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Heavy metal and metalloid concentrations in soils under pasture of southern New Zealand

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ABSTRACT

Heavy metal and metalloid (As, Cd, Cr, Cu, Hg, Ni, Pb, Zn) levels in 284 topsoil (0–30 cm) samples were measured from 20,000 km^2 of southern New Zealand in a systematic survey and the concentrations and patterns between samples sites were studied. Samples were analysed by the inductively coupled mass spectrometry method on an aqua regia digest. Except for Hg, median concentrations from land classed as high producing exotic grassland (pasture; 241 samples) were consistently elevated relative to median natural background levels under native vegetation. The major control of heavy metal enrichment in pasture is P-based fertiliser application (Cd, Cu, Zn), the soil parent material (Ni, Hg) or a combination of both (As, Cr, Pb), with Pb also affected by proximity to urban centres and major roads. There may be a trend of increasing heavy metal concentration with increasing intensity of land use. Comparison shows there is strong, regional variation in median heavy metal concentrations in topsoil around New Zealand and highlight a need for systematic and consistent study of heavy metals in soil nationally.

1. Introduction

Heavy metals and metalloids [with atomic density > 6 g/cm^3; Alloway, 2013; referred to as heavy metals for brevity hereafter] occur naturally in the environment and are harmless at concentrations typically found there (Gardea-Torresdey et al., 2005). However, when these metals become bioavailable, i.e. can pass the living cell-membrane (Stoeppler, 1992), and are anthropogenically or naturally concentrated, they can reach levels toxic to plants, animals or humans. Heavy metal contamination of soils by anthropogenic activity has been recognised for decades (e.g. Bramley, 1990; Hutchinson and Whitby, 1974; Ward et al., 1977b). It can occur via fertiliser, animal manure or pesticide application, industrial emissions, leaded gasoline and leaded paint contamination, atmospheric deposition, coal combustion residues, mine tailings and wastewater irrigation (Khan et al., 2008; Nriagu and Pacyna, 1988). Heavy metal contamination is a major concern that can lead to, for example, bioaccumulation in the food chain which affects human health (Peralta-Videa et al., 2009), inhibition of the biodegradation of organic contaminants (Maslin and Maier, 2000), groundwater contamination (Mulligan et al., 2001) and reduction of land and food quality (McLaughlin et al., 2000). Anthropogenic heavy metal input typically accumulates in topsoil and nutrient uptake by exotic grasses is also predominantly from topsoil (Hou et al., 2014; Kismányoky and Tóth, 2010). Hence topsoil (typically the top 0–30 cm) analysis is most valuable for studying heavy metal contamination in pastures. In New Zealand, unmodified and weakly modified soils are generally low in nutrients, but maintain their nutrient status by relying upon natural biogeochemical processes (McLaughlin et al., 2000), that make them especially sensitive to the effects of heavy metal contamination. Developed agricultural soils in New Zealand on-the-other-hand have relatively high nutrient levels and mineralisable nitrogen and phosphorous (P). Around 17% of New Zealand's gross domestic product depends upon soil resources, making soil quality an economic, as well as socially, important topic, both in New Zealand and globally.

In New Zealand, there has been an historical reliance upon northern hemisphere data to set regulatory guidelines and frameworks for heavy metal contamination in soils (e.g. McLaughlin et al., 2000). Where New Zealand data are used, there has been a tendency to focus on single or a few elements (Reiser et al., 2014; Taylor et al., 2017), sometimes mined from legacy data, for example the extensive Cadmium Working Group report (2008). These studies tend to involve non-systematic spatial coverage of samples analysed at a variety of times by a variety of

