Spatial And Temporal Relationships Between Blood Lead And Soil Lead Concentrations In Detroit, Michigan

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SPATIAL AND TEMPORAL RELATIONSHIPS BETWEEN BLOOD LEAD AND SOIL LEAD CONCENTRATIONS IN DETROIT, MICHIGAN

by

MICHAEL JONATHAN BICKEL

THESIS

Submitted to the Graduate School of Wayne State University, Detroit, Michigan

in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

2010

MAJOR: CIVIL AND ENVIRONMENTAL ENGINEERING

Approved by:

______________________________  ____________________
Advisor                                Date
Acknowledgments

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Thanks to Dr. Carol Miller for making it possible for me to attend Wayne State and for serving on my committee. Thanks to my advisor, Dr. Shawn McElmurry for his constant enthusiasm and help; Dr. Larry Lemke for his help with variograms and interpretation of results; Dr. Savolainen for his help with statistics.

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CHAPTER 1: BACKGROUND

Literature Review

Historic and Current Blood Lead Levels

Typical blood lead levels (BLLs) in the United States have decreased in the last generation. In 1970, average annual BLLs observed in New York City were 20.0 to 30.4 micrograms per deciliter (µg/dL) for different demographic groups (Billick et al. 1979). In 1976, annual averages for the same groups had decreased to 17.2 to 21.2 µg/dL (Billick et al. 1979). A “slow exponential decline” in several cities was observed from 1970 through 1999 with the annual average BLL around 4 µg/dL in the late 1990s (Haley and Talbot 2004).

While BLLs have decreased, previously un-associated medical problems have been associated with low BLL, including decreased IQ and brain function (Jusko et al. 2008; Lanphear et al. 2005). The Center for Disease Control (CDC) has set unacceptable blood lead levels progressively lower. The unacceptable level was set to 60 µg/dL in 1960, 30 µg/dL in 1970, 25 µg/dL in 1985, and 10 µg/dL in 1991 (ATSDR). Recent research associates even 5 to 10 µg/dL with health risks (Jusko et al. 2008; Lanphear et al. 2005).

Previous Correlations to BLL

Lead exposure involves sources, pathways, and bioavailability. Ryan et al. (2004) summarized the current understanding of lead sources in the United States: “Paint, drinking water, soil, and dust that contain lead are the major remaining sources of exposure”. Intake by ingestion and inhalation are assumed to be the dominant routes of exposure (Clark et al. 2006; Clark et al. 2008; Ryan et al. 2004). The portion of ingested or inhaled lead which can be subsequently measured in the body is known as the bioavailable portion. Numerous studies have contributed toward quantifying bioavailability of various species of lead (Hettiarachchi and Pierzynski 2004; Ryan et al. 2004). Identifying the bioavailable fraction of environmental lead requires estimation based on the physical form of lead (i.e. aqueous,
solid, gaseous) and chemical speciation (e.g. PbSO₄) (Hettiarachchi and Pierzynski 2004) or by measuring the intake of a known dose of lead to an organism (Gulson 2008; Ryan et al. 2004). Bioavailability testing which observes a direct dose-response relationship generally ignores the influence of other environmental exposures. Testing is time and resource intensive. Another approach to observing exposure pathways is to examine BLL concurrently with environmental factors to observe correlations. This approach has been used extensively (Table 1) but does not prove exposure response relationships. Many of the observed correlations are weak or cannot be related deterministically. For example, Lanphear and Roghmann (1997) proposed several exposure pathways by this approach, but observed a stronger correlation of blood lead to race than to any environmental variable. At this time, the relationship of lead poisoning to environmental exposure is not established.

Correlations have been useful for identifying and comparing risks. Demographic correlations including welfare, race, and household income have been used to target high risk children for intervention (Kim et al. 2008; Miranda et al. 2002). Lewin et. al (1999) used regression analysis to create a multivariate predictive model for individual BLLs. Another product of this approach was the comparison of potential influences on BLL by the relative weights of observed correlations. Mielke et al. (2007) used median soil lead in a census tract to predict median BLL in the same tract. Lanphear and Roghmann (1997) used “a linear structural equation modeling procedure” to compare the relative weights of several exposure pathways. All these studies have relied on correlations between BLL and other variables. However, many of the correlations are weak. Many of the variables are not recorded in existing BLL data sets. Correlations offer suggestions about possible factors contributing to lead poisoning, but do not provide mechanistic understanding.
<table>
<thead>
<tr>
<th>Correlated Variable</th>
<th>Category of Variable</th>
<th>Citation(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Race</td>
<td>Demographic, Biological</td>
<td>(Lanphear and Roghmann 1997; Lewin et al. 1999; Miranda et al. 2002)</td>
</tr>
<tr>
<td>Income</td>
<td>Demographic</td>
<td>(Lanphear and Roghmann 1997; Lewin et al. 1999; Miranda et al. 2002)</td>
</tr>
<tr>
<td>House Age</td>
<td>Demographic, Indirect Environmental</td>
<td>(Miranda et al. 2002)</td>
</tr>
<tr>
<td>Education</td>
<td>Demographic</td>
<td>(Lewin et al. 1999)</td>
</tr>
<tr>
<td>Sex</td>
<td>Demographic, Biological</td>
<td>(Lewin et al. 1999)</td>
</tr>
<tr>
<td>Smoker in Household</td>
<td>Indirect Environmental</td>
<td>(Lewin et al. 1999)</td>
</tr>
<tr>
<td>Air Conditioning in House</td>
<td>Indirect Environmental</td>
<td>(Lewin et al. 1999)</td>
</tr>
<tr>
<td>Soil Lead (indirect)</td>
<td>Indirect Environmental</td>
<td>(Lanphear and Roghmann 1997)</td>
</tr>
<tr>
<td>Soil Lead (direct)</td>
<td>Direct Environmental</td>
<td>(Lewin et al. 1999; Mielke et al. 2007)</td>
</tr>
<tr>
<td>Dust Lead on Hands</td>
<td>Direct Environmental</td>
<td>(Lanphear and Roghmann 1997)</td>
</tr>
<tr>
<td>Airborne Lead</td>
<td>Direct Environmental</td>
<td>(EPA 1995)</td>
</tr>
<tr>
<td>Floor dust lead</td>
<td>Direct Environmental</td>
<td>(Adgate et al. 1998; EPA 1995)</td>
</tr>
<tr>
<td>Furniture Dust Lead</td>
<td>Direct Environmental</td>
<td>(EPA 1995)</td>
</tr>
<tr>
<td>Window Sill Dust Lead</td>
<td>Direct Environmental</td>
<td>(EPA 1995)</td>
</tr>
<tr>
<td>Interior Dust Lead (Composite)</td>
<td>Direct Environmental</td>
<td>(Lewin et al. 1999)</td>
</tr>
<tr>
<td>Gasoline Sold</td>
<td>Indirect Environmental</td>
<td>(Billick et al. 1980)</td>
</tr>
</tbody>
</table>

Table 1: Variables that have been correlated to BLL

**Soil Lead**

Previous studies have found soil lead concentration to be spatially continuous (Lin et al. 2001; Rawlins et al. 2005; Schaefer et al. 2010; Shinn et al. 2000). Studies have also justified describing soil lead concentrations as log-normal distributions (Lin et al. 2001; Rawlins et al. 2005). Where samples are composites of multiple sample points, normal distribution of lead concentration has been reported (Hu
et al. 2006). Spatial continuity of soil lead indicates the primary source of lead is diffuse airborne deposition (Howard and Sova 1993; Mielke 1994; Wheeler and Rolfe 1979). The pattern of soil lead concentrations in cities has been described as a “bulls-eye”, with areas of highest concentration surrounded by areas of slightly lower concentration (Laidlaw and Filippelli 2008).

Street side soil lead is not necessarily representative of soil lead on a residential lot. Mielke (1994) found house side soil lead concentrations 2 to 5 times higher than street side concentrations in urban New Orleans. Both Mielke (1994) and Linton et al. (1980) found much different lead content at the house side than near the street. Neither study reports the setbacks (distances between house and street) or the variance of the samples. Lewin (1999) reported soil “located in areas considered to be play areas for the household’s children”. Laidlaw and Filippelli (2008) have stated that soil lead “decays exponentially away from the roadside, with the concentration proportional to historical traffic volume”. Wheeler and Rolfe (1979) proposed a binomial exponential decay and suggested different dispersion distances for different sizes of car exhaust particles. Soil sample location has a large impact on soil lead measurements.

Soil lead concentration varies even in a single horizontal location. Several researchers have found that lead concentration varies among size fractions of the same soil (Gulson et al. 1995; Linton et al. 1980). Some researchers consider the top portion of the soil (the organic horizon) a homogenous pool which accumulates and releases lead (Kaste et al. 2005; Klaminder et al. 2006). In such a model, lead concentration is assumed to be uniform throughout the top “pool”. Other researchers have determined that lead concentration varies with depth near the surface (Erel 1998; Howard and Sova 1993; Laidlaw 2001). Sampling technique and documentation are important components of soil lead measurement.

Researchers have used many methods to sample soil for lead measurement, but there is no universal standard. Laidlaw (2001) sampled only areas thought to be undisturbed. His samples were
composites of 3 sub-samples of the top 5 centimeters, which were sieved to exclude all particles greater than 63 μm diameter. Concentrations were reported for the fraction of soil less than 63 μm. Mielke’s sampling convention took “surface scrapes from the top 2.5 cm of the soil” and sieved with a number 10 (2 mm) sieve (Mielke 1994). Lewin et al. (1999) took composite samples from the top inch; no sieving was reported. The Detroit Lead Assessment Project took composites of 5 soil aliquots from the top 3 inches of soil (Weston 2004). No sieving was reported. Marin (2007) took samples “from the upper 3 inches of soil” and sieved with a number 10 (2 mm) sieve, following the method of Howard and Sova (1993). The lack of a standard sampling procedure makes data comparisons across multiple studies difficult.

