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Human geography of New Orleans' high-lead geochemical setting

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Abstract Previous soil lead studies in New Orleans focused on the geochemical footprint and its health impacts. This study examines the human geography of race, income, and age in pre-Katrina metropolitan New Orleans within the context of lead accumulation in soils. Sample points of soil lead data ($n = 5{,}467$) collected in 1998–2000 were mapped in a geographic information system (GIS), binned into 9 ranges, and queried by (1) 2000 Census racial demographic data, (2) 1999 median household income, and (3) 2000 age data. The absolute population generally declines as lead levels increase except at lead levels from 200–400 to 400–1,000 mg/kg when population increases; the African–American population comprises a disproportionate share of this cohort. The high-lead areas occur in the inner city, home to the largest populations of African-Americans in New Orleans. The mean household income curve indicates that lower economic groups are at risk to higher levels of lead. A total of 44,701 children under the age of 5 years, plus 123,579 children aged 5–17, lived in census block groups containing at least one sample point with over 100 mg/kg lead, and these include 23,124 and 64,064 young people, respectively, who live near at least one point over 400 mg/kg. Lead exposure affects a panoply of outcomes that influence the health and welfare of the community. Unless corrected, children are likely to return to the same or, because of lack of lead-safe practices during renovation, even higher exposure risks than before the flooding of New Orleans.

Keywords Environmental justice · Ethnicity · Health disparities · Income · Lead exposure · Lead poisoning · New Orleans · Race · Soil contamination

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Introduction

After the catastrophic failure of the flood-protection system following Hurricane Katrina (29 August 2005) inundated 80% of New Orleans, several public agencies, including the U.S. Environmental Protection Agency and the Louisiana Department of Environmental Quality, surveyed the city's sediments and soils for contamination. While results indicated that soils were severely contaminated with lead, the agencies' official notice-of-finding about New Orleans' post-Katrina urban geochemistry was of "no significant impact," because the postdiluvian geography of lead contamination resembled prediluvian spatial patterns (U.S. EPA and LADEQ 2006) and thus was not attributable to Hurricane Katrina (Elkins 2006). In essence, regardless of the degree of soil lead contamination, officials deemed the problem in New Orleans as "historic;" federal agencies were therefore not responsible for providing funds to assist with post-Katrina soil lead remediation.

"Historic lead" contamination of soils is an issue in virtually all U.S. cities. Wong et al. (2006) reviewed basic urban geochemistry themes but do not provide salient details about the soil lead studies conducted in U.S. cities. For perspective, a brief review is provided below on studies conducted since the mid-1970s in Baltimore, Maryland, extended to several towns and cities of Minnesota, and then intensively focused on urban geochemistry and health in Louisiana. This information on urban soil lead provides the background for discussing the human geography of New Orleans' geochemical setting.

- In several cities, enormous differences were found between highly contaminated soils in the inner city compared with the relatively uncontaminated soils in the outlying areas of the city; chance cannot explain the difference (i.e., extremely small P-values $\ll 0.001$ were noted) (Mielke et al. 1983, 1984; Mielke 1991).
- The hypothesis that lead-based paint alone explains the observed pattern of urban lead is not supported by the predominance of unpainted brick buildings in the inner city of Baltimore in contrast with the predominantly painted wood residential structures in the outlying areas of the city. An alternate hypothesis is that tetra-ethyl lead in gasoline is at least a co-equal source that contaminated the inner city and helps to explain the commonly recognized pattern of U.S. cities first observed in Baltimore (Mielke et al. 1983; Mielke and Reagan 1998).
- City size is directly related to the amount of lead in soil; i.e., the larger the city the larger the amounts of lead (Mielke et al. 1984/85; 1989; Mielke 1993).
- The amount of lead in the soil of a community is strongly associated with exposure of children as measured by blood lead (Mielke et al. 1989, 1997, 1999, 2007).

The previous studies in New Orleans focused primarily on the geochemical footprint of lead and the health impacts of lead in urban soils. The purpose of this study is to examine the human geography of race, income, and age in pre-Katrina metropolitan New Orleans within the context of the geochemical pattern of lead accumulation in soils, and to explore potential environmental health and policy implications of these patterns.

