Associations between Soil Lead and Childhood Blood Lead in Urban New Orleans and Rural Lafourche Parish of Louisiana
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This study evaluates associations between soil lead concentrations (SPb), age of housing, and blood lead levels (BPb) of children in metropolitan New Orleans and Lafourche Parish, Louisiana. The database includes over 2,600 SPb and 6,000 BPb samples paired by their median values and pre-1940 housing percentages for 172 census tracts. Associations were evaluated with Fisher's exact test and Spearman's rho test and modeled with the least sum of absolute deviations regression. Census tracts with low SPb are associated with new housing, but census tracts with high SPb are evenly split between old and new housing [Fisher's exact test, p = 8.60 × 10^{-13} for the percentage of housing built before 1940 (per cent pre-1940 housing) versus SPb]. The p-value for SPb versus BPb is 12 orders of magnitude stronger than the p-value for percent pre-1940 housing versus BPb. Census tracts with low BPb are associated with new housing, but census tracts with high BPb are split evenly between old and new housing [Fisher's exact test, p = 1.67 × 10^{-12} for percent pre-1940 housing versus BPb]. Census tracts with high SPb are associated with high BPb and census tracts with low SPb are associated with low BPb [Fisher's exact test, p = 3.18 × 10^{-24} for BPb versus SPb]. The Spearman's rho test of the association of SPb and BPb in Orleans and Lafourche Parishes yielded a p-value of 6.12 × 10^{-24}. The least sum of absolute deviations regression model of the data is BPb = 1.845 + 0.7215 (SPb)^{0.4}. A comparison of the modeled BPb versus observed BPb has an r^2 of 0.552 and a p-value of 2.83 × 10^{-23} that this relation was due to chance. If blood lead in children is more closely associated to soil lead than to the age of housing, then primary lead prevention should also include soil lead. Key words: age of housing, blood lead, childhood lead exposure, lead-based paint, leaded gasoline, soil lead, urban--rural blood lead and soil lead differences.

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An inner-city pattern of elevated lead in garden soils has been described for Baltimore, Maryland, and concern was expressed about the risk that soil poses to lead exposure of children living in the inner city (1). The initial study of Baltimore was followed up by soil lead surveys in several cities in Minnesota (2–4). In ordinary communities that contain soil but do not have a lead smelter, the pattern of lead is distinctly distributed. The highest quantities of soil lead (SPb) occur in the inner city, and a steep decline takes place toward outlying communities. The soils of suburbs and small cities contain substantially lower quantities of lead than inner city areas of large metropolises. The soil lead surveys of Baltimore and Minnesota were influential in the legislation to rapidly phase out lead in gasoline (5,6). With the removal of lead from gasoline, as well as other steps taken to reduce exposure such as reduction of lead in the canning process, there was a corresponding national decline in blood lead (BPb) (7–9). Some groups, however, especially children living in inner city areas of major cities, continue to be excessively exposed to lead (7,8). Surveys have been conducted in New Orleans and several small cities of Louisiana; the SPb contamination patterns found are similar to the patterns previously described in Baltimore and Minnesota (10–12).

For perspective on the risk that SPb poses to children, two major historical uses of lead have been considered, lead-based paint and leaded gasoline (13). The peak use of lead-based paint occurred in the 1920s and sharply declined by the 1940s; it was banned from household use in 1978. Exterior lead-based paint accumulates in soils when it deteriorates or when it is removed by scraping or sanding. Because old housing often has lead-based paint, age of housing has been used as a surrogate measure for lead-based paint (14,15).

Although leaded gasoline was introduced in the 1920s, its use was minuscule until the 1950s to the early 1970s. Its use, however, exceeded the use of lead-based paint by the 1940s; then leaded gasoline use increased steeply to its peak in the late 1960s and early 1970s. Its use declined rapidly up to the phase down in 1986 (10). There is no known surrogate measure for use of leaded gasoline by census tract. Previous research has estimated that at peak use of leaded gasoline, an average of about 5.2 metric tons of lead were emitted annually within a half mile of major intersections in the inner city of New Orleans; by comparison, an average of about 0.5 metric tons of lead were emitted annually within half a mile of major intersections in the center of Thibodaux, Louisiana (16). Even though lead has been essentially eliminated from U.S. gasoline, as with lead-based paint, its legacy of use also remains in urban soils.

