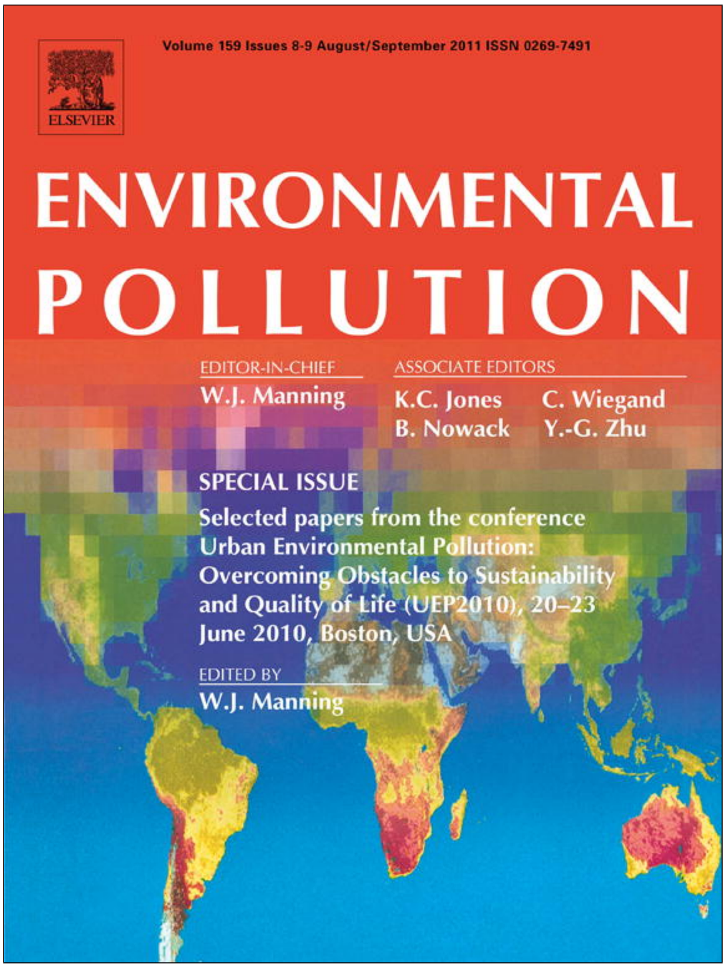
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Soil intervention as a strategy for lead exposure prevention: The New Orleans lead-safe childcare playground project

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The feasibility of reducing children's exposure to lead (Pb) polluted soil in New Orleans is tested. Childcare centers (median = 48 children) are often located in former residences. The extent of soil Pb was determined by selecting centers in both the core and outlying areas. The initial 558 mg/kg median soil Pb (range 14–3692 mg/kg) decreased to median 4.1 mg/kg (range 2.2–26.1 mg/kg) after intervention with geotextile covered by 15 cm of river alluvium. Pb loading decreased from a median of 4887 μg/m^2 (454 μg/ft^2) range 603–56650 μg/m^2 (56–5263 μg/ft^2) to a median of 398 μg/m^2 (37 μg/ft^2) range 86–980 μg/m^2 (8–91 μg/ft^2). Multi-Response Permutation Procedures indicate similar (*P*-values = 0.160–0.231) soil Pb at childcare centers compared to soil Pb of nearby residential communities. At ~$100 per child, soil Pb and surface loading were reduced within hours, advancing an upstream intervention conceptualization about Pb exposure prevention.

1. Introduction

Children, because of their physiological requirements for essential minerals, rapidly developing nervous systems, and their age-specific hand-to-mouth behaviors, are especially vulnerable to Pb exposure. Recent reviews indicate that blood Pb (BPb) as low as 2 μg/dL has adverse health effects to multiple organ systems including cardiovascular (Navas-Acien et al., 2007), renal (Fadrowski et al., 2010), and the neurological (Jusko et al., 2008).

The usual practice for determining environmental contamination is through children's BPb. The U.S. Centers for Disease Control and Prevention (CDC) guideline for elevated BPb is currently ≥10 μg/dL (U.S. CDC, 2005). A child's elevated BPb triggers an environmental investigation to find the source of Pb exposure; the approach is consistent with thinking downstream or a reactionary secondary prevention approach that responds only after poisoning and health damage has occurred (Butterfield, 2006; Steingraber, 1998). An alternative and proactive approach is what Butterfield (2006) considers upstream thinking; a focus on primary prevention and protection of children from ever being exposed. The possibility for primary prevention in metropolitan New Orleans exists because the environmental hazard, soil Pb, has been identified, surveyed and mapped using a relatively high median density of 19 samples per km^2 that are stratified by Census Tract (Mielke et al., 2005). The associations between soil Pb, age of housing, and BPb have been evaluated, and overall the strongest association is found between soil Pb and BPb (Mielke et al., 1997, 1999; 2007a). Additional supporting evidence concerning the strength of the association between soil Pb and BPb occurred after the devastating storms Hurricanes Katrina and Rita which washed Pb-safe sediments into New Orleans, variously covering the soils during the flooding of the city; as expected, the decrease of soil Pb was accompanied by a reduction of BPb (Zahran et al., 2010).

