Science of the Total Environment 551–552 (2016) 622–630

Contents lists available at ScienceDirect

Science of the Total Environment

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

Potential sources and racial disparities in the residential distribution of soil arsenic and lead among pregnant women

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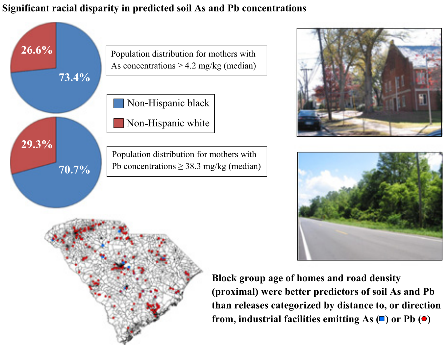
HIGHLIGHTS

- Small but persistent racial disparity in soil As and Pb concentration distribution.
- Neighborhood deprivation did not modify racial disparity in distribution of soil As and Pb.
- Older homes and road density were strongly associated with soil As and Pb.
- Industries categorized by distance/direction were not associated with soil As and Pb.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 25 October 2015
Received in revised form 2 February 2016
Accepted 2 February 2016
Available online 18 February 2016

Editor: D. Barcelo

Keywords:
Neighborhood deprivation
Racial disparity
Residential soil metals
Industrial facility distance/direction
Maternal exposure
Road density

ABSTRACT

Exposure to arsenic (As) or lead (Pb) has been associated with adverse health outcomes, and high-risk populations can be disproportionately exposed to these metals in soils. The objectives of this study were: to examine if predicted soil As and Pb concentrations at maternal residences of South Carolina (SC) low-income mothers differed based on maternal race (non-Hispanic black versus white), to examine whether differences in predicted residential soil As and Pb concentrations among black and white mothers differed by socioeconomic status (SES), and to examine whether such disparities persisted after controlling for anthropogenic sources of these metals, including direction from, and distance to industrial facilities. Kriged soil As and Pb concentrations were estimated at maternal residences in 11 locations in SC, and models with maternal race and individual and US Census block group level SES measures were examined. US Environmental Protection Agency Toxics Release Inventory (TRI) facility As and Pb releases categorized by distance and direction to block groups in which mothers resided were also identified, as were proxy measures for historic use of leaded gasoline (road density) and Pb-based paint (categories of median year home built by US Census block group). Consistent racial disparities were observed for predicted residential soil As and Pb concentrations, and the disparity was stronger for Pb than As (betas from adjusted models for black mothers were 0.12 and 2.2 for As and Pb, respectively, all $p < 0.006$). Higher road density and older homes in block groups were more closely associated with higher predicted soil As and Pb concentrations than on-site releases of As and Pb categorized by facility location. These findings suggest that non-Hispanic black mothers in this study population had elevated residential As and Pb soil concentrations, after adjusting for SES, and that soil As and Pb concentrations were not associated with recent industrial releases.

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http://dx.doi.org/10.1016/j.scitotenv.2016.02.018
0048-9697/

1. Introduction

Exposure to metals in soils has the potential to impact human health, and metals such as arsenic (As) and lead (Pb) are pervasive and long-lived in this environmental medium (Aelion et al., 2014; Nriagu and Pacyna, 1988). While As occurs naturally in the environment, elevated soil concentrations are often due to inputs from anthropogenic sources, such as mining, smelting, and other industrial activities (Hinwood et al., 2004; Luo et al., 2008). Arsenic can also leach into soils from chromated copper arsenate (CCA) treated wood (Mielke et al., 2010; Shalat et al., 2006), which was routinely used in residential areas until the early 2000s. Elevated concentrations of Pb in soils are most often the result of anthropogenic inputs, especially in residential locations. Soil Pb concentrations are strongly associated with the historic use of leaded gasoline (Datko-Williams et al., 2014; Kayhanian, 2012) and lead-based paints (Mielke et al., 2008; Mielke and Reagan, 1998), as well as industrial practices (Landsberger et al., 1999; Luo et al., 2009).

Arsenic or Pb exposure can elicit neurological (Ahamed et al., 2008; Bellinger, 2008; Llop et al., 2013; Mukherjee et al., 2005; Naujokas et al., 2013; Pabello and Bolivar, 2005), and cardiovascular impacts (Balakumar and Kaur, 2009; Kim et al., 2008; Moon et al., 2013; Poreba et al., 2011), and contribute to adverse reproductive outcomes (Ahamed et al., 2009; Ahmad et al., 2001; Ahmed et al., 2011; Jelliffe-Pawlowski et al., 2006; Mukherjee et al., 2005; Myers et al., 2010; Torres-Sanchez et al., 1999; Yang et al., 2003). Contaminated soils can become a component of household dust (Hinwood et al., 2004; Petrosyan et al., 2004), and the contribution of soil to house dust can range from a third to half (Calabrese and Stanek, 1992; StellaLevinson, 2008). Since the dust can then be inadvertently ingested or inhaled (Caussey et al., 2003), monitoring As and Pb soil contamination, especially in residential areas, can be important for preventing exposure and associated negative health outcomes in these settings.