Soils reflect all sources of lead, including lead-based paint deterioration (or its haphazard removal by sanding), lead in gasoline emissions, and incinerator or industrial lead emissions that have accumulated in the environment. Previous studies that have evaluated the association between SPb and BPb generally lack extensive empirical data on the pattern of SPb in a major city. In general, they rely on a mix of data often derived from smelter and mining sites, as well as limited urban data, to model associations between SPb and BPb (17,18). In this study, the census tract patterns of soil lead content, the age of housing as a surrogate for lead-based painted housing, and the BPb levels of children have been assembled for a large portion of metropolitan New Orleans and the Lafourche Parish of Louisiana. The purpose of the study is to evaluate and model the empirical differences and the associations within residential environments between soil lead concentrations, age of housing, and childhood BPb levels.

Materials and Methods
Three data sets were assembled for this study. The SPb data set was assembled from a survey of residential neighborhoods of metropolitan New Orleans (10,11) and Lafourche Parish, Louisiana. Soil samples were collected from the surface 2.5 cm within residential communities, at least one block away from major streets and in the middle of blocks away from street intersections. A U.S.

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Geological Survey number 10 (2 mm) sieve was used to separate the soil sample from larger particles. The extraction was based on room temperature leachate extraction methods (1); analysis of the samples was done using atomic absorption spectrometry, a method that correlates well with total methods (18). As an indicator of lead-based paint, an age of housing data set was assembled from the 1990 Census (19). Because the strongest association between the age of housing and BPb was the percentage of housing built before 1940 (percent pre-1940 housing), that category was selected for the data set. The BPb data set of children under 6 years old was analyzed by the Louisiana Office of Public Health. The median number of children tested for each census tract was 29 (range 5–253). The program follows the Centers for Disease Control and Prevention (CDC) protocols for collection, preparation, and analysis of BPb results (20).

The data set reflects those who obtain their health care from public health clinics. It is biased toward the poor and minority portion of the population and therefore represents the more lead-exposed children of society. All the data sets were partitioned according to 1990 U.S. census tracts.

The SPb, age of housing, and BPb data sets include the following information: median SPb concentration for all census tracts in which at least 10 samples were collected, percent of housing built before 1940 from the U.S. Census Bureau, and the median BPb concentrations in census tracts with BPb results from five or more children. The final database was created from >2,600 soil samples and >6,000 BPb samples. Median BPb and median SPb data sets were available for 154 census tracts (out of a possible 156 pairs) in metropolitan New Orleans and for 19 census tracts (out of a possible 20 pairs) in rural Lafourche Parish, for a total of 173 census tracts. Age of housing data is not available for census tract 17.14 in New Orleans. Therefore, in the case of pairing age of housing with median SPb and median BPb data, there were 153 census tracts available for metropolitan New Orleans and 19 census tracts available for Lafourche Parish, or 172 census tracts.

Three-dimensional surface plots were made for each of the data sets using a mapping program (21). The z-values for each of the data sets were plotted on the same x and y geographic coordinates that represent centroids for the corresponding census tracts of metropolitan New Orleans. Statistical analyses were conducted to evaluate the differences between the median SPb in the two parishes with the two-sided, two-sample Kruskal-Wallis test (also termed the Mann-Whitney-Wilcoxon test) (22). Similarly, median BPb differences were evaluated using the same tests. The associations between percent pre-1940 housing and median SPb, the percent pre-1940 housing and median BPb, and the median soil lead and median blood lead were then evaluated using Fisher’s exact test (23). In addition, the associations between median BPb and median SPb for the paired samples were evaluated using Spearman’s rho Test (22). Finally, a least sum of absolute deviations regression function was derived to produce a model of the data (24). p-Values are used throughout the analysis to determine strength of results, and a p-value is the probability of a test statistic being equal to or more extreme than the observed statistic when random allocations are assumed.

Results

Table 1 provides the median BPb results of the paired portion of the data. Table 2 provides the paired median SPb data for both metropolitan New Orleans and Lafourche Parish. The differences in median BPb for children <6 years old and median SPb concentrations between the two locations are easily observed in Tables 1 and 2. Analyses of the metropolitan New Orleans and Lafourche results with the two-sided, two-sample Kruskal-Wallis test demonstrates the substantial differences between the median BPb levels and median SPb content of the two places (p-values are $1.27 \times 10^{-2}$ and $1.15 \times 10^{-3}$, respectively).

