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Spatiotemporal dynamic transformations of soil lead and children's blood lead ten years after Hurricane Katrina: New grounds for primary prevention

Howard W. Mielke [a,*], Christopher R. Gonzales [a], Eric T. Powell [b], Paul W. Mielke Jr. [c]

[a] Department of Pharmacology, Tulane University School of Medicine, New Orleans, LA, USA
[b] Lead Lab Inc., Department of Pharmacology, Tulane University New Orleans, LA, USA
[c] Department of Statistics, Colorado State University, Fort Collins, CO, USA

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ABSTRACT

Background: The contribution of lead contaminated soil to blood lead, especially as it is a large reservoir of lead dust, has been underestimated relative to lead-based paint. On 29 August 2005 Hurricane Katrina flooded and disrupted habitation in New Orleans. Soil and blood lead were mapped prior to Katrina. This unique study addresses soil and blood lead conditions pre- and ten years post-Katrina and considers the effectiveness of low lead soil for lead exposure intervention.
Objectives: Comparison of soil and blood lead levels pre- and ten years post-Katrina to evaluate and assess the impact of flooding on soil and blood lead at the scale of the city of New Orleans.
Methods: Post-Katrina soil and blood lead data were stratified by the same census tracts ($n = 176$) as pre-Katrina data. This unique city scale data-set includes soil lead ($n = 3314$ and 3320, pre- vs. post-Katrina), blood lead ($n = 39{,}620$ and 17,739, pre- vs. post-Katrina), distance, and changes in percent pre-1940 housing. Statistical analysis entailed permutation procedures and Fisher's Exact Tests.
Results: Pre- vs. ten years post-Katrina soil lead median decreased from 280 mg/kg to 132 mg/kg, median blood lead decreased from 5 μg/dL to 1.8 μg/dL, respectively. Percent pre-1940 housing did not change significantly (P-value = 0.674). Soil and blood lead decrease with distance from the center of New Orleans. Except for age-of-housing results, P-values were extremely small ($<10^{-12}$).
Conclusions: Ten years after Katrina, profound changes in soil lead and children's blood lead occurred in New Orleans. Decreasing the lead on soil surfaces reduces children's interaction with lead dust, thus underscoring soil as a major of source of exposure.

1. Introduction

Following Hurricane Katrina, there were enormous challenges for rebuilding New Orleans and great hopes for the future of community health (DeSalvo, 2016). One invisible feature of New Orleans, recognized before the Hurricane, was the uneven accumulation of inorganic and organic pollutant chemicals in the soils of communities across the city (Copeland, 2012; Mielke et al., 2004; Wang et al., 2004). The current study compares New Orleans communities before and ten years after the 29 August 2005 storm surge from Hurricanes Katrina and a month later, Rita, which in combination flooded 80% of Orleans Parish (Parish = U.S. County). The focus is on a single element, lead (Pb). Blood lead is a biomarker of children's Pb exposure (CDC, 2014). The clinical health effects of Pb are well documented in the human population (CDC, 2012; NIOSH, 2013).

The extent of soil lead (SPb) contamination of urban soils is documented by multiple urban studies (Datko-Williams et al., 2014; Mielke et al., 2011a). A unique feature of this study is that it includes repeated surveys of SPb and blood lead (BPb) at the scale of US census tracts (communities constituted with an average of 4000 people) for the entire city. This is in contrast to addressing lead contamination at the scale of a single residence in terms of abatement, renovation or disclosure, it should be emphasized that lead exposure is a public health problem shared by communities, encompassing entire neighborhoods, multiple residences and associated businesses, parks, schools, streets, and open spaces. An individual residence influences and is in turn influenced by the movement of lead in dust beyond property boundaries (Filippelli and Laidlaw, 2010; Laidlaw and Filippelli, 2008; Laidlaw et al., 2014; Zahran et al., 2013).

For background information regarding New Orleans research there have been four SPb surveys completed. Survey One, completed in 1991, was a follow-up to studies conducted in Baltimore and cities in Minnesota (Mielke, 1991) and provided the environmental context for comparing age-of-housing, SPb, and BPb within Orleans and Lafourche

* Corresponding author.
E-mail address: hmielke@tulane.edu (H.W. Mielke).

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Parishes (equivalent to U.S. counties). Strong associations were found for SPb, age-of-housing and BPb. The findings suggested that combining SPb into the lead-based paint intervention protocol would be complementary for primary prevention to reduce BPb (Mielke et al., 1997). Survey Two completed in 2001, revealed the consistency of SPb within communities (Mielke et al., 2005a). It also provided the basis to study the seasonal relationship between SPb and BPb in three different climates: Syracuse, NY, Indianapolis, IN, and New Orleans, LA where Pb contaminated soil became resuspended into the ambient air during late summer and early fall resulting in an increased children's BPb (Laidlaw et al., 2005).

Survey Three, collected immediately after Katrina, was conducted in 16% of the census tracts revealing a SPb decrease due to low Pb sediment deposited on New Orleans by the storm surge (Zahran et al., 2010). The results were consistent with other findings (Plumlee et al., 2006a, 2006b). Noting corresponding BPb reductions, Zahran et al. (2010), hypothesized that children's future risk and BPb would undergo a downward trend. However, another hypothesis proposed the opposite outcome, i.e., that hurricane cleanup and renovation of housing was haphazard and not lead-safe, placing future children at increased risk for exposure (Rabito et al., 2012). Survey Four, the present study, provides observations about SPb and children's BPb exposure in communities ten years after Katrina. It exploits the storm surge and flooding of 80% of New Orleans as a defining environmental event allowing for the evaluation of the spatiotemporal dynamic transformations of SPb and BPb before and after the event (McQuaid and Schleifstein, 2006).

