal for stormwater quality improvement.

2. Materials and methods

2.1. Site selection

The study area was selected from Shenzhen City, which experienced rapid economic development in the past three decades and has become one of the most developed cities in China. Anthropogenic influence was regarded as the primary criteria in study site selection. Thus, three road sites located in different land use types were selected for the PAH build-up investigations (Fig. 1). Site I was a major road located in a light industrial area with the majority of manufacturing industries. Site II was a minor road located in a commercial area with many open-air snack booths. Site III was a minor road located near a typical residential community with a multi-story block of flats and public green-belt.

2.2. Sample collection

Four successive sampling campaigns were conducted after real rainfall events at all study sites. Each campaign lasted up to 10 days and began on November 29, 2013, October 4, 2014, November 9, 2014, and December 5, 2014. The antecedent daily precipitation data were 6.6, 13.7, 9.0, and 8.8 mm. Sampling campaigns were conducted at a certain time (14:00 to 17:00) every day to determine the consistent initial conditions. RDS samples were collected using a dry and wet vacuuming system (Herngren et al., 2006). A domestic vacuum cleaner (Delonghi WF1500E) with a water filtration system was utilized to enhance the efficiency of retaining fine particulates during sample collection. The road surface was wetted using an electric sprayer after careful dry vacuuming without creating runoff, and wet vacuuming was then conducted.

Zhang and Krebs (2013) reported that an appreciable amount of pollutants could persist on the road surface even after heavy rainfall; moreover, repeated vacuuming at the same plot could remove the pollutants and provide additional space for accumulation of new pollutants, leading to inconsistent build-up in the plot. In this context, the build-up samples were collected at different plots daily. RDS samples were collected from four different plots at each study site (Fig. S1) and mixed into one sample to minimize the influence of spatial heterogeneity. The sampling area of each successive sampling would not exceed 150 m^2; hence, the influence of wind, rainfall, traffic, street sweeping, and surrounding land use was treated as the same in such a small area. Accordingly, a total of 120 RDS samples (10 mixed samples $\times$ 4 times successive sampling $\times$ 3 land use types) were collected.

Traffic characteristics and road surface conditions were regarded as primary influencing factors for pollutant build-up on road surface; hence, road surface texture depth (RTD) and traffic volume (TV) were measured at each sampling site. RTD was determined according to Mahbub's research (2011a). In addition, TV was collected by manual counting. Table S1 shows the relative data as well as the frequency and the method of street sweeping employed at each study site.

2.3. Sample testing

The total volume of each sample was measured first after the samples were transported to the laboratory. Each sample was

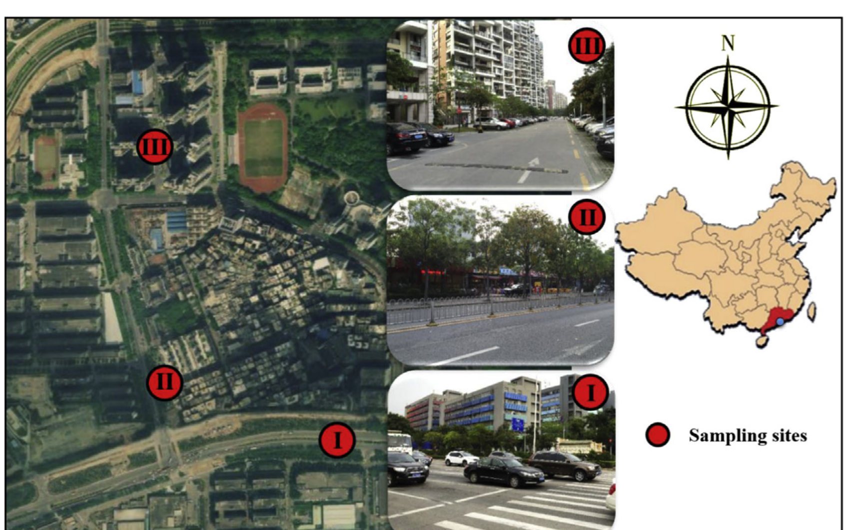

Fig. 1. Location of sample sites and their characteristics.