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Environmental and health disparities in residential communities of New Orleans: The need for soil lead intervention to advance primary prevention ☆

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

[a] Department of Pharmacology, Tulane University School of Medicine, 1430 Tulane Avenue-SL 83, New Orleans, LA 70112-2632, United States
[b] Department of Chemistry, Tulane University, New Orleans 70118, United States
[c] Lead Lab, Inc., New Orleans, LA 70179-1125, United States
[d] Department of Statistics, Colorado State University, Fort Collins, CO 80523-1877, United States

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ABSTRACT

Urban environments are the major sites for human habitation and this study evaluates soil lead (Pb) and blood Pb at the community scale of a U.S. city. There is no safe level of Pb exposure for humans and novel primary Pb prevention strategies are requisite to mitigate children's Pb exposure and health disparities observed in major cities. We produced a rich source of environmental and Pb exposure data for metropolitan New Orleans by combining a large soil Pb database (n = 5467) with blood Pb databases (n = 55,551 pre-Katrina and 7384 post-Katrina) from the Louisiana Childhood Lead Poisoning Prevention Program (LACLPPP). Reanalysis of pre- and post-Hurricane Katrina soil samples indicates relatively unchanged soil Pb. The objective was to evaluate the New Orleans soil Pb and blood Pb database for basic information about conditions that may merit innovative ways to pursue primary Pb exposure prevention. The city was divided into high (median census tract soil ≥ 100 mg/kg) and low Pb areas (median census tract soil < 100 mg/kg). Soil and blood Pb concentrations within the high and low Pb areas of New Orleans were analyzed by permutation statistical methods. The high Pb areas are toward the interior of the city where median soil Pb was 367, 313, 1228, and 103 mg/kg, respectively for samples collected at busy streets, residential streets, house sides, and open space locations; the low Pb areas are in outlying neighborhoods of the city where median soil Pb was 64, 46, 32, and 28 mg/kg, respectively for busy streets, residential streets, house sides, and open spaces (P-values $< 10^{-16}$). Pre-Katrina children's blood Pb prevalence of ≥ 5 μg/dL was 58.5% and 24.8% for the high and low Pb areas, respectively compared to post-Katrina prevalence of 29.6% and 7.5%, for high and low Pb areas, respectively. Elevated soil Pb permeates interior areas of the city and children living there generally lack Pb safe areas for outdoor play. Soil Pb medians in outlying areas were safer by factors ranging from 3 to 38 depending on specific location. Patterns of Pb deposition from many decades of accumulation have not been transformed by hastily conducted renovations during the seven year interval since Hurricane Katrina. Low Pb soils available outside of cities can remedy soil Pb contamination within city interiors. Mapping soil Pb provides an overview of deposition characteristics and assists with planning and conducting primary Pb exposure prevention.

1. Introduction

This paper concerns the chemical nature of the city of New Orleans, U.S.A., and related health effects on individuals and communities within the urban setting. We focused on lead (Pb) because blood Pb data is available as a measure of children's exposure. No acceptable blood Pb exposure has been identified that is free from deleterious health effects (Advisory Committee on Childhood Lead Poisoning Prevention, 2012; Centers for Disease Control and Prevention Response to Advisory Committee, 2012; U.S. Department of Health and Human Services National Toxicology Program, 2012). Although blood Pb testing is a common method for targeting remediation, it is a practice that is ethically dubious and fails to promote methods for avoiding exposure (Moodie and Evans, 2011). Primary prevention requires strategies to assess the underlying chemical conditions that influence children's blood Pb response. The major strategy for reducing Pb exposure in children has focused on educational and household dust interventions; a review of these intervention efforts indicates that they are not successful at lowering Pb exposure among young children (Yeoh et al., 2012). Recognizing the current CDC emphasis on primary prevention, our study is both timely and critical for advancing innovative ways to promote the health of children and their future as citizens in modern cities.

Hurricane Katrina struck New Orleans on August 29th 2005, breaching the federal levee system and flooding 80% of the city. This

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* Corresponding author at: Department of Pharmacology, Tulane University School of Medicine, 1430 Tulane Avenue-SL 83, New Orleans, LA 70112-2632, United States.
E-mail address: hmielke@tulane.edu (H.W. Mielke).

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event marks a major division for this study. Pre-Katrina associations between soil Pb and blood Pb were evaluated by two independent datasets (Mielke et al., 1997, 2005a, 2007a). In addition, several post-Katrina soil surveys were conducted in New Orleans. The EPA and Louisiana Department of Environmental Quality collected 147 soil samples; their widely publicized report supported the data previously reported by Mielke et al. (2000, 2001a) (U.S. EPA, 2006). Two post-Katrina soil sample analyses produced compatible results. Zahran et al. (2010) analyzed soil and blood Pb both before and after Katrina (post-Katrina soil survey consisting of 874 soil samples during April, 2006 on 46 census tracts surveyed pre-Katrina) and reported soil and blood Pb decreases in post-Katrina New Orleans. While the blood Pb decreases stand, further analysis of the pre- and post-Katrina soil samples using permutation statistical methods found a relatively large agreement (0.4445) and small P-value of agreement (0.79×10^{-9}) for the two sets of soil samples (Mielke and Berry, 2007); the post-Katrina samples are most likely from the same sample collection as the pre-Katrina sample set. Abel et al. (2010) collected 128 Pb soil samples post-Katrina from busy street corners that were relatively evenly distributed throughout Orleans Parish; EPA extraction methods were used and showed similar results to those we reported earlier (Mielke et al., 2005a). The most recent survey of New Orleans soil Pb arrived at a different conclusion. Rabito et al. (2012) reported results of 109 samples and suggested that large areas of the city became Pb-contaminated because of unsafe housing renovations post-Katrina, and also suggested that soil Pb increased by 61% in all communities based on foundation (i.e. house side) samples compared with *median* soil Pb by census tract data from Mielke et al. (2005a). The implication is that post-Katrina children's Pb burden will increase in all communities irrespective of location, demographic, and racial characteristics of New Orleans.

Strong associations have been found between soil Pb and children's blood Pb in both Minnesota and New Orleans (Mielke and Reagan, 1998; Mielke et al., 1997, 1999, 2007a; Zahran et al., 2011). Other studies in Syracuse, New York by Johnson and Bretsch (2002) and Los Angeles, California by Wu et al. (2010) corroborate the same strong statistical association between soil Pb and children's blood Pb as observed in New Orleans. In fact, a growing body of evidence supports the strong association between children's blood Pb response and Pb dust contamination, especially within interiors of cities (Laidlaw website; Mielke et al., 2011a).

New Orleans is an excellent study site because the city is located on alluvial soils derived from Mississippi River sediments. Modern sediments contain a median Pb of ~5 mg/kg while the urban alluvial soils contain a median Pb of >100 mg/kg (Mielke et al., 2000). Soils are a reservoir for anthropogenic Pb deposition; they capture and integrate all aerosol sources of Pb, including but not limited to smelter sites, Pb-based paint (either deteriorated or haphazardly removed by power sanding, sand blasting, or scraping without capturing the paint), Pb additives in gasoline, and incinerator or industrial Pb emissions (Filippelli et al., 2005; Mielke and Reagan, 1998; Mielke et al., 2011a). Several studies identify soil Pb as a major risk factor for human exposure through direct contact and/or re-suspension of Pb dust from contaminated soils (Laidlaw et al., 2005, 2012; Mielke and Reagan, 1998; Reagan and Silbergeld, 1990).