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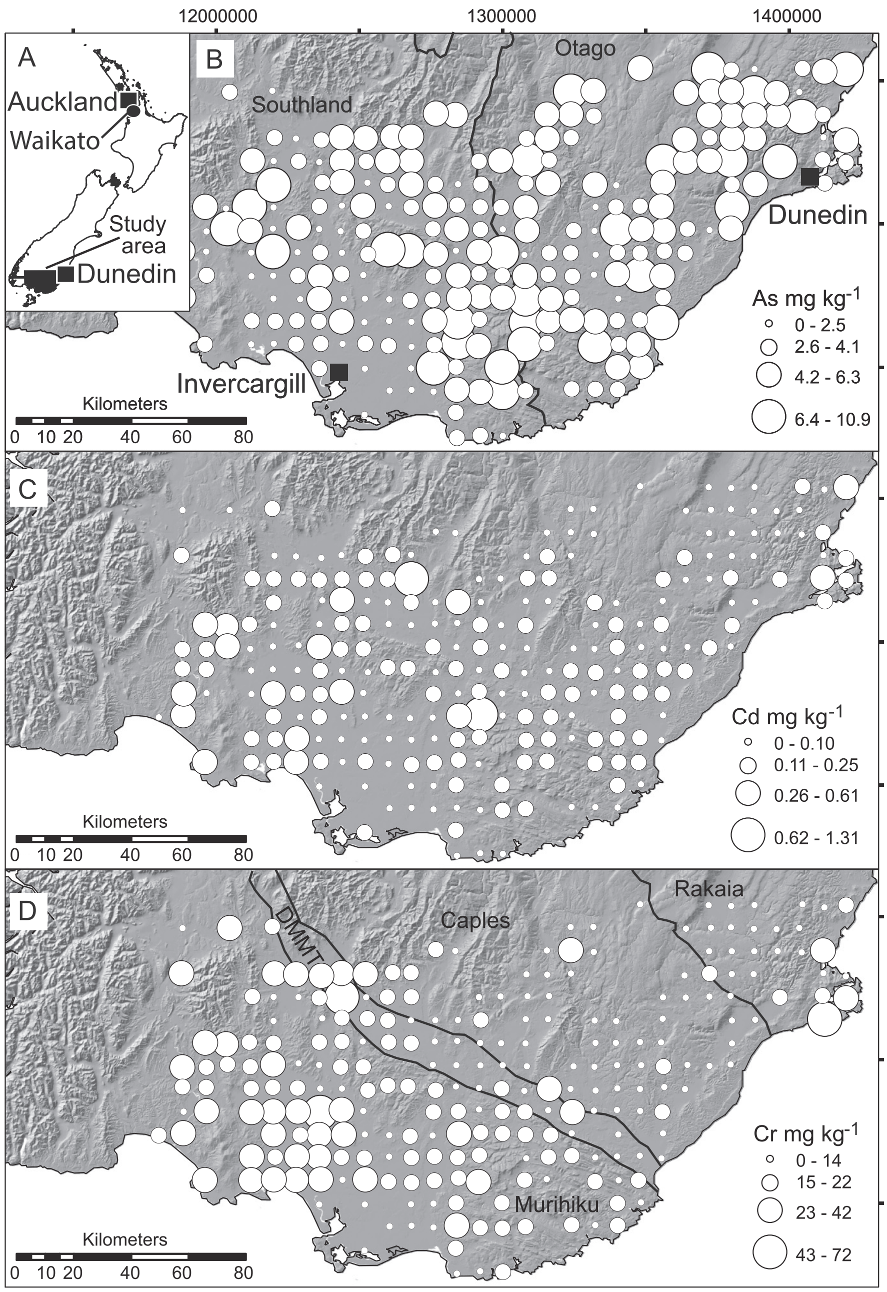

Fig. 1. Survey location and element distribution maps superimposed on a 40 m digital elevation model of southern New Zealand. Concentrations are in mg kg^{-1} and subdivided using Jenks natural breaks into four categories. Data shown is for high producing exotic grassland (pasture). The location of the survey in the southern South Island is shown in the inset (A). B. Arsenic, with the regional boundary between the provinces of Otago and Southland outlined by a black line. B. Cadmium C. Chromium. Black lines show the boundary between the Rakaia, Caples, Dun Mountain – Maitai (DMMT) and Murihiku terranes (Heron, 2014).

different analytical methods on a limited number of elements. This work attempts to improve upon this by utilising a recent study of southern New Zealand (Fig. 1A) soil that was acquired on a systematic, 8 km spaced grid and analysed for a variety of elements by dilution inductively coupled plasma mass spectrometry (ICPMS). The results of eight heavy metals from topsoil (0–30 cm) for arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), nickel (Ni), lead (Pb) and zinc (Zn) are presented from this study. These eight heavy metals are the most commonly identified at contaminated soil sites worldwide (Evanko and Dzombak, 1997; Gardea-Torresdey et al., 2005; Wuana and Okieimen, 2011). Furthermore, land cover divides these data into those obtained from high producing exotic grassland (most commonly pasture for dairy, sheep or beef; n = 241; referred to as pasture hereafter) and those obtained from relatively undisturbed land under native vegetation (e.g. indigenous forest or tall tussock grassland; n = 43; referred to as natural background hereafter). The source of heavy metals will be discussed and concentrations contrasted between pasture and natural background settings. The data will be compared to other data available for New Zealand topsoil. The results are the most comprehensive and up-to-date picture of heavy metal concentrations in southern New Zealand topsoil and could be used to inform regulatory guidelines and best-practice soil management.

2. Regional setting

The survey covered c. 20,000 km^2 of southern New Zealand (Fig. 1), equivalent to West Virginia or Wales in size. Most of southern New Zealand is sparsely populated at ≤ 10 residents per km^2, with many of the c. 220,000 people living in the cities of Dunedin (c. 120,000) and Invercargill (c. 50,000; Fig. 1A and B). Land use in southern New Zealand is predominantly agricultural, particularly dairy, sheep and beef, with smaller areas of horticulture, deer farming and exotic forestry. Rainfall generally decreases from west (> 4000 mm) to east (< 250 mm) and elevation rises from sea level to > 2400 m on some range crests. The region is underlain by diverse geology (Fig. S1) that can be subdivided into older basement terranes of the Austral