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Short communication

Sources and transport pathways of common heavy metals to urban road surfaces

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ABSTRACT

Heavy metals that are built-up on urban impervious surfaces such as roads are transported to urban water resources through stormwater runoff. Therefore, it is essential to understand the predominant pathways of heavy metals to the build-up on roads in order to develop suitable pollution mitigation strategies to protect the receiving water environment. The study presented in this paper investigated the sources and transport pathways of manganese, lead, copper, zinc and chromium, which are heavy metals commonly present in urban road build-up. It was found that manganese and lead are contributed to road build-up primarily by direct deposition due to the re-suspension of roadside soil by wind turbulence, while traffic is the predominant source of copper, zinc and chromium to the atmosphere and road build-up. Atmospheric deposition is also the major transport pathway for copper and zinc, and for chromium, direct deposition by traffic sources is the predominant pathway.

1. Introduction

Heavy metals, deposited on the urban impervious surfaces such as roads, are washed off to water sources during a rain event, causing adverse impacts on the receiving aquatic ecosystem (Gill et al., 2014; Ladislas et al., 2014; Wicke et al., 2012). Therefore, it is important to control heavy metal pollution of urban water sources (Borne et al., 2013), for which the knowledge of heavy metal transport pathways from the source of origin to the impervious surfaces is essential.

Heavy metals are primarily deposited on urban roads by vehicular traffic via two major pathways: (1) direct deposition; and (2) indirectly, where heavy metals are first emitted to the atmosphere and eventually deposited (Gunawardena et al., 2012). Heavy metals deposited on roads can be re-entrained to the atmosphere due to vehicular, natural and anthropogenic activities induced dust movements. This highlights the complexity of the interaction between pollutants in the atmosphere and road build-up.

Several studies have investigated heavy metal emissions to the urban atmosphere and build-up on urban impervious surfaces. For example, Gunawardena et al. (2012) found that traffic related emissions is the major source of zinc (Zn), copper (Cu) and chromium (Cr) to the urban atmosphere, while soil related sources are responsible for the accumulation of lead (Pb) and manganese (Mn). Similarly, Egodawatta et al. (2013) concluded that Mn and Pb are contributed to urban road build-up via geogenic sources, whereas traffic activities are the primary contributors of Zn and Cu.

However, very limited knowledge is available regarding the linkage between heavy metal accumulation in the atmosphere and build-up on urban roads and, specifically the transport pathways from the atmosphere to road build-up. Furthermore, the influence of traffic activities on heavy metal transport pathways has not been investigated in detail.

This paper presents the outcomes of a research study which investigated: (1) the sources and transport pathways of common heavy metals from the urban atmosphere to road build-up; and (2) the influence of key traffic variables on heavy metal transport pathways. The study outcomes will contribute to overcoming current knowledge gaps constraining the development of effective strategies to mitigate urban water pollution.

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2. Materials and methods

2.1. Sample collection and testing

Eleven road sites encompassing different traffic and land use characteristics were selected from the Gold Coast, Queensland, Australia, for the study (Fig. 1). Air sampling was conducted over a period of 8 h covering morning and evening traffic peaks, using the high volume polyurethane foam (PUF) sampler designed by USEPA as per Method TO-13A (USEPA, 1999). Road build-up samples were collected from 2.0 m × 1.5 m plot areas in the middle of a traffic lane using a wet and dry vacuuming system. A detailed discussion on air and build-up sampling protocols adopted can be found in Gunawardena et al. (2012) and Herngren et al. (2006), respectively.

The study investigated Cr, Cu, Pb, Zn and Mn, which are common heavy metals present in the urban environment. The laboratory analyses were undertaken according to Method 200.8 for inductively coupled plasma-mass spectroscopy (USEPA, 1994) with TraceSELECT (Product no. 54704) as the certified reference material.

2.2. Data analysis

As traffic volume, congestion and vehicle mix have been found to exert influence on heavy metal build-up (EPASGV, 1999), annual average daily traffic volume (ADT_to), volume to capacity ratio (V/C) and total heavy traffic volume (ADT_hv) were used as surrogates, respectively. Volume to capacity ratio (V/C) is the ratio between the actual volume of traffic and the theoretical traffic capacity of a road. Hence, a V/C ratio above 1.0 suggests that the road capacity is exceeded and the road is congested.

