Science of the Total Environment 593–594 (2017) 202–210

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

The influence of lead content in drinking water, household dust, soil, and paint on blood lead levels of children in Flin Flon, Manitoba and Creighton, Saskatchewan

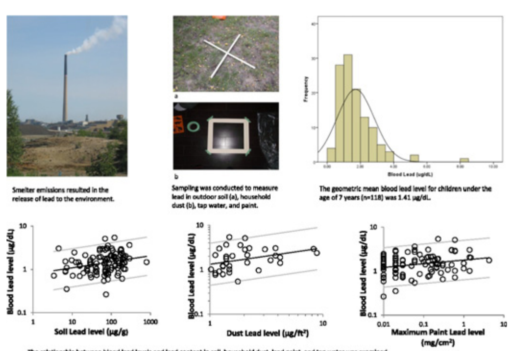
Adam M. Safruk [a,*], Erin McGregor [a], Melissa L. Whitfield Aslund [a], Paul H. Cheung [a], Celine Pinsent [b], Blair J. Jackson [c], Alan T. Hair [d], Murray Lee [e], Elliot A. Sigal [a]

[a] Intrinsik Corp., 6605 Hurontario Street, Suite 500, Mississauga, Ontario L5T 0A3, Canada
[b] Pinrae Research Associates, 56 de Castillou, Gatineau, Québec J8T 5S6, Canada
[c] University of Ottawa, 550 Cumberland, Ottawa, Ontario K1N 6N5, Canada
[d] Hudbay Minerals Inc., 25 York Street, Suite 800, Toronto, Ontario M5J 2V5, Canada
[e] Habitat Health Impact Consulting, #310, 908 17th Avenue SW, Calgary, Alberta T2T 0A3, Canada

HIGHLIGHTS

- Elevated levels of environmental lead were measured in a smelter community.
- Biomonitoring of children identified a geometric mean BLL of 1.41 μg/dL.
- Lead was measured in co-located soil, household dust, tap water, and paint.
- Soil, dust, paint, and age of home were significantly correlated to BLLs.
- Variability in BLLs was poorly explained by environmental factors alone.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 23 January 2017
Received in revised form 14 March 2017
Accepted 15 March 2017
Available online 24 March 2017

Editor: D. Barcelo

Keywords:
Biomonitoring
Blood lead levels
Drinking water
Paint
Soil
Household dust

ABSTRACT

Lead exposure continues to be an important health issue despite the general removal of lead sources in commercial and industrial applications. Low levels of lead exposure have been found to produce adverse neurodevelopmental effects in children with no evidence that a threshold exists for this critical endpoint. Blood lead levels (BLLs) were measured in children ($n = 118$) under the age of 7 years in the northern Canadian smelter community of Flin Flon, Manitoba and Creighton, Saskatchewan. An environmental sampling component was included to examine the relationship between lead content in outdoor soil, household dust, tap water, and paint within a given household and the corresponding BLLs in participating children. The geometric mean (GM) BLL for study participants was 1.41 μg/dL. Blood lead levels varied slightly by age category with the lowest levels found among the children under age 2 (GM = 1.11 μg/dL) and the highest levels found among children between 2 and 3 years of age (GM = 1.98 μg/dL). Results from the multivariate modeling indicated that BLLs had a significant positive association with the age of housing ($p < 0.05$), with children living in households constructed prior to 1945 being more likely to have higher levels ($p = 0.034$). Outdoor soil (GM = 74.7 μg/g), household dust from kitchen floors (GM = 1.34 μg/ft^2), and maximum household lead paint were found to be significantly correlated ($p < 0.05$) to BLLs. Although a statistically significant association between concentrations

Abbreviations: BLL, blood lead levels; GM, geometric mean; HHRA, human health risk assessment; HUD, Housing and Urban Development; IVBA, in vitro bioaccessibility; PBET, physiological-based extraction tests; RBA, relative bioavailability; UCLM, upper confidence limit on the mean; XRF, X-ray fluorescence.

* Corresponding author.
E-mail address: asafruk@intrinsik.com (A.M. Safruk).

http://dx.doi.org/10.1016/j.scitotenv.2017.03.141

of lead in these household media and the corresponding BLLs exists, the variability in BLLs was poorly explained by these factors alone ($r^2 = 0.07$, 0.12 and 0.06 for soil, household dust, and paint, respectively). Lead concentrations in flushed (GM = 0.89 μg/L) and stagnant (GM = 2.07 μg/L and 1.18 μg/L) tap water samples were not significantly correlated ($p > 0.05$) to BLLs.