The Louisiana Environmental Epidemiology and Toxicology Program cooperated in evaluating SPb, BPb, and age-of-housing (Mielke et al., 1997). The present study continues collaboration with the Louisiana Healthy Homes and Childhood Lead Prevention Program of the Department of Health and Hospitals (Louisiana Department of Health and Hospitals, 2015). The Louisiana Healthy Homes and Childhood Lead Poisoning Prevention Program assembles and maintains children's BPb records for the State.

Our purpose was to evaluate the spatiotemporal dynamic transformation of SPb and BPb outcomes in New Orleans ten years after Katrina from the perspective of "the metabolism of the city" whereby inputs, outputs, and transformations of energy and materials drive the functioning and the quality of cities (Wolman, 1965). Over half (~54%) of the human population and 62.7% of the US population inhabits cities and an essential requirement is to ensure that cities are safe environments for everyone (Cohen et al., 2015; UN, 2014). The dynamics of New Orleans encompass age-of-housing and distance factors that relate to the quality of the environment and the health of children in urban communities. In addition to the core area of Orleans Parish, selected areas of the outlying metropolitan Jefferson and St. Bernard Parishes were included in the SPb and BPb survey.

One major objective for the medical community is to find methods for reducing children's BPb because currently there is no effective intervention (Yeoh et al., 2014). The contribution of SPb to childhood BPb and disease has been termed "insufficiently characterized" by the public health community and "insufficient evidence" to evaluate SPb abatement on BPb (Levin et al., 2008; Yeoh et al., 2014). Devising an effective SPb intervention for reducing BPb of young children is a major research question that requires addressing in order to improve knowledge about interventions for primary Pb prevention for young children.

2. Methods

2.1. Soil lead data

The same personnel, Eric T. Powell and Christopher R. Gonzales, conducted Surveys Two and Four. For each Survey, recognizing that the soil surface is the zone of contact for children, the top ~2.5 cm (~1 in.) of soil was systematically collected from Orleans, Jefferson, and St. Bernard Parishes in Louisiana. Dry weather permitting, soil sample collecting was conducted throughout the entire year. The 1990 census tract (CTs) boundaries were used to maintain consistent stratification for each of the surveys (U.S. Census, 1993). Wherever possible, 19 samples per CTs were collected as previously described (Mielke et al., 2005a). All samples were collected (and archived) from residential areas of the CTs. The SPb and BPb data available for matching in both pre- and post-Katrina surveys were 176 CTs. These CTs included 163 from Orleans, 5 from Jefferson, and 8 from St. Bernard Parish. This amounts to 61% of CT's collected in Survey Two (Fig. 1). For the pre-Katrina (1998–2000) survey, 3314 soil samples were included and, correspondingly, 3320 soil samples were collected for the post-Katrina (2013–2015) Survey Four.

The SPb surveys used screening methods developed from experience with previous studies (Mielke et al., 1983, 1989, 2005a). The soil samples were geocoded by address matching using Google Maps and integrated into Arc-GIS 10 (Environmental Systems Research Institute). Lead extraction was conducted by leaching soil at room temperature with 1 M nitric acid. For urban soil samples the method strongly correlates and is quantitatively similar to "total" Pb extraction methods that employ boiling concentrated nitric acid (Mielke et al., 1983; US EPA, 1996). For extraction, 0.4 g of air dry, 2 mm sieved soil was mixed with 20 ml of 1 M HNO_3 in a 50 ml polypropylene tube, and agitated at low speed on an Eberbach reciprocal shaker for 2 h at room temperature (~22 °C). The samples were then centrifuged for 10 min at 1600 $\times g$ and filtered using Fisherbrand qualitative P4 paper. The filtrate was stored in 20 ml High Density Polyethylene with Polypropylene cap scintillation vials until analyzed.

A Spectro CIROS CCD (Spectro Analytical Instruments) inductively coupled plasma optical emissions spectrometer (ICP-OES) was used to analyze samples for Pb and other leached trace metals. The ICP-OES was calibrated with National Institute of Standards and Technology (NIST) traceable metal standards. For Quality Assurance/Quality Control measures, a NIST traceable calibration check standard, a sample blank, an in-house laboratory reference soil (New Orleans City Park collected in 1996), and one duplicate sample extraction were included in the analysis for every 19 samples.

2.2. Children's (≤6 years old) blood lead data

Blood lead data were provided by the Louisiana Healthy Homes and Childhood Lead Poisoning Prevention Program. The BPb data from individual children were not identifiable. The BPb data were sorted to eliminate duplicates and stratified by CTs. Only CTs with at least five unique individual children's BPb were included for this study. As shown in Table 1, 39,620 BPb test results, stratified by 176 CTs, were available for pre-Katrina (2000–2005) and 17,739 individual BPb results were available for ten years post-Katrina (2011–2015) for matching with the SPb data.

2.3. Age-of-housing

Age-of-housing is regularly used as a surrogate for the presence of lead-based paint. Previous research demonstrated a strong association between BPb and percentage of housing built pre-1940 (Mielke et al., 1989, 1997). Table 1 shows CT data partitioned by median values of percent pre-1940 housing pre- and post-Katrina. The pre-Katrina age-of-housing data is from the 2000 U.S. Census (US Census, 2000) and post-Katrina from the American Community Survey (2015).

2.4. Distance from the City Center and SPb, BPb, and age-of-housing

Previous research in Baltimore, Minnesota, and Detroit demonstrated a strong distance decay pattern of SPb from the Main Post Office (MPO) for each city. This pattern has been observed in many urban SPb studies published between 1970 and 2012 (Datko-Williams et al., 2014). For this study, we evaluated the associations of SPb, BPb, and