Methods

Soil collection, extraction and analysis

The data used in this paper is from the second New Orleans soil lead survey (Survey II) begun in 1998 and completed in 2000; details of the study were published previously (Mielke et al. 2005). The main features of the collection are: 19 soil samples ($\sim$2.5 cm deep) were collected per census tract (10 samples from within 1 m of residential streets and not next to intersections, four samples from within 1 m of busy streets, three samples, each matched with street side samples, were obtained within 1 m of house sides, and two samples were collected from vacant land or parks as far as possible from streets and house sides). The protocol for extraction includes: acid pH (1M HNO_3), shaker time (2 h), and room temperature ($\sim$22°C). Soil extractions were prepared with 0.4 g of soil and 20 ml trace metal grade 1M HNO_3. A Spectro^{TM} analytical instruments inductively coupled plasma atomic emission spectrometer (ICP-AES) was used to analyze for lead. The ICP-AES was calibrated with National Institute of Standards and Technology traceable reference standards, included in analytical runs at the rate of 1 per 15 samples. Internal laboratory references and quality assurance and control were achieved by participation in the Analytical Products Group laboratory proficiency environmental testing program. Results from 5,467 soil samples (given as mg lead/kg soil, or ppm) were geocoded and made up the environmental lead dataset for metropolitan New Orleans (Mielke et al. 2005).

Demographics, income levels and age by soil lead content in the greater New Orleans metropolitan area

The 5,467 sample points of lead data collected in 1998–2000 were mapped in a geographic information system (GIS), binned into ranges as shown in the tables, queried by the selected range, and spatially intersected with (1) 2000 census racial demographic data at the highly detailed "block" level, (2) 1999 median household income at the spatially coarser "block group" level, and (3) 2000 age data, also at the block group level. Those census polygons containing at least one sample point within the selected lead range were extracted and tabulated for the demographic data presented in the tables and graphs below. An additional analysis was conducted for young children, in which the percent of the block group's population below the age of 5 years was binned into five ranges, from below 3% to the maximum of 20.08%. Those block-group polygons were then intersected with the lead sample points that lay upon them, and the 25, 50 and 75th percentiles of their respective lead quantities were computed.

The "total population" figures shown in the columns on the left of some tables represent the population of the respective census polygon (block or block group) that overlays upon a sampling point with a lead level in the selected range. Those census polygons visited by more than one sampling point, whose lead levels may have straddled multiple ranges, were counted multiple times. For this reason, the "total population" columns do not comprise mutually exclusive rows, and do not sum to the total population of the metropolis. When the table reads that 74,714 people lived in blocks with lead levels of 50–100 mg/kg (e.g., Table 1), it implies that when we query the sampling points for that range and identify the census blocks that spatially overlay them, their total population sums to 74,714. Repeating this same spatial analysis using block groups rather than blocks, we find the population swells to 535,858 people (e.g., Table 3, below). This apparent contradiction is explained by the fact that block groups are spatially 5–10 times coarser than blocks, and thus aggregate far more people. Despite their coarseness, block groups must be used because US Census does not aggregate income and age at the block level.

Results

Demographics

Table 1 and Figs. 1 and 2 show the racial demographic characteristics of the New Orleans metropolitan area's population broken down by nine ranges of soil lead content. When broken down by lead levels (Fig. 1), we see that the absolute population declines fairly steadily as lead levels increase. Nevertheless, a disturbingly large number of New Orleanians live near lead levels deemed by many to

Table 1 2000 Census demographics (greater New Orleans region, i.e., tri-parish area Orleans, Jefferson, and St. Bernard, plus upper Plaquemines Parish) of blocks in which at least one sample point at the indicated lead level was retrieved

Soil lead in mg/kg	Total population	White population	Black population	Asian population	Hispanic ethnicity, regardless of race
	1,034,115	531,972	441,448	26,626	51,102
<20	80,284	45,228	29,320	2,459	4,926
20–50	87,507	46,210	36,316	1,822	4,659
50–100	74,714	39,571	30,850	1,508	3,967
100–200	64,513	29,439	31,684	1,176	3,284
200–400	47,623	20,207	25,652	552	1,743
400–1,000	49,190	14,369	33,378	338	1,520
1,000–5,000	27,023	9,233	16,739	280	1,073
5,000 and 20,000	5,888	1,696	3,991	31	215
20,000 and above	443	178	243	1	21

Double counting may occur for populations in blocks that were sampled more than once; therefore, no summations should be made on columns