Previously we evaluated a small portion of the pre-Katrina database (587 of 5467 soil Pb samples and 9807 of 55,551 blood Pb samples) and observed strong disparity patterns between soil Pb and children's blood Pb at public and private properties, especially between inner city and outer city locations (Mielke et al., 2011b). Our current study evaluates the entire soil Pb database to elucidate contamination patterns at four different sample locations that are potential play areas in high and low Pb areas of the city. In addition, we link the soil Pb data with all available children's blood Pb data for both pre- and post-Katrina New Orleans. The purpose is to expand the perspective on the soil chemical characteristics within urban communities that are relevant to children and to seek innovative ways for advancing primary Pb exposure prevention.

2. Materials and methods

2.1. Soil Pb data

Our soil collection protocols have evolved over three decades as a result of studies conducted in Baltimore, Minnesota, and New Orleans (Mielke, 1991; Mielke et al., 1983, 1984, 1989, 1999). The New Orleans collection conducted in 1999–2001 is the most refined survey to date (Mielke et al., 2005a). Residential communities as defined by the census tract boundaries were the focus of the soil sampling. To be able to compare the same geographic tracts over a period of two decades, our sample results were consistently stratified by the 1990 U.S. census tracts (i.e., enumeration districts) (U.S. Census Tracts and Block Numbering Areas, 1993).

The soil sample collection process included the following: prior to field collection, maps were printed for each residential census tract. Within each census tract we collected soil samples to represent four locations (n *in parentheses*) which are indicative of the potential play areas for children within each residential community. Samples were collected within 1 m of *busy streets* (4), *residential streets* (9), and *house sides* (3). In addition, samples were collected from *open spaces* (3) i.e., potential play areas at parks or larger yards that were located away from house sides and residential streets. All sample locations were marked on the corresponding census tract map. Sample locations were matched to the closest street address. Busy streets in each community are often through streets which have commercial properties located along them which carry heavier traffic volumes than residential streets. Soil samples along busy and residential streets were collected in the middle of blocks to avoid the influence of traffic flow from two directions at intersections. The soil Pb dataset was assembled from samples collected from the upper 2 to 3 cm of the soil surface within residential communities of metropolitan New Orleans (Mielke et al., 2005a). The survey sought to collect 19 soil samples per census tract (n = 286) and the completed soil survey consisted of 5467 surface samples (for additional details refer to Mielke et al., 2005a).

The modified Chaney–Mielke extraction protocol required mixing 0.40 g of air dried and sieved [#10 United States Geological Survey (USGS)—2 mm] portions of soil with 20 mL of trace metal grade 1 M HNO_3 and agitating the mixture for 2 h as described previously (Mielke et al., 2005a). An important characteristic of our soil extraction protocol is the use of room temperature 1 M nitric acid (HNO_3), pH = 0. The advantage of our room temperature extraction is that it is milder, faster, and safer than other extraction methods which often use boiling or microwaving and concentrated acids. For Pb the modified Chaney–Mielke extraction correlates closely with several other methods, including total extractions (U.S. EPA, 1996).

2.2. Blood Pb data

The Childhood Blood Lead Surveillance System (CBLSS) datasets were obtained from the Louisiana Childhood Lead Poisoning Prevention Program (LACLPPP). In accordance with existing legislation, LACLPPP requires case reporting of blood Pb from health care providers (Louisiana Lead Poisoning Prevention Program Rules, 2008). The CBLSS document details the combined datasets of both public and private labs used to monitor Pb exposures (Louisiana CBLSS, 2004). Approximately 3% of the blood samples were venous, the most accurate biomarker; 66% were capillary samples, a less accurate biomarker; and unknown specimen types resulting in mixed reliability were reported for the remaining 31% of blood samples (Louisiana CBLSS, 2004). We do not know how, or if, the mix of different blood Pb specimen types affects our analysis.

Each blood Pb sample was geocoded by address and matched to the corresponding 1990 census tract. The pre-Katrina dataset (2000–29 August 2005) consists of 55,551 independent blood Pb results from

280 census tracts where there were at least five blood Pb results; six census tracts with soil Pb data were excluded because less than five blood Pb test results were available. The post-Katrina dataset (2006–2008) consists of 7384 blood Pb sample results that were geocoded in the same manner as the pre-Katrina dataset. New Orleans families tend to remain settled in the same community as indicated by records showing that 85% of the population in metropolitan New Orleans had the same address from 1995 to 2000 (Zahran et al., 2011). This information supports the rationale that during early development children exhibit an exposure response linked with the chemical characteristics of the soils of a given community.

2.3. Dividing the city: high and low Pb environments

We divided the city into high Pb and low Pb areas according to the median soil Pb by census tract. For analysis, the division was <100 mg/kg (low Pb) and ≥100 mg/kg (high Pb) (see Table 1). This division is supported by previous research which found a steep increase of blood Pb response of children when the median soil Pb ranged from <20 to 100 mg/kg, with the response curve flexing downward between 100 and 300 mg/kg, and finally flattening out above 300 mg/kg (Mielke et al., 1999, 2007a). Table 1 shows that the median of the soil Pb medians is 99 mg/kg for 287 census tracts and 112 mg/kg for all 5467 soil samples collected from residential areas of metropolitan New Orleans.

Fig. 1, Panel A shows the spatial distribution of the pre-Katrina median blood Pb by census tracts and classified into two groups, higher (i.e., equal or above the median, red triangles—3.6–10.8 μg/dL) and lower (i.e., below the median, blue dots, blood Pb (2.0–3.5 μg/dL)). The symbols correspond to the polygon center of mass for each census tract (Jenness, 2006). The pre-Katrina blood Pb overlays the soil Pb which appears as a gray scale from higher (darker) to lower (lighter) derived from the median census tract soil Pb interpolation (Mielke et al., 2005a). Also included on the map is the 100 mg/kg soil Pb isoline. The post-Katrina blood Pb is shown in Fig. 1, Panel B. The map contains the same features as Panel A, but it shows the post-Katrina median blood Pb results stratified by census tracts using the same classification interval. Note the overall decreases in blood Pb of census tracts from pre-Katrina to post-Katrina New Orleans as depicted by Fig. 1, Panel A and Panel B.