Literature suggests that exposure risks associated with lead in soil do not decrease with time in the absence of remediation (Filippelli and Laidlaw 2010; Ryan et al. 2004). Filippelli and Laidlaw (2010) wrote, “We have hit the wall in terms of improving the lead-poisoning outlook for some children, particularly those living at or below the poverty level in older cities...”. However, residence time of lead in soil has been studied with a wide variety of results. Several researchers have estimated residence time on the order of centuries (Kaste et al. 2005; Klaminder et al. 2006). Ryan et al. (2004) states, “lead usually remains near the surface of the soil”. Other research shows that lead moves through soils relatively quickly. Wheeler and Rolfe (1979) estimated that 72-76% of the total lead deposited by vehicle emissions is not present in the top 10 cm of soil. Howard and Sova (1993) concluded that soil lead from vehicle emissions migrates downward through soil. Erel (1998) estimated a downward velocity of soil lead of 0.5 cm/year. More comprehensive knowledge of soil lead residence time would improve understanding of lead poisoning risks.

**Water Lead**

Lead contaminated drinking water has been investigated as a potential source of lead to children (Edwards et al. 2009; Miranda et al. 2007; Ryan et al. 2004). Lead in drinking water comes from
metal pipes installed prior to 1940 and from solder at pipe connections installed prior to 1986 (Miranda et al. 2007). Edwards et al. (2009) define sample types as follows: “A “first draw” sample refers to a 1 L sample collected from a tap after greater than 6 h holding time in the household plumbing. After first draw samples are collected, water is flushed for a short time period (typically 30 s to 5 min) and a 1 L “second draw” sample is collected.” Addition of chloramines for water treatment may increase dissolution of lead (Edwards et al. 2009). A 2003 study observed that water lead concentration in Washington DC homes with lead pipes varied from less than 15 ppb to 48,000 ppb (Edwards et al. 2009). Lewin et al. (1999) reported a 5% correlation coefficient between BLL and the concentration of lead in drinking water (both log transformed) using first draw samples from the cold water tap. This was weaker than correlations of BLL to paint (8%), dust (36%), and soil (38%), with all variables log transformed. Lanphear and Roghmann (1997) reported a -17% correlation between blood lead and water lead using both first and second draw samples.

**Previous Soil and Blood Lead Work in Detroit, Michigan**

The Michigan Department of Community Health (MDCH) maintains an extensive database of blood lead records in Michigan. To protect privacy, individual identifiers are removed from sample records before data is released to researchers.

Soil lead has been measured in Detroit in the last 10 years (Wendland-Bowyer 2003a; Weston 2004). These studies provide a large existing data pool of soil samples in residential neighborhoods. The large number of data points, broad collection area, and varying sample spacing are strengths of this combined data set. Unfortunately, samples were taken by different researchers using different procedures, a weakness of the data set.

Remediation projects are common in Detroit. Soil cleanups have been completed at two former smelter sites and one industrial site (Lam 2003a; Wisdom and Bhambhani 2004). Lead abatement has
been completed in houses (Lam 2007; Wendland-Bowyer et al. 2003). Lead contaminated soil has also been removed and replaced in several residential areas located near industrial sites (Lam 2003b; Lam 2006; Lam 2007; Wendland-Bowyer 2003b; Wendland-Bowyer and Lam 2003). These projects should reduce the residual lead exposure in specific locations.

**Spatial and Temporal Variability of Environmental Lead**

Spatial and temporal variability varies for different pools of environmental lead. Table 2 summarizes the current understanding of typical variability of several of these pools.

<table>
<thead>
<tr>
<th>Environmental Lead</th>
<th>References</th>
<th>Year to Year Time Variation</th>
<th>Seasonal Variation</th>
<th>Spatial Variation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drinking Water</td>
<td>Edwards et al. 2009</td>
<td>0 – 70 ppb</td>
<td>Not reported</td>
<td>&lt;15 ppb - 48,000 ppb, by House</td>
</tr>
<tr>
<td>Paint</td>
<td>With demolition/ remediation</td>
<td>None</td>
<td>By House</td>
<td></td>
</tr>
<tr>
<td>Soil</td>
<td>Mielke et al. 2007</td>
<td>None</td>
<td>1,000 – 2,000% on a single lot</td>
<td></td>
</tr>
<tr>
<td>Dust</td>
<td>EPA 1995</td>
<td>40 – 60%</td>
<td>Proximate to roadways</td>
<td></td>
</tr>
<tr>
<td>Gasoline</td>
<td>Billick et al. 1980; Wheeler and Rolfe 1979</td>
<td>Source eliminated in 1986; still present in soil</td>
<td>With Traffic</td>
<td></td>
</tr>
<tr>
<td>Ambient Air</td>
<td>Duggan 1984; EPA 1995</td>
<td>23 – 30%</td>
<td>By Mother</td>
<td></td>
</tr>
<tr>
<td>Prenatal</td>
<td>Manton et al. 2003</td>
<td>NA</td>
<td>100% during pregnancy</td>
<td></td>
</tr>
<tr>
<td>Blood</td>
<td>Billick et al. 1979; EPA 1995; Haley and Talbot 2004; Laidlaw et al. 2005; Mielke et al. 2007</td>
<td>-11 to -15%</td>
<td>150%</td>
<td>1,800% by Census Tract</td>
</tr>
</tbody>
</table>

Table 2: Variability of environmental lead contrasted with BLL

**Census Tracts**

United States census tracts have been used in previous studies to establish correlations between BLL and soil lead (Mielke et al. 1997; Mielke et al. 2007; Mielke et al. 1999). Census tracts have been
used as a basis of measurement because the tracts are generally based on a population size (Mielke 1994). This is not necessarily true in Detroit, where the population has decreased from 1.85 million in 1950 to 950,000 in 2000 (Gavrilovich and McGraw 2000). However, census tract boundaries are readily available and are an excellent way to reference new data to old.

GIS

Geographical Information Systems (GIS) (ESRI 1999) has been used for research in a number of ways. Facchinelli et al. (2001) used GIS to interpret the results of geostatistical studies of metal concentration. Yesilonis et al. (2008) overlaid patterns of metal concentrations on GIS maps to check proximity of high concentrations to natural and man-made features. Other studies have used only the database capabilities of GIS, comparing medical risk factors to zip codes or demographic groups (Miranda et al. 2002). More recent studies have used the geocoding capability of GIS along with database capability and census information to improve risk assessment (Kim et al. 2008). GIS is a powerful tool that can be used to assess spatial relationships.

The Geometric Mean

The geometric mean is the median of a log-normal distribution. Researchers have historically used the log-normal distribution and geometric mean to describe the BLL of populations (Billick et al. 1979; Haley and Talbot 2004). Soil lead has also been found to have a log-normal distribution (Lin et al. 2001; Rawlins et al. 2005). Statistical operations on a log-normal data set are done to the natural logs (i.e. transformed) of data, which are approximately normally distributed. Results are adjusted using an inverse transform. In this thesis, all “averages” are geometric means unless otherwise stated.
Objective and Methods

A significant reduction in urban childhood BLL could be achieved by identifying and eliminating the current predominant exposure to lead. Average BLLs have dropped approximately 80% since the elimination of leaded gasoline (Haley and Talbot 2004), suggesting that gasoline previously provided up to 80% of total exposure to lead. It may be possible to further reduce the exposures associated with lead by studying existing exposure patterns.

This thesis examined spatial and temporal relationships between soil lead and blood lead. The assumptions of this study are:

- One “primary” exposure is responsible for the majority of blood lead in Detroit children. A change in this primary exposure would correspond directly to a change in the population BLL.
- The distribution (mean, variance, and percentiles) of individual BLL is related to the distribution of exposure.
- Naturally occurring (background) levels of soil lead are present across the study area.
- Soil lead above natural conditions (anthropogenic lead) has approximately equal bioavailability.

Experiments were designed to answer the following question: how well does variation in soil lead concentration correlate with temporal and spatial variation in blood lead in the Detroit area? BLLs in the Detroit area were studied to determine trends and areas with high BLL (Chapter 2). Three hypotheses were then tested:

- The relationship of blood lead to soil lead is described by a predictive equation (Chapter 3).
- A predictive equation is more accurate where soil lead and blood lead samples are close together (Chapter 4).
- Blood lead and soil lead are decreasing concurrently (Chapter 5).

Tests of all three hypotheses used a combination of graphical and statistical methods. Summary statistics of BLL and soil lead were prepared for spatial and temporal subsets of the Detroit area.
Comparison of the subsets was done graphically (Chapters 3, 4, and 5) and statistically (Chapters 4 and 5) using the summary statistics. Conclusions are reported in Chapters 3, 4, and 5 and discussed in Chapter 6. The findings support soil lead as a potential source of blood lead.
CHAPTER 2: BLOOD LEAD DATA AND OBSERVATIONS

Introduction

The blood lead data set was examined to locate unique areas for more detailed study. These could be areas where average BLL is increasing, areas where average BLL is decreasing, or areas where average BLL is consistently high or low. Locating and comparing these areas could reveal differences that suggest exposure pathways. Patterns in BLL were used to determine soil testing locations and studies.

Methods

The Michigan Department of Community Health (MDCH) maintains an extensive database of blood lead records in Michigan. For this research, child blood lead data was provided by MDCH for Wayne, Macomb, and Oakland counties. The original data set contained blood samples collected from January, 2000 through the beginning of April, 2009 and is described in more detail in Table 3. A data sharing agreement between Wayne State University and MDCH allowed individual BLLs to be provided with home addresses attached. To protect privacy, addresses were rounded to the city block, giving each blood sample a geographical precision of plus or minus approximately 200 feet. Additional data identifiers were city, county, zip code, month and year of sampling, child age in years, blood draw type (venous, capillary, or unreported), and detection limit. Blood lead measurements are reported as integers, with units of micrograms lead per deciliter of blood (μg/dL). The limit of detection was one μg/dL for at least 96% of records. Non-detect samples are reported as one μg/dL.