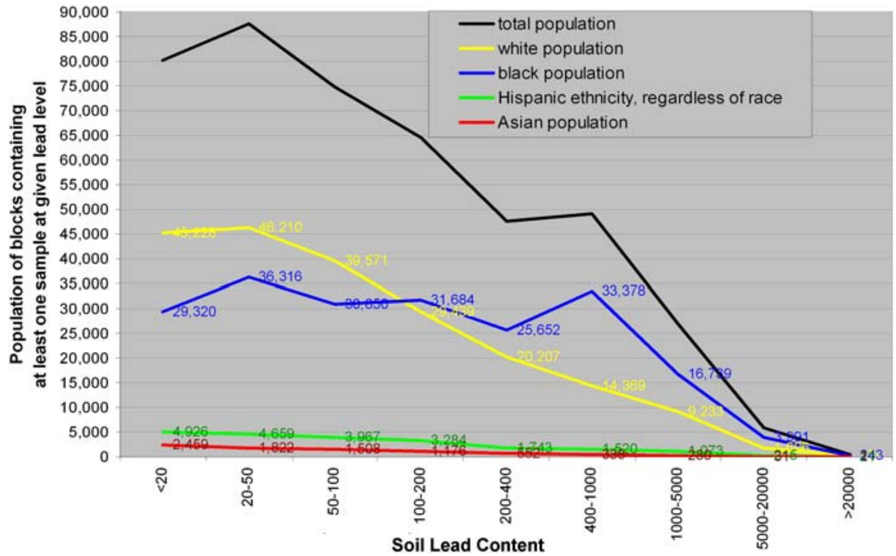

Fig. 1 New Orleans total population and racial demographics by soil lead (in mg/kg) 1998–2000

represent a public health concern. ("Near" in this case means within the distance of a typical US city block, spanning 100–200 m on each side.) About 738,000 people resided near relatively safe levels of lead (≤100 mg/kg). But nearly 297,000 people lived on blocks in which samples yielded >100 mg/kg lead, sometimes significantly higher.

We also see that population does not decline consistently with increasing lead level. It actually rises as lead levels increase from 200–400 to 400–1,000 mg/kg. When broken down by race, as shown in Fig. 2, it becomes apparent that the African–American community comprises a disproportionate share of this exposure cohort. This is explained by the fact that high-lead areas occur in the inner city, which is home to the largest and most concentrated populations of African–Americans in the metropolis (Campanella 2006).

Racial and ethnic geography also explains the patterns in Fig. 2. Whites, who predominate in suburban Jefferson and St. Bernard parishes, make up diminishing percentages of the population subjected to progressively higher levels of lead. African-Americans, who mostly live in Orleans Parish and particularly in its old inner city, home to thousands of old wooden homes with lead paint as well as heavy

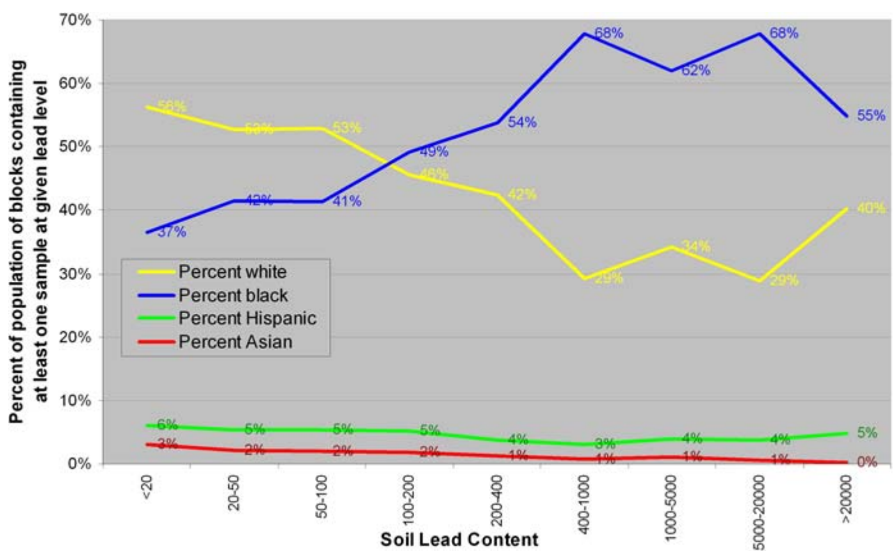

Fig. 2 New Orleans percentage breakdown of racial demographics by soil lead content (in mg/kg) 1998–2000

traffic and congestion, are relatively more exposed to high-lead areas by a roughly 2-to-1 ratio. Those of Asian and Hispanic ancestry, who comprise relatively small components of the population and (unlike many other metropolises) tend to live far from the city center, made up a consistently small percent of all levels of lead exposure (Campanella 2006).

