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Metal and metalloid accumulation in cultivated urban soils: A medium-term study of trends in Toronto, Canada

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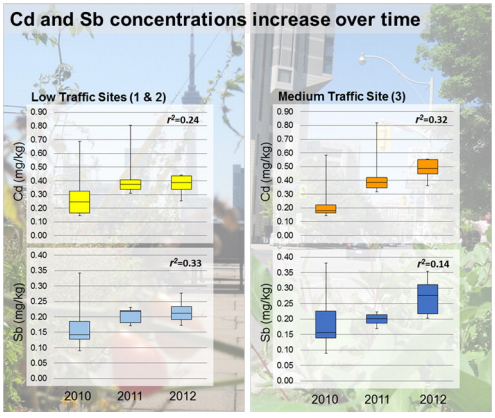
HIGHLIGHTS

- Metal and metalloid levels in urban soils examined over a 3 year period.
- Cd, Sb and Pb concentrations significantly increased in bulk soils over time.
- Cd and Sb are attributed to traffic sources of emissions.
- Atmospheric inputs likely contribute to metal enrichment at low traffic sites.

GRAPHICAL ABSTRACT



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ABSTRACT

This study aims to examine the elemental enrichment patterns in low to medium traffic areas over a three year period in Toronto, Canada. Soils were sampled at three locations with different volumes of traffic between 2010 and 2013. A range of elements, including V, Cr, Mn, Cu, Cd, As, Sb and Pb, were measured in acid digested samples using ICP-MS. While the concentrations of Cd, Sb and Pb were found to be relatively low, a significant, albeit small increase in their levels over time was determined for all sites. For the low traffic areas, median Cd, Sb and Pb concentrations increased from 0.18 mg Cd/kg, 0.14 mg Sb/kg and 12 mg Pb/kg in 2010 to 0.38 mg Cd/kg, 0.21 mg Sb/kg and 15 mg Pb/kg in 2012, respectively. For the medium traffic site, the respective levels of Cd and Sb rose from 0.19 mg Cd/kg and 0.14 mg Sb/kg in 2010 to 0.49 mg Cd/kg and 0.28 mg Sb/kg in 2012. Median Pb concentrations at the medium traffic site were comparable to those at the low traffic sites (13 mg/kg in 2010 and 15 mg/kg in 2012). Principal Component Analysis (PCA) revealed the existence of two components (rotated), which explained 77% of the variance for all sites: 1. PC1 with large loadings of V, Cr, Co and Cu that likely originate from the commercial soil originally used for monitoring purposes, and 2. PC2 with high correlations between Cd, Sb and Pb, attributed to traffic sources of emissions. The resuspension and transport of more mobile fractions of contaminated dust and soil particles is hypothesized to be contributing to an elemental enrichment of soils located in low traffic areas.

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1. Introduction

Urban soils are often enriched with contaminants originating from various pollutant sources such as domestic heating systems, industrial facilities, construction activity, municipal waste treatment plants and hospitals. In particular, traffic is recognized as a major source of elemental enrichment in the urban environment, especially in roadside soils (Fergusson and Kim, 1991; Adachi and Tainosho, 2004; Lough et al., 2005). Metals and metalloids are emitted directly from automobiles via the combustion of fossil fuels, as well as indirectly in the form of non-exhaust emissions, such as that due to the erosion of roadway surfaces and attrition of automotive components (Sternbeck et al., 2002; Lough et al., 2005; Hjortenkrans et al., 2006; Amato et al., 2009; Harrison et al., 2012). For instance, brake lining materials have been reported to be a major environmental source of copper (Cu) and antimony (Sb), especially in areas with a high occurrence of braking such as traffic intersections (Adachi and Tainosho, 2004; Hjortenkrans et al., 2006; Harrison et al., 2012). Although lead (Pb) concentrations have greatly decreased since leaded fuels were banned, this toxic element continues to be emitted by traffic through the continued use of lead wheel weights (Root, 2000) and lead sulfochromate ($Pb(Cr, S)O_4$) yellow paint for road markings (Adachi and Tainosho, 2004) in certain political jurisdictions such as Canada. The resuspension of metal and metalloid enriched dust along roads, particularly those with high volumes of traffic and fleets with large numbers of heavy weight vehicles, can also contribute significantly to elemental loadings in roadside soils (Sternbeck et al., 2002; Lough et al., 2005). The potential of non-exhaust sources of traffic emissions to impact not only urban soil quality but that of the atmosphere has been underestimated to date, as the most recent evidence suggests (Amato et al., 2009; Harrison et al., 2012; Kumar et al., 2013). Kumar et al. (2013), for instance, demonstrated that non-exhaust forms of emissions can contribute large quantities of fine ($PM_{2.5}$) and ultrafine ($PM_{0.1}$) airborne particulate matter (PM), which are of particular concern for human health. In addition, such particle fractions are also capable of traveling longer distances, contributing to contaminant loadings in areas located farther away from source emissions. The potential importance of long distance sources of atmospheric metal and metalloid inputs at a local level has also been demonstrated by Zereini et al. (2012), who reported that platinum group elements measured in airborne PM_{10} collected in rural areas of Germany likely originated from sources located elsewhere in Europe. The significance of long-distance sources of elemental emissions, in addition to local sources of pollution, has also been confirmed by the results of a pan-European biomonitoring program using moss and lichen to assess contaminant levels and deposition trends since 1990 in over 25 countries (Agnan et al., 2015; Harmens et al., 2015). While anthropogenic emissions tend to be the focus of research interest in urban areas, geogenic sources may also significantly contribute to elemental concentrations in soils (Argyraki and Kelepertzis, 2014).

