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Is the wash-off process of road-deposited sediment source limited or transport limited?

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HIGHLIGHTS

- Road-deposited sediment wash-off was explored by field and simulated experiments.
- Wash-off of finer and coarser particles tends to be source and transport limited.
- Smaller and larger rain events tend to be source and transport limited.
- The wash-off process is generally source and transport limited.

GRAPHICAL ABSTRACT

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ABSTRACT

An in-depth understanding of the road-deposited sediments (RDS) wash-off process is essential to estimation of urban surface runoff pollution load and to designing methods to minimize the adverse impacts on the receiving waters. There are two debatable RDS wash-off views: source limited and transport limited. The RDS build-up and wash-off process was characterized to explore what determines the wash-off process to be source limited or transport limited based on twelve RDS sampling activities on an urban road in Beijing. The results showed that two natural rain events (2.0 mm and 23.2 mm) reduced the total RDS mass by 30%–40%, and that finer particles (<105 μm) contributed 60%–80% of the wash-off load. Both single- and multi-rain events caused the RDS particle grain size to become coarser, while dry days made the RDS particle grain size finer. These findings indicated that the bulk RDS particles wash-off tends to be transport limited, but that finer particles tend to be source limited. To further explore and confirm the results of the field experiment, a total of 40 simulated rain events were designed to observe the RDS wash-off with different particle size fractions. The finer particles have a higher wash-off percentage (F_w) than the coarser particles, and the F_w values provide a good view to characterize the wash-off process. The key conclusions drawn from the combined field and simulated experiments data are: (i) Finer and coarser particle wash-off processes tend to be source limited and transport limited, respectively. (ii) The source and transport limited processes occur during the initial period (the first flush) and later periods, respectively. (iii)

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The smaller and larger rain events tend to be transport limited and source limited, respectively. Overall, the wash-off process is generally a combination of source and transport limited processes.

1. Introduction

Road-deposited sediments (RDS) are ubiquitous and important carriers of diffuse urban pollutants (Sansalone et al., 1998; Sartor and Boyd, 1972; Sutherland, 2003). With the rapid urbanization and industrialization that has occurred in China and other developing countries, urban diffuse pollution caused by RDS wash-off has been recognized a major problem in urban areas (Li et al., 2013; Lu et al., 2009; Zhao et al., 2011). Therefore, it is important to have a clear understanding of the process of urban diffuse pollution resulting from RDS so that it can be effectively controlled.

The generation of urban diffuse pollution (stormwater pollution) is usually divided into a two-stage process, RDS build-up over dry days and RDS wash-off during rainfall events (Goonetilleke et al., 2009; Vaze and Chiew, 2002). The build-up process is very important for characterizing pollutant accumulation on urban impervious surfaces (Miguntanna et al., 2013). However, only limited actual direct measurements of RDS build-up are available, and it has instead been inferred from the measurements of RDS wash-off (Pitt et al., 2004; Shaw et al., 2006; Vaze and Chiew, 2002). In recent years, a few studies have revealed that RDS build-up is influenced by antecedent dry periods, rainfall events and street sweeping (Deletic and Orr, 2005; Egodawatta et al., 2013; Shen et al., 2016; Tian et al., 2009).

It is well known that the wash-off process is influenced by many factors, including rainfall characteristics, surface characteristics, particle grain size of RDS, land use, urban–rural gradients, etc. (Brodie and Rosewell, 2007; Mahbub et al., 2010; Vaze and Chiew, 2003; Zhao et al., 2011). However, there is still no consensus on whether wash-off is source limited or transport limited. The decisive factors influencing whether wash-off is source or transport limited are RDS load and wash-off capacity, respectively. Some studies support the view that wash-off is transport limited and common storms only remove a small proportion of the total RDS, after which build-up occurs relatively quickly to return the surface pollutant load back to the level before the storm (Vaze and Chiew, 2002; Zhao et al., 2010). On the other hand, most event water quality models adopt the view of source limited, assuming that most RDS is washed off during storm events and RDS then builds-up from zero over the antecedent dry days (Sheng et al., 2008; SWMM, 2010). These contradictory views highlight the fact that the complexity of wash-off processes is far greater than what process replication equations in current stormwater quality models actually consider, although RDS wash-off is the most important processes in stormwater quality modeling. Thus, further investigations are warranted.

