



## Research article

## Impacts of iron and steelmaking facilities on soil quality

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## ABSTRACT

Iron and steel are highly important materials used in a wide range of products with important contribution to the economic development. The processes for making iron and steel are energy intensive and known to contribute to local pollution. Deposition of the metals may also have adverse impacts on soil quality, which requires detailed assessment. The aim of this study was to investigate the impacts of iron and steelmaking facilities on the local soil quality. Soil samples were collected in the vicinity of two steelmaking sites in Australia, one based on blast furnace steelmaking operation, while the second site was based on electric arc furnace steel recycling. The soil samples were compared to a background site where no industrial impact is expected. The soil collected near industrial facilities contained larger toxic metal contents, however this concentration for all priority metals was within the Australian National Environmental Protection Measure guidelines for the acceptable recreational soil quality. When compared to the international soil quality guidelines, some of the soils collected near the industrial sites, particularly near the blast furnace operated steelmaking, exceeded the arsenic, iron and manganese (according to United States Environmental Protection Agency guidelines) and chromium, copper and nickel concentrations (according to the Canadian guidelines). The work further provided a novel environmental assessment model taking into consideration the environmental and health impacts of each element. The environmental assessment revealed most significant contribution of manganese, followed by titanium, zinc, chromium and lead. Titanium was the second most important contributor to the soil quality, however this metal is currently not included in any of the international soil quality guidelines.

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## 1. Introduction

Mineral processing industries have considerable input to the global economies and wealth of nations. Iron and steelmaking are one of the most important mineral processing industries with significant contribution to the economic development. However, these activities also pose considerable environmental risks through emissions and deposition of pollutants and the management of toxic waste. The balance between the economic input of the steelmaking industry and its environmental footprint is the fundamental expression of its contribution to sustainable development (Strezov et al., 2013).

The formation of trace metals during processing of iron and steel has been a subject of intensive investigations in the past (Kan et al., 2015). The iron and steelmaking processes produce waste products, such as slag rich in Mn, Zn and Pb, which can range

between 5 and 40% (Mocellin et al., 2015) and waste off-gas that is subjected to gas cleaning where particles from the blast furnace are transferred to the gas cleaning system (Kiventera et al., 2016). The gas cleaning systems work under limited efficiencies where, for sinter plant conditions, range between 60 and 80% for cyclones, 95% for electrostatic precipitators and 99% for fabric filters (European Commission, 2001). This means that some of the volatile trace metals are released to the environment through atmospheric processes and particle emissions. Mohiuddin et al. have demonstrated the relative impact of the different steelmaking activities on the local atmospheric particle chemistry (Mohiuddin et al., 2014a) and particle size distribution (Mohiuddin et al., 2014b) indicating the importance of particles to the environmental impact assessment of the industrial processes. The atmospheric particles eventually deposit and may potentially affect the surrounding soil quality, often used by residents for recreational or agricultural purposes.

The impact of non-ferrous smelting on soil quality has been a subject of significant investigations in the past. The subject of these investigations was the assessment of the impact of lead and zinc

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smelting on residential and agricultural soil quality (Chary et al., 2008). The concentrations of heavy metals As, Cd, Cu, Ni, Pb and Zn nearby industrial zones (Li et al., 2009) and lead smelter (Douay et al., 2013) were found to be higher than in background sites. As, Cd and Pb in soils and atmospheric aerosols have been associated with substantial health (Zhang et al., 2012) and intellectual impacts (Dong et al., 2015), specifically on children. The lead blast furnace and imperial blast furnace slag pose environmental difficulties due to leaching of lead and zinc (Yin et al., 2016), which is additionally subject to weathering.

The environmental impact assessment of ferrous smelting on soil quality has been a subject of only limited investigations in the past. Yuan et al. (2013) performed an extensive study on top soil quality assessment near closed steel smelter at the Capital Iron and Steel Factory, Beijing in China. The plant area included blast furnace and smelting, pyrogenation, steel casting and steel-rolling. The study revealed higher concentrations of Cu, Pb, Cd, Zn and Hg near the steelmaking site, comparing to a background sampling site. A multivariate geostatistical analysis suggested that Cu, Pb, Cd and Zn were mainly associated from steel smelting activities, while Hg contaminations were weakly related to the steelmaking activities, partially due to other anthropogenic influences. Schulin et al. (2007) investigated heavy metal contamination of soil near an iron smelter in Bulgaria. The agricultural soils near the smelter were found to have been affected by the dust emitted from the iron smelter with As, Pb, and Zn identified as the main pollutants. Dragović et al. (2014) investigated the impact of the steel industry in Serbia on soil quality. They identified the concentrations of Cd, Co, Cu, Ni, Pb and Zn higher than the values reported for European soils and also higher than the mean worldwide concentrations. Some of these elements were also found to exceed the limits established by local regulations.

The aim of this study was to investigate the impact of iron and steelmaking facilities on the surrounding soils, particularly investigating the soil quality near two different types of steelmaking industries, the blast furnace and electric arc furnace based steelmaking. Australian steelmaking sites were selected as case studies for these investigations. The study further aims to determine the soil quality relative to the international soil quality guidelines and present a novel approach to the environmental assessment of the toxic trace elements present in the soil, based on their toxicological and environmental profiles.

