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Atmospherically deposited trace metals from bulk mineral concentrate port operations

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HIGHLIGHTS

- Bulk mineral port operations associated with emissions of metal-rich dusts
- Children's playgrounds and urban areas contaminated on a daily basis
- Lead and nickel dust loadings significantly exceed state and international benchmarks.
- Lead isotopes identify Mount Isa type ores as the primary source of contamination.

GRAPHICAL ABSTRACT

Post-play hand wipe, Headland Park, Townsville, Australia.

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ABSTRACT

Although metal exposures in the environment have declined over the last two decades, certain activities and locations still present a risk of harm to human health. This study examines environmental dust metal and metalloid hazards (arsenic, cadmium, lead and nickel) associated with bulk mineral transport, loading and unloading port operations in public locations and children's playgrounds in the inner city of Townsville, northern Queensland. The mean increase in lead on post-play hand wipes (965 μg/m^2/day) across all sites was more than 10-times the mean pre-play loadings (95 μg/m^2/day). Maximum loading values after a 10-minute play period were 3012 μg/m^2, more than seven times the goal of 400 μg/m^2 used by the Government of Western Australia (2011). Maximum daily nickel post-play hand loadings (404 μg/m^2) were more than 26 times above the *German Federal Immission Control Act* 2002 annual benchmark of 15 μg/m^2/day. Repeat sampling over the 5-day study period showed that hands and surfaces were re-contaminated daily from the deposition of metal-rich atmospheric dusts. Lead isotopic composition analysis of dust wipes ($^{208}Pb/^{207}Pb$ and $^{206}Pb/^{207}Pb$) showed that surface dust lead was similar to Mount Isa type ores, which are exported through the Port of Townsville. While dust metal contaminant loadings are lower than other mining and smelting towns in Australia, they exceeded national and international benchmarks for environmental quality. The lessons from this study are clear — even where operations are considered acceptable by managing authorities, targeted assessment and monitoring can be used to evaluate whether current management practices are truly best practice. Reassessment can identify opportunities for improvement and maximum environmental and human health protection.

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1. Introduction

Outside of mining and smelting and major industrial locations, environmental contamination problems are greatly improved due to the removal of leaded petrol in most countries and the introduction of stringent environmental guidelines. However, the problem of inadvertent contamination of urban and natural environments through related industrial activities such as bulk mineral rail transport and port loading and unloading operations has the potential to add significantly to the burden of exposure (Parshkov et al., 1997; Alaska Department of Environmental Conservation, 2001; Gulson et al., 2009; Kristensen et al., 2015). In terms of the environmental impact from bulk mineral port operations on air quality and dust composition there are limited peer-reviewed studies, particularly in Australia, which is a global leader in metal mining and exportation of its products (Geoscience Australia, 2014).

This study evaluates the extent and significance of dust metal deposition in the city of Townsville, Queensland, where bulk ore and concentrate metalliferous minerals are imported and exported. The study responds to long-standing complaints from sectors of the local Townsville community who have raised concerns with regard to dust deposits and their composition coming from loading and unloading bulk mineral operations at the Port of Townsville (Wolanski and Ducrotoy, 2013). The study examines playgrounds as places of potential exposure because these are readily accessible public places where children interact with the outside environment. Previous work in Port Pirie, South Australia, and Broken Hill, NSW, has demonstrated the potential risk of exposure in playgrounds (Taylor et al., 2013, 2014b).

Children are at higher risk of heavy metal poisoning because of their small body size, developmental stage, and because of their tendency to engage in hand-to-mouth behaviour (Jarup, 2003; National Toxicology Program (NTP), 2012; Needleman, 2004). The effects of metal exposure in children, particularly in the case of lead, include irreversible damage to neurological functioning (National Toxicology Program (NTP), 2012; Needleman, 2004; Taylor et al., 2012a,b). For this reason, identifying childhood exposure pathways is critical in order to interrupt the cycle of adverse health effects associated with environmental metals. Lead is the specific focus for this study because of its well-known adverse effects on human health.

Mineral transport operations at the Port of Townsville include the importation of nickel ore and zinc concentrate and the export of copper, lead and zinc concentrate from a range of sources (Port of Townsville Limited, 2012). Ores are moved in and out of the Port via rail, with nickel ore being unloaded in the uncovered dock area and then railed in open wagons (Supplementary Figs. S1 and S2). By contrast copper, lead and zinc concentrates are railed in covered wagons, unloaded in closed sheds with the minerals being loaded into the hull of ships via a closed conveyor belt system. With respect to the metal ores being transported, lead in particular, has a well-known toxicological profile, while the human health effects of nickel are relatively less well understood (ATSDR, 2011). Nevertheless, nickel has known adverse outcomes on respiratory health, can increase dermatitis, is considered to be a human carcinogen and can affect neonatal development (ATSDR, 2011).