2.4. Permutation statistical methods

The soil Pb data is positively skewed (12.7) and does not fit a normal distribution. Therefore the requirements for parametric statistical tests were not met and non-parametric statistics were used to evaluate the data. Distribution-free permutation tests for matched-pairs (PTMP) and multi-response permutation procedures (MRPP) were both used for the analyses, and the USGS MRPP software was used for the statistical analyses (Blossom, 2008; Mielke and Berry, 2007). Robust Euclidean distance functions instead of squared Euclidean distance functions were used to account for the extreme values encountered with this data (Mielke and Berry, 2007, see Sections 2.9 and 4.4). Using MRPP with Euclidean functions yields permutation analyses that are congruent with the ordinary geometry of the map data (Mielke, 1984). When the P-value approximations were ≥0.005, re-sampling of P-values was obtained based on 1,000,000 random permutations; when P-values<0.005 were encountered, exact moment approximations were used (Blossom, 2008; Mielke and Berry, 2007).

3. Results

3.1. Soil Pb by high and low census tract medians

Table 1 summarizes soil Pb results organized by census tract medians (census tracts ≥100 mg/kg and <100 mg/kg); note the large differences and extremely significant (P-value $= 4.7 \times 10^{-45}$) between the high Pb and low Pb census tracts. Results are also given for all individual samples stratified by the four residential collection locations of each of the census tracts: residential streets, busy streets, house sides, and open spaces where children are likely to play. Overall the median soil Pb of the four sample locations from highest to lowest showed the following order: busy streets > house sides > residential streets > open spaces.

3.2. Four soil Pb locations stratified by high and low Pb census tracts

Table 2 shows soil Pb data stratified by the four soil collection locations in the high and low Pb areas of the city. In addition to the Pb concentrations varying in intensity, they also showed significant differences in the potential Pb exposure within specific locations. For example, the median soil Pb within 1 m of the house side is 1228 mg/kg in the high Pb area compared with 32 mg/kg in the low Pb area of New Orleans. Therefore, the potential Pb exposure, in decreasing order in high Pb areas shows that house sides > busy streets > residential streets > open spaces. In contrast, the ranking in the low Pb area is: busy streets > residential streets > house sides > open spaces. Table 2 shows that the comparisons between the high and low Pb areas of the city are significantly different with P-values of $<10^{-205}$ for all samples (the P-value was too extreme even for MRPP based on the Pearson type III distribution). Also the P-values range from 10^{-61} to 10^{-202} for comparisons between soil sample locations within the high Pb and low Pb areas of metropolitan New Orleans.

Table 2 also compares the soil Pb along busy and residential streets within both the high and low Pb areas of New Orleans. In the high Pb area median soil Pb values for busy streets and residential streets are both above 300 mg/kg with a relatively large P-value (0.016) indicating a relatively small difference between the quantities of Pb accumulated in soils along all streets in the high Pb area of the

Table 1
Overview of the descriptive statistics for soil Pb samples collected in New Orleans by census tract medians and by soil Pb associated with each location.

Soil Pb (mg/kg)	N	Min	10%	25%	Median	75%	90%	Max	P-value[a]
By census tract (CT) medians	287	6.2	25	45	**99**	414	661	1789	
CT median≥100 mg/kg	142	106	126	210	**425**	605	879	1789	
CT median<100 mg/kg	145	6.2	18	31	**45**	70	83	99	4.70E−45
By location, all samples[b]	5467	2.5	13	36	**112**	398	1100	52,798	
Residential street side	2537	2.5	15	38	**105**	325	799	16,815	
Busy street side	1078	3.7	21	58	**156**	414	762	45,071	
House side	887	2.5	9	29	**137**	1287	4621	52,798	
Open space	958	2.5	10	23	**71**	299	870	19,671	

[a] Multi-response permutation procedure using Blossom W2008.04.02.
[b] Note: information about location was missing for 7 of the 5467 soil samples collected for the survey.

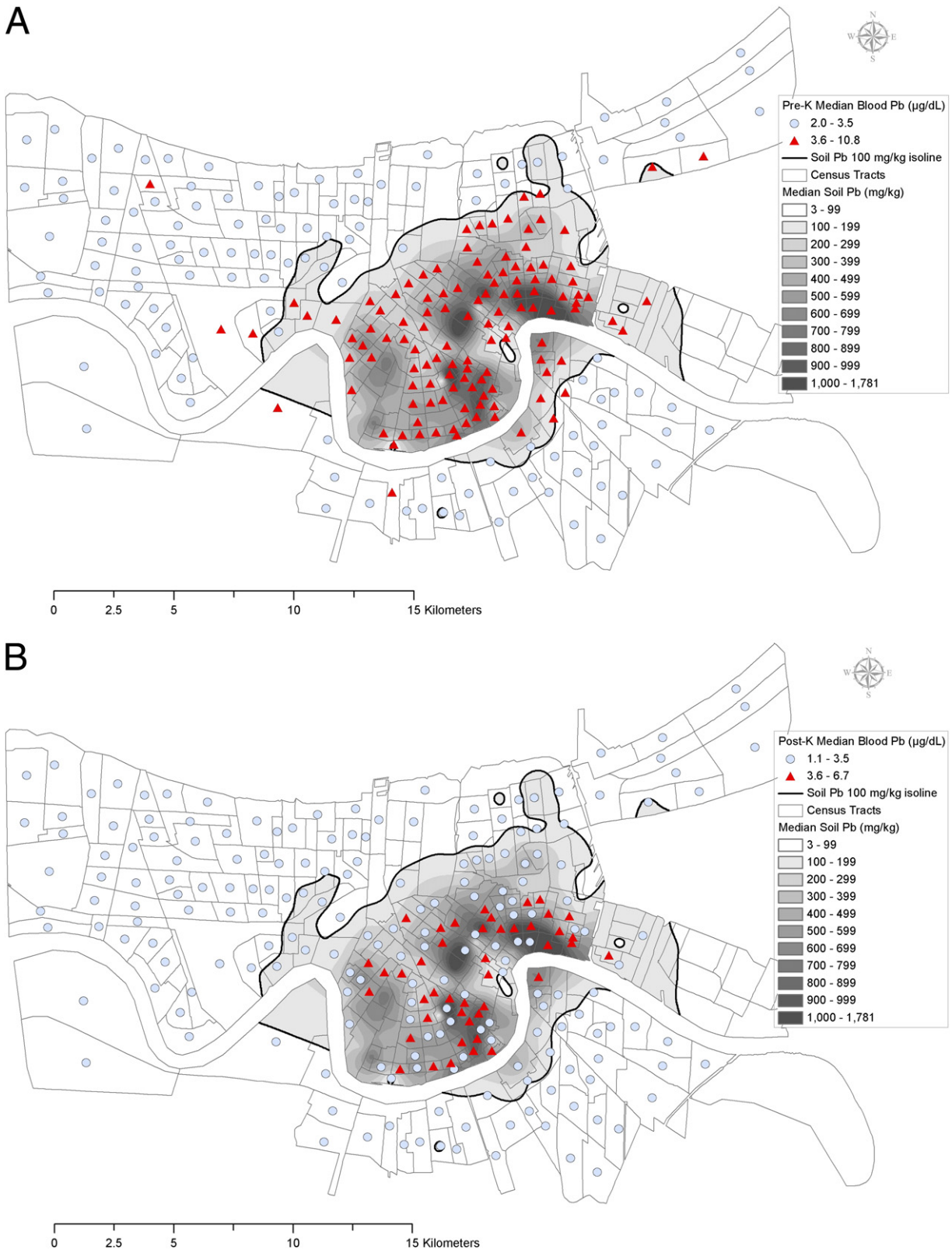

Fig. 1. Panel A, pre-Katrina spatial distribution of median blood Pb by census tract overlaying the interpolated median census tract soil Pb shown in graduated shades of gray. The 100 mg/kg soil Pb isoline is also indicated. Panel B, post-Katrina spatial distribution of median blood Pb by census tract.

city. In contrast, median soil Pb is below 64 mg/kg for both busy and residential streets in the low Pb area of the city. However, the small P-value (8.4×10^{-11}) indicates a significant difference between larger amounts of Pb in soil along busy streets compared with the substantially lower amounts of soil Pb along residential streets in the low Pb areas of New Orleans.