The data were geocoded by rounded address using ArcGIS 9.3 (ESRI 1999). Geocoding is a process which assigns a spatial reference to each data point by matching the zip code and street address to a reference map. Latitude and longitude coordinates are assigned and the data are projected onto a two dimensional map. This study used the Lambert Conformal Conic projection (State Plane, Michigan, south zone) and NAD 1983 datum.
Approximately 87% of the original dataset points were geocoded. Reasons data points could not be placed include: the lack of a directional identifier (e.g. Adams Street instead of North or South Adams Street) alternate street names, misreported or unreported addresses, and outdated reference directories. ArcGIS is able to compensate for misspelled street names, but not for streets which are not listed in the reference directory. Processes for improving the percentage of georeferenced points are available but require enormous effort that results in only marginal improvements in analysis capabilities (Kim et al. 2008). Because of the high percentage of data that was successfully geocoded, both in total numbers and within groups (Table 3), no additional steps to improve geocoding were taken.

<table>
<thead>
<tr>
<th></th>
<th>Original Dataset</th>
<th>After Geocoding</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total</strong></td>
<td>693,483</td>
<td>604,129 (87%)</td>
</tr>
<tr>
<td><strong>Method</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capillary Blood Draw</td>
<td>147,997 (21%)</td>
<td>129,260 (21%)</td>
</tr>
<tr>
<td>Venous Blood Draw</td>
<td>509,441 (73%)</td>
<td>445,352 (74%)</td>
</tr>
<tr>
<td><strong>County</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oakland County</td>
<td>97,093 (14%)</td>
<td>74,614 (12%)</td>
</tr>
<tr>
<td>Macomb County</td>
<td>60,543 (9%)</td>
<td>49,035 (8%)</td>
</tr>
<tr>
<td>Wayne County</td>
<td>535,847 (77%)</td>
<td>480,480 (80%)</td>
</tr>
<tr>
<td><strong>Age</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 Years Old</td>
<td>1,901 (0.3%)</td>
<td>1,618 (0.3%)</td>
</tr>
<tr>
<td>1 Year Old</td>
<td>162,842 (23%)</td>
<td>139,530 (23%)</td>
</tr>
<tr>
<td>2 Years Old</td>
<td>107,332 (15%)</td>
<td>93,202 (15%)</td>
</tr>
<tr>
<td>3-6 Years Old</td>
<td>348,393 (50%)</td>
<td>306,392 (51%)</td>
</tr>
<tr>
<td>7-15 Years Old</td>
<td>72,425 (10%)</td>
<td>63,387 (10%)</td>
</tr>
</tbody>
</table>

Table 3: Comparison of blood lead data set before and after geocoding

The blood lead data set was examined to find areas where soil lead and blood lead would be studied concurrently. A total of 1,202 census tracts were analyzed in Wayne, Oakland, and Macomb
counties. Target areas were census tracts with high BLL or with a high rate of change in BLL. GIS was used to sort data into spatial and temporal subsets at multiple scales and to quickly visualize the results. To find areas of high and low average BLL, the geometric mean BLL was computed for each census tract and shown using an ArcGIS color scale (Figure 1). Areas with the highest average concentrations were examined more closely as potential soil sampling sites.

An ArcGIS color scale was also used to locate census tracts where BLL was changing over time. To create a color scale showing change in BLL, BLL measurements were sorted by census tract and by calendar year. ArcGIS was used to sort samples and to compute summary statistics (number of records, geometric mean, and geometric standard deviation) for each subset of records. Summary statistics were exported to Microsoft Excel (Microsoft 2006). Excel was used to regress annual average BLL against calendar year. Slope, intercept, and coefficient of determination ($R^2$) were recorded and imported back into ArcGIS. A color scale was applied to slope to locate the areas of greatest change.

The regression analysis was effective for determining trends, but had limitations. Some false positives were noted because all annual averages were weighted equally, regardless of the number of measurements. Coefficients of determination ($R^2$) were used to compare regression trend lines. However, $R^2$ alone is not an adequate measure of goodness of fit (Fonticella 1998). The 95% confidence of the mean was also used to check the validity of regression trend lines. These checks showed consistent trends which are described below.

**Results and Discussion**

**Overall Trends**

Annual average BLL in the Detroit area decreased from 3.5 to 1.9 µg/dL from 2000 to 2008. This is consistent with the “slow exponential decline” reported by Haley and Talbot (2004).
Tracts with High Average Blood Lead

Overall average BLL is shown in Figure 1. Census tracts with the highest average BLL are concentrated within the cities of Detroit and Pontiac. They are surrounded by areas of slightly lower...
BLL, consistent with the “bulls-eye” pattern described by Laidlaw and Filippelli (2008). These areas clearly exhibit spatial continuity, the phenomenon that areas close to one another can be expected to be more similar than areas that are far apart (Isaaks and Srivastava 1989). Spatial continuity implies that average BLL is the result of environmental factors within a geographical range of influence. This pattern of elevated BLL suggests environmental exposures to lead that decrease with increasing distance from local sources.

**Tracts with Increasing Average BLL**

Of 1,202 census tracts studied, only a few had apparent increasing BLL trends. Upon closer examination, an increasing trend could not be established in even one of the tracts.

Table 4 shows tracts with the greatest apparent increases as determined by trend line slope.

Figure 2 shows average BLL by year for these tracts, along with trend lines\(^1\). Three of these tracts (194500, 251300, and 511100) had fewer than 3 BLL measurements per year. In each of these tracts, a single “high” measurement (3-6 μg/dL) after 2005 is the primary influence on the trend line.

<table>
<thead>
<tr>
<th>Census Tract</th>
<th>Total Number of BLL Measurements 2000-2009</th>
<th>Change in BLL (Trend Line Slope) (μg/dL)</th>
<th>(R^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>194500</td>
<td>16</td>
<td>+0.22/yr</td>
<td>0.06</td>
</tr>
<tr>
<td>231300</td>
<td>23</td>
<td>+0.17/yr</td>
<td>0.28</td>
</tr>
<tr>
<td>511100</td>
<td>10</td>
<td>+0.38/yr</td>
<td>0.01</td>
</tr>
<tr>
<td>520900</td>
<td>40</td>
<td>+0.61/yr</td>
<td>0.36</td>
</tr>
</tbody>
</table>

Table 4: Census tracts with apparent increasing BLL trends

---

\(^1\) Confidence intervals of annual average (95%) are shown on each plot as vertical whiskers. Confidence intervals of the geometric mean are computed using the t-statistic with the log-transformed mean and standard deviation. No whiskers on a point indicates a single measurement (i.e. an infinite confidence interval). Confidence intervals extending off the top of the graph indicate that the number of measurements was too small to compute a reasonable confidence interval.
Care must be taken when attempting to infer trends based on slope. A good example of this is census tract 520900, where an increase in blood lead is overestimated by looking at only the slope. This “trend” is dominated by one high measurement in 2009 and two low measurements in 2000 and 2001. The low coefficient of determination ($R^2=0.36$) clearly indicates a weakly correlated decrease and suggests the trend may not be true. Further examination shows that 27 of the 40 measurements were from 2002 through 2005; a decreasing trend in BLL appears to exist in these years. Thus, the “strongest” increasing BLL trend is likely a false positive.
Many tracts had apparent marginal BLL increases in areas of very low average BLL. A typical increase was from 1.3 to 1.5 μg/dL over 10 years. This increase (+0.02 μg/dL annually) would be difficult to verify statistically. Furthermore, the final average is close to detection limits, reducing the precision of the measurement. These tracts were more indicative of stable BLL than of increases.

**Tracts with Decreasing Average BLL**

An overwhelming majority of census tracts showed a decreasing trend in average BLL from 2000 to 2009. The coefficient of determination ($R^2$) was used to estimate the consistency of decreases. A high $R^2$ (close to one) indicates a consistent linear decrease in average while a low $R^2$ (close to zero) indicates...
a sporadic decrease in average. Decreasing trends were frequent and consistent. Tracts with the greatest decreasing trends are shown in Table 5, Figure 3, and Figure 4. Decreases in average BLL were generally consistent ($R^2 > 0.5$) throughout areas of high average BLL. These tracts are shown in Figure 5.

Figure 4: Census tracts with extreme decreasing trends
Figure 5: Census tracts where average BLL is decreasing consistently ($R^2 > 0.5$)

Many tracts had marginal BLL decreases in areas of very low average BLL. A typical decrease (-0.02 μg/dL annually) would be difficult to verify statistically. Furthermore, the initial average is close to
detection limits, reducing the precision of the measurement. These tracts were more indicative of stable BLL than of decreases.

<table>
<thead>
<tr>
<th>Census Tract</th>
<th>Total Number of BLL Measurements 2000-2009</th>
<th>Change in BLL (Trend Line Slope) (µg/dL)</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>515600</td>
<td>1,044</td>
<td>-0.52/yr</td>
<td>0.93</td>
</tr>
<tr>
<td>516400</td>
<td>490</td>
<td>-0.54/yr</td>
<td>0.76</td>
</tr>
<tr>
<td>518500</td>
<td>810</td>
<td>-0.73/yr</td>
<td>0.95</td>
</tr>
<tr>
<td>521300</td>
<td>388</td>
<td>-0.60/yr</td>
<td>0.86</td>
</tr>
</tbody>
</table>

Table 5: Census tracts with the greatest decreasing BLL trends

Conclusions

Average BLL appears to be decreasing throughout the Detroit area. Decreases are consistent where average BLL is highest. No census tracts with increasing BLL trends were found in Wayne, Oakland, or Macomb counties. In areas where average BLL is close to the detection limit, increases and decreases are negligible. The consistent decrease of BLL throughout the tri-county area suggests a decrease in child exposure to lead.

