Potential lead on play surfaces: Evaluation of the “PLOPS” sampler as a new tool for primary lead prevention

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Abstract

This New Orleans study tested the “potential lead on play surfaces” (PLOPS) sampler, as a tool for measuring the potential lead (Pb) surface loading per area (e.g., \( \mu g/ft^2 \) of the soil. The PLOPS is a cylindrical vinyl envelope filled with 1 kg (2.2 lbs) water. A wet wipe, the same type as used for floor wipes, is clipped to the bottom of the cylindrical vinyl envelope and placed on the soil and turned one quarter of a turn and back to obtain a sample. PLOPS samples paired with one conventional soil lead (SL) sample (amount of Pb per mass) up to 2.5 cm (1 in) deep were collected from 25 properties and 67–69 field sites before and after covering them with clean Mississippi River alluvial soil from the Bonnet Carré Spillway (BCS). Permutation methods were used to evaluate results. The correlation was 0.85 between Plops 1 and 2 and the agreement was 0.79 (\( P \)-values \( \leq 0.0000001 \), i.e., extreme). The averages of PLOPS duplicates were used to correlate PLOPS and SL. The simplest mathematical expressions are in the forms \( y = a + bx^c \) and \( x = d + ey^f \), where \( x \) is PLOPS and \( y \) is SL. The results were: \( y = -7.42 + 0.408x^{0.97} \) and \( x = -43.74 + 24.85y^{0.69} \). The agreements were 0.61 and 0.62, respectively (\( P \)-value \( \leq 0.0000001 \)).

According to the relationship, when the PLOPS measure 40 \( \mu g/ft^2 \), the predicted SL is 7.2 mg/kg. Also, when SL measures 400 mg/kg, 1508 \( \mu g/ft^2 \) is predicted for PLOPS; therefore, SL concentration underestimates the potential for Pb exposure from the soil surface. The PLOPS tool provides a measurement that is comparable with interior floor wipes because it measures the amount of Pb per area a child is likely to encounter while at play on the soil surface.

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1. Introduction

Interior dust and exterior soil are recognized as sources of lead (Pb) exposure, particularly through children’s play and hand to mouth activities (Lioy et al., 2002; Clark et al., 2004). In the home interior, where hard floor surfaces are common, Pb loading per area is relatively easy to measure. By contrast, the three-dimensional characteristic of soil poses more difficulty in measuring lead loading per area of the soil surface. This paper describes a new tool for measuring the potential Pb loading of the soil surface. All of the research was conducted between March 2004 and August 2005.

Lead loading of surface environments is a developing topic of research. In New York City, Pb loading on exterior surfaces was shown to be a continuous process (Caravanos et al., 2005). Within 2 weeks, on average, the amount of Pb dust collected on an exterior surface exceeds the US interior wipe guideline of 40 \( \mu g/ft^2 \) (431 \( \mu g/m^2 \)) (Caravanos et al., 2005; US EPA, 2001; US HUD, 1999). Resuspension of Pb from soil was noted as a major contributor of Pb dust to the urban atmosphere. In Los Angeles, resuspension of Pb dust must be taken into account in order to accurately model the mass balance of inputs and outputs of air quality within the LA basin (Harris and Davidson, 2005). In Syracuse, Indianapolis and New Orleans, blood Pb of children increases and decreases directly with soil dryness, and the authors identified resuspension of soil Pb during dry periods as...
the driving force behind the seasonality related peak in children’s blood Pb (Laidlaw et al., 2005).

Some previous studies have incorporated measurements of Pb dust on children’s hands before and after outdoor play and demonstrated that children’s hands became relatively Pb-contaminated after playing outdoors, especially in inner-city communities (Sayer et al., 1974; Viverette et al., 1996; Mielke et al., 1997a). A study comparing hand exposure following outdoor playground activities before and after soil intervention noted a significant reduction in children’s hand Pb when soil containing 100–200 mg/kg (several times the Danish Pb guideline of 40 mg/kg residential soil standard) was remediated with soil containing less than 10 mg Pb/kg (Nielsen and Kristiansen, 2004).