A Queensland Government study (Queensland Government, 2010) reported on a range of aerosol contaminants in the Townsville environment, including total suspended particles (TSP, μg/m^3), and airborne concentrations (μg/m^3) of arsenic, cadmium, lead, manganese, nickel, vanadium and mercury. In terms of dust deposition, only total insoluble dust (μg/m^2/day) and lead concentrations in those deposited dusts (lead μg/m^2/day) were reported.

This study presents the results from surface dust and post-play hand wipe dust samples collected from six locations across Townsville. The study focuses on atmospheric lead deposition but also reports on the post-play hand wipe loadings (μg/m^2) of arsenic, cadmium and nickel (cf. Taylor et al., 2013, 2014b). These elements formed part of the Queensland Government's (2010) air quality study (measured primarily as metals in μg/m^3) and are included as part of regular air quality monitoring programmes in the city (Queensland Government, 2014a). This study asks 3 main questions:

1. What are the spatial and temporal distributions of dust-metal contamination in playgrounds around inner Townville and how, if at all, do they relate to the operations at the Port?
2. What are the risks to public health?
3. What actions are required to reduce the risk of exposure?

2. Methods

The methods and approach undertaken in this study of surface dusts are similar to studies published previously on the Australian cities of Port Pirie and Broken Hill (Taylor et al., 2013, 2014b). A brief description of the field methods undertaken for this study is provided below.

2.1. Study site and field sampling

This study examined the atmospheric deposition of metallic dusts from port operations in the city of Townsville in North Queensland. Townsville is Australia's largest tropical city with an urban population of 158,000 with 21.4% under 14 years of age (Australian Bureau of Statistics, 2011). The city's business centre is at the edge of the Great Barrier Reef and is proximal to the Port of Townsville, which processes a diverse range of bulk commodities. These commodities are dominated by nickel ore imports (35%), oil and petroleum imports (9%), cement imports (4%), mineral concentrate exports (16%), sugar exports (9%), fertilizer exports (8%) and refined mineral product exports (8%) (Port of Townsville Limited, 2013). Average rainfall is ~1100 mm with most of it falling in the 'wet season' between November and March (Bureau of Meteorology, 2014a). Relevant to this study, the prevailing wind direction is dominated by south easterly morning winds and north easterly afternoon winds, that move across from the direction of the Port towards the city (Bureau of Meteorology, 2014b).

Dust metals were sampled from six flat surfaces across Townsville city for arsenic, cadmium, lead and nickel loadings from 26th September to 1st October 2014. The six sample surfaces were wiped before the start of the daily playground sampling programme. The purpose of this 'pre-wipe' (conducted 26th September), was to establish a historical measure of longer-term deposition as compared to the daily 24-hour values that were collected subsequently via the surface wipes. The length of time these 'pre-wiped' surfaces had been exposed to atmospheric loading without prior wiping or any cleaning or washing from precipitation is unknown. Subsequent surface wipes ($n = 30$) provided a measure of the 24-hour metal and metalloid (hereafter referred to as metals) loadings over the remaining study period from 27th September to 1st October, 2014. Sample sites were determined partly by access to suitable playgrounds, paint-free surfaces, locations proximal and downwind from the Port and existing environmental data for Townsville (Queensland Government, 2010, 2014a).

The surfaces selected for sampling were exposed to the atmosphere and were considered unlikely to be disturbed by users of the playgrounds. The surfaces at Sister Kenny Park, Headland Park, Soroptimist Park, Queens Park Oval and Anzac Memorial Park were stainless steel surfaces of council rubbish bins or other utility boxes. At Reid Park similarly constructed surfaces were not available so a flat surface on top of the playground equipment was marked out and sampled for surface dust metal loading.

Surface areas were demarked using masking tape and the dimensions measured. Wiped surface areas were 30 cm × 30 cm, except where suitably sized surfaces were unavailable: Reid Park — 60 cm × 13 cm; Queens Park Oval — 40 cm × 24 cm; Anzac Memorial Park — 30 × 29 cm. Metals measured in the wipe samples (μg/wipe) were subsequently standardised to μg/m^2, to allow comparison with a range of relevant surface dust standards. Dust wipes were collected using the method