Table 2
Soil Pb at various locations stratified by high Pb census tracts (≥100 mg/kg) and low Pb census tracts (<100 mg/kg).

	N	Min	10%	25%	Median	75%	90%	Max	P-value[a]
All soil Pb data									
CT median≥100 mg/kg	2677	2.5	61	155	**366**	846	2124	52,798	
CT median<100 mg/kg	2790	2.5	9	18	**44**	94	190	10,184	<1.0E−205
Busy street side									
CT median≥100 mg/kg	549	4.9	86	179	**367**	658	1134	45,071	
CT median<100 mg/kg	527	3.7	12	28	**64**	128	269	3504	4.4E−92
Residential street side									
CT median≥100 mg/kg	1239	2.5	63	142	**313**	666	1369	16,815	
CT median<100 mg/kg	1298	2.5	10	20	**46**	93	166	4045	1.2E−202
House side									
CT median≥100 mg/kg	436	2.5	83	264	**1228**	3908	9169	52,798	
CT median<100 mg/kg	450	2.5	6	12	**32**	88	216	10,184	5.3E−61
Open space									
CT median≥100 mg/kg	451	2.5	18	41	**103**	282	714	1538	
CT median<100 mg/kg	506	2.5	8	13	**28**	65	146	969	6.1E−68
Busy vs. residential streets									
CT median≥100 mg/kg									
Residential street	1239	2.5	63	142	**313**	666	1369	16,815	
Busy street side	549	4.9	86	179	**367**	658	1134	45,071	0.016
CT median<100 mg/kg									
Residential street side	1298	2.5	10	20	**46**	93	166	4045	
Busy street side	527	3.7	12	28	**64**	128	269	3504	8.4E−11

[a] Analysis was by multi-response permutation procedure using Blossom W2008.04.02.

3.3. Blood Pb by high and low census tracts

Table 3 shows children's blood Pb values associated with census tracts containing a median soil Pb≥100 mg/kg vs. median soil Pb<100 mg/kg for both pre- and post-Katrina databases. In the case of the entire pre-Katrina blood Pb database, the individual blood Pb results are so numerous (n=28,537 vs. 27,014) that permutation methods could not be calculated because of computer memory limitations; Mann–Whitney Rank Sum Test analysis between the two areas of the city is significant (P-value$<1.0\times10^{-16}$). In the case of the post-Katrina database, the MRPP P-value is 2.6×10^{-190}. The blood Pb differences are enormous and significant (i.e., extreme) as indicated by the small P-value when comparing blood Pb results between the high Pb and low Pb areas of the city.

3.4. Pre- and post-Katrina blood Pb data, medians by census tract

Table 4 lists the median blood Pb results by census tract for data from pre-Katrina (2000–2005) with matching post-Katrina (2006–2008) data and for the pre- and post-Katrina data stratified by census tracts<100 mg/kg vs. census tracts≥100 mg/kg. Blood Pb has undergone a substantial and significant reduction after Katrina. The blood Pb decreases occurred in both the low Pb and high Pb areas of the city.

3.5. Pre- and post-Katrina soil and blood data for high Pb vs. low Pb areas

Table 5 summarizes the blood Pb and soil Pb characteristics of the high Pb and low Pb areas in New Orleans. After Katrina, children's blood Pb exhibited a sharp decline in New Orleans. In pre-Katrina New Orleans approximately the same number of children were tested in the two areas of the city whereas in post-Katrina New Orleans more than three times the number of children were included from the low Pb area of the city as from the high Pb sector of the city. Comparison of pre- and post-Katrina results, showed that the prevalence of blood Pb≥5 μg/dL decreased by a factor of two in the high Pb area of the city and by a factor of over three for the children living in the low Pb area of the city. Comparing blood Pb results for pre- and post-Katrina results indicates large and significant differences as indicated by footnote c in Table 5. Overall, even though the blood Pb levels decreased, the disparity actually increased between the high lead and the low Pb areas of the city. Finally, note that the

Table 3
Overview of descriptive statistics of blood Pb results for pre-Katrina 2000–2005 and post-Katrina 2006–2008 for high Pb areas and low Pb areas of metropolitan New Orleans, Louisiana.

Blood Pb (μg/dL)	N	Min	10%	25%	Median	75%	90%	Max	%≥5 μg/dL	%≥10 μg/dL	P-value
Pre-Katrina											
CT median≥100 mg/kg	28,537	0.0	2.4	3.3	**5.6**	9.0	14.5	107	58.5	21.8	
CT median<100 mg/kg	27,014	0.0	1.6	2.9	**3.0**	4.9	7.0	117	24.8	3.0	<1.0E−16[a]
Total	55,551										
Post-Katrina											
CT median≥100 mg/kg	2510	0.9	1.1	2.1	**3.0**	5.2	8.7	40	29.6	6.5	
CT median<100 mg/kg	4874	0.9	1.0	1.5	**3.0**	3.0	4.0	38	7.5	1.0	2.6E−190[b]
Total	7384										

[a] Mann–Whitney Rank Sum Test using SigmaStat 3.5 (note that the data base is too large for MRPP calculation of permutations, see Blossom, 2008).
[b] Multi-response permutation procedure using Blossom W2008.04.02.

Table 4
Comparison of blood Pb results matched by census tracts for New Orleans pre-Katrina vs. post-Katrina and by pre-Katrina vs. post-Katrina in low Pb and high Pb census tracts.

Median blood Pb (μ/dL)						
All census tracts (blood Pb matched pairs)			Low Pb[a]		High Pb[b]	
	2000–05	2006–08	2000–05	2006–08	2000–05	2006–08
Min	2.0	1.1	2.0	1.1	3.0	1.1
10%	3.0	2.0	3.0	2.0	4.0	2.6
25%	3.0	2.5	3.0	2.1	4.9	3.0
Median	**3.6**	**3.0**	**3.0**	**3.0**	**6.0**	**3.1**
75%	6.0	3.1	3.0	3.0	7.0	3.9
90%	7.0	4.0	3.5	3.0	7.5	4.8
95%	7.5	4.8	3.8	3.0	8.3	5.2
99%	8.7	6.0	4.9	3.0	8.9	6.2
Max	10.8	6.7	6.0	3.4	10.8	6.7
Census tracts (N)	239	239	122	122	117	117
MRPP P-value		1.1E−23		1.3E−17		3.9E−29

[a] Soil Pb <100 mg/kg.
[b] Soil Pb ≥100 mg/kg.