Table 3 shows the percent pre-1940 housing for the census tracts in metropolitan New Orleans and Lafourche Parish; the difference in the age of homes between the two locations is readily apparent. Each census tract was placed into one of two categories: the percent pre-1940 housing ≤25% and the percent pre-1940 housing >25%. The Fisher’s exact test p-value for this two-way partitioning is $1.29 \times 10^{-6}$ and infers a significant difference between the two places.

The maps of the metropolitan New Orleans distribution of median BPb, median SPb, and percent pre-1940 housing are presented in Figure 1. Note the visual similarities and differences between BPb, SPb, and percentage age of housing. Specifically, the peak of the oldest housing is shifted toward another part of the city than the peak of both median SPb concentration and median BPb.

The relationships between median SPb and percent pre-1940 housing, median BPb and pre-1940 housing, and median SPb and median BPb were determined from the following two by two contingency tables for the combined paired data of Orleans and Lafourche study areas. In Table 4, the quantity 173 µg/g represents the median of the 173 median values for SPb. In Table 5, 7.5 µg/dl represents the median of the 173 median values for BPb. In Tables 4 and 5, categories ≥50% and <50% were used for the 172 census tracts with percent pre-1940 housing data.

There is a strong trend between low SPb and communities with new housing (Table 4). In the case of communities with high SPb, there is an even split between old and new housing. The Fisher’s exact test shows a p-value of $8.60 \times 10^{-13}$ for the association between pre-1940 housing and median SPb.

There is a strong trend between low BPb and new housing (Table 5). In the case of high BPb, there is about an even

Table 1. Frequencies of census tracts exhibiting various ranges of median soil lead concentrations within metropolitan New Orleans and Lafourche Parish, Louisiana

| Blood lead (µg/dl) | New Orleans | Lafourche |
|-------------------|-------------|-----------|
| <5                | 25          | 16        | 84.2     |
| 5–9               | 72          | 3         | 15.8     |
| 10–19             | 50          | 3         | 32.5     |
| 15–19             | 6           | 0         | 3.9      |
| 20–24             | 0           | 0         | 0.0      |
| ≥25               | 1           | 0.6       | 0.0      |
| Total             | 154         | 100.0     | 19.00    |

Table 2. Frequency of census tracts exhibiting various ranges of median soil lead concentrations within metropolitan New Orleans and Lafourche Parish, Louisiana

| Soil lead (µg/dl) | New Orleans | Lafourche |
|-------------------|-------------|-----------|
|                  | Number | Percent | Number | Percent |
| <25               | 8      | 5.2     | 10     | 52.8    |
| 25–49             | 15     | 9.7     | 6      | 31.6    |
| 50–99             | 23     | 14.9    | 3      | 15.8    |
| 100–199           | 30     | 19.5    | 0      | 0.0     |
| 200–399           | 34     | 22.1    | 0      | 0.0     |
| 400–799           | 23     | 14.9    | 0      | 0.0     |
| 800–999           | 12     | 7.8     | 0      | 0.0     |
| ≥1000             | 3      | 2.0     | 0      | 0.0     |
| Total             | 154    | 100.0   | 19     | 100.0   |

Table 3. Frequency of census tracts with various percentages of housing built before 1940 (percent pre-1940 housing) in metropolitan New Orleans and Lafourche Parish, Louisiana

| Percent pre-1940 housing | New Orleans | Lafourche |
|--------------------------|-------------|-----------|
| <10                      | 50          | 37.7      | 11      | 57.9    |
| 11–25                    | 18          | 11.8      | 8       | 42.1    |
| 26–50                    | 40          | 26.1      | 0       | 0.0     |
| 51–70                    | 33          | 21.6      | 0       | 0.0     |
| >70                      | 12          | 7.8       | 0       | 0.0     |
| Total                    | 153         | 100.0     | 19     | 100.0   |
split between old and new housing. The Fisher’s exact test shows a p-value of $1.67 \times 10^{-12}$ for the association between pre-1940 housing and median BPb.