Data analysis was conducted using factor analysis and multi-criteria decision making methods, Preference Ranking Organization Method for enrichment Evaluation (PROMETHEE) and Geometric Analysis for Interactive Aid (GAIA). Factor analysis was performed using StatistiXL software (v. 1.8, 2008, StatistiXL, Broadway-Nedlands, Australia). The factors were extracted from the raw data matrix consisting of metal build-up loads and atmospheric metal concentration (Table 1), using principal component extraction method based on the initial eigenvalue criteria ≥1. The factor rotation was performed using the orthogonal VARIMAX rotation technique to simplify the interpretation of a

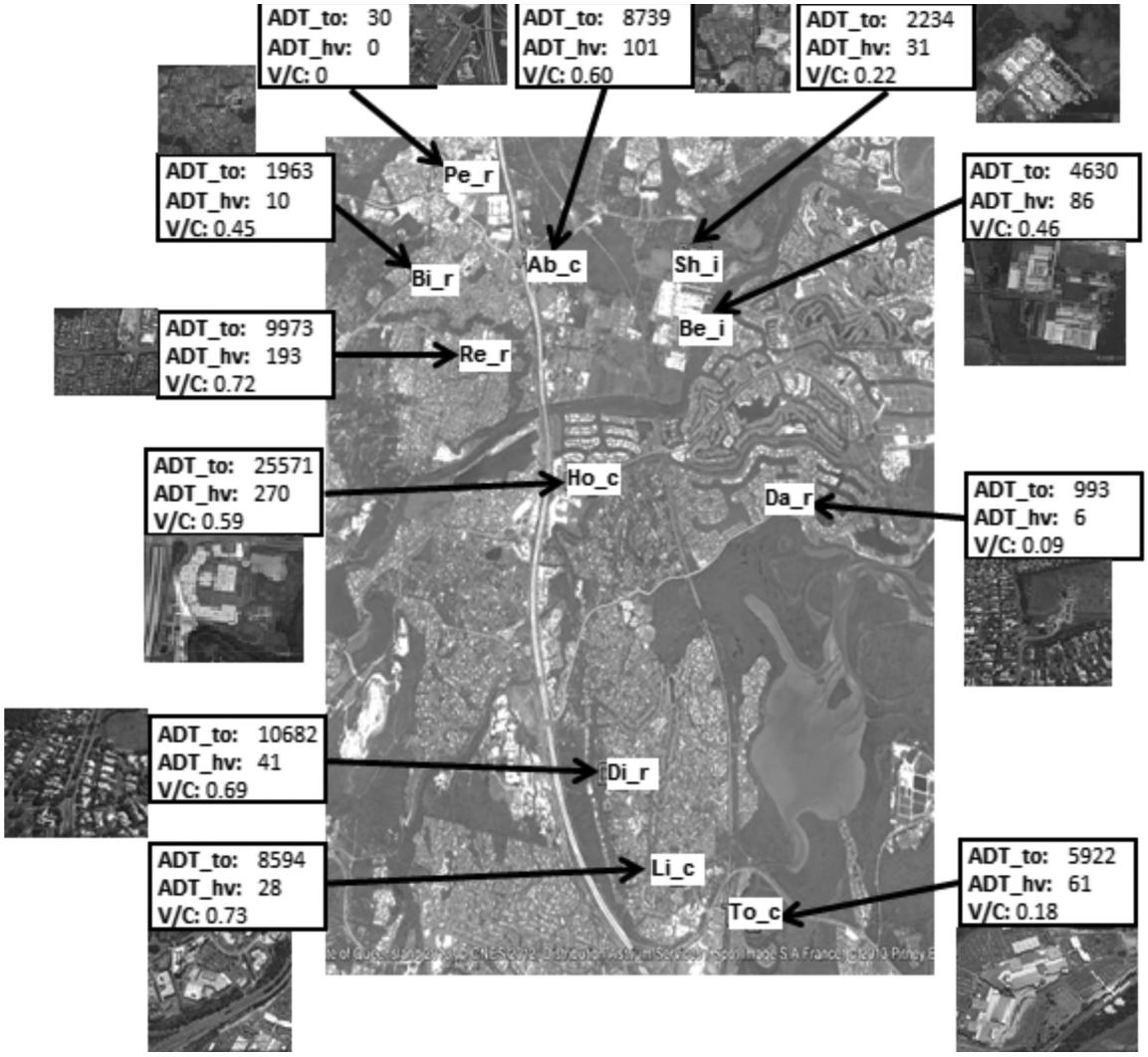

Fig. 1. Study sites (legend: ADT_to – annual average daily traffic volume; V/C – volume to capacity ratio; ADT_hv – total heavy traffic volume; r – residential site; c – commercial site; i – industrial site).
(Adapted from Gunawardena et al., 2014b)