From these data we may surmise the following:

- Nearly one-third of residents of metropolitan New Orleans live on or near levels of lead that many experts regard as a potential public health risk.
- While people of all backgrounds live on or near the full range of lead levels, historically based racial and ethnic residential patterns render the distributions lop-sided. In relative numbers, black people are more likely than white people to live in high-lead areas by a roughly 2-to-1 ratio, but both groups are well over five times more likely to live in high-lead areas than people of Hispanic and Asian ancestry.

Income

Table 2 and Fig. 3 show the minimum, maximum, average, and standard deviation of median household income (MHHI) figures at the census block group level, broken down by nine ranges of soil lead content. Income data in the US Census are only available as median statistics at levels of detail no finer than block groups (which are fairly consistent in their population sizes); this explains why some particular MHHI figures appear repeatedly in the table. (Block groups were selected if they contained at least one sample point at the indicated soil lead. A typical block group incorporates 5–10 city blocks; thus, the selected point may be anywhere from a few meters to a few hundred meters from a resident's actual dwelling.)

The mean MHHI curve indicates that economic class declines with remarkable consistency as lead levels increase. Lower economic classes, it may be surmised, risk exposure to higher levels of lead.

An exception occurs at the higher end of lead levels. The standard deviation increases slightly in the 1,000–5,000 mg/kg level, indicating that, while poorer block groups are predominating, some wealthier block groups are among them. Then, at the highest lead levels, mean MHHI increases while standard deviation diminishes, implying that the areas in question are somewhat more consistently higher-income. What explains this minor trend is the fact that while some historic inner-city districts of New Orleans are home to poorer areas which are more likely to be African–American, others, such as the French Quarter, Garden District, and Uptown, are prosperous and more likely to be white (Campanella 2006). Old wooden homes and traffic congestion, which drive lead levels, prevail in both areas. The neighborhoods accounting for this particular datum

Table 2 2000 census median household income (MHHI) for greater New Orleans region (Orleans, Jefferson, and St. Bernard, upper Plaquemines), in 1999 dollars, by block groups in which at least one sample point at the indicated soil lead content was retrieved

Area and soil lead content in mg/kg	Minimum MHHI ($)	Maximum MHHI ($)	Mean MHHI ($)	Standard deviation MHHI ($)
Tri-parish area	4,089	200,001	35,071	19,249
2.5–20	4,962	146,158	40,457	19,846
20–50	4,962	146,158	37,249	18,103
50–100	4,089	146,158	35,036	17,854
100–200	4,089	146,158	32,770	17,804
200–400	4,089	125,889	30,330	16,699
400–1,000	4,089	125,889	28,212	16,685
1,000–5,000	5,219	200,001	26,255	18,173
5,000–20,000	8,068	73,125	24,145	10,835
20,000 and above	13,993	45,677	27,129	10,043

Note: Block groups are much larger than blocks, and thus encompass more sample points. This explains why some MHHI figures appear repeatedly in the table

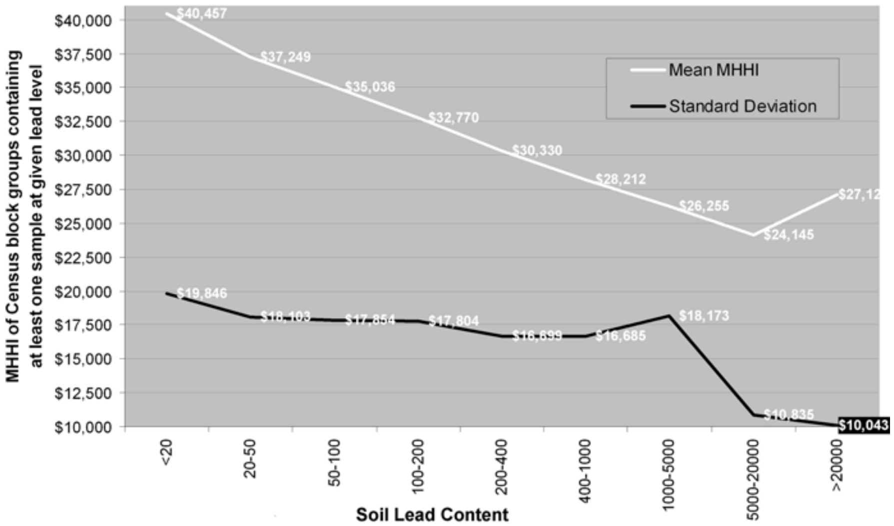

Fig. 3 New Orleans median household income (MHHI) by soil lead content (in mg/kg) 1998–2000

include seven block groups, home to 5,917 residents, located in both the more prosperous and poorer sections of the older portion of the city (Campanella 2006).