In this study, field and simulated experiments were conducted to explore (i) the roles of particle size and rainfall characteristics in the RDS wash-off process and (ii) to identify factors determining whether the RDS wash-off process is source limited or transport limited.

2. Materials and methods

2.1. Study site description

The study site was located on an urban road surface in the Haindian District of Beijing, China (Fig. 1), which is located in the northwest portion of the city. This street had two lanes for traffic (one lane in each direction), and the average traffic flow for each lane was about 3550 cars/day according to our field investigation. Both sides of the street

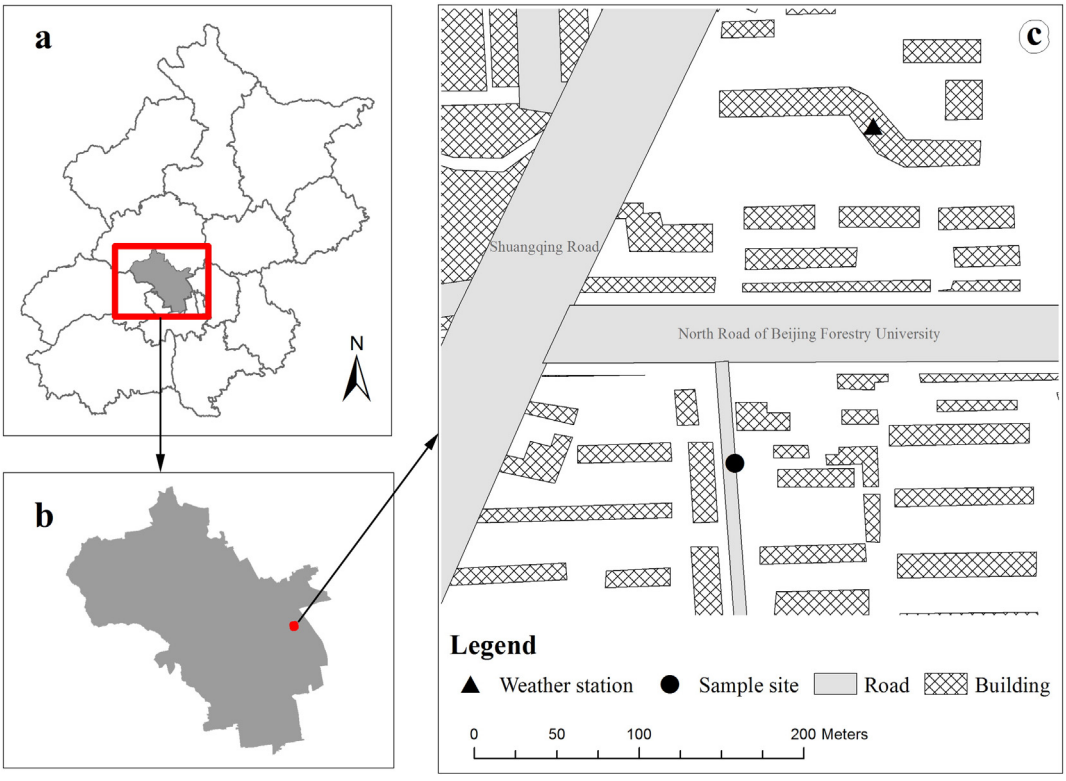

Fig. 1. Study area and sampling site locations in Haidian District, Beijing, China. **a** indicates the administrative region of Beijing, **b** indicates the administrative region of Haidian District, and **c** is the study area and locations of sampling sites and weather stations.