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Research paper

Multi-scale assessment of metal contamination in residential soil and soil fauna: A case study in the Baltimore–Washington metropolitan region, USA

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HIGHLIGHTS

- Soil contamination of metals occurred in residences located in older, more urbanized areas.
- Earthworm burdens correlated with soil Pb and isopod burdens correlated with As, Cr, Ni, Pb and Zn.
- Bird blood Pb correlated with earthworm Pb burdens suggesting a high risk to wildlife.
- The persistence of Pb contamination in urban soils after decades of reduced emissions is alarming.

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ABSTRACT

This study examined the distribution of metals in residential soils from the scale of a residential yard to a metropolitan area by comparing residences along an urbanization gradient in the Baltimore–Washington area, USA. In addition, earthworms and terrestrial isopods were sampled from residential yards to measure body burdens of metals. Soil metal concentrations from lawns and planting bed (road, foundation, and yard) patches were compared (1) among land-use types (inner urban, outer urban, suburban, and rural); (2) between pre- and post-1940 built residential structures; and (3) among yard patch types. Lawn soil concentrations of As, Cd, and Pb varied statistically among the land-use types. Differences between inner urban and rural lawn soils varied almost eight-fold for Pb, three-fold for Cd, and more than two-fold for As. Bed patches exhibited a slightly stronger relationship than lawns across the urbanization gradient. A similar relationship was shown for pre- and post-1940 structures with older having higher concentrations than post-1940 structures. Earthworm body burdens were statistically correlated with soil Pb, while isopod burdens exhibited a significant relationship with soil As, Cr, Ni, Pb, and Zn. A post-hoc analysis with bird blood Pb data that was available for the residences, showed a significant relationship with earthworm Pb body burdens. This study suggests that despite policy efforts to reduce metal emissions, contamination of soil persists in urban residences at levels that have health implications for people and wildlife living in the Baltimore–Washington, DC area.

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1. Introduction

Urban landscapes are conspicuously contaminated by trace metals and thus pose a potential health risk to people and wildlife (Mielke, 1999; Wong, Li, & Thornton 2006; Luo, Yu, Zhu, & Li 2012). Although many studies have demonstrated that trace metals accumulate in soils of urban landscapes, less is known about their spatial distribution at finer scales (Schwarz et al., 2012) and potential for accumulating into soil fauna and the animals that feed on these organisms (Roux & Marra, 2007). Metal accumulations in urban soils have been associated with roadside environments and vehicular emissions (Manta, Angelone, Bellanca, Neri, & Sprovieri

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2002; Zhang, 2006; Werkenthin, Kluge, & Wessolek 2014), interior and exterior paint (Trippler, Schmitt, & Lund 1988), stack emissions (Govil, Reddy, & Krishna 2001; Walsh, Chillrud, Simpson, & Bopp, 2001; Kaminski & Landsberger, 2000), management inputs (Russell-Anelli, Bryant, & Galbraith 1999), distance from roads (Wang, Ren, Liu, Yu, & Zhang, 2006; Yesilonis, Pouyat, & Neerchal 2008; Schwarz et al., 2012), land use (Xia, Chen, Liu, & Liu 2011; Mao, Huang, Ma, & Sun 2014), and age of structures (Schwarz et al., 2012; Stewart, Farver, Gorsevski, & Miner 2014). The spatial pattern resulting from these factors is dependent on characteristics of the source such as whether the metal was emitted from a point or non-point source, the height of emission, and the particle size fraction of the pollutant (Cook & Ni, 2007).

Lead (Pb) for example has been emitted into the environment as a gasoline additive and in paint and has over time accumulated in soils. In the United States, both uses have been banned through policy actions for more than 30 years, but nonetheless, the ability of Pb and other metals to persist in the environment has resulted in a distinct spatial pattern of accumulation in soil and riparian sediments (e.g., Bain, Yesilonis, & Pouyat 2010; Schwarz et al., 2012; Datko-Williams, Wilkie, & Richmond-Bryant 2014). Given the aforementioned factors, the resultant spatial pattern of Pb or other trace metals in urban soils should, in part, be determined by the amount and length of exposure to emissions. For example, patterns differ because of the age of the structure (older structures have been exposed to emitted Pb for a longer duration and are more likely to have Pb based paint), the nature of the emitting source, such as the juxtaposition to a road and the volume of traffic on that road, and how far from the source the aerosols and particulates have been dispersed.

In a review of the literature, Yesilonis et al. (2008) found that globally, urban soils consistently accumulated above background levels of Pb, copper (Cu), and zinc (Zn). The authors associated this relationship with automobile usage, specifically tire wear (Zn), brake and radiator wear (Cu), and the accumulation of Pb from historic use of leaded gasoline and paint. Moreover, due to the ability of soil to chemically or physically immobilize these metals, soils have the capacity to accumulate them (Yong, Mohamed, & Warkentin 1992). In addition to Pb, Cu, and Zn, other metals including nickel (Ni), arsenic (As), cadmium (Cd), and chromium (Cr) have been reported to accumulate in urban environments (Kay, Arnold, Cannon, & Graham 2008; Odewande & Abimbola, 2008; Zheng, Chen, & He 2008). Like Pb, Cu, and Zn, the presence of Ni, Cd, and Cr in the environment can be related to automobile use (Van Bohemen & Janssen Van de Laak, 2003) but also industrial sources (Rawlins, Lark, O'Donnell, Tie, & Lister, 2005), while As has been introduced into residential areas as a wood preservative (Townsend, Solo-Gabriele, Tolaymat, Stook, & Hosein 2003).