1. Introduction

The health effects of lead have been extensively studied and the most sensitive targets of toxicity in humans identified as the developing nervous system and the cardiovascular, renal, and hematological systems (ATSDR, 2007). In children, adverse neurodevelopmental effects, including decreased cognitive function, impulsivity, and inattention, have been found to occur at blood lead levels (BLLs) < 10 μg/dL, with no clear evidence of a threshold (Canfield et al., 2003; Lanphear et al., 2005; U.S. EPA, 2006). The pooled analysis conducted by Lanphear et al. (2005) of data from seven cohort studies provides strong evidence of the non-linear relationship between BLL and reduced intelligence quotient (IQ), with the largest IQ decrements observed for children with a maximal BLL of <7.5 μg/dL. Correspondingly, various international regulatory agencies have moved from a BLL of concern of 10 μg/dL based on health risks, to values established using a normative approach such as the 97.5th percentile (5 μg/dL) for U.S. children (CDC, 2012) or the 95th percentile (3.5 μg/dL) for children in Germany (Schulz et al., 2009). Children are more sensitive to the effects of lead than adults as a result of comparatively higher absorption from ingested materials and lower urinary excretion (Health Canada, 2013). Further, children have a higher potential for environmental exposure to lead than adults due to normal child-specific activities such as frequent hand-to-mouth contact resulting in additional opportunities for intake of lead-contaminated media such as household dust, soil, and paint chips (Health Canada, 2013).

Although ongoing efforts to reduce lead content in food, water, consumer products, and commercial and industrial applications have been effective in lowering BLLs, exposure to lead continues to be a significant concern given the non-threshold nature of effects. Drinking water distribution systems and plumbing materials, particularly those existing prior to 1990, represent a potential source of lead in drinking water (Health Canada, 2013). In Canada, lead was permitted for use in service lines until 1975 and in solder until 1986 (Health Canada, 2016). In paint, large quantities of lead were added either as a pigment or for improved performance through the 1960s, with concentrations progressively decreasing since the mid-1970s via both regulated restrictions as well as voluntary actions by paint manufacturers (Health Canada, 2013). The deterioration of lead-containing paint in older homes contributes to elevated concentrations in both outdoor soil and household dust (Lanphear et al., 1998a). Despite a phase-out of lead additives in gasoline in the 1980s and a ban of leaded gasoline for motor vehicles in the U.S. and Canada in the 1990s, elevated levels of lead in soil are largely associated with historical automobile exhaust in older urban environments (ATSDR, 2007; Mielke, 1999). Contaminated soil can then be tracked in to home environments where it can increase lead loadings in household dust (Richardson et al., 2011; Zahran et al., 2011).

A number of studies have identified positive associations between BLLs and lead content in water (Bell et al., 2011; Etchevers et al., 2014; Lanphear et al., 1998b; Levallois et al., 2013; Richardson et al., 2011), household dust (Bell et al., 2011; Dixon et al., 2009; Gaitens et al., 2009; Lanphear et al., 1998a, 1998b; Levallois et al., 2013; Wilson et al., 2007), and soil (Bell et al., 2011; Lanphear et al., 1996; Lanphear et al., 1998b; Mielke et al., 1997). While many of the strong correlations identified in these studies have focused on urban environments or smelter communities with highly elevated concentrations of environmental lead, significant relationships have also been observed between BLLs and relatively low lead concentrations in these media (Gaitens et al., 2009; Lanphear et al., 1998a; Mielke et al., 1999; Mielke et al., 2007).

The city of Flin Flon, located in west-central Manitoba, Canada, sharing the provincial border with the city of Creighton, Saskatchewan, has been the site of a base metal mining and smelting complex since the 1930s. A number of different metals have been emitted at the smelter, including copper, lead, zinc and cadmium, in addition to by-products such as gold, silver and selenium (Henderson et al., 1998; Manitoba Conservation, 2007). Concentrations of several elements in surface soils in this area, including lead, were found to exceed the Canadian Council of Ministers of the Environment (CCME) soil quality guidelines for human health (CCME, 1999).

A comprehensive study was completed to determine if exposure to lead and other elements posed an increased health risk to residents. This included a human health risk assessment (HHRA) conducted between July 2007 and April 2010, which triggered an initial biomonitoring study conducted in fall 2009. The results of the biomonitoring study indicated that children may have an atypical source of exposure to lead in the community (BLL GM = 2.73 μg/dL; 13% > 5 μg/dL). A second biomonitoring study was conducted in fall 2012, approximately 26 months after the closure of the smelter in June 2010. In addition to identifying changes in BLLs following the smelter closure and the implementation of various risk management measures, a component of the follow-up study was to examine the impact of various environmental media, including outdoor soil, household dust, tap water and lead paint, on the BLLs of Flin Flon-area children. Environmental samples were collected from the households of study participants. The relationship between lead content in co-located environmental samples and children's BLLs is presented here.

2. Methods

2.1. Study design

The study consisted of three main components: the collection of household information via an in-home survey, the collection and analysis of blood samples from children under 7 years of age at a designated clinic, and the collection and analysis of environmental samples from the households of study participants. The study was commissioned by Hudson Bay Mining and Smelting Co., Limited (HBMS) and overseen by a Technical Advisory Committee comprised of representatives of Canadian federal and provincial health and environmental authorities, as well as a Community Advisory Committee comprised of members of the public. Study protocols also received ethics approval by the Institutional Review Board Services in compliance with Health Canada regulations and the Tri-Council Policy Statement for Ethical Conduct of Research Involving Humans.

Recruitment of participants and data collection occurred in September and October 2012. The chosen study period allowed for BLLs to be measured immediately following the summer months, the period hypothesized that children would have the highest exposure to soil as a result of outdoor activity. This timing also coincides with the return to school and work which facilitated participation in the study.

2.2. Participant recruitment

The sampling plan was developed based on stratification by geographical area and age of residents. The Flin Flon area was divided into