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Heavy metals in suburban gardens and the implications of land-use change following a major earthquake

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ABSTRACT

Numerous studies have shown that urban soils can contain elevated concentrations of heavy metals (HMs). Christchurch, New Zealand, is a relatively young city (150 years old) with a population of 390,000. Most soils in Christchurch are sub-urban, with food production in residential gardens a popular activity. Earthquakes in 2010 and 2011 have resulted in the re-zoning of 630 ha of Christchurch, with suggestions that some of this land could be used for community gardens. We aimed to determine the HM concentrations in a selection of suburban gardens in Christchurch as well as in soils identified as being at risk of HM contamination due to hazardous former land uses or nearby activities. Heavy metal concentrations in suburban Christchurch garden soils were higher than normal background soil concentrations. Some 46% of the urban garden samples had Pb concentrations higher than the residential land use national standard of 210 mg kg^{-1}, with the most contaminated soil containing 2615 mg kg^{-1} Pb. Concentrations of As and Zn exceeded the residential land use national standards (20 mg kg^{-1} As and 400 mg kg^{-1} Zn) in 20% of the soils. Older neighbourhoods had significantly higher soil HM concentrations than younger neighbourhoods. Neighbourhoods developed pre-1950s had a mean Pb concentration of 282 mg kg^{-1} in their garden soils. Soil HM concentrations should be key criteria when determining the future land use of former residential areas that have been demolished because of the earthquakes in 2010 and 2011. Redeveloping these areas as parklands or forests would result in less human HM exposure than agriculture or community gardens where food is produced and bare soil is exposed.

1. Introduction

Heavy Metals (HMs), comprising metal(loids) with a density >5, can be toxic to organisms at relatively low concentrations (Robinson et al., 2009). The total HM concentration in soil is a function of the background concentration (Guagliardi et al., 2012) plus anthropogenic contributions, which include past and current application of soil conditioners (composts, manures and fertilisers), metal-containing agrichemicals, paints, vehicle emissions, local industries, and coal and fuel combustion (Paramashivam et al., 2016; Simmler et al., 2013; Szolnoki and Farsang, 2013).

Even small increases in concentrations of HMs such as cadmium (Cd) and lead (Pb) in soils may endanger the environment and human health (Ajmone-Marsan and Biasioli, 2010). Humans may ingest soil-borne HMs by direct consumption of soil or consumption of plants that either take up HMs into the edible portions or have HMs attached to the surfaces of the edible portions (Robinson et al., 2009). Exposure can also occur through inhalation of suspended soil particulates, and dermal contact (De Miguel et al., 1999; Kachenko and Singh, 2006). Children are particularly vulnerable because they have greater hand-to-mouth activities and gastrointestinal absorption (Calabrese et al., 1997). Childhood Pb poisoning remains a major environmental health concern in cities with Pb-contaminated soils (Ikem et al., 2008).

Urban and suburban soils are more likely than rural soils to become contaminated with HMs because they are more affected by human activities (Hough et al., 2004). Elevated HM concentrations occur in urban soils worldwide (Ajmone-Marsan and Biasioli,

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2010). Table 1 shows common heavy metal(loid)s that may be found at elevated concentrations in urban and suburban soils, along with their anthropogenic source.

El Khalil et al. (2013) showed that concentrations of copper (Cu), Pb and zinc (Zn) in soils from Marrakesh city, Morocco could be used as indicators of industrialisation. Similarly, areas of Annabeh city centre (Algeria) contained Pb, up to 823 mg kg^{-1} (Maas et al., 2010). Garden soils in Nantes, France, also revealed high arsenic (As) and Pb concentrations, and suggested human activities as the main origin (Jean-Soro et al., 2015). Analysis of soil samples from Madrid showed concentrations of Cd, Cu, Pb and Zn were inversely correlated with distance from the city centre (Vázquez de la Cueva et al., 2014).

Christchurch is New Zealand's third largest city with a population of some 390,000 (Statistics New Zealand, 2014). It was founded some 150 years ago and has vast tracts of suburban land (Wilson, 2005) where humans may be exposed to metals through home grown fruits and vegetables as well as direct ingestion of soil by children playing in backyard gardens. Major earthquakes in 2010 and 2011 have resulted in some 630 ha of the city being demolished with redevelopment of the affected land prohibited due to land stability issues (Scott and Carville, 2016). Potentially, this affected land may be used for agriculture, recreation, or community gardens, which may exacerbate human exposure to soil-borne HMs. A single study on a Christchurch residential red zone, Avon-Otakaro, showed that Pb was the only element, among As, Cd, Cu and Pb, exceeding the residential land use standard (260 mg kg^{-1}) (Gilmour, 2013).