Since most of the emission sources for trace metals are associated with urban land uses, there have been a number of studies examining the relationship between metal concentrations in remnant patches, such as a forest patch, with distance to the urban core or some metric of urban land use, i.e., an urbanization gradient. For example, Pouyat et al. (2008) showed evidence of a depositional pattern of metals in forest soils along urbanization gradients in the New York City, Baltimore, and Budapest metropolitan areas. The authors found a two to three-fold increase in contents of Pb, Cu, and Ni in urban forest remnants compared to suburban and rural counterparts. A similar pattern but with greater differences was found by Inman and Parker (1978) in the Chicago, IL metropolitan area, where levels of heavy metals were more than five times higher in urban than in rural forest patches. Other urbanization gradient studies have shown a similar pattern (Watmough, Hutchinson, & Sager 1998; Sawicka-Kapusta, Zakrzewska, Bajorek, & Gdula-Argasinska 2003), although smaller cities or cities having more compact development patterns exhibited less of a difference between urban and rural forest soils (Pavao-Zuckerman, 2003; Pouyat et al., 2008; Carreiro, Pouyat, & Tripler 2009). In all of these studies, regional relationships were established by sampling relatively undisturbed remnant patches and did not include more disturbed or managed soils associated with residential land use, which are the soils most implicated with metal exposure to humans, e.g., Pb in children (Mielke, Gonzales, Powell, & Mielke 2008). For urban soils in the United States, a recent review of the literature showed that for all studies considered, soils in urban centers had higher Pb concentrations than in suburban areas, with the exception of New Orleans (Datko-Williams et al., 2014).

Besides human exposure, the accumulation of trace metals in urban soils can also affect soil fauna. Indeed, soil invertebrates are often used as indicators of pollutant levels (Dallinger, 1994; Nahmani & Lavelle, 2002), although interpreting the results can be challenging due to the multiple factors involved (Beyer & Cromartie, 1987; Nahmani, Hodson, & Black 2007). Soil taxa exhibit differences in their response to trace metal exposure due to their physiology, feeding habits, mobility, and microhabitat preferences (Beyer & Cromartie, 1987; Pižl & Josens, 1995; Scharenberg & Ebeling, 1996; Kamitani & Kaneko, 2007). For instance, earthworms are less mobile and consume a mixture of soil and detritus while isopods and millipedes are more active and feed mainly on plant detritus. An additional effect of metals in soil fauna is the potential for the bioconcentration of metals up the food chain (Hopkin & Martin, 1985; Raczuk & Pokora, 2008). Soil organisms are a primary food source for many invertebrate and vertebrate predators, and thus in heavily contaminated areas there is an increased risk of secondary poisoning (Spurgeon & Hopkin, 1996; Reinecke, Reinecke, Musibono, & Chapman 2000; Maerz, Karuzas, Madison, & Blossey 2005). For example, earthworms are an especially important component of the diet of ground feeding birds due to their high energy and nutrition content (Török & Ludvig, 1988).

Because soil fauna can accumulate trace metals from soil and relatively few studies have compared metal concentrations of residential soils at multiple scales (residential yard to metropolitan region), the objectives of this study were threefold: (1) compare metal concentrations of soils in residential yards that varied in age from inner urban to rural areas in the Baltimore–Washington metropolitan area; (2) compare metal concentrations of soils in patch types that differ in location and soil cover within individual residential yards; and (3) correlate soil metal concentrations with the body burden of metals in earthworms (*Annelida*:*Oligochaeta*) and terrestrial isopods (*Crustacea*:*Isopoda*), both of which are potential food sources for several bird species in the region (Roux & Marra, 2007). In the first case, a comparison of soil metal concentrations of residences along an urbanization gradient will reflect, in part, the age of the structures (e.g., before and after policy changes in Pb additives to paint and gasoline) and the effect of vehicular traffic occurring in residential areas in the Baltimore–Washington metropolitan area. In the second and third cases, a comparison of metals in soils, earthworms, and isopods associated with five yard patch types comprised of either lawn (front and back) or planting beds (building foundation, yard or road) along an urbanization gradient will reflect spatial patterns at regional and lot, or yard, scales.

For the first and second objectives, we expected metal concentrations would be greater in more densely populated areas due to higher emissions, and that soils associated with patch types within yards that were closer to roads and adjacent to house foundations would have greater accumulations of metals than in the front or back lawns, particularly for Pb, Cu, and Zn. Moreover, we expected these differences to be magnified by the time of exposure (i.e., age of structure). For objective 3, we expected that the body burdens of earthworms would reflect concentrations of metals in the soils