Calculations of the amounts of Pb on soil surfaces of large Minnesota and Louisiana cities revealed that, assuming an even distribution of Pb across the profile (a conservative assumption because the amount of Pb decreases with increasing soil depth), the top 0.025 mm (0.00984 in) of the soil collected along streets, open spaces and foundations contain 6000–32,000 µg Pb/m² (558–2976 µg Pb/ft²) (Mielke, 1993). In general, these calculations of surface Pb per area significantly exceed the interior floor Pb dust wipe guideline of 40 µg/ft² for the interior of a home (US EPA, 2001; US HUD, 1999). The exterior urban environment exhibits severe Pb accumulation as predicted by Clair Patterson (1980). Children are vulnerable to accumulated Pb because at this critical stage of development children are crawling and they tend to place their Pb contaminated hands and objects into their mouths. Also, at this stage of development there is a large mineral requirement to meet nutritional needs for rapid physiological growth of all organ systems and if Pb is present it is readily ingested and absorbed.

In order to eliminate the use of children as direct indicators of Pb contamination and improve methods for primary Pb prevention, a new tool is needed to directly measure and describe the Pb loading of the soil surface (Mielke, 2002). The purpose of this paper is to describe one such tool, the potential lead on play surfaces (PLOPS) sampler developed to measure Pb loading of the soil surface. The PLOPS sampler was tested in New Orleans on contaminated urban soils before and after they were covered with low Pb Mississippi River alluvial soil.

2. Methods

To study the PLOPS sampler, the methods included selection of field sites, the use of the PLOPS sampler to measure the Pb loading on the soil surface, and the use of conventional soil sampling to measure the concentration of Pb per mass on the same field site. Because human subjects were not directly involved in measurements done for this project, expedited approval of the methods and consent forms were given by the Xavier University Institutional Review Board.

2.1. Field sites

Twenty-five residential properties (n = 15) and vacant lots (n = 10) were selected for field study within 10 census tracts (or communities) previously identified as having median soil Pb of 1000 mg/kg soil or more in New Orleans. The locations of these 10 contaminated census tracts are shown in Fig. 1 (Mielke, 2002; Mielke et al., 2002, 2005). PLOPS and soil lead (SL) samples were collected before and after clean soil from the Bonnet Carré Spillway (BCS) was transported to cover the contaminated soil on the 25 properties. In total 67–69 field sites were sampled from the 25 properties of this study.
2.2. PLOPS samples

The PLOPS sampler is a cylindrical polyvinyl envelope filled with water to a mass of 1 kg. A clean wet wipe (Huggies Natural CareTM) is attached to the bottom of the PLOPS sampler with four small binder clips. The PLOPS sampler with attached wipe is placed on the soil surface and given a quarter turn twist and back. The wipe is then removed from the clips, folded, and placed into a labeled cup for transport to the laboratory. The PLOPS sampler was rinsed with deionized water between sample collections.

PLOPS samples were collected in duplicate at the same field site. The laboratory analysis of the wipes involves adding 40 mL of trace metal collections. PLOPS sampler was rinsed with deionized water between sample fold, and placed into a labeled cup for transport to the laboratory. The wipe is then removed from the clips, PLOPS sampler with attached wipe is placed on the soil surface and given to the bottom of the PLOPS sampler with four small binder clips. The area of the wipe footprint as it is attached to the PLOPS sampler was 0.085 m² (0.28 ft²) and this area was used to calculate the amount of Pb per area that the wipe picks up from the soil surface. The final PLOPS samples can be compared with the interior floor standard which is 40 μg Pb/ft² (US EPA, 2001; US HUD, 1999).

2.3. Conventional soil samples

Conventional soil samples (SL), 2.5 cm (1 in) deep, were collected from the same field sites as the duplicate PLOPS samples. The SL samples were taken to the laboratory for extraction and analyzed according to protocols previously described (Mielke et al., 1997b, 1999, 2000). The SL samples are treated with the same 1 M strength of HNO₃ as the PLOPS wipes. The unit of measure used for soil Pb is mg Pb/kg. The US EPA HUD standard for bare soils where children play is 400 mg Pb/kg (US EPA, 2001).