P-values remained extremely small for the pre- and post-Katrina blood Pb results between the high and low Pb areas of the city.

4. Discussion

4.1. Sources and quantities of Pb in New Orleans

The high Pb areas correspond with the inner-city and the low Pb area corresponds with the outer city of New Orleans. Several Pb sources have played a role in the inner city–outer city Pb footprint reported in this study as well as most of the post-Katrina soil Pb surveys of New Orleans. Nationally, the main residential Pb sources consisted of around six million metric tons of Pb used in each of two products, Pb-based paint and Pb additives in gasoline, for a total of about 12 million metric tons (Mielke and Reagan, 1998). In New Orleans the median Pb content of exterior house paint is 3.5% (Mielke et al., 2001b). If all homes included a 372 m^2 (~4000 ft^2) living space (over 2 times the usual size of residential dwellings) and contained 3.5% Pb exterior paint, the estimated potential Pb dust from power sanding all the paint from 86,000 residences would be ~250 metric tons (Mielke et al., 2001b, 2011b). The Pb additives in gasoline from 1950 to 1985 contributed an estimated ~10,000 metric tons of Pb dust from vehicle travel in New Orleans (Mielke and Zahran, 2012; Mielke et al., 2011a). Although Pb additives in gasoline account for ~40 times more Pb dust than estimated for Pb-based paint, many homes still contain intact paint which when converted into dust poses severe hazards, especially to pets and children (Mielke et al., 2001b).

The New Orleans soil Pb map (Fig. 1, Panels A and B) reflects many decades of accumulated Pb dust in soil from all sources of Pb including transportation-related sources, industrial, incinerator, and building materials including Pb-based paint, plaster, caulking, etc. (Mielke et al., 2001b, 2011a, 2011b). Power sanding Pb-based painted homes is an ongoing problem that must be restricted (Jacobs et al., 2003). However, the many decades of pre-Katrina Pb dust loading of soil was too large to be significantly transformed by post-Katrina unsafe housing renovations, as suggested by Rabito et al. (2012). Furthermore, the post-Katrina blood Pb data listed in Table 3 and summarized in Table 5 indicate that there were substantial decreases in children's blood Pb, with the largest decreases taking place in outlying, low Pb areas of New Orleans. Thus the blood Pb data do not support the Rabito et al. (2012) suggestion that children's Pb burden will increase throughout the city because of widespread, unsafe post-Katrina housing renovation. Nevertheless, the childhood Pb burden shown in Fig. 1, Panels A and B indicates a strong disparity and a severe Pb problem in many neighborhoods of the city.

4.2. Margin of safety and health risks from ingestion

In 2012 the CDC replaced language regarding *acceptable blood Pb levels* with a *reference value* defined as the blood Pb of the 97.5th percentile of the childhood population; the reference value is currently 5 μg/dL and that number will decrease as population exposure is reduced (CDC response, 2012). Table 5 shows that the prevalence of children with a blood Pb reference value ≥5 μg/dL was 58.5% and 24.8% pre-Katrina vs. 29.6% and 7.5% post-Katrina within high and low Pb areas, respectively, of New Orleans. According to these results, neither pre- nor post-Katrina New Orleans is Pb safe for children, especially in the high soil Pb areas of the city.

Table 5
Summary of the pre-Katrina vs. post-Katrina blood Pb results of children (μg/dL) and soil Pb (mg/kg) in high and low Pb areas of New Orleans. Also summarized and emphasized are medians by census tract for the high lead and low lead areas of New Orleans and the percentiles of the four different soil locations.

	N	Min	10%	25%	Median	75%	90%	Max	%≥5 μg/dL	%≥10 μg/dL
High Pb areas of New Orleans										
Pre-Katrina blood Pb[a]	28,537	0	2.4	3.3	**5.6**	9.0	14.5	107	58.5[a]	21.8[a]
Post-Katrina blood Pb[b,c]	2510	0.9	1.1	2.1	**3.0**	5.2	8.7	40	29.6[b]	6.5[b]
Soil Pb≥100 mg/kg										
Median by census tract	142	106	126	210	**425**	605	879	1789		
All soil samples	2677	2.5	61	155	**366**	846	2124	52,798		
Busy streets	549	4.9	86	179	**367**	658	1134	45,071		
Residential streets	1239	2.5	63	142	**313**	666	1369	16,815		
House sides	436	2.5	83	264	**1228**	3908	9169	52,798		
Open spaces	451	2.5	18	41	**103**	282	714	1538		
Low Pb areas of New Orleans										
Pre-Katrina blood Pb[a]	27,014	0	1.6	2.9	**3.0**	4.9	7.0	117	24.8	3.0
Post-Katrina blood Pb[b,c]	4874	0.9	1.0	1.5	**3.0**	3.0	4.0	38	7.5	1.0
Soil Pb<100 mg/kg										
Median by census tract	145	6.2	18	31	**45**	70	83	99		
All soil samples	2790	2.5	9	18	**44**	94	190	10,184		
Busy streets	527	3.7	12	28	**64**	128	269	3504		
Residential streets	1298	2.5	10	20	**46**	93	166	4045		
House sides	450	2.5	6	12	**32**	88	216	10,184		
Open spaces	506	2.5	8	13	**28**	65	146	969		

[a] LACLPPP pre-Katrina blood Pb results for 2000 to August, 2005 (Hurricane Katrina made landfall on August 29, 2005).
[b] LACLPPP post-Katrina blood Pb results for 2006 to 2008. Comparison between high and low Pb areas, MRPP P-value = 2.6E−190.
[c] MRPP comparison of pre-Katrina and post-Katrina blood Pb results for high Pb and low Pb areas are P-values = 5.3E−39 and 1.4E−20, respectively.

The current 5 μg/dL reference value for 2012 has major implications for current Pb standards. The U.S. EPA (2001) national soil Pb standard for bare soil where children play is 400 mg/kg. In the high Pb areas of the city, shown in Table 1, the census tract soil Pb median is 425 mg/kg, indicating that over half of the census tracts had a median soil Pb above the EPA standard. Although community patterns of soil Pb are the focus of this study, unmeasured environmental Pb attributable to other sources of exposure such as drinking water and house interiors cannot be determined from this study (Lanphear et al., 1998). However Pb exposure from soil is sufficient that factors such as Pb dust suspension from contaminated soil during periods of drought relates directly to changes in children's blood Pb (Laidlaw et al., 2005) and to air Pb (Laidlaw et al., 2012).

Soil ingestion is now recognized as common among humans (Starks and Slabach, 2012). When ingestion is involved, a factor of 10 is normally used for a margin of safety (U.S. EPA, 2002; US DHHS, 2005). Adding this margin of safety, the EPA soil Pb standard would be appropriately lowered from 400 mg/kg to 40 mg/kg. Also, if the goal is to prevent Pb exposure ≥ 10 μg/dL for children living in a community, then the median soil Pb for the community must be <80 mg/kg (Mielke et al., 1999). Given the current CDC blood Pb 5 μg/dL reference value, the soil Pb standard should be less than 40 mg/kg to ensure that most children are reasonably protected from the risks of inadvertent exposure by environmental sources of Pb dust.