Average BLL in Detroit area census tracts is spatially continuous, implying that it is the result of environmental factors within a geographical range of influence. The “bulls–eye” pattern (Laidlaw and Filippelli 2008) of elevated BLL suggests environmental exposures to lead that decrease with increasing distance from local sources. Within the context of decreasing BLL, it can be inferred that local sources of lead may be decreasing.
CHAPTER 3: VALIDATION OF A PREDICTIVE BLOOD LEAD EQUATION IN DETROIT

Introduction

Based on data collected in the city of New Orleans from 2000 to 2005, Mielke et al. (2007) published a predictive equation describing average BLL in a US census tract based on median soil lead concentration. Mielke’s equation is

\[
BL = 2.038 + 0.172 \times \sqrt{SL}
\]

where BL is median predicted BLL (μg/dL) and SL is median observed soil lead (mg/kg) in a census tract, with a minimum of 5 measurements each. The equation is based on 55,551 BLL samples and 28,115 soil lead samples. It is an empirical equation which uses predefined political boundaries (census tracts) to separate populations. Most census tracts in Detroit and New Orleans are between 0.1 and 1 square miles and have 1,000 to 6,000 people (ESRI 1999). In this study, geometric mean was substituted for median in all data sets for consistency with other BLL studies (Billick et al. 1979; EPA 1995; Haley and Talbot 2004) and to compute confidence intervals. The geometric mean of a log-normal distribution is equal to the median. It is not known whether this equation is universal or specific to New Orleans.

A consistent positive relationship between BLL and soil lead would support soil lead as the primary source of lead to children. An equation showing this relationship could contain several significant components of lead exposure. The intercept should represent the baseline BLL independent of soil lead exposure. Slope and curvature should represent some aspect of human exposure and response. It is important to determine if Equation 1 describes this relationship in Detroit.

If soil lead is the source of blood lead, then the relationship of soil lead to BLL may represent the human response to environmental exposure. An accurate description of this relationship can guide future lead poisoning research. To determine whether Equation 1 describes this relationship, the hypothesis that it predicted BLLs in the Detroit area was tested. Satisfactory prediction was determined
by the percentage of measured BLL averages that were close to predicted values, as determined by confidence windows of measured values.

Methods

Data

Soil lead data were taken by Dr. Howard Mielke in 2002 and published by the Detroit Free Press (Wendland-Bowyer 2003a). Mielke’s sampling protocol included 10 street side soil samples, 3 house side soil samples, and 2 open space soil samples in each census tract; all samples were taken from the top inch of soil (Mielke 1994). This particular data set included 19 samples in each of 15 Detroit area census tracts.

Blood lead data were provided by MDCH for Wayne, Macomb, and Oakland counties. Data were geocoded by rounded street address and sorted by year and census tract using ArcGIS. Blood lead samples taken in 2002 from the 15 census tracts noted above were used.

Analysis

This study compared average soil lead to average BLL in 15 census tracts to check for consistency with the equation published by Mielke et al. (2007). For each census tract, (geometric) mean soil lead and BLL were computed. Confidence intervals of both BLL and soil lead were computed using Student’s t-statistic (Student 1908) using the log transformed values of measured concentrations. A scatter plot was created, showing mean soil lead versus mean BLL.

To check the reliability of equations, the precision of the measured data was used as an estimator. The 95% confidence intervals of mean soil lead and mean blood lead were plotted, resulting in two dimensional confidence windows on the scatter plot. The equation was superimposed on the plot to determine if it was as precise as the measured data. The equation was expected to pass through 9 of
10 confidence windows\(^2\). If the equation did not meet this standard of precision, it was considered unreliable.

Coefficients of determination (\(R^2\)) were computed both for Equation 1 and for a linear fit using the ANOVA approach to regression analysis (Fonticella 1998). Coefficients of determination were used qualitatively to compare equations.

**Results and Discussion**

Equation 1 was plotted with the experimental data (Figure 6). The data show a definite trend of increasing BLL with increasing soil lead. Equation 1 follows that trend, with an \(R^2\) of 0.34. The intercept, slope, and curvature of the prediction do not agree with the experimental data, which appears to follow a linear trend with a y-intercept of one. The prediction intersects the (90%) confidence windows of only 7 of 15 points. Based on the observations, Equation 1 does not accurately describe the relationship of soil lead to BLL in the Detroit area and the hypothesis is rejected.

An alternate equation was composed to visually fit the experimental data. The slope, intercept, and shape reflect the observed relationships between the variables. An interpretation of these observations follows.

The intercept should represent the baseline BLL independent of the observed environmental exposure. The experimental data indicate a y-intercept at BLL near 1 microgram per deciliter (µg/dL). This is consistent with the way that BLL is measured and reported. The detection limit of BLL measurements used in this study was one µg/dL; concentrations below this level are reported as 1 µg/dL. Because of this, an intercept of one µg/dL corresponds to negligible baseline exposure.

The shape of the plot (slope and curvature) should represent the human exposure and response to soil lead. Dose-response curves showing ingested versus absorbed lead in swine show a decreasing

\(^2\) Probability that the true intersection of the two means is within the 95% confidence interval of both is approximately 90%.
rate of response as dose increases (Ryan et al. 2004). One possible assumption is that an exposure-
response curve for humans may have the same shape. However, a linear slope is also a reasonable
assumption because many non-linear slopes are approximately linear near the origin. The slopes may
be shown very precisely as linear within the proper range. The assumption of a linear slope does not
deny the possibility that the slope is non-linear outside its measured range. A linear slope has only two
parameters: slope and intercept. Use of additional parameters should be justified.

Figure 6: Detroit area BLL compared to BLL predicted by Equation 1 (Mielke et al. 2007)

An equation with an intercept of one and a slope between 0.016 and 0.018 can intersect the
windows defined by confidence intervals of all 15 data points. The slope could be determined by linear
regression, which gives a slope of 0.0173 when forced through (0, 1). This slope appears to adjust significantly to compensate for one low point which has a large confidence window. Linear regression does not weight the points by their precision or symmetry about the line. A better visual fit (Figure 7) is described by an equation which gives less weight to the point with the largest confidence window:

$$BL = 1 + 0.018 \times SL$$  \hspace{1cm} \text{Equation 2}

where BL is blood lead concentration (µg/dL) and SL is soil lead between 0 and 300 mg/kg.

Figure 7: Detroit area BLL compared to BLL predicted by Equation 2

Equation 2 fits the experimental data. The intercept, slope, and shape are consistent. The coefficient of determination ($R^2 = 0.41$) is only slightly higher than for Equation 1. However, all
discrepancies between predicted and measured data may be explained by the precision of measured data. The prediction intersects all (15 of 15) 90% confidence windows, showing that it is as precise as the measured data.

This study attempts to predict BLL and explain prediction error by soil lead alone, since soil lead is the only independent variable in Equation 1. However, different soil types, exposure times, human behavior, and biological factors are also likely to play a significant role in determining BLLs. Other potential sources of error include sampling and quality control discrepancies with existing data sets. The total and recent amounts of time children spent near their homes, the air and water lead levels, recent changes in soil lead due to remediation projects or other excavations were not quantified. All these factors are likely to have impacted the observations of this study.

Conclusions

The equation developed by Mielke et al. (2007) does not describe the variation in average BLL observed in Detroit. While Equation 1 does follow the trend of increasing BLL with increasing soil lead, it does not predict BLL accurately; it is consistently and predictably incorrect. The linear equation $BL = 1 + 0.018*SL$ (Equation 2) describes the observed relationship where BL is average BLL in a census tract and SL is average soil lead in a census tract less than 300 mg/kg.
CHAPTER 4: SPATIAL COVARIANCE OF BLL AND SOIL LEAD

Introduction

Previous studies have found soil lead concentration to be spatially continuous (Lin et al. 2001; Rawlins et al. 2005; Schaefer et al. 2010; Shinn et al. 2000). Studies have also justified describing soil lead concentrations as log-normal distributions (Lin et al. 2001; Rawlins et al. 2005). Where samples are composites of multiple sample points, normal distribution of lead concentration has been reported (Hu et al. 2006).

Average blood lead appears to be spatially continuous (Figure 1). Spatial continuity of blood lead implies that average BLL is the result of environmental factors within a geographical range of influence. An approximation of that range of influence could suggest an exposure source or pathway. If the concentration of lead in soil drives BLL, then areas with high soil lead should coincide with areas of high BLL.

This chapter tests the hypothesis that Equation 2 is a better predictor of average blood lead when soil lead and blood lead samples are close together (i.e. within the range of continuity). Moving window analysis was used to compare differently sized areas. The range of continuity was determined using semi-variograms. The average moment of inertia about the prediction line was used to compare different moving window sizes.

Methods

Data

Blood lead data were provided by MDCH for Wayne, Macomb, and Oakland counties. The initial data set contained blood samples collected from January, 2000 through the beginning of April, 2009. For this set of experiments, blood lead data over the tri-county area was used to represent 2002. For 2009, blood lead data over the 2009 calendar year was used in only the 3 census tracts where soil lead was measured. A data sharing agreement between Wayne State University and MDCH allowed individual
BLLs to be provided with home addresses attached. To protect privacy, addresses were rounded to the city block, giving each blood sample a geographical precision of plus or minus 200 feet.

Soil lead has been measured in Detroit in the last 10 years (Wendland-Bowyer 2003a; Weston 2004), providing a large existing data pool (shown in Table 6). These studies collected soil samples in residential neighborhoods. The large number of data points, broad collection area, and varying sample spacing are strengths of this combined data set. Unfortunately, samples were taken by different researchers at different times using different procedures, a weakness of the data set. The precision of published soil sample locations varies by source, but all are estimated to be within the 150 foot lag tolerance.