High-risk populations, such as those of racial/ethnic minorities and lower socioeconomic status (SES), have been found to be disproportionately exposed to As and Pb in soils (Aelion et al., 2012, 2013; Calderon et al., 2003; Calderon et al., 2004; Campanella and Mielke, 2008; Diawara et al., 2006; Mielke et al., 1999) and are potentially more susceptible to any associated health impacts. This may result from living in neighborhoods located on prior industrial sites, or in close proximity to industries and/or high volume roadways (McClintock, 2012; Pellow, 2000). This highlights the importance of examining neighborhood features when assessing high-risk populations and their potential exposure to environmental contaminants like As and Pb.

This study used environmental sampling to examine whether a racial disparity existed in predicted soil As and Pb concentrations at the residences of mothers during pregnancy who gave birth while enrolled in the South Carolina (SC) Medicaid program (a federally funded insurance program for low-income families) from 1996 to 2001 (Aelion et al., 2008, 2009a, 2009b, 2012, 2013, 2014; Davis et al., 2009, 2014; Liu et al., 2010; McDermott et al., 2011, 2014; Zhen et al., 2008, 2009). We controlled for individual SES (maternal education and receipt of federally-provided food assistance commonly referred to as food stamps) and neighborhood SES, measured by neighborhood deprivation, a composite measure of Census variables with higher values indicating more deprivation. It was hypothesized that non-Hispanic black mothers would have higher predicted soil As and Pb concentrations at their residence relative to non-Hispanic white mothers, after controlling for SES, and that SES measures would be positively associated with higher predicted soil As and Pb concentrations. It was also hypothesized that neighborhood deprivation would modify the association between predicted soil As and Pb concentrations and maternal race, because non-Hispanic black mothers living in neighborhoods with higher deprivation (as compared to non-Hispanic black mothers in neighborhoods with lower deprivation) would have higher predicted soil As and Pb concentrations in their neighborhoods.

Proximal and distal sources of As and Pb were also expected to impact concentrations in residential soils, and if racial/ethnic minorities lived in closer proximity to more sources, then their residential soil metal concentrations were expected to be higher. Sources investigated included road density and median home age (proximal) at the neighborhood level, as well as direction and distances of maternal residences from SC industrial facilities releasing As and/or Pb on-site (distal) categorized by median average annual release of As or Pb. It was hypothesized that living in close proximity, and within the path of prevailing winds (e.g., in the southwest or northeast direction) of As- and Pb-emitting industrial facilities with cumulative on-site releases at or above the median for all TRI facilities in the state for the time period of interest would be associated with higher predicted soil As and Pb concentrations at maternal residences, and that the racial disparity in potential exposure to As and Pb in soils would no longer be apparent after accounting for these sources in the analysis. Associations between soil metal concentrations and distance from industrial facilities have been reported (Aelion et al., 2009b; Bermudez et al., 2009; Douay et al., 2007). We chose to further examine the relation between soil metal concentrations and locations of industries by categorizing them by both the direction and distance to the location of potential exposure, and cumulative on-site releases dichotomized at the median.

2. Methods

2.1. Study design and population

This study utilized data sets from a retrospective cohort study initiated in 2006 that examined associations between maternal exposure to residential soil metal concentrations and both intellectual disability (ID) and developmental delay (DD) among children in a Medicaid population of mother–child pairs giving birth to singletons (Kim et al., 2009, 2010; Liu et al., 2010; McDermott et al., 2011, 2014; Zhen et al., 2008, 2009). Medicaid, a federal assistance program that is managed by individual states, offers insurance coverage to income qualifying, medically verified pregnant women throughout pregnancy, and up to 60 days postpartum (SC DHHS, 2013). Information on mothers and children who were enrolled in SC Medicaid during pregnancy from 1996 to 2001 was obtained from SC birth certificates, Medicaid billing records, and the SC Department of Social Services (SC DSS). United States (US) Census 2000 block group level data for SC were also utilized.

Eleven areas in SC were selected for sampling based on prevalence of ID/DD in SC (McDermott et al., 2011, 2014). Nine of these areas had an ID/DD prevalence that was significantly higher than the statewide background prevalence (3.5%) for all Medicaid mothers (Zhen et al., 2008). The areas were identified using Bayesian local-likelihood cluster analysis of geocoded maternal residences by month of pregnancy (Zhen et al., 2008, 2009), ranged in size from 60 to 490 km^2 (mean of 130 km^2) and were sampled from 2006 to 2011. The exact geographic locations of the maternal addresses and sampling areas were undisclosed to protect participant confidentiality. The sampling areas were located throughout SC, covered 1,500 km^2, and are representative of different land uses and categories (Davis et al., 2014); five were classified as urban, five as rural, and the largest sampling area was mixed urban/rural.

In each of the 11 areas, a regular 120-node grid was laid out and single grab surface soil samples of approximately 25 g were collected as close to each grid node as possible. The distances between sampling locations were approximately 0.5 km; for the largest sampling area, distances were 3 km. Soil sample locations were selected to maximize the probability of collecting undisturbed native soil with no visible contamination or previous development. Samples were analyzed for total As and Pb (in mg/kg dry weight) using inductively coupled plasma optical emission spectroscopy (ICP-OES) by an independent environmental laboratory. Both the soil sampling protocol and metal analysis procedures have been previously described in detail (Aelion et al.,