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Geochemical sources, forms and phases of soil contamination in an industrial city

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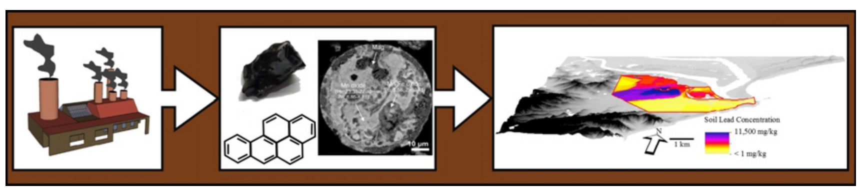
HIGHLIGHTS

- Ferrous and non-ferrous metal smelting have caused an environmental contamination legacy in the city environment.
- Children exposed to the soils in the city are vulnerable to metal(loid) and polycyclic aromatic hydrocarbon exposure.
- Human health exposure risks should be considered when repurposing industrial cities for changing land-uses.

GRAPHICAL ABSTRACT



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ABSTRACT

This study examines current soil contamination in an Australian industrial city, Newcastle. Public (roadside verges and parks) and private (homes) surface soils ($n = 170$) contained metal(loid)s elevated above their respective Australian Health Investigation Levels (HIL). Lead (Pb), the most common contaminant in the city, exceeds the HIL for residential soils (HIL-A, 300 mg/kg) in 88% of private soils (median: 1140 mg/kg). In-vitro Pb bio-accessibility analysis of selected soils ($n = 11$) using simulated gastric fluid showed a high affinity for Pb solubilisation (maximum Pb concentration: 5190 mg/kg, equating to 45% Pb bio-accessibility). Highly soluble Pb-laden Fe- and Mn-oxides likely contribute to the bio-accessibility of the Pb. Public and private space surface soils contain substantially less radiogenic Pb (range: $^{208}Pb/^{207}Pb$: 2.345–2.411, $^{206}Pb/^{207}Pb$: 1.068–1.312) than local background soil ($^{208}Pb/^{207}Pb$: 2.489, $^{206}Pb/^{207}Pb$: 1.198), indicating anthropogenic contamination from the less radiogenic Broken Hill type Pb ores ($^{208}Pb/^{207}Pb$: 2.319, $^{206}Pb/^{207}Pb$: 1.044). Source apportionment using Pb isotopic ratio quantification and soil mineralogy indicate the city's historic copper and steel industries contributed the majority of the soil contaminants through atmospheric deposition and use of slag waste as fill material. High-temperature silicates and oxides combined with rounded particles in the soil are characteristic of smelter dust emissions. Additionally, a preliminary investigation of polycyclic aromatic hydrocarbons in soils, sometimes associated with ferrous metal smelting, coal processing or burning of fossil fuels, shows that these too pose a health exposure risk (calculated in comparison to benzo(*a*)pyrene: $n = 12$, max: 13.5 mg/kg, HIL: 3 mg/kg).

1. Introduction

Urban environmental contamination is an issue common to industrial cities throughout the world (Filippelli et al., 2015). Historically, employees would live close to their work, resulting in dense urban

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development around industrial operations. Due to the proximity of industrial operations to urban environments there is the potential for adverse impacts on human health arising from industrial emissions (Csavina et al., 2012; Dong et al., 2015; Ettler et al., 2009; Gulson et al., 1994; Gulson et al., 2004; Gulson et al., 2009; Morrison, 2003; Taylor et al., 2010; Taylor et al., 2013; Taylor et al., 2014a; Taylor et al., 2014b).