This study aimed to determine the nature and extent of soil HM contamination in suburban and rural garden soils in an around the city of Christchurch as a function of the age of the district, with a view to identifying potential risks associated with home or community gardens. We sought to compare HM concentrations in Christchurch suburban soils with background concentrations in Canterbury soils (Tonkin and Taylor, 2007), as well as the New Zealand Soil Contaminant Standards for health (SCSs) for inorganic substances (Ministry for the Environment, 2012) and Dutch Standards.

2. Materials and methods

2.1. Soil sampling: suburban gardens

Crowd sourcing was used to obtain soils from 31 vegetable gardens in Christchurch city and surrounding areas in 2009–2010. Following advertisements in local newspapers, participants were sent labelled and sealable plastic bags along with instructions on soil collection. After removal of any surface litter or vegetation, ca. 250 g samples were collected from the top 10 cm of soil, representing the 'A' horizon in most soils, and certainly within the rootzones of most vegetable plants. For each garden, up to six samples were collected from different locations and individually analysed. Fig. 1 shows the sampling locations of the vegetable garden soils.

2.2. Soil sampling: suspected contaminated sites

The Canterbury Regional Council (CRC) is responsible for investigating land for the purposes of identifying and monitoring contamination. In conducting its regulatory duties, CRC created the Listed Land Use Register (LLUR) of sites it considers are potentially contaminated or known to be contaminated. A site will be classed as potentially contaminated if it previously or currently had an activity or land use occurring at the site which is present on the Ministry for the Environment (MfE) Hazardous Activities and Industries List (HAIL), which are activities it considers to be hazardous (MfE, 2016). HAIL sites include fuel storage sites, orchards, timber treatment yards, landfills, sheep dips and any other activities where hazardous substances could cause land and water contamination.

Soils from 99 sites where the residential buildings had suffered earthquake damage were sampled between 2012 and 2015. The sites were assessed as they were listed on the LLUR as potentially contaminated due to the land having been used previously for horticulture. The site investigation focused on the house rebuild footprint (within 1 m of the house) on 'easily accessed areas' (in other words, exposed or vegetated soils – not paved or otherwise covered). For each site, four separate soil samples (250 g) were collected from 0 to 0.3 m below ground level within or around the house footprint. The samples were collected using a stainless steel spade or hand auger, and placed directly into sample jars supplied by Hills Laboratories. The sampling equipment was decontaminated between samples. Fig. 1 shows the locations of the HAIL sites.

2.3. Soil analysis

Garden soils were dried at 105 °C and sieved to <2 mm using a Nylon sieve. Pseudo-total elemental analysis was carried out using microwave digestion in 8 mL of Aristar nitric acid (±69%), filtered using Whatman 52 filter paper (pore site 7 μm), and diluted with milliQ water to a volume of 25 mL and stored for chemical analyses. Concentrations of aluminium (Al), As, boron (B), Cd, Cr, Cu, iron (Fe), potassium (K), manganese (Mn), nickel (Ni), phosphorus (P), Pb, and Zn were determined using inductively coupled plasma optical emission spectrometry (ICP-OES Varian 720 ES). Mercury (Hg) was analysed using hydride generation coupled with the aforementioned ICP-OES. Wageningen reference soil (ISE 921) material was analysed for quality assurance. Recoverable concentrations were 91%–108% of the certified values. The HAIL soil samples were analysed by Hill Laboratories. Hill laboratories are an accredited laboratory (IANZ, 2017) and therefore have rigorous quality assurance procedures. Briefly, soils were air dried at 35 °C and sieved to <2 mm. These dried and sieved samples were then composited and

Table 1
Common heavy metal contaminants that may occur in urban or suburban soils (LaCoste et al., 2001; Mills et al., 2005; Robinson et al., 2006, 2009).

Heavy Metal(loid)	Source
Arsenic (As)	As-based insecticides used in horticulture, treated timber, or former sheep-dip sites
Cadmium (Cd)	Cd-rich phosphate fertilisers, sludges, industrial emissions, runoff from roads
Chromium (Cr)	Fixative in treated timber, industrial emissions
Copper (Cu)	Cu-based fungicide, Cu used for roofing
Mercury (Hg)	Industrial emissions, crematoria
Nickel (Ni)	Industrial emissions
Lead (Pb)	Historic use of leaded petrol, Pb-based paints, historic use of Pb-based pesticides. Pb flashings on roofs
Thallium (Tl)	Coal combustion
Zinc (Zn)	Galvanised metal

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