Age

Children are exceptionally sensitive to lead accumulated in soil because of their ubiquitous hand-to-mouth behavior. Also, their relatively small size means that they have a high mineral demand per body mass to support growth and physiologic development. These two factors produce the connection between soil lead and exposure by children. The spatial relationship between the sampling data and populations below the age of 5 and below 18 are therefore of special interest. A total of 44,701 children under the age of 5, plus 123,579 children aged 5–17, lived in census block groups containing at least one sample point with over 100 mg/kg lead. These figures include 23,124 and 64,064 young people, respectively, who live near at least one point over 400 mg/kg. (Because these data are aggregated by block group, "near" in this case means anywhere from a few meters to a few hundred meters from the child's home.)

While any number of children living in possible exposure to lead represents cause for concern, these data show no evidence for disproportionate exposure by means of spatial concurrence. When broken down by lead levels, numbers and percentages of young people generally decline slightly in areas that have progressively higher lead levels. Tables 3 and 4 shows the percent of block group population below

Table 3 2000 census age and family size data for greater New Orleans region (Tri-parish area of Orleans, Jefferson, and St. Bernard, upper Plaquemines), by block groups in which at least one sample point at the indicated soil lead content was retrieved

Soil lead in mg/kg	Population, 2000	Ages < 5	Ages 5–17	Percent, ages < 5 (%)	Percent, ages 5–17 (%)
2.5–20	445,769	29,750	83,489	6.67	18.73
20–50	544,667	36,590	101,250	6.72	18.59
50–100	535,858	35,994	99,592	6.72	18.59
100–200	491,103	33,138	91,181	6.75	18.57
200–400	389,635	25,582	71,501	6.57	18.35
400–1,000	310,645	20,623	56,543	6.64	18.20
1,000–5,000	190,990	12,012	33,719	6.29	17.65
5,000 and 20,000	69,276	4,219	12,079	6.09	17.44
20,000 and above	5,917	336	914	5.68	15.45

Table 4 2000 Census, percent of block group population below age of 5 years; population, and 25, 50 and 75 percentiles for lead content of soil for each group of children

	Total population (not population of children)	25th percentile	50th percentile (median)	75th percentile
≤3.0% young children	34,261	66	214	682
>3.0 to ≤5.5%	264,800	53	161	476
>5.5 to ≤7.5%	412,588	57	166	478
>7.5 to ≤10.0%	216,357	58	188	593
> 10.0% (max is 20.08%)	86,461	33	94	340

Soil lead given in mg/kg

5 years old and the percentiles of soil lead for each group. When broken down by percentage of children per block group, the percentiles of lead content declined as the percentage of young children living in block groups increased, with one exception. The block groups with >7.5 to ≤10.0% of the children has larger soil lead quantities than expected given the decreasing trend for the other block group categories. What is driving this pattern is the large number of families living in expansive suburban areas where lead levels are lower. Young single adults, dual-income households with no children, elders living alone, and wealthier families who have fewer children live in sufficient numbers in the high-lead inner city to "pull down" the total percentage of children there (Campanella 2006). These trends should not draw attention away from specific areas of concern, such as the Iberville Housing Project, an overwhelmingly poor African-American subsidized-housing community in which over 18% of residents are below the age of 5, and over half are under age 18. Those children live within a few meters of 24 sample points that yielded lead levels as high as 916 mg/kg (Table 4).

Discussion

The environmental health and policy implications of "historic" lead in New Orleans are far reaching.

Children's blood lead response to soil lead

Blood lead is the commonly accepted method for determining exposure. The current centers for disease control and prevention (CDC) blood lead guideline is ≥10 μg/dl. Blood lead exposure response of children to lead in the soil has been evaluated several times in New Orleans and all results show remarkably robust trends (Mielke et al. 1997, 1999, 2007). The current EPA guidelines for soil lead are 400 mg/kg in bare soil where children play and 1,200 mg/kg in soil on the rest of the property. On the basis of research conducted on children in New Orleans these guidelines are not protective. For the children of New Orleans, below a median of 100 mg/kg lead in soil the median blood lead response is steep, with an overall increase of 1.4 μg/dl per 100 mg/kg. Above 300 mg/kg, the blood lead exposure response slope to soil lead flexes to 0.32 μg/dl per 100 mg/kg (Mielke et al. 2007). These exposure responses have been independently corroborated by Johnson and Bretsch (2002) who found that, when compared to the children of New Orleans, the children of Syracuse, New York, have a remarkably similar blood lead exposure response to soil lead (see also, Laidlaw et al. 2005).