## 2. Materials and methods

The soil sampling was carried out at ten different locations surrounding two industrial sites, one based on electric arc furnace steelmaking, while the other based on blast furnace steelmaking operations. Both sites were located in New South Wales, Australia and one sampling location was selected as a background site to represent soil quality of a typical urban site. The sampling locations with coordinates shown in Table 1 were: (1) Rooty Hill (RT) sampling locations located in close proximity to the Rooty Hill mini-mill steelworks based on electric arc furnace steelmaking, with moderate traffic and strong industrial influence; (2) Port Kembla (PK) sampling sites located in the surrounding of the integrated iron and steelworks based on blast furnace and basic oxygen furnace steelmaking, with moderate traffic and strong industrial influence and (3) Macquarie Park (MQ) sampling site located at the Macquarie University sports field surrounded by residential areas, one highway and commercial activities, with little or no industrial influence nearby to the sampling site. The samples were named according to the location with the relative distance from the industry shown in the brackets. Each sampling location was selected at several distances from the corresponding industry in a radius of up to 6 km. The sampling locations were mainly parks easily accessible for sampling, but also areas where residents, including children, will most likely be exposed to the soil through recreational activities.

Soil samples were collected with a dorrer steel soil sampler, collecting samples at a depth of 10 cm. From each sampling site, three samples within few meters apart were collected and mixed to ensure composite soil sample. In order to avoid cross-contamination, after each sampling, the sampler was thoroughly cleaned with MilliQ water. After collection the samples were kept in a freezer.

The reference method Australian Standard (AS) 4479 and the United States Environmental Protection Agency (USEPA) methods 3050; 200.8; 200.7, 6010 and 6020 were used for trace element analysis in the soils. As, Cd, Cr, Cu, Fe, Hg, Mn, Mo, Ni, Pb, Ti, Zn, Mg, K, P, S, Si and Na were the elements studied in this work. Two grams of soil sample was digested in nitric acid (HNO<sub>3</sub>) and hydrochloric acid (HCl) HNO<sub>3</sub>/HCl at 100 °C for two hours and diluted. After dilution Integrated Coupled Plasma - Atomic Emission Spectroscopy (ICP-AES) with the instrument Varian 730-ES was used for the determination of the trace elements. Cold Vapour Atomic

**Table 1**  
Sampling locations and distance from industry.

| Sampling Area          | Sample name | Sampling location name             | Coordinates                    | Distance from industry (km) |
|------------------------|-------------|------------------------------------|--------------------------------|-----------------------------|
| Rooty Hill Steelworks  | RT(1.24)    | Blacktown International Sportspark | 33° 46' 19.2"S 150° 51' 18.0"E | 1.24                        |
|                        | RT(1.59)    | May Cowpe Reserve                  | 33° 46' 49"S 150° 49' 57"E     | 1.59                        |
|                        | RT(2.17)    | Nurrangingly Reserve               | 33° 45' 24"S 150° 51' 29"E     | 2.17                        |
|                        | RT(2.89)    | Bungaribee Creek Reserve           | 33° 46' 56.8"S 150° 52' 22.6"E | 2.89                        |
|                        | RT(3.9)     | Harvey Park                        | 33° 44' 38"S 150° 52' 56"E     | 3.9                         |
|                        | RT(3.99)    | Melrose Park                       | 33° 44' 9.1"S 150° 52' 25.4"E  | 3.99                        |
|                        | RT(4.39)    | Whalan Reserve                     | 33° 45' 18"S 150° 48' 3"E      | 4.39                        |
|                        | RT(4.58)    | Colebee Nature Reserve             | 33° 43' 38.9"S 150° 51' 40.5"E | 4.58                        |
|                        | RT(5.81)    | Faulkland Crescent Reserve         | 33° 44' 33"S 150° 54' 5"E      | 5.81                        |
|                        | RT(6)       | Sydney Motorsport Park             | 33° 46' 56.8"S 150° 52' 22.6"E | 6                           |
| Port Kembla Steelworks | PK(1)       | BHP Centenary park                 | 34° 26' 7"S 150° 53' 36"E      | 1                           |
|                        | PK(1.17)    | John Crehan Park                   | 34° 27' 46"S 150° 52' 9"E      | 1.17                        |
|                        | PK(2.75)    | JJ Kelly Park                      | 34° 26' 7"S 150° 53' 36"E      | 2.75                        |
|                        | PK(2.89)    | Semaphore Road                     | 34° 28' 29" S 150° 51' 11"E    | 2.89                        |
|                        | PK(3.04)    | Nan Tien Temple                    | 34° 27' 51"S 150° 51' 8"E      | 3.04                        |
|                        | PK(3.43)    | Mangerton Park                     | 34° 25' 37"S 150° 52' 34"E     | 3.43                        |
|                        | PK(3.5)     | Winnima way                        | 34° 29' 1" S 150° 51' 11"E     | 3.5                         |
|                        | PK(3.8)     | Kelly Street                       | 34° 28' 59"S 150° 51' 11"E     | 3.8                         |
|                        | PK(4.06)    | Brownlee Park                      | 34° 25' 46" S 150° 52' 38"E    | 4.06                        |
|                        | PK(4.98)    | Macedonia Park                     | 34° 28' 41"S 150° 50' 28"E     | 4.98                        |
| Macquarie Park         | MQ          | Macquarie Park sports ground       | 33° 46' 2"S 151° 6' 54"E       | N/A                         |

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