Further insight into the Pb dust characteristics of soil was obtained from the Potential Lead on Play Surfaces (PLOPS) measurement of Pb loading of soil. If soil Pb measures 400 mg/kg then the Pb surface loading is ~16 mg/m^2 (~1500 μg/ft^2), or 37 times larger than the ~0.430 mg/m^2 (40 μg/ft^2) HUD Pb loading standard for interior floors (Mielke et al., 2007b). A soil Pb standard of <40 mg/kg is possible for all cities because the median soil Pb in non-urban areas in the U.S. is 16 mg/kg (Gustavsson et al., 2001). Given the volume of material commonly hauled around by trucks during construction activities there do not appear to be serious limitations about transporting clean soil to child sensitive locations such as childcare centers, playgrounds, elementary schools, and residential play areas in all cities of the U.S.

4.3. Signs and symptoms of Pb exposure in New Orleans

Racial and socioeconomic disparities exist between the high and low Pb areas of New Orleans (Campanella and Mielke, 2008). Poorer African American populations tend to inhabit the high Pb areas of the city; wealthier white populations, with some exceptions, tend to inhabit the low soil Pb areas of the city (Campanella and Mielke, 2008). Furthermore, New Orleans studies indicate that learning achievement is markedly diminished in communities with high soil and blood Pb (Mielke et al., 2005b; Zahran et al., 2009). There are whole communities of New Orleans (see Fig. 1 and Table 2) where children lack Pb safe places to play. Many of the children living in these communities tend to exhibit behavior problems, and research in New Orleans and other cities indicates a strong association between the rise and fall of Pb additives in gasoline and a latent two decade surge and decrease of aggravated assault rates (Mielke and Zahran, 2012; Nevin, 2007).

The Pb contamination of New Orleans shown in Table 5 is an issue that generates large societal costs to all citizens. The overall health of the inhabitants of some areas of the city is reported as so severely compromised by inadequate education, violence, heart disease, and stroke that the average life expectancy is as low as 55 years; 25 years shorter than life expectancy of up to 80 years in other parts of the city (Joint Center for Political and Economic Studies, 2012). Lead and other toxins appear to play a role in this disparity (Mielke et al., 2001a). Because of the importance of this topic to the current and future health and quality of life of the citizens of New Orleans, environmental contamination must be addressed.

4.4. Pb exposure prevention in post-Katrina New Orleans

The common method for detecting Pb contamination is a *medical* or *downstream model*, which uses exposed children as a trigger for action, but is of limited use because it does not target the source of the blood Pb. However, the soil Pb map of New Orleans is a *preventive*, *upstream model* of Pb detection that can show the way to viable remedies such as a clean soil policy. The U.S. has a clean air act and a clean water act, but lamentably, no clean soil act. In Norway a clean soil policy has been vetted by the government where action is underway to map and create Pb-safe (in addition to other toxins) playgrounds at all childcare centers, public parks, and elementary schools (Ottesen et al., 2008). Such a policy is needed to protect children in the United States.

The New Orleans soil Pb map provides information for selecting sites to conduct soil remediation projects. We instituted a pilot study to test the feasibility of transporting low Pb soils into New Orleans to remediate Pb contamination which was guided by the Pb map (Mielke et al., 2006a). Selected properties containing a median soil Pb of ~1000 mg/kg were covered by alluvium with a median Pb of 5 mg/kg transported into the city from along the Mississippi River (Mielke et al., 2006a). After Katrina, the treated soils were re-sampled and only small Pb increases were found (Mielke et al., 2006b).

The soil Pb map was also used as a tool for targeting childcare center play areas (Mielke et al., 2011c). The play areas were treated by covering Pb contaminated soils with geotextile and then adding a 15 cm layer of low Pb (~5 mg/kg) Mississippi alluvial soil on top of the geotextile. The bright orange geotextile is water permeable, and it delineates the underlying Pb contaminated soil from the low Pb surface soils. The (2012) cost for soil intervention is about 4000 USD per play area in New Orleans (Mielke et al., 2011c).

The abundant low Pb Mississippi alluvium is a beneficial resource for changing the soil Pb map of New Orleans (Mielke et al., 2000). For example, currently nine of ten federal public housing projects in New Orleans have been rebuilt post-Katrina. Public housing units were closed and razed; to elevate the properties massive quantities (hundreds of truck loads) of low Pb alluvium were transported from along the river outside of the city to the housing sites during the rebuilding process (Reckdahl, 2011). This process resulted in significant decreases of soil Pb surrounding the public housing properties in New Orleans. The tenth public housing property, Iberville, is scheduled for renovation (including clean soil) in the near future (Reckdahl, 2012). The City of New Orleans also implemented remediation of Pb contaminated soil at public parks and playgrounds to create Pb safer environments for children. Eleven public parks have been remediated (Copeland, 2012; Playgrounds remediated for lead, 2011; Schleifstein, 2011). The intervention method was the same as the Pb-safe play area project conducted at childcare centers in New Orleans (Mielke et al., 2011c).

Post-Katrina New Orleans is undergoing rapid change. Future evaluation of soil Pb and blood Pb should continue to decline compared with the pre- and post-Katrina conditions described in this study. Although soil Pb and children's blood Pb are expected to undergo significant decreases at public housing properties, unless environmental Pb conditions are improved on private residential properties in the high Pb areas of the city, environmental health disparities with enormous societal impact will likely continue in New Orleans (Campanella and Mielke, 2008; Mielke et al., 2011b). An important goal is to create well-publicized clean soil projects at childcare centers, public parks, and elementary schools for the children living in every community of New Orleans.

4.5. Conclusions

Significant spatial differences in soil Pb and children's blood Pb responses exist in New Orleans. Areas of high soil Pb and elevated blood Pb prevalence are located toward the interior of New Orleans where

traffic flows are historically larger, housing is older, properties are smaller, and housing is crowded; children's potential play areas are located in the immediate vicinity of homes and streets and the soil tends to be Pb contaminated (median = 425 mg/kg). The areas of low soil Pb and low blood Pb prevalence are located in the outlying areas of New Orleans where traffic flows are historically smaller, housing is often newer, and properties are larger; children's play areas are generally located away from the houses and streets and soil tends to have lower Pb contamination (median = 45 mg/kg). Because the same processes of Pb contamination have occurred in other urban environments, the lessons from the studies of soil and blood Pb in New Orleans also apply to other cities. Low Pb soil is available to all municipalities and it is relatively inexpensive to remedy Pb contaminated soil to prevent children's exposure to Pb dust from soil.

Definitions: mg/kg = milligrams per kilogram = micrograms per gram, also parts per million (ppm).
Blood lead concentration: 10 μg/dL is equivalent to 0.48 micromoles per liter (μmol/L).
Measure of dust loading: 10.76 $\mu g/m^2 = 1\ \mu g/ft^2$.