<table>
<thead>
<tr>
<th>Source</th>
<th>Year</th>
<th>Sample Depth</th>
<th>Number of Samples</th>
<th>Sample Locations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detroit Free Press, taken by Dr. Howard Mielke (Wendland-Bowyer 2003a)</td>
<td>2002</td>
<td>Top inch</td>
<td>362</td>
<td>Street side, house side, and open space</td>
</tr>
<tr>
<td>Detroit Lead Assessment Project (Weston 2004)</td>
<td>2003</td>
<td>Top 3 inches</td>
<td>204</td>
<td>“undisturbed areas”</td>
</tr>
<tr>
<td>AKT Peerless (Weston 2004)</td>
<td>2003 or Earlier</td>
<td>Unreported</td>
<td>38</td>
<td>Not Reported</td>
</tr>
<tr>
<td>Michael J. Bickel, WSU</td>
<td>2009</td>
<td>Top inch</td>
<td>58</td>
<td>Street side</td>
</tr>
</tbody>
</table>

Table 6: Comparison of soil sample sources

Soil lead data from 2009 was collected in 3 Detroit area census tracts. Precision of 2009 soil sample locations was ± 30 feet based on GPS precision. Sample and test procedures were adapted from Mielke (1994) and EPA method 3051 (2007). Adaptations were based on available laboratory equipment, property access, and the estimated precision of the techniques considered. A detailed description the analytical procedures implemented including quality control, sample precision, and cleaning can be found in “Appendix A: Detailed Soil Lead Measurement Procedure”.
Soil Sampling Procedure

Soil cores were taken using an AMS stainless steel 2-inch by 6-inch soil core sampler with a slide hammer. Cores were taken from grassed areas near the street, with distance to the street noted for each core. The grassed surface was retained as part of the core. Soil core sleeves were capped and labeled by sample number, ground cover, and time of collection. The location of each sample was recorded on a log sheet, as well as recorded with a GPS unit (Garmin 72) with a horizontal precision of 15 to 30 feet. Photographs of each sample site were taken. Between samples, the core sampler was rinsed with de-ionized water and wiped with clean paper towels and Kim-wipes.

Field Observations

Several potential influences on metal content were observed. These included peeling paint, cans, broken bottles, concrete chunks, variations in soil type and vegetation, and fire hydrants. Visible litter was avoided during sampling. Evidence of recent soil mixing was seen in many places. This evidence included new curb, new sidewalk, recent demolition of houses, new construction, and painted marks indicating recent utility excavation. Most of the cores were primarily dark grey sand. A few cores were entirely uniform graded brown sand that appeared to be non-native backfill. With the exception of a few sites with very recent construction, the year or extent of the most recent soil mixing could not be estimated. However, several of the cores likely consist of very recent soil. The impact of this on soil lead concentrations has not been determined.

Sample Preparation

The top inch of each soil core was separated into two soil samples: top half inch and second half inch. Each sample was placed in a 7 ounce Whirl-Pak bag and air dried for a minimum of 48 hours, until no visible moisture was present. The soil was extruded from the core using a custom made plastic plunger. Extruded sections were cut off with a stainless steel knife, bagged, and hand crushed within the sample bag. The stainless steel knife was rinsed in deionized water and dried using a Kim Wipe.
between each cut. Samples included grass, roots, and other organics. No sieving of the soil was done. After air drying, the sample was hand crushed again within the sample bag.

Total lead measurements were taken from each sample. The arithmetic average concentrations of the 2 measurements was considered the lead concentration in the top inch. Triplicate measurements were made of 18 of the 116 subsamples. Subsamples with triplicate measurements were reported as the arithmetic average of the three measurements.

**Soil Digestion**

Based on EPA method 3051a (EPA 2007), 0.45 - 0.55 g of each soil sample were placed in a Teflon PFA digestion tube using a stainless steel scoop. Foreign materials, clumps, stones, bark, and other organic materials were avoided to the extent possible. Trace metal grade nitric acid (10.0 mL) was added to each tube. The samples were heated to 175 °C over a period of 9 minutes and maintained at 175 °C for 4.5 minutes in a digestion microwave (CEM Mars Xpress), then cooled to room temperature. The heating time was extended from the recommended time of 5.5 minutes to 9 minutes due to heating capacity of the microwave. Samples were digested in batches of 35. Each batch also included 2 blanks (acid with no soil), one spiked control soil sample, one un-spiked control soil sample, and one Standard Reference Material (NIST 2008) sample. The SRM contained 432 ± 17 mg/kg lead from paint. Each digestion tube was emptied into an acid washed 50 mL polypropylene centrifuge tube containing 10.0 mL nanopure water. The digestion tube was rinsed with 10.0 mL nanopure water, hand shaken, and emptied into the centrifuge tube. Each digestion tube was rinsed twice, placing a total volume in the centrifuge tube of 39 mL (experiments showed that 10.0 mL HNO₃ added to 30.0 mL H₂O yielded 39.0 mL total volume). The digestion tubes were shaken for 20 minutes in a wrist action shaker (Burrell Model 75) at a setting of 5, then spun for 20 minutes in a centrifuge (IEC International) at 5,000 rpm. The centrifuged samples were decanted into clean 30 mL bottles (polypropylene or polyethylene).
**Atomic Absorption Spectroscopy**

Dissolved lead concentration was measured by flame Atomic Absorption Spectrometer (Perkin-Elmer AA200). The instrument uses air-acetylene flame direct aspiration, and is equipped with automatic deuterium lamp background correction. Lead was measured using a slit 2.7 mm wide by 1.05 mm high, a wavelength of 283.31 nm, an integration time of 3 s, and an average of 3 measurements. Typical relative standard deviations within the 3 measurements was less than 1%, with the exception of samples near the detection limit (generally about 0.05 ppm in solution). Where relative standard deviation was more than 5% and lead content was significant, a second reading was taken and used in place of the initial reading. The atomic absorption spectrometer was checked against a calibration standard every 5 to 10 measurements and re-calibrated as necessary.

Dissolved concentration represented a mass of lead dissolved in a volume of liquid. Final liquid volumes were approximately 39 mL; thus, multiplication by 39 determined the mass of lead in the liquid sample. Soil lead concentrations were determined by dividing the mass of lead by the dry mass of the sample (0.45 - 0.55 g). Soil lead concentrations were determined using the following equation:

\[
Cs = \frac{Cd \times 39}{Ms}
\]

where Cs is soil concentration (mg/kg), Cd is dissolved concentration (mg/L), and Ms is dry mass of soil (g).

**Semi-Variograms**

A semi-variogram is a visual representation of the expected variance between two measurements separated by various distances. The expected difference is based on statistical summaries of previous measurements. The semi-variogram is presented as a graph with units of distance on the x-axis and units of variance (difference squared) on the y-axis. The “nugget” is the expected variance at a distance of zero (two measurements in the same place). The expected variance typically increases with increasing distance, then levels off at the “range” (x-axis) and “sill” (y-axis). The
“variance” measurement is derived from the moment of inertia about a prediction line, with 0 being a perfect prediction. An “experimental” semi-variogram is a plot of computed variances at various sample distances. A “semi-variogram model” is a mathematical function which is visually fit to the experimental semi-variogram. Semi-variograms are typically an intermediate step in a surface prediction modeling process called kriging.

Experimental semi-variograms and semi-variogram models (Isaaks and Srivastava 1989) were created for both soil lead and blood lead. Because the distribution of both soil lead and blood lead was expected to be log-normal, log transformed values of both soil lead and blood lead were used. All geocoded blood lead data from the calendar year 2002 was used to create a blood lead semi-variogram. Three soil lead semi-variograms were constructed. Two were built using a composite data set of soil measurements taken in and prior to 2003 (see Table 6) using different lags and lag tolerances. The third was built using measurements taken in 2009. All semi-variograms were isotropic (omni-directional).

An attempt was made to build a cross-variogram showing the co-variance of blood lead and soil lead. This graph could be used to weight proximate soil lead measurements to estimate individual BLLs. A traditional cross-variogram could not be made because no co-located data were available; data came from multiple sources with varying geographical precision. The traditional cross-variogram formula as described by Isaaks and Srivastava (1989) is shown below:

\[ \Xi(h) = \sum_{(i,j)|h_{ij} = h} (u_i - u_j) \times (v_i - v_j) \]  

Equation 4

Where \( \Xi \) is the cross-variance, \( h \) is the lag distance, and \( u \) and \( v \) are two different types of co-located data. To work around the lack of co-located data, the semi-variogram (rather than the cross-variogram) formula was used. This necessitated that BLL and soil lead be transformed into comparable quantities\(^3\).

\(^3\) A decrease or increase in the variance of two concentrations is only meaningful if the concentrations are being measured on the same scale. Soil lead ranged from 20 to 400 mg/kg, while BLL ranged from 1- 20 µg/dL. Thus, a transform was required to relate soil lead concentration to BLL.
Both Equation 1 and Equation 2 were used to transform individual soil lead measurements into predicted BLL values. Semi-variograms were then generated using pairs of predicted BLL versus measured BLL over various lag distances.

**Moving Window Analysis**

Moving window analysis (Isaaks and Srivastava 1989) involves analysis of many small geographic areas separately. Each area is isolated as if viewed through a small “window” that “moves” over the entire analysis area. The averages (or summary statistics) in each window are taken to represent the geographic area viewed through the window.

Three separate moving window analyses were conducted to determine if BLL predictability improved with decreasing window size. The Detroit area was divided into “windows” of varying sizes. Soil measurements from 2003 and prior were used with blood lead data from 2002. Geometric mean soil lead and BLL were computed for each window. Windows with at least 5 blood lead and 5 soil lead measurements in 2002 were plotted, consistent with Mielke et al. (2007). Confidence intervals (95%) of both BLL and soil lead were computed and plotted.

To check the reliability of Equation 2, the precision of the measured data was used as an estimator. The 95% confidence intervals of mean soil lead and mean BLL were plotted, resulting in two dimensional confidence windows on the scatter plot. The equation was superimposed on the plot to determine if it was as precise as the measured data. The equation was expected to pass through 9 of 10 confidence windows\(^4\). If the equation did not meet this standard of precision, it was considered unreliable.

Soil lead data for the moving window analysis included data from 3 sources (Table 6) taken prior to 2003 (Wendland-Bowyer 2003a; Weston 2004) to take advantage of the large combined data

\(^4\) Probability that the true intersection of the two means is within the 95% confidence interval of both is approximately 90%.
Sample depths and locations vary by source, as shown in Table 6. Moving window analysis was not done with 2009 data due to time constraints and the limited amount of data.