Although many studies have investigated elemental emissions and their associated enrichment patterns in urban environments, few have systematically monitored or reported metal and metalloid accumulation trends in aging field soils over time as a function of proximity to traffic. Data regarding elemental accumulation would enable policy makers to identify priority metals of concern for monitoring and possible regulation over the longer term. This is particularly important in the context of urban gardening, which has become popular in many urban areas as a way to meet the needs of growing populations and to promote community health and development (Wakefield et al., 2007; Grewal and Grewal, 2012).

The aim of this study is to investigate changes in metal and metalloid concentrations in soils over a three year period (2010–2013) in a major urban center, Toronto, Canada. This is part of a larger study, initiated in 2010, to examine the fate and uptake of traffic-related metals and metalloids in cultivated soils and plants grown in close proximity to traffic in Toronto (see Wiseman et al., 2013, 2014). The objectives are as follows: (1) to monitor trends in metal and metalloid concentrations in bulk soils at three sites previously established as part of the roadside cultivation study over a three year period, (2) to assess differences in elemental accumulation between the study sites as a function of proximity to variable traffic volumes (i.e. low vs. medium traffic density), and (3) to conduct a preliminary source apportionment study with the application of Principal Component Analysis (PCA).

2. Experimental

2.1. Sample sites and collection

As originally described in Wiseman et al. (2013, 2014), four different locations were cultivated in Toronto, Canada, beginning in May 2010 to assess the accumulation and bioaccessibility of traffic-related elemental emissions in common garden-variety plants (oregano (*Origanum vulgare*), beets (*Beta vulgaris*) and eggplant (*Solanum melongena*)). Of these sites, three were sampled until 2013 to assess medium-term elemental accumulation trends (Fig. 1): 1. a private residential, low traffic address located in the West end of Toronto (coordinates: 43°38′34.31″N, 79°26′33.32″W; <500 vehicles/24 hour weekday average; tempo limit: 40 km/h), 2. a rooftop at the downtown campus of the University of Toronto (UofT) (coordinates: 43°39′35.62″N, 79°23′45.23″W; ca. 28 m in height), and 3. a medium volume traffic intersection at the downtown campus of UofT (coordinates: 43°39′49.81″N, 79°23′53.55″W; 28,000 vehicles/24 hour weekday average; tempo limit: 40 km/h). A commercial triple soil mix, with equal parts top soil, peat and compost, was used to cultivate plants in containers at Sites 1 and 2 and to replace the pre-existing soil at Site 3 (i.e. top 30–40 cm of soil). The existing soil at an additional location, Site 4, situated in a heavily forested, city park, was sampled for reference purposes (coordinates: 43°64′07.92″N, 79°45′91.88″W).

Topsoils (0–5 cm) were collected on a monthly basis from May to November in 2010, 2011 and 2012 from Sites 1, 2 and 3, respectively. At Site 3, which is bounded by concrete on all sides with the exception of the front, which faces the street, samples were collected from the front and the back of the bed and composited for analysis. The results for soil and plant tissue samples collected from all sites during the growing period in 2010 were originally reported in Wiseman et al. (2013, 2014). Common garden variety plants (e.g. oregano (*O. vulgare*), eggplant (*S. melongena*)) continued to be cultivated at the sites in 2011 and 2012. While plant tissue samples were collected during this period, the focus of analyses after 2010 was on assessing soil elemental concentrations over time.

Depth samples were taken each May in 2010, 2011, 2012 and 2013 at Site 3 from 0–40 cm in depth, at increments of 0–5, 5–10, 10–15, 15–20, 20–30 and 30–40 cm. The first depth samples (2010) were collected prior to the replacement of soil with the commercial triple mix to assess the extent of pre-existing contamination (not reported previously). Curbside road dust samples were collected annually in front of the bed at Site 3 using a plastic brush (approximate area of sweep: 450 cm × 15 cm) to assess traffic-associated elemental inputs to soils via resuspension processes Soils were sampled from two different spots located in the heavily forested, park area (Site 4) and composited for analysis (each involving 3 discrete samples) to serve as reference values.

During the study period, fertilizers were not used to avoid the introduction of contaminants. However, soils at Sites 1, 2 and 3 were amended with a commercially available compost in May 2012 to ensure continued agricultural productivity. For this, a premeasured volume of compost was gently mixed into the preexisting soils at a dilution ratio of 1:8, using a stainless steel spade and taking care to ensure consistent coverage. Compost is a recognized source of possible elemental contamination. Depending on its source, compost has been reported to have elevated levels of toxic metals such as cadmium (Cd) and Pb (Tomati et al., 2002). Prior to amendment, 3 discrete samples were taken from each respective bag