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References

Abel MT, Suedel B, Presley SM, Rainwater TR, Austin GP, Cox SB, et al. Spatial distribution of lead concentrations in urban surface soils of New Orleans, Louisiana USA. Environ Geochem Health 2010;32:379–89.
Advisory Committee on Childhood Lead Poisoning Prevention. Low level lead exposure harms children: a renewed call for primary prevention. Atlanta, GA: US Department of Health and Human Services, CDC, Advisory Committee on Childhood Lead Poisoning Prevention; 2012 [http://www.cdc.gov/nceh/lead/acclpp/final_document_010412.pdf. Accessed 23 October 2012].
Blossom. Edition W2 008.04.02. http://www.fort.usgs.gov/products/software/blossom/blossom.asp 2008. [Accessed 23 October 2012].
Campanella R, Mielke HW. Human geography of New Orleans' urban soil lead contaminated geochemical setting. Environ Geochem Health 2008;30(6):531–40.
Centers for Disease Control and Prevention. Response to Advisory Committee on Childhood Lead Poisoning Prevention recommendations in *Low level lead exposure harms children: a renewed call for primary prevention*. Atlanta, GA: US Department of Health and Human Services; 2012 [MMWR 61(20):383. http://www.cdc.gov/nceh/lead/acclpp/cdc_response_lead_exposure_recs.pdf. Accessed 23 October 2012].
Copeland CS. What lies beneath: lead poisoning in New Orleans. Healthcare J New Orleans 2012;1:36–40.
Filippelli GM, Laidlaw M, Latimer J, Raftis R. Urban lead poisoning and medical geology: an unfinished story. GSA Today 2005;15:4-11.
Gustavsson N, Bølviken B, Smith DB, Severson RC. Geochemical landscapes of the conterminous United States—new map presentations for 22 elements. Denver CO: US geological survey 2001; professional paper 1648; 2001.
Jacobs D, Mielke HW, Pavur N. The high cost of improper removal of lead-based paint from housing: a case report. Environ Health Perspect 2003;111:185–6.
Jenness J. Center of mass (center of mass.avx) extension for ArcView 3.x. Jenness Enterprises; 2006 [available at: http://www.jennessent.com/arcview/centermass.htm. Accessed 23 October 2012].
Johnson DL, Bretsch JK. Soil lead and children's blood lead levels in Syracuse, NY, USA. Environ Geochem Health 2002;24:375–85.
Joint Center for Political and Economic Studies. Place matters for health in Orleans Parish: ensuring opportunities for good health for all. A report on health inequities in Orleans Parish, Louisiana. Washington, D.C: Joint Center for Political and Economic Studies; 2012 [http://www.jointcenter.org/sites/default/files/upload/research/files/40532_JC.pdf. Accessed 23 October 2012].
Laidlaw MAS. Association between soil lead and blood lead — evidence. website http://www.urbanleadpoisoning.com/. [Accessed 23 October 2012].
Laidlaw MAS, Mielke HW, Filippelli GM, Johnson DL, Gonzales CR. Seasonality and children's blood lead levels: developing a predictive model using climatic variables and blood lead data from Indianapolis, Indiana, Syracuse, New York and New Orleans, Louisiana (USA). Environ Health Perspect 2005;113(6):793–800.
Laidlaw MAS, Zahran S, Mielke HW, Taylor MP, Filippelli GM. Re-suspension of lead contaminated urban soil as a dominant source of atmospheric lead in Birmingham, Chicago, Detroit and Pittsburgh, USA. Atmos Environ 2012;49:302–10. http://dx.doi.org/10.1016/j.atmosenv.2011.11.030.
Lanphear BP, Burgoon DA, Rust SW, Eberly S, Galke W. Environmental exposures to lead and urban children's blood lead levels. Environ Res 1998;76(2):120–30.
Louisiana Childhood Blood Lead Surveillance System (CBLSS). http://www.dhh.louisiana.gov/offices/publications/pubs-360/Statewide2004AnnualReport.pdf 2004.
Louisiana Lead Poisoning Prevention Program Rules. Louisiana Register 2008;34(7):1511–2. http://www.dhh.louisiana.gov/offices/miscdocs/docs-263/LEAD/Rules_Lead.pdf.
Mielke PW. Meteorological applications of permutation techniques based on distance functions. In: Krishnaiah PR, Sen PK, editors. Handbook of statistics, volume 4. Amsterdam: North Holland; 1984. p. 813–30.
Mielke HW. Lead in residential soils: background and preliminary results of New Orleans. Water Air Soil Poll 1991;57–58:111–9.
Mielke PW, Berry KJ. Permutation methods: a distance function approach. 2nd edition. New York: Springer–Verlag; 2007.
Mielke HW, Reagan PL. Soil is an important pathway of human lead exposure. Environ Health Perspect 1998;106(Supplement 1):217–29.
Mielke HW, Zahran S. The urban rise and fall of air lead (Pb) and the latent surge and retreat of societal violence. Environ Int 2012;43:48–55.
Mielke HW, Anderson JC, Berry KJ, Mielke PW, Chaney RL, Leech M. Lead concentrations in inner-city soils as a factor in the child lead problem. Am J Public Health 1983;73:1366–9.
Mielke HW, Blake B, Burroughs S, Hassinger N. Urban lead levels in Minneapolis: the case of the Hmong children. Environ Res 1984;34:64–76.
Mielke HW, Adams JL, Reagan PL, Mielke PW. Soil-dust lead and childhood lead exposure as a function of city size and community traffic flow: the case for lead contaminated soil abatement in Minnesota. Environ Geochem Health 1989;9:253–71. [Book supplement Lead in Soil: Issues and Guidelines, ISBN 0-905927-92-3].
Mielke HW, Dugas D, Mielke PW, Smith KS, Smith SL, Gonzales CR. Associations between soil lead concentrations and childhood blood lead in urban New Orleans and rural Lafourche Parish, Louisiana, USA. Environ Health Perspect 1997;105(5):950–4.
Mielke HW, Smith MK, Gonzales CR, Mielke PW. The urban environment and children's health: soils as an integrator of lead, zinc and cadmium in New Orleans, Louisiana, USA. Environ Res 1999;80(2):117–29.
Mielke HW, Gonzales CR, Smith MK, Mielke PW. Quantities and associations of lead, zinc, cadmium, manganese, chromium, nickel, vanadium, and copper in fresh Mississippi alluvium and New Orleans alluvial soils. Sci Total Environ 2000;246:249–59.
Mielke HW, Wang G, Gonzales CR, Le B, Quach VN, Mielke PW. PAH and metal mixtures in New Orleans soil and sediment. Sci Total Environ 2001a;281(1–3):217–27.
Mielke HW, Powell E, Shah A, Gonzales C, Mielke PW. Multiple metal contamination from house paints: consequences of power sanding and paint scraping in New Orleans. Environ Health Perspect 2001b;109:973–8.
Mielke HW, Gonzales C, Powell E, Mielke PW. Changes of multiple metal accumulation (MMA) in New Orleans soil: preliminary evaluation of differences between survey I (1992) and survey II (2000). Int J Environ Res Public Health 2005a;2(2):84–90.
Mielke HW, Berry KJ, Mielke PW, Powell ET, Gonzales CR. Multiple metal accumulation as a factor in learning achievement within various New Orleans communities. Environ Res 2005b;97:67–75.
Mielke HW, Powell ET, Gonzales CR, Mielke PW, Ottesen RT, Langedal M. New Orleans soil lead (Pb) cleanup using Mississippi River alluvium: need, feasibility and cost. Environ Sci Technol 2006a;40(08):2784–9.
Mielke HW, Powell ET, Gonzales CR, Mielke PW. Hurricane Katrina's impact on New Orleans soils treated with low lead Mississippi River alluvium. Environ Sci Technol 2006b;40(24):7623–8.
Mielke HW, Gonzales CR, Powell E, Jartun M, Mielke PW. Nonlinear association between soil lead and blood lead of children in metropolitan New Orleans, Louisiana: 2000–2005. Sci Total Environ 2007a;388:43–53.
Mielke HW, Powell ET, Gonzales CR, Mielke PW. Potential lead on play surfaces: evaluation of the "PLOPS" sampler as a new tool for primary lead prevention. Environ Res 2007b;103:154–9.
Mielke HW, Laidlaw MAS, Gonzales CR. Characterization of lead (Pb) from traffic in 90 U.S.A. urbanized areas: review of urban lead dust and health. Environ Int 2011a;37:248–57.
Mielke HW, Gonzales CR, Mielke PW. The continuing impact of lead (Pb) dust on children's blood lead: comparison of public and private properties in New Orleans. Environ Res 2011b;111(8):1164–72.
Mielke HW, Covington TP, Mielke PW, Wolman FJ, Powell ET, Gonzales CR. Soil intervention as a strategy for primary lead exposure prevention: the New Orleans lead-safe child care playground project. Environ Pollut 2011c;159:2071–7.
Moodie SM, Evans DL. Ethical issues in using children's blood lead levels as a remedial action objective. Am J Public Health 2011;101:S156–60.
Nevin R. Understanding international crime trends: the legacy of preschool lead exposure. Environ Res 2007;104:315–36.
Ottesen RT, Alexander J, Langedal M, Haugland T, Høygaard E. Soil pollution in day-care centers and playgrounds in Norway: national action plan for mapping and remediation. Environ Geochem Health 2008;30:623–37.