Coefficients of determination ($R^2$) were computed using the ANOVA approach to regression analysis (Fonticella 1998). This method can be used to computes $R^2$ for any equation, regardless of whether it is the best fit. However, if the equation slope is steeper than the best fit, $R^2$ can be a negative number.

Results and Discussion

Lead Measurements

Lead measurements are summarized in Figure 8 and Figure 9. Blood lead measurements for 2002 represent Wayne, Oakland, and Macomb Counties. Blood lead measurements for 2009 represent only the three census tracts where soil lead was measured.

Figure 8: Histograms of (natural) log transformed BLL data for A) 2002 and B) 2009. The horizontal axes show numerical intervals, while the vertical axes show the number of measurements.
Figure 9: Histograms of (natural) log transformed soil lead data for A) 2002 and B) 2009. The horizontal axes show numerical intervals, while the vertical axes show the number of measurements.

Semi-variograms

The “cross-variogram” resulted in graphs showing high variances between predicted and measured BLL. Predictability was poor at any distance, but improved with increasing distance (contrary to expected). Both Equation 1 and Equation 2 produced similar results, suggesting that process may have influenced the result more than data. Clustered blood lead data may also have influenced the result. It could not be determined whether any part of the analysis was productive.

The natural log of BLL does not show spatial continuity in Detroit. It has a straight nugget of 0.5 (Figure 10). Other studies showing BLL as a semi-variogram were not found. Because BLL studies have consistently described BLL distributions as log-normal (Billick et al. 1979; EPA 1995; Haley and Talbot 2004), the natural log of BLL was used in Figure 10. Spatial continuity (i.e. a low relative nugget) would indicate similar exposure for children in close proximity; a child’s BLL could be predicted by the BLL of a child next door. This would indicate primary environmental exposure outside the home. The converse cannot be concluded. The lack of spatial continuity may be a result of seasonal effects, differences in time spent outdoors, nutrition, metabolism, cleanliness, or other factors.
Spatial continuity in BLL was expected because (census tract) BLL averages appeared to be spatially continuous. Different lag distances and tolerances were tested to determine any indication of spatial continuity. The geographic precision of blood lead data limited analysis to lag distances of 300 feet or greater. The results show that BLL varies tremendously in individuals, regardless of their residential distance from one another. One explanation of this is that a population of individuals having the same environmental exposure to lead would show a log-normal distribution of BLL responses. Another explanation is that environmental exposure of individuals varies tremendously at distances less than 300 feet. These two possibilities are topics for future research.

Spatial continuity of soil lead is necessary to test the co-variance of soil lead with BLL. Continuity provides a basis for estimating the average value of a census tract, block, or residential lot. It is possible that different models of soil lead continuity exist for house sides, street side, front yard, side yard, and back yard areas. Three semi-variograms of street side soil lead concentration are shown (Figure 11, Figure 12, and Figure 13). Different lag distances and tolerances resulted in slightly different variogram...
models. The range varied from 1,000 to 1,500 feet. While these semi-variograms can be used to estimate street side lead concentration, many more soil samples would be necessary to estimate the true average lead concentration on a block or lot. The observed range of continuity was on the same order of magnitude as reported by Lin et al., (2001), who observed a range of 1,065 meters in rural Taiwan, Schaefer et al. (2010), who found a range of 1.0 km in Bulgaria, and Shinn et al. (2000), who found a range of 73 meters in residential Chicago. The range suggests the distance within which a correlation may be found.

The relative nugget effect is “the ratio of the nugget effect to the sill” (Isaaks and Srivastava 1989). For example, the relative nugget of Figure 11 is 0.2 (the nugget) divided by 0.8 (the sill), or 25%. This means that immediate variability is approximately 25% of global variability. The relative nugget effects for both 2003 and 2009 soil lead data sets range from 25-36%, depending on lags and lag tolerances.

![Figure 11: Semi-variogram of the natural log of soil lead. Numbers represent the number of data pairs; lag tolerances are +50 feet; variogram model shown is $\gamma = 0.2 \text{ Nugget} + 0.6 \text{ Spherical}$; range is 1,500 feet; nugget is 0.2; relative nugget is 25%.](image-url)
Figure 12: Semi-variogram of the natural log of soil lead. Numbers represent the number of data pairs; lag tolerances are ±300 feet; variogram model shown is $\gamma = 0.25$ Nugget + 0.45 Spherical; range is 1,000 feet; nugget is 0.25; relative nugget is 36%.

Figure 13: Semi-variogram of the natural log of soil lead. Numbers represent the number of data pairs; lag tolerances are ±150 feet; variogram model shown is $\gamma = 0.08$ Nugget + 0.2 Spherical; range is 1,200 feet; nugget is 0.2; relative nugget is 29%.
Street side soil lead is not necessarily representative of soil lead on a lot. Mielke (1994) found house side soil lead concentrations 2 to 5 times higher than street side concentrations in urban New Orleans. In the census tracts sampled for this project in the city of Detroit, the setbacks ranged from approximately 10 to 70 feet. Restricting sample locations to street side is necessary to produce stationary data, which is necessary to produce a semi-variogram. However, it is unlikely that street side samples accurately represent lead exposure to children. Ideally, soil lead would be measured in multiple locations on each city block to estimate maximum, minimum, and mean concentrations by block.

**Moving Window Analysis**

Results of the moving window analysis are shown in Appendix B and summarized in Table 7. A window size of one million square feet was expected to have the best correlation with Equation 2. This window size is 1,000 feet from border to border, which is within the observed range of spatial continuity of soil lead, based on Figure 11-13. This was not the result. All correlations were poor, as evidenced by the low coefficients of determination ($R^2$). There was no increasing or decreasing pattern in strength of correlation to window size.

Because the windows were being checked for correlation with a specified equation (Equation 2) rather than for correlation with a best fit line, $R^2$ is not necessarily positive\(^5\). Equation 2 intersected a high percentage of the 90% confidence windows of all sizes. The number of confidence windows intersected means that Equation 2 may be a valid predictor of soil lead for areas smaller than a census tract. However, precision of the data was much weaker than for the census tract averages. This is shown by the moment of inertia ($M_o$), which increases as window size decreases. More samples inside each window would likely result in more precise averages, making this experiment more conclusive.

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\(^{5}\) Negative $R^2$ means that the sum of the squares of the residuals is greater than the “total” sum of the squares (squares of the difference between arithmetic mean and predicted value). The correlation is poor if $R^2$ is negative.
<table>
<thead>
<tr>
<th>Window Size</th>
<th>Number of Windows</th>
<th>Windows Intersected</th>
<th>$R^2$</th>
<th>$M_o$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Census Tract – average 20 million ft$^2$</td>
<td>15</td>
<td>15 (100%)</td>
<td>0.42</td>
<td>1.56</td>
</tr>
<tr>
<td>9 million ft$^2$</td>
<td>41</td>
<td>36 (88%)</td>
<td>-0.20</td>
<td>2.19</td>
</tr>
<tr>
<td>4 million ft$^2$</td>
<td>34</td>
<td>28 (83%)</td>
<td>-0.41</td>
<td>4.50</td>
</tr>
<tr>
<td>1 million ft$^2$</td>
<td>14</td>
<td>12 (86%)</td>
<td>0.05</td>
<td>11.15</td>
</tr>
</tbody>
</table>

Table 7: Comparison of window sizes for moving window analysis

Conclusions

Experiments targeted at building a cross variogram of blood lead to soil lead must have a way to co-locate blood lead and soil lead samples. This will likely consist of a moving window comparison using multiple soil lead measurements within each block. The number of soil lead measurements used in this experiment was not sufficient to determine average soil lead. More than 20 measurements may be necessary (19 measurements were taken with mixed results in Chapter 3).

While average BLL is spatially continuous in Detroit, it appears that individual blood lead is not. If individual blood lead is spatially continuous, the range of continuity is expected to be less than 300 feet. To determine whether blood lead levels are spatially continuous at distances less than 300 feet, data must be precisely located to individual addresses. The high variance in individual BLL could be due to a high variance in individual exposure, or to a high variance in response to similar environmental exposure.

Street side soil lead concentration in Detroit is spatially continuous with a range of 1,000 to 1,500 feet and a relative nugget of 25 to 36%.
CHAPTER 5: LONG TERM DECREASE OF SOIL LEAD IN DETROIT

Introduction

Decreases in average BLL suggest decreases in human exposure to lead over time. Recent decreases in Detroit BLLs could be attributed to many factors. Lead cleanups have been done at two former smelter sites and one industrial site (Lam 2003a; Wisdom and Bhambhani 2004). Lead abatement has been done in houses (Lam 2007; Wendland-Bowyer et al. 2003). Lead contaminated soil has also been removed and replaced in several residential areas located near industrial sites (Lam 2003b; Lam 2006; Lam 2007; Wendland-Bowyer 2003b; Wendland-Bowyer and Lam 2003). These factors could result in significant improvements in specific locations. Another potential factor is residual soil lead. If elevated soil lead is the primary source leading to elevated BLL, long term decreases in average BLL may correspond to decreases in average soil lead. This chapter explores whether the long term decrease in BLL could be associated with a continuous decrease in surface soil lead.

This study attempts to compare current data collected to data published by the Detroit Free Press in 2003 (Wendland-Bowyer 2003a; Wendland-Bowyer and Lam 2003) to observe changes in surface soil lead levels with the hypothesis that soil lead in Detroit is decreasing over time in areas where average BLL is decreasing. A one tailed t-test of independent samples was used to compare 2009 soil lead to 2002 soil lead in each tract. Significant decreases in soil lead were expected in the two tracts where BLL decreased. No decrease in soil lead was expected in the third tract, which had consistently low BLLs.