Census tracts with low SPb concentrations tend to be associated with low BPb concentrations and census tracts with high BPb tend to be associated with high SPb (Table 6). The Fisher’s exact test reveals a p-value of $3.18 \times 10^{-24}$ for the association between median BPb and median SPb. The particularly strong association between BPb and SPb, as illustrated in Figure 1 and supported by the Fisher’s exact test, is reason for further evaluation.

Paired median BPb and median SPb data exist for 173 census tracts. The Spearman’s rho test shows that the p-values for these associations in metropolitan New Orleans and Lafourche Parish were $3.85 \times 10^{-20}$ and $0.7575$, respectively. This means that, in New Orleans, a very strong association exists whereby soils with low lead content are associated with low BPb levels, and high SPb contents are associated with high BPb levels. In Lafourche, the combination of the small number of cases, together with the fact that all median lead values are low for both soil and blood, makes it unlikely that any statistical association could be observed between median SPb and median BPb. Pooling the paired median SPb and the median BPb data of metropolitan New Orleans and Lafourche resulted in a p-value of $6.12 \times 10^{-24}$ for the association.

Least sum of absolute deviations regression is used to model the data for all 173 cases. The resulting equation for the model is BPb = $1.845 + 0.7215 (SPb)^{0.7575}$ (24). The correlation between observed and predicted BPb values is $r = 0.743$ and $r^2 = 0.552$. The chance that predicted BPb is a random fit of the observed BPb is very remote because the p-value of such an occurrence is $2.83 \times 10^{-24}$.

**Discussion**

**Differences between urban and rural environments.** In this study, major differences between urban and rural communities were suggested. These findings are supported by studies in which children in large cities have been observed to exhibit higher BPb levels than children in small cities (7,25). In the case of Lafourche Parish, there is no

**Figure 1.** Three dimensional surface plot of median blood lead, soil lead, and the percentage of housing built before 1940 for New Orleans, Louisiana. z-Values were plotted on the same x and y coordinates of centroids for all census tracts with available New Orleans data.

| Soil lead (μg/g) | Census tracts (n) | Blood lead (μg/dl) | Census tracts (n) | Soil lead (μg/g) | Blood lead (μg/dl) |
|------------------|-------------------|--------------------|-------------------|------------------|-------------------|
|                  | ≥50% pre-1940 housing | <50% pre-1940 housing | ≥50% pre-1940 housing | <50% pre-1940 housing | ≥7.5 | <7.5 |
| ≥173             | 43                | 43                 | 43                | 76               | <7.5 |
| <173             | 3                 | 83                 | 12                | 74               | <7.5 |

Table 4. Contingency table of the pre-1940 housing (≥50% vs. <50%) and median soil lead concentrations (≥173 μg/g vs. <173 μg/g)

Table 5. Contingency table of the pre-1940 housing (≥50% vs. <50%) and median blood lead concentrations (≥7.5 μg/dl vs. <7.5 μg/dl)

Table 6. Contingency of median blood lead (≥7.5 μg/dl vs. <7.5 μg/dl) and median soil lead (≥173 μg/g vs. <173 μg/g)
census tract in which the median BPb concentration is above 9 μg/dl. Also, there is no indication of any statistical association between median BPb and either median SPb or age of housing. In all census tracts, median SPb concentrations are below 100 mg/kg and fewer than 25% of the homes were built before 1940. In Lafourche Parish, the risk factors for lead exposure are low. This is not the case for metropolitan New Orleans.

For the matched data sets of metropolitan New Orleans, 57 (37%) of the census tracts have blood lead concentrations of ≥10 μg/dl. Also, soils in 44 (28.5%) of the census tracts exhibit a median lead dust content of ≥400 mg/kg and 45 (29%) of the census tracts have over 50% of their homes built before 1940. Communities of metropolitan New Orleans differ significantly from communities of Lafourche Parish.

**Association between age of housing and SPb concentrations.** If housing contributes major quantities of SPb to cities, then SPb concentrations should be associated with the age of housing. As shown in Figure 1, the communities with the oldest housing in metropolitan New Orleans are generally associated with high median SPb concentrations; however, the peak area of oldest housing is more extensive than the peak area of highest SPb concentrations and is shifted to another part of the city. The lack of conformity between the age of housing and SPb content was noted for older, but low traffic flow, communities of North Minneapolis, Minnesota, and newer, but high traffic flow, communities of South Minneapolis (25). Also, the soils of the oldest communities of the small, low traffic flow town of Rochester, Minnesota, contain a fraction of the lead of the heavily traveled communities of South Minneapolis (25). Likewise, Natchitoches, a small town and among the oldest communities of Louisiana, has a fraction of the SPb concentration of New Orleans (12). The association between the age of housing and SPb concentration is strongest in large cities. In small towns, such as Thibodaux in Lafourche Parish, where historic traffic flows have been consistently small, the association between the age of community housing and SPb concentration is essentially nonexistent.