The location of contaminated soils was within the inner city of New Orleans as described above in the section on field sites. The source of clean soil was the BCS. The BCS soils are relatively fresh sediments that were deposited as alluvium at the time that the spillway gates were last opened during the 1997 Mississippi River spring flood event, and previous research showed that the BCS alluvium has a median of 4.7 mg/kg Pb with deposits as alluvium at the time that the spillway gates were last opened.

2.4. Data analysis

Data analysis included comparing the paired PLOPS samples and evaluating the relationships between PLOPS and SL. To avoid making any artificial distributional assumptions, permutation methods were used to evaluate all results (Mielke and Berry, 2001). A more detailed discussion of the statistical method follows:

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<th>Percentile</th>
<th>Before treatment</th>
<th>After treatment</th>
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<tbody>
<tr>
<td></td>
<td>PLOPS</td>
<td>Soil</td>
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<tr>
<td>Min</td>
<td>38</td>
<td>5</td>
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<tr>
<td>25%</td>
<td>756</td>
<td>390</td>
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<tr>
<td>Median</td>
<td>2333</td>
<td>1051</td>
</tr>
<tr>
<td>75%</td>
<td>5175</td>
<td>1887</td>
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<tr>
<td>Max</td>
<td>24,629</td>
<td>19,627</td>
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PLOPS units are μg Pb/ft² and conventional soil lead units are mg Pb/kg.

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There are a number of complex polynomials that can be used to fit paired PLOPS values with SL values. The simplest expressions are in the forms y = a + bx² and x = d + ey², where x denotes PLOPS and y denotes SL.

3. Results and discussion

A critical aspect of developing a tool that provides direct measurements of soil surface Pb loading is to explore the relationships between the duplicate PLOPS samples and between the PLOPS results paired with conventional SL samples.

3.1. Overall results

The permutation statistical test shows that the correlation coefficient r between duplicate PLOPS is 0.85 and the measure of agreement R = 0.79 (P-value < 0.000001, i.e., extreme). Because of the strong correlation and agreement, the duplicate results were averaged to obtain a single value. The PLOPS values were then evaluated with the paired SL values for the entire database (n = 136). Table 1 is an overview of the entire database stratified by before and after clean soil cover treatment for PLOPS and SL results.
The central tendency results are shown by the medians and range and indicate the varying quantities of soil Pb at the test sites in these communities. Before covering with new soil, the median SL was 1051 mg/kg (range 5–19,625). This validates the previous SL mapping results which predicted that the median SL would be >1000 mg Pb/kg soil in these census tracts (Mielke, 2002; Mielke et al., 2002, 2005). These amounts illustrate the enormity of the Pb reservoir in soils of some communities of New Orleans.

Even more striking is the amount of Pb loading measured on the surface of these soils by the PLOPS sampler. The median of the PLOPS before cover treatment was 2333 µg/ft² (range 38–24,629) while the median SL before covering with clean soil was 1051 mg/kg (range 5–19,627). As described in the introduction, the urban soil surface contains an amount of Pb that greatly exceeds the interior floor Pb standard of 40 µg/ft², and the PLOPS sampler demonstrates this same characteristic for New Orleans. Only at the minimum value of SL did PLOPS results meet the HUD/EPA 40 µg/ft² guideline for floor surfaces of the indoor environment. The PLOPS results illustrate the importance of soil as a pathway for childhood exposure to Pb (Maisonet et al., 1997; Mielke and Reagan, 1998; Mielke et al., 1999; Johnson and Bretsch, 2002; Gonzalez et al., 2002).

After treatment with clean soil, the median amount of Pb was 6 mg/kg (range 3–18) (Mielke et al., 2006). It appears however, that even clean soils present Pb loading that exceeds the interior floor wipe standard. As shown for PLOPS in Table 1, the median Pb of 45 µg/ft² is slightly higher than the 40 µg/ft² interior floor standard. Pb from various urban sources may accumulate so rapidly on the soil that within weeks the surface becomes recontaminated (Caravanos et al., 2005).