Methods

Sampling, field observations, sample preparation, soil digestion, and atomic absorption spectroscopy are described in Chapter 4.
Data

Blood lead data were provided by MDCH for Wayne, Macomb, and Oakland counties. The original data set contained blood samples collected from January, 2000 through the beginning of April, 2009. A subsequent data set was also provided containing blood lead samples collected in 2009 in specific areas. Soil lead data categorized as 2002 were taken by Dr. Howard Mielke in 2002 and published by the Detroit Free Press (Wendland-Bowyer 2003a). Mielke’s sampling protocol included 10 street side soil samples, 3 house side soil samples, and 2 open space soil samples in each census tract taken from the top inch of soil (Mielke 1994).

Soil lead data from 2009 were collected in 3 Detroit area census tracts. Sample and test procedures are described in detail in Chapter 4, and in “Appendix A: Detailed Soil Lead Measurement Procedure”.

Sample Area Selection

Sample areas were selected from the 15 census tracts where soil lead measurements were published by the Detroit Free Press (Wendland-Bowyer 2003a). For each tract, geometric mean BLL was plotted by year. Two patterns were observed: several of the tracts had decreases in average BLL, while some maintained low BLL throughout. Tracts with more BLL samples had smaller confidence intervals. Of the tracts with decreasing average BLL, some decreases were more consistent than others. A consistent decrease resulted in a high coefficient of determination ($R^2$).

Three Wayne County census tracts were selected for sampling based on small confidence intervals, high coefficient of determination, and overall trend. In two tracts, average blood lead decreased; in one, blood lead remained steadily low (Figure 14). A total of 19-20 soil cores were taken in each of these tracts. The two tracts where blood lead declined (530200 and 510300) were in the city of Detroit. The third tract (167500) was in Farmington Hills Township.
A total of 58 soil cores were collected. Soil cores were taken from the public right-of-way generally between the curb and the sidewalk. All cores were taken along residential streets. Because the distance between curb and sidewalk varied from one to 20 feet, the sample locations were not a consistent distance from the road. Distance to the road was generally 0 to 10 feet, and was noted for each sample. All but one core was taken at least 5 feet from visible sources of potential contamination such as hydrants, fence posts, and manhole castings. One core was taken approximately one foot from a metal fence post. Cores were taken in front of occupied houses, vacant lots, abandoned houses, and islands, common areas, schools, or other non-residences.

Table 8 shows how these samples were distributed in the three census tracts sampled in 2009.
<table>
<thead>
<tr>
<th>Sample Census Tract</th>
<th>167500</th>
<th>530200</th>
<th>510300</th>
</tr>
</thead>
<tbody>
<tr>
<td>Occupied House</td>
<td>14</td>
<td>14</td>
<td>5</td>
</tr>
<tr>
<td>Vacant Lot</td>
<td>0</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>Abandoned House</td>
<td>0</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Common Area/Other</td>
<td>5</td>
<td>1</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 8: Housing at soil core locations, by tract

**Statistical Comparison**

Soil lead averages in 2002 and 2009 were compared statistically using a one tailed student’s t-test for independent samples. The null hypothesis was that average soil lead did not decrease from 2002 to 2009. Rejection of the hypothesis would mean a statistically significant decrease in soil lead.

**Results and Discussion**

Soil lead measurements were compared to the 2002 measurements published by the Detroit Free Press (Wendland-Bowyer 2003a). Geometric mean lead concentrations were computed and plotted for each census tract for both 2002 and 2009 (Figure 15). As mentioned previously, soil lead was expected to decrease in tracts 530200 and 510300. It was expected to remain steady in tract 167500. Figure 15 indicates that the observed average soil lead concentration has decreased in tract 530200, increased in tract 510300, and remained steady in tract 167500. Vertical whiskers represent 95% confidence of annual mean. Confidence intervals of the geometric mean are computed using the t-statistic of the log-transformed mean and standard deviation. The minimum, maximum, median and quartiles of each set of measurements are also shown in a Box and Whisker plot (Figure 16). This plot shows that the observed changes in the median and upper and lower quartiles follow the same trend as the mean concentrations.

Soil lead averages in 2002 and 2009 were compared statistically using a one tailed student’s t-test for independent samples. The null hypothesis was that average soil lead did not decrease from 2002
to 2009. Rejection of the hypothesis would mean a statistically significant decrease in soil lead. The null hypothesis was rejected for tract 530200 at the 99% confidence level. This result gives 99% confidence that soil lead concentration is decreasing. This is the only conclusion with statistical significance.

Figure 15: Geometric means of soil lead measurements for three census tracts in 2002 and 2009

In tract 510300, the observed average soil lead level increased slightly. One explanation for this is that one or more of the data sets are not representative. The wide distribution of lead concentrations in tract 510300 in 2002 makes the average concentration less certain than the others. A second explanation is that tracts 530200 and 510300 may be fundamentally different in the soil or soil lead. Additional observation could reveal differences and similarities that could lead to a better understanding of lead distribution.
In tract 167500, soil lead concentration was steady; the null hypothesis could not be rejected. Tract 167500 contains the low extremes of both blood lead and soil lead. Average BLL was near the (low) limit of detection in both 2002 and 2009, while average soil lead was close to the Michigan background soil lead level of 21 mg/kg (MDEQ 2006). No increase or decrease in soil lead was expected. Soil lead concentrations in the 2 other tracts are much higher than background, indicating a large
amount of anthropogenic lead. It may be that anthropogenic lead is decreasing, while natural lead is stable.

The 2009 BLL and soil lead averages were added to Figure 7 for visual examination (Figure 17). This exercise shows that tract 530200 is close to Equation 2 both in 2002 and 2009. Soil lead and BLL both decreased in this tract. Tract 510300 was far away from Equation 2 in 2002 and in 2009, but moved from one side of the line to the other. Tract 167500 was stationary.
One potential confounding factor on results is soil mixing. High lead concentrations in the top inch could be diluted by lower lead concentrations below the surface when soil is moved. The amount of soil mixing and its effect on results could not be determined from this experiment. Soil could be mixed by landscaping activity, curb or sidewalk construction, utility maintenance, animals, or children. Mixing would result in surface lead being dispersed deeper into the ground and decreasing lead concentration in the top inch. Soil mixing could vary geographically. If lead concentrations at the ground surface are decreasing, the mechanism of the decrease should be studied further. Soil mixing is one potential mechanism.

Conclusions

Decreased lead in soil is a possible cause of average BLL decreasing. However, soil does not appear to be the only source of exposure, given the assumptions of this study.

Lead concentration in the top inch of soil decreased concurrently with BLL in census tract 530200 from 2002 to 2009 with 99% confidence. This supports the idea that soil is the primary source of lead to children. This result was not reproduced in census tract 510300. The experiment should be replicated to determine whether the decrease found in tract 530200 was legitimate. Differences between the two tracts may also hold valuable information about exposure pathways.
CHAPTER 6: CONCLUSIONS

Hypotheses and Results

This study attempted to compare BLL to soil lead over geographical areas and over time. Three hypotheses were proposed and tested: two compared BLL to soil lead over space, and one compared BLL to soil lead over time. Hypotheses and their results are as follows:

- **Hypothesis 1:** The relationship of blood lead to soil lead is described by a predictive equation developed by Mielke et al. (2007) (Chapter 3). The hypothesized equation did not fit the data from the Detroit metropolitan area. An alternate linear equation was proposed which described the Detroit data satisfactorily.

- **Hypothesis 2:** A predictive equation is more accurate where soil lead and blood lead samples are close together (Chapter 4). Tests of this hypothesis were not conclusive, possibly due to: 1) no spatial relationship of blood lead, and 2) the lack of co-located soil lead and blood lead samples.

- **Hypothesis 3:** Blood lead and soil lead are decreasing concurrently (Chapter 5). Soil lead was tested in three census tracts. Average soil lead decreased significantly in one of two tracts with decreasing BLL.

Summary of Observations

Tests were intended to determine whether soil lead may be the predominant environmental exposure leading to elevated BLL. Results show that variation in soil lead is one potential explanation of variation in BLL. Table 9 summarizes types of BLL variation that can be compared to soil lead. Concurrent variation of soil lead does not establish a cause and effect relationship, but acknowledges the possibility of one.

Average blood lead has decreased throughout Detroit over the last 10 years (2000-2009) (Chapter 2). The rate of decrease is high where average BLL is high. No census tracts could be found that had a reliable increasing trend in BLL.
The geometric mean BLL over a United States census tract can be predicted by the geometric mean of soil lead samples where average street side soil lead is less than 300 mg/kg (Chapter 3). The reliability of this prediction can be approximated using the 95% confidence intervals of average soil lead and average BLL. This observation suggests that soil lead could be the predominant urban lead exposure.

<table>
<thead>
<tr>
<th>Variations in Average BLL</th>
<th>Concurrent Variation in Street-side Soil Lead Concentration</th>
<th>Other factors which could drive BLL Variation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temporal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Long term decrease</td>
<td>Yes</td>
<td>Inherited lead, drinking water</td>
</tr>
<tr>
<td>Seasonal</td>
<td>Untested</td>
<td>Dust lead, ambient air, time outdoors,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>physiological</td>
</tr>
<tr>
<td>Spatial</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neighborhood scale</td>
<td>Yes</td>
<td>Housing, drinking water</td>
</tr>
<tr>
<td>Single block scale</td>
<td>Yes</td>
<td>Dust lead, ambient air</td>
</tr>
<tr>
<td>Individual children</td>
<td>Yes</td>
<td>Time outdoors or indoors, diet, hygiene,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>physiological</td>
</tr>
</tbody>
</table>

Table 9: Types of BLL variation explained by soil lead variation

The observed correlation of average soil lead to average BLL was weak for areas smaller than a typical census tract (Chapter 4). The moving window test showed that as sample area decreased smaller than one census tract, the correlation of average soil lead to average blood lead decreased. While the correlation decreased, the expected precision of measured averages also decreased. This indicates that 20 or more samples may be necessary to establish blood lead and soil lead averages even in small geographic areas.