Playgrounds remediated for lead. City of New Orleans. https://data.nola.gov/Administrative-Data/Playgrounds-Remediated-for-Lead-2011-Map/bg76-nvb3 2011. [Accessed 23 October 2012].
Rabito FA, Iqbal S, Perry S, Arroyave W, Rice JC. Environmental lead after Hurricane Katrina: implications for future populations. Environ Health Perspect 2012;120: 180–4.
Reagan PL, Silbergeld EK. Establishing a health based standard for lead in residential soils. In: Hemphill, Cothern, editors. Trace Subst. Environ. Health, Supplement, Environ Geochem Health. 12; 1990. p. 199–238. [See a synopsis in http://wonder.cdc.gov/wonder/prevguid/p0000015/p0000015.asp Accessed 23 October 23, 2012].
Reckdahl K. HANO to remove tons of contaminated dirt from former B.W. Cooper site. The Times-Picayune; November 25 2011 [http://www.nola.com/politics/index.ssf/2011/11/hano_to_remove_tons_of_contami.html Accessed 23 October 2012].
Reckdahl K, 15 April 2012. Iberville housing complex redevelopment has its wheels set in motion. The Times-Picayune. http://www.nola.com/politics/index.ssf/2012/04/iberville_housing_complex_rede.html [Accessed 23 October 2012].
Schleifstein M, 29 March 2011. Parks begin lead remediation efforts today. The Times-Picayune. http://www.nola.com/health/index.ssf/2011/03/more_parks_to_get_the_lead_out.html [Accessed 23 October 2012].
Starks PTB, Slabach BL. The scoop on eating dirt. Sci Am 2012;306:30–2. http://dx.doi.org/10.1038/scientificamerican0612-30.
U.S. Census Tracts and Block Numbering Areas. New Orleans, LA MSA, table 32: selected structural characteristics of housing units: 1990; and summary tape file 3A, Louisiana 040, Lafourche Parish 050, census tracts 140. Washington, DC: U.S. Department of Commerce, Economics and Statistics Administration, Bureau of Census; 1993. p. 565–615.
U.S. Department of Health and Human Services. National Toxicology Program. Monograph on health effects of low-level lead; 2012 [http://ntp.niehs.nih.gov/go/36443 Accessed 23 October 2012].
U.S. Department of Health and Human Services, Pharmacology and Toxicology. Guidance for industry estimating the maximum safe starting dose in initial clinical trials for therapeutics in adult healthy volunteers. http://www.fda.gov/downloads/Drugs/GuidanceComplianceRegulatoryInformation/Guidances/ucm078932.pdf 2005. [Accessed 23 October 2012].
U.S. EPA. Urban soil lead abatement demonstration project. Volume 1: EPA integrated report. EPA/600/P-93/001aF. Research Triangle Park, NC: U.S. Environmental Protection Agency; 1996. p. 4–6. [Chap 3].
U.S. EPA. Residential lead hazard standards — TSCA section 403. http://epa.gov/lead/pubs/leadhaz.htm2001. [Accessed 23 October 2012].
U.S. EPA. Determination of the appropriate Food Quality Protection Act (FQPA) safety factor(s) in tolerance assessment. http://www.epa.gov/oppfead1/trac/science/determ.pdf 2002. [Accessed 23 October 2012].
U.S. EPA. Summary assessment of the results of sampling of localized areas identified for focused investigations following Hurricane Katrina. http://www.epa.gov/katrina/testresults/sediments/focused_sampling.html 2006. [Accessed 23 October 2012].
Wu J, Edwards R, He XE, Liu Z, Kleinman M. Spatial analysis of bioavailable soil lead concentrations in Los Angeles, California. Environ Res 2010;110:309–17.
Yeoh B, Woolfenden S, Lanphear B, Ridley GF, Livingstone N. Household interventions for preventing domestic lead exposure in children (review). The Cochrane Collaboration. John Wiley & Sons, Ltd.; 2012 [http://onlinelibrary.wiley.com/doi/10.1002/14651858.CD006047.pub3/pdf, Accessed 23 October 2012].
Zahran S, Mielke HW, Weiler S, Berry KJ, Gonzales C. Children's blood lead and standardized test performance response as indicators of neurotoxicity in metropolitan New Orleans elementary schools. NeuroToxicol 2009;30:888–97.
Zahran S, Mielke HW, Gonzales CR, Powell ET, Weiler S. New Orleans before and after Hurricanes Katrina/Rita: a quasi-experiment of the association between soil lead and children's blood lead. Environ Sci Technol 2010;44:4433–40.
Zahran S, Mielke HW, Weiler S, Gonzales CR. Nonlinear associations between blood lead in children, age of child, and quantity of soil lead in metropolitan New Orleans. Sci Tot Environ 2011;409(7):1211–8.