### 3.2. Relation between PLOPS and soil Pb

Fig. 2 is a scatter plot of values of PLOPS as a function of SL. The simplest mathematical expressions to describe the relationship between PLOPS and SL follow: SL = −7.42 + 0.408(PLOPS)0.97, and PLOPS = −43.74 + 24.85(SL)0.69. The agreements were 0.61 and 0.62, respectively. In both cases, the P-value is ≪0.0000001. The resulting relationship between PLOPS as a function of SL and indicates that for a PLOPS of 40 µg Pb/ft² the SL is 7.2 mg Pb/kg. The clean BCS soil with median of 6 mg Pb/kg provides an approximate match with the 40 µg Pb/ft² indoor surface dust standard. After covering with clean soil, the surface of these soils becomes contaminated with new or existing sources of Pb. The potential for recontamination of the soils is extremely large and this is probably caused by multiple Pb sources such as power sanding of Pb-based paint, Pb vehicle wheel weight dust, and Pb dust resuspension and deposition from Pb contaminated neighboring soil (Mielke et al., 2001; Root, 2000; Harris and Davidson, 2005). The PLOPS sampler is a sensitive tool that picks up small changes in Pb that are not evident from conventional soil sample results.

### 3.3. Need for surface soil Pb measurement

Researchers evaluating the contribution of SL to the exposure of children lack a tool for measuring the quantity of Pb accumulated per area on the soil surface. The PLOPS sampler assists with determining the size of the SL reservoir as a source of Pb dust and thereby supports primary prevention by providing perspective on the potential of the soil surface as a source of Pb exposure. Compared to conventional soil samples, the PLOPS sample results provide a measure that is more likely to be representative.

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**Fig. 2.** Log–log scatter plot of soil lead concentrations (mg Pb/kg) vs. PLOPS loading value (µg Pb/ft²) (n = 136). The descriptive data for SL and PLOPS are provided in Table 1. The values toward the upper right of the figure are for the initial SL and associated PLOPS results and the values in lower left are for the new soil cover from the Bonnet Carré Spillway and their association PLOPS results.
of the amount of Pb that children would be potentially exposed to during outdoor play on the soil surface. The PLOPS sampler also provides a measure of the amount of surface Pb available for resuspension or that could be tracked into the interior environment.

In pre-Katrina New Orleans, around 14% of all children had elevated blood Pb (10 µg/dL or higher) (Mielke, 2005; Louisiana Office of Public Health, 2005). At 25%, the prevalence was much larger in the inner city. There was also a seasonal increase and decrease of blood lead directly related to soil dryness (Laidlaw et al., 2005). Meeting the US Centers for Disease Control (CDC) Healthy People (2010) goal of no children with an elevated blood lead level (10 µg/dL or higher) will require a major primary prevention program in New Orleans (Healthy People, 2010). If primary prevention is to become a reality, then instead of using the unfortunate poisoning of children as a trigger for conducting tests of the environment, it is essential to develop tools such as the PLOPS sampler for direct measurement of the environment to spur proactive efforts for controlling all easily available sources of Pb (Mielke, 2002).

4. Conclusions

Direct measurement of Pb sources and eliminating children as indicators of environmental Pb is the goal of this research. Primary prevention refers to actions taken to directly measure and correct hazards before actual exposure can occur. Ideally, children’s blood measurement is used only to assure that Pb exposure is not taking place. One example of a method for direct measurement of Pb in the environment is the indoor floor wipe sample. On exterior soil the conventional method of soil Pb measurement is Pb concentration per soil mass (e.g., mg/kg). The PLOPS sampler provides information about the soil surface Pb concentration per surface area (e.g., µg/ft²) as a source of Pb dust for children at play. The PLOPS results provide insight into the potential of soil for transferring Pb either directly, via hand-to-mouth behavior, or indirectly, via track-in and Pb dust resuspension.

Acknowledgments

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References