Potential health impacts of lead exposure

Multiple health effects are associated with lead exposure. Increasingly, IQ deficits from lead exposure are becoming recognized as non-linear with the largest effects occurring at the lowest exposures. While the U.S. guideline for elevated blood lead is ≥10 μg/dl, deficits from exposures as low as 2 μg/dl are being demonstrated. Below the U.S. guideline a larger decline in IQ (7.4 points per 10 μg/dl) is being found than blood Pb over the entire range of exposures (4.6 I.Q. points per 10 μg/dl) (Canfield et al. 2003). A non-linear dose-response of blood lead and intelligence quotient was also found in a pooled data set of seven international prospective studies (Rothenbesrg and Rothenberg 2005). The neurotoxic issue was indicated in New Orleans by 4th grade students whose achievement scores were directly associated with the amount of lead accumulated in the soils of each school district (Mielke et al. 2005).

Similar results were found in a North Carolina study where a discernible impact on 4th grade achievement scores were related to childhood blood lead levels as low as 2 μg/dl, and a blood lead level of 5 μg/dl was associated with about a 15% decline in reading and mathematics scores (Miranda et al. 2007). The exposure related declines continue into adulthood (Shih et al 2007). Lead exposure is also being tied to behavioral disorders such as violent crime (Nevin 2007; Reyes 2007) but not to crimes on property (Reyes 2007). The association is consistent with the hypothesis that neurobehavioral damage in early life has an impact on human behavior later in life (Needleman et al. 1996, 2003). The strong association appeared universally in U.S. states (Reyes 2007), as well as in Britain, Canada, France, Australia, Finland, Italy, West Germany and New Zealand (Nevin 2007). Relentless violence in New Orleans may be, to some extent, a manifestation of lead exposure. Other health research demonstrates that lead exposure is significantly associated with both myocardial infarction and stroke mortality, at blood lead levels >2 μg/dl and a range of chronic diseases and health effects including cataracts, kidney function, osteoporosis and diabetes (Lin et al. 2003; Schaumberg et al. 2004; Campbell et al. 2004; Menke et al. 2006; Tsaih et al. 2004). Thus, there are multiple observed health effects from Pb exposure that extend over the entire human lifespan (Schwart and Hu 2007).

The steep exposure response to soil lead below 100 mg/kg combined with the steep health effects of low blood lead exposure exacerbates the problem for children. In accord with the non-linear relationships, children are far more sensitive to lower amounts of lead in soils than is generally recognized. The current CDC Healthy People 2010 goal is no child with a BL > 10 μg/dl by the year 2010 (Healthy People 2010). In pre-Katrina New Orleans, 11.8% of the entire childhood population and 20–30% of the inner-city children were excessively lead exposed (Mielke et al. 2007). For the years 2000–2005, the average blood lead prevalence ≥2 μg/dl for New Orleans children was 92.8%, and above the 2 μg/dl blood lead level indicated for neurotoxicity and many health disorders (Canfield et al. 2003; Miranda et al. 2007; Menke et al. 2006). If research continues to find blood lead exposures of ≤2 μg/dl associated with health disorders then the amount of lead accumulated in New Orleans has an even larger than previously recognized influence on the health and welfare of the citizens of New Orleans.

As the current study results show, the racial demographics indicate a source for tension regarding the lead exposure issue in New Orleans. In pre-Katrina metropolitan New Orleans, African American residents were overrepresented in high lead locations and underrepresented in low lead locations, and lead exposure assists with understanding health disparities and environmental justice issues in metropolitan New Orleans.

Need, feasibility and costs of corrective action

"Historic" lead is still lead. The lead exposure of citizens in pre-Katrina New Orleans not only affected children but also influenced the lifelong health and welfare of the community. The need, feasibility and costs for corrective action have been evaluated for New Orleans, and compared with the estimated annual costs of $76 million for treatment, the investment of ~$300 million for community-wide soil corrective action within the most contaminated communities of New Orleans would be expected to reap a long term benefit to the city (Mielke et al. 2006). Without corrective action, the children returning to New Orleans are likely to return to an environment with the same or, because of lack of lead-safe practices during most of the renovation, even higher exposure risk than they experienced before the catastrophic flooding of New Orleans.

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