While average BLL over a census tract appeared to be spatially continuous, the natural log of individual BLL measurements did not show spatial continuity (Chapter 4). Tests were limited to a
minimum lag distance of around 300 feet by the precision of the blood lead data. To conclusively determine whether BLL or the natural log of BLL is spatially continuous in Detroit, data must be precisely located to individual addresses. If BLL is spatially continuous, the range of continuity is expected to be less than 300 feet. The high variance in individual BLL could be due to a high variance in individual exposure, or to a high variance in response to similar environmental exposure.

The natural log of street side soil lead showed some spatial continuity. The 2003 and prior data set had a relative nugget of 25 to 36% and a range of 1,000 to 1,500 feet. The 2009 data had a relative nugget of 29% with a range of 1,000 feet.

Future experiments targeted at building a cross variogram of blood lead to soil lead will require co-located blood lead and soil lead samples. This may consist of a moving window comparison using multiple soil lead measurements within each block. Sampling and analysis schemes should also consider that soil lead may vary significantly on each lot as well as from one lot to another.

Soil lead may be decreasing concurrently with BLL on a neighborhood scale. The long term time decrease of lead in soil coupled with the observed decrease of BLL are strong evidence that soil lead is part of the exposure pathway if the results of this test can be replicated.

The ages, deposition patterns, sources, and chemical forms of soil lead have not been differentiated in this thesis. Variations in these factors could help to explain different or varying bioavailability of soil lead in different locations. These factors may vary outside of and within Detroit, and also may be affected by climate, urban history, and cultural differences.

Implications

Removal, isolation, or reduction of bioavailability may be effective means of soil lead remediation in Detroit. Regardless of interventions, it appears that soil lead concentration is decreasing at the ground surface.
Future Study

The distribution of blood lead measurements within a single block may reflect a range of exposures, or a range of responses to a single exposure. To test the spatial continuity of soil lead and blood lead, it will be necessary to obtain data with single address precision. A semi-variogram prepared from precise data would show the true nugget and range of blood lead continuity. The study may be focused on smaller areas. If blood lead or log of blood lead displays strong spatial continuity between 50 and 200 feet, it will indicate that exterior rather than interior conditions are the primary exposure. If no spatial continuity in blood lead is observed, individual BLLs may not be predictable by environmental variables.

The long term time decrease of blood lead in Detroit warrants additional study. Decreases could be compared to known changes in the environment such as lead remediation projects, ambient air concentrations, and house demolitions. This decrease could also be compared to legislation of products containing lead.

The potential decrease in soil lead should be investigated further. This study cannot conclude whether soil lead is decreasing or why. If soil lead is decreasing concurrently with blood lead, it will indicate that soil lead is a critical link in the primary exposure pathway leading to elevated blood lead.

This study does not consider the short term (seasonal) fluctuations in blood lead measurements, or the wide range of blood lead levels in any sample population. The seasonal variation in blood lead should be examined with respect to the entire distribution of measurements. If a small percentage of measurements is responsible for the change in average, it would indicate a seasonal variation superimposed on a non-seasonal pattern. If a large percentage of measurements is responsible for the change in average, it would indicate that environmental conditions are a dominant factor in either lead exposure or human response.
Appendix A: Detailed Soil Lead Measurement Procedure

Un-spiked Control Soil

Control Soil of previously unknown lead content was collected from a site in Royal Oak, Michigan. The soil was air dried for 24 hours. The dried soil was sieved through a number 16 (1.18 mm) brass sieve to remove stones and debris. The sieve was shaken by hand to pass the soil. Bark, roots, clumps, and larger particles were discarded, not forced through the sieve. The sieved soil was very sandy and appeared to contain many very small pieces of bark. When the pan holding the sieved sample was shaken, the fine bark rose to the top. Sieved control soil was collected in an acid washed polypropylene bottle. Total lead analysis of 13 samples revealed an average lead content in the control soil of $113 \pm 3$ mg/kg with 95% confidence.

Spiked Control Soil

Sieved control soil was collected in an acid washed polypropylene bottle. Lead standard solution of 1,000 ppm lead as lead nitrate in 2% nitric acid (Acros Organics) was diluted with deionized water to increase the volume such that the control soil could be thoroughly mixed. The solution was well mixed with the control soil. The wet soil was then placed in a convection oven (Blue M) at 100°C to remove the liquid. Total drying time was 44 hours. The calculated concentration of lead was $311 \pm 8$ mg/kg in addition to the initial concentration of $113 \pm 3$ mg/kg. Total concentration was $424 \pm 11$ mg/kg. Total lead analysis of 13 samples revealed an average lead content in the spiked control soil of $402 \pm 21$ mg/kg with 95% confidence. High variation in the spiked soil measurements suggests that some variation is not due to measurement error, but to varying lead concentration.

Calibration and Total Error

The atomic absorption spectrometer was calibrated using standards prepared from certified Atomic Absorption standard (Ricca, $1000 \pm 5$ ppm lead metal in 3% nitric acid). Each calibration
standard was prepared in a 100 mL volumetric flask, using 25 mL of 70% trace metal grade nitric acid, the certified lead standard, and the remaining volume nanopure water.

Sources of error in the measurements include uncertainty in calibration of the AA, variation in measured quantities due to background absorbance, incomplete digestion, and variability in the samples themselves. The sum of these errors was estimated to be less than 5%, based on the accuracy of measurements of known quantities.

Measured SRM concentration ranged from 411 to 434 mg/kg, with 6 of 7 measurements within 2% of the expected 432 mg/kg. One measurement of 411 falls slightly outside of the certified amount (415-449), but is within 5% of the expected 432 mg/kg. Standard deviation of SRM measurements was 8 mg/kg; thus, an individual measurement two standard deviations from the mean would have an error of 16 mg/kg, or approximately 4%.

Un-spiked control soil measurements ranged from 106 to 120 mg/kg. The mean measured concentration of un-spiked control soil was 113 ± 3 mg/kg with 95% confidence. The sample standard deviation was 5 mg/kg; thus, an individual sample two standard deviations from the mean would have an error of 10 mg/kg, or 9%.

Spiked sample measurements ranged from 380 to 479 mg/kg. The mean measured concentration was 402 ± 21 mg/kg with 95% confidence. The sample standard deviation was 35 mg/kg; thus, an individual sample two standard deviations from the mean would have an error of 70 mg/kg, or 17%. Spiked sample concentration can also be estimated by adding 311 mg/kg to the un-spiked concentration of 113± 3. This technique yields a concentration of 424 ± 11 mg/kg. The highest measured “error” (55 mg/kg) would be 13% The fact that spiked soil varied more than un-spiked and SRM suggests variability in the soil rather than measurement error.
Blank measurements ranged from -2 to 6 mg/kg. The mean measured concentration was $2 \pm 2$ mg/kg with 95% confidence. Sample standard deviation was 2, suggesting an expected absolute error of $2 \pm 4$ (mean plus two standard deviations).

Cleaning

Pippette tips, centrifuge bottles, and final solution bottles were cleaned by a multi-step procedure. Bottles (and lids) and pipette tips were soaked for a minimum of 2 hours in 18% (v/v) trace metal grade hydrochloric acid. Bottles were removed, filled with 35% (v/v) trace metal grade nitric acid, capped, and immersed in nanopure water in a bin. Pippette tips were immersed in 35% trace metal grade nitric acid in a bin. The bins were heated in a thermostatic bath (VYR International) to 45 °C for a minimum of 2 hours. Articles were removed from the nitric acid and triple rinsed in nanopure water. All items were soaked in the third rinse for a minimum of 2 hours.

Volumetric flasks and other miscellaneous glassware used were cleaned using the above steps but excluding the nitric acid portion.

Digestion tubes were cleaned by scrubbing with a 1% solution of phosphate free liquid detergent (Liquinox) in tap water, then heating 10 mL trace metal grade nitric acid in each tube to 150°C for 10 minutes. Tubes were then triple rinsed with nanopure water and air dried.
Appendix B: Moving Window Analysis Results

Figure 18: Detroit area BLL compared to BLL predicted by Equation 2 for 9 million square foot window
Figure 19: Detroit area BLL compared to BLL predicted by Equation 2 for 4 million square foot window

\[ \text{BL} = 0.018 \times \text{SL} \]
Figure 20: Detroit area BLL compared to BLL predicted by Equation 2 for 1 million square foot window

\[ BL = 0.018 \times SL \]
References


ATSDR. "Lead Toxicity." Case Studies in Environmental Medicine, Agency for Toxic Substances & Disease Registry.


Abstract

SPATIAL AND TEMPORAL RELATIONSHIPS BETWEEN BLOOD LEAD AND SOIL LEAD CONCENTRATIONS IN DETROIT, MICHIGAN

by

MICHAEL JONATHAN BICKEL

December 2010

Advisor: Dr. Shawn P. McElmurry
Major: Civil & Environmental Engineering
Degree: Master of Science

This study explored variations in child blood lead levels (BLLs) relative to street-side soil lead in Detroit, Michigan. Findings showed that average BLLs steadily decreased throughout Detroit from 2000 through 2009. Soil lead samples from 58 locations showed spatial continuity with a range of 1,000-1,500 feet and a relative nugget of 25-36%. Average BLLs over a US census tract were also found to be spatially continuous while individual BLLs were not, suggesting that individual BLLs may not be predictable by environmental variables. The equation previously developed by Mielke et al. (2007) predicting average BLLs based on soil lead concentrations observed in New Orleans, Louisiana was not found to accurately describe Detroit data. An alternative linear equation is proposed that describes average BLLs as a function of average soil lead concentrations. Additionally, results suggest that in some areas average BLLs may be decreasing concurrently with soil lead concentrations.
Autobiographical Statement

Michael Bickel has a Bachelor of Science in Civil Engineering (Rose-Hulman Institute of Technology, 1997). He has worked as a consulting engineer and as a field engineer creating utility maps. His interests include sustainable development, environmental responsibility, teamwork, leadership, and family.