By 2050, the majority of the global population is expected to transition from rural to urban-metropolitan living, increasing the risk associated with contaminated urban lands (United Nations (UN), 2015). The resulting environmental contamination burden from industrial cities is demonstrated in Detroit, USA, which has been considered one of the most contaminated cities in the USA (Lougheed, 2014). Sulfur dioxide, heavy metals, hydrocarbons and other organic contaminants that were emitted to the atmosphere during the city's automobile manufacturing era, accumulated in the urban soil environment and have been subsequently linked to a range of health impacts including

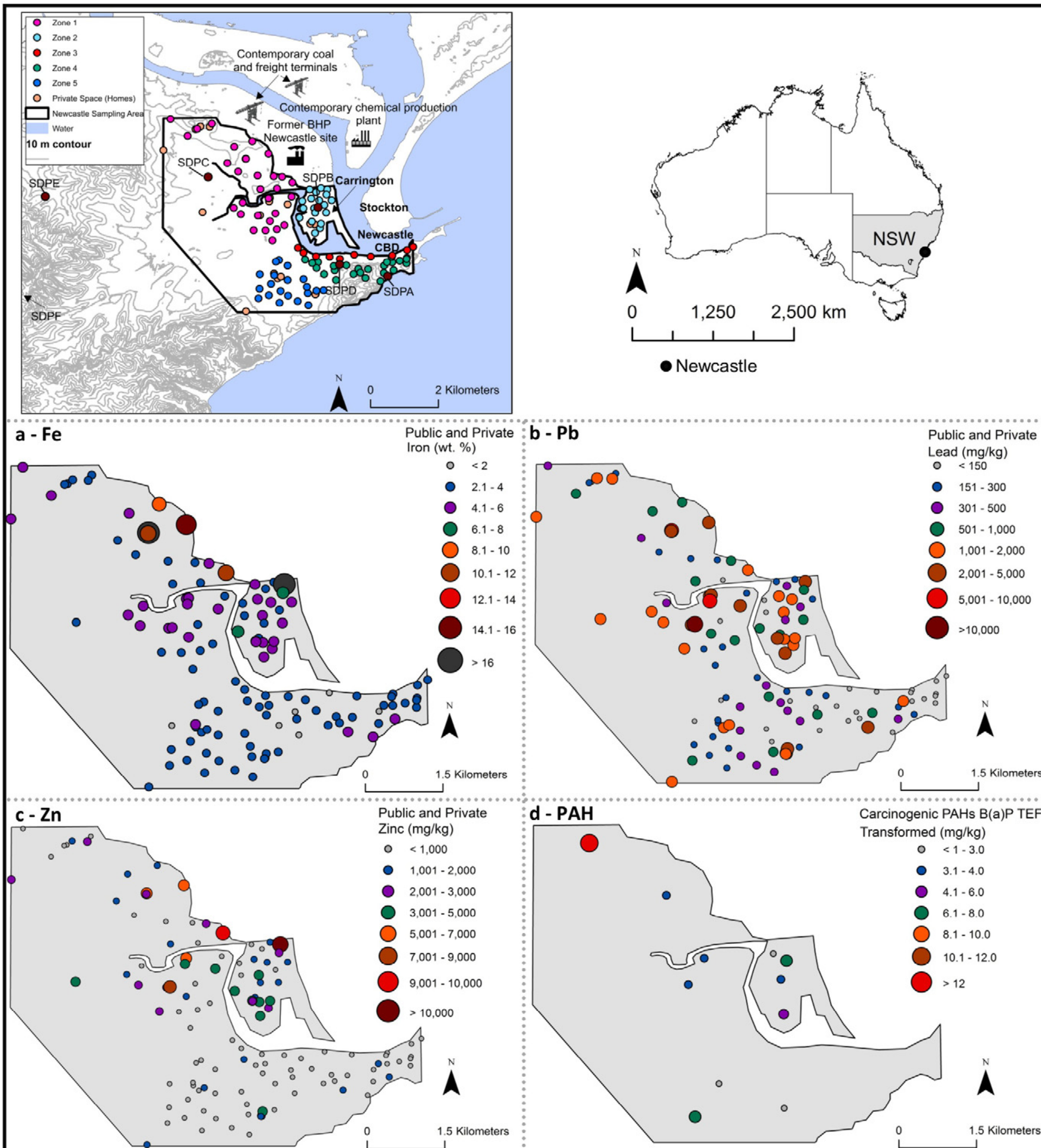

Fig. 1. Soil analyte concentrations within Newcastle (Australia) (panel a - iron, b - lead, c - zinc, d - TEF transformed PAHs). Sites marked SDP- are soil depth profiles.