**Association between age of housing and BPb.** Age of housing may also be associated with BPb. This association has been observed by several investigators (14,26). The association between the age of housing and median BPb concentration is about as strong as the relationship between the age of housing and median SPb concentration in this study. As shown in Figure 1, however, the peak of the age of housing data does not appear to coincide with the peak of median BPb data. The peak area of old housing is in another part of the city and is more extensive than the area of peak BPb levels. What is more important is that while low BPb levels are strongly associated with new housing, high BPb levels are nearly evenly split between old and new housing (Table 5). The age of housing does not indicate the locations where the childhood populations with the highest BPb levels are found. Other investigators have described similar findings. For example, in Omaha, Nebraska, there was a lack of conformity between BPb and the age of housing (27). Many small towns have relatively old housing and, as in the case of the communities with the oldest housing in Louisiana, when the age of housing is used to predict the number of children with exposure >10 μg/dl or >15 μg/dl (28), the actual exposures are unlikely to match estimated exposures. The use of age of housing as a predictor of BPb tends to overestimate the exposure of children in small towns, and this is contrary to what is known about lead exposure in small towns (7).

**Association between SPb concentration and BPb.** Given the p-value of 10⁻¹⁰ for median SPb compared to 10⁻¹⁰ for the age of housing in association with median BPb, there is a response 12 orders of magnitude stronger for soils than for age of housing. This difference in response means that the legacy of accumulated lead in the soil of the urban environment is an especially important potential source of exposure to children. The correspondence between SPb concentration and BPb indicates that the peak of SPb concentrations coincides with the peak of BPb (Fig. 1). Furthermore, the least sum of absolute deviations model derived from empirical data in this study applies across the board for communities in both large cities and small towns of Louisiana.

The mechanism connecting SPb concentration and BPb levels is most likely the ubiquitous hand-to-mouth activities exhibited by children (29,30). In a study measuring hand lead in day care center children in New Orleans, the amount of hand lead increased significantly after outdoor play compared to after indoor play (31,32). The higher the amount of lead dust in outdoor soils, the higher the amount of lead that appears on hands and the greater the potential for children to ingest increased amounts of lead in this route of exposure. In this study, the communities of the city that require priority attention are located at sites that, besides the ages of their houses, are better defined by SPb concentration. This finding is consistent with other research (25,27,29–32). Our results strongly support the EPA report that, along with attention to lead-based paint, there must be a reduction of exposure to lead-contaminated soil (18). The current EPA guideline for lead in soils is 400 μg/g for residential sites (18). The EPA guideline refers to a peak value of a composite sample and not to the median value of a group of samples collected from different sites. If most of the soil samples of a community meet the EPA guideline, then the median would be substantially less than 400 μg/g. According to the empirical model of SPb to BPb developed in this study, when the median lead content in soil is 430 mg/g, the median BPb will be 10 μg/dl. When the median SPb is 310 μg/g, groups of children will exhibit a median BPb level of 9 μg/dl. This study suggests that remedial actions and specific community-based public health interventions can prevent childhood lead exposure where median SPb concentrations exceed 300 μg/g. Several measures have proven effective in reducing lead exposure, including educating parents and child-care providers about residential play sites, establishing plant coverings on soils, covering soils with wood chips, and adding play boxes with clean sand (33,34).

**Conclusions**

Given the strong association between median BPb and median SPb, we predict that reducing soil lead in populated areas with lead-contaminated soils will also reduce childhood lead poisoning. Collection and analysis of soil is a relatively inexpensive undertaking. Given the predictive value of soil lead, the effort is worthwhile because it provides an additional method for developing primary prevention strategy for managing lead exposure. Efforts to remediate or encapsulate contaminated soils are among the actions that can be encouraged to reduce the lead exposure to our society's population of inner-city children.

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