Numerous (n = 155) childcare centers including Head Start programs have opened in post-Hurricane Katrina/Rita New Orleans (Agenda for Children). Childcare centers are often created within established buildings that were previously used as residential properties. Because childcare centers are places with large numbers

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of children (median = 48) they are ideal intervention settings to lessen the impact of Pb pollution. For this project we build on experience regarding soil Pb surveys in New Orleans and Pb loading of soil surfaces (Mielke, 2005; Mielke et al., 2006, 2007b).

The purpose of this study is to test the feasibility of creating Pb-safe playgrounds at childcare centers as a starting point for primary Pb exposure prevention in New Orleans. The objectives were to determine the magnitude and extent of soil Pb on exterior play areas at childcare centers, to review the relationship between soil Pb and soil surface Pb loading at childcare centers throughout the city, and to compare the soil Pb results obtained from this project with the results of the New Orleans Survey II soil Pb map completed in 2001.

2. Methods

2.1. Project protocol

To determine the extent and magnitude of soil Pb within play areas of childcare centers of New Orleans, communities in both the core and outlying areas of New Orleans were selected for the project. Childcare center proprietors were contacted in the different communities and offered the opportunity for Pb-safe soil emplacement on their outdoor play areas. The location of 10 childcare centers and one community center selected for this project are shown Fig. 1 in the context of the 2001 Survey II residential soil Pb map (Mielke et al., 2005). Note that some residential communities within the inner city of New Orleans have excessive soil Pb where over half of the soil samples contain several times higher amounts of Pb than the U.S. EPA guideline of 400 mg/kg for areas where children may play.

Once a childcare center proprietor consented to be part of the project, our contractor was contacted to initiate the soil project. In order to shield childcare centers from liability, the soil emplacement was done prior to laboratory analysis of the soil and Pb loading samples. Using protocols established for the soil mapping projects, soil samples were collected from the 2.5 cm (1 inch) depth of the soil (Mielke et al., 2005), and wipe samples were collected to measure the *potential lead on play surfaces* (PLOPS) (Mielke et al., 2007b). Thus, on the day of the project, initial (i.e., before intervention) soil and PLOPS samples were collected and stored for subsequent chemical analysis.

The soil emplacement was conducted by first spreading out a bright orange, water pervious geotextile material to cover the original soil of the play area. The geotextile layer prevents Pb-safe soil from mixing with the underlying original soil and acts as a warning layer to anyone digging into soil. Soil was not removed from the play areas in this project.

The Pb-safe soil was from the Bonnet Carré Spillway, located up-river from New Orleans (U.S. ACE or Army Corps of Engineers). The alluvial soil, derived from the sediments of the Mississippi River at the Bonnet Carré Spillway, has a median Pb content of 5 mg/kg (Mielke et al., 2000). The Bonnet Carré soil was transported to the childcare center and emplaced on top of the geotextile layer to a depth of at least 15 cm (6 inches). This alluvial soil was deposited by the Mississippi River through the Bonnet Carré Spillway during April 2008, the most recent opening of the spillway gates (U.S. ACE). After the Bonnet Carré alluvial soil was emplaced on the childcare center properties, a second collection (i.e., after intervention) of soil samples and PLOPS were obtained.

2.2. Chemical analysis

After interventions on the exterior play areas were completed, all of the stored soil samples and PLOPS were prepared for Pb quantification according to our revised Survey II Chaney–Mielke room temperature (~22 °C) extraction protocols (Mielke et al., 2005, 2007b).

First the soil samples were dried and sieved (USGS # 10 sieve-2 mm). The extraction method involved weighing out 0.4 g soil portions into 50 ml polypropylene centrifuge tubes, adding 20 mL of 1 mol/L HNO_3acid to the soil, shaking the samples for 2 h, centrifuging the tubes, and filtering through Fisher brand P4 paper into 20 mL HDPE scintillation vials. An Inductively Coupled Plasma-Atomic Emissions Spectrometer (ICP-AES) was used for measuring Pb in the filtrate. The ICP-AES was calibrated with U.S. Department of Commerce, Technology Administration National Institute of Standards and Technology traceable standards (SPEX). Internal laboratory references included one low metal soil sample and one high metal sample collected from different parts of the city. Laboratory references were included in each run at a rate of 1 per 15 samples. Duplicate extractions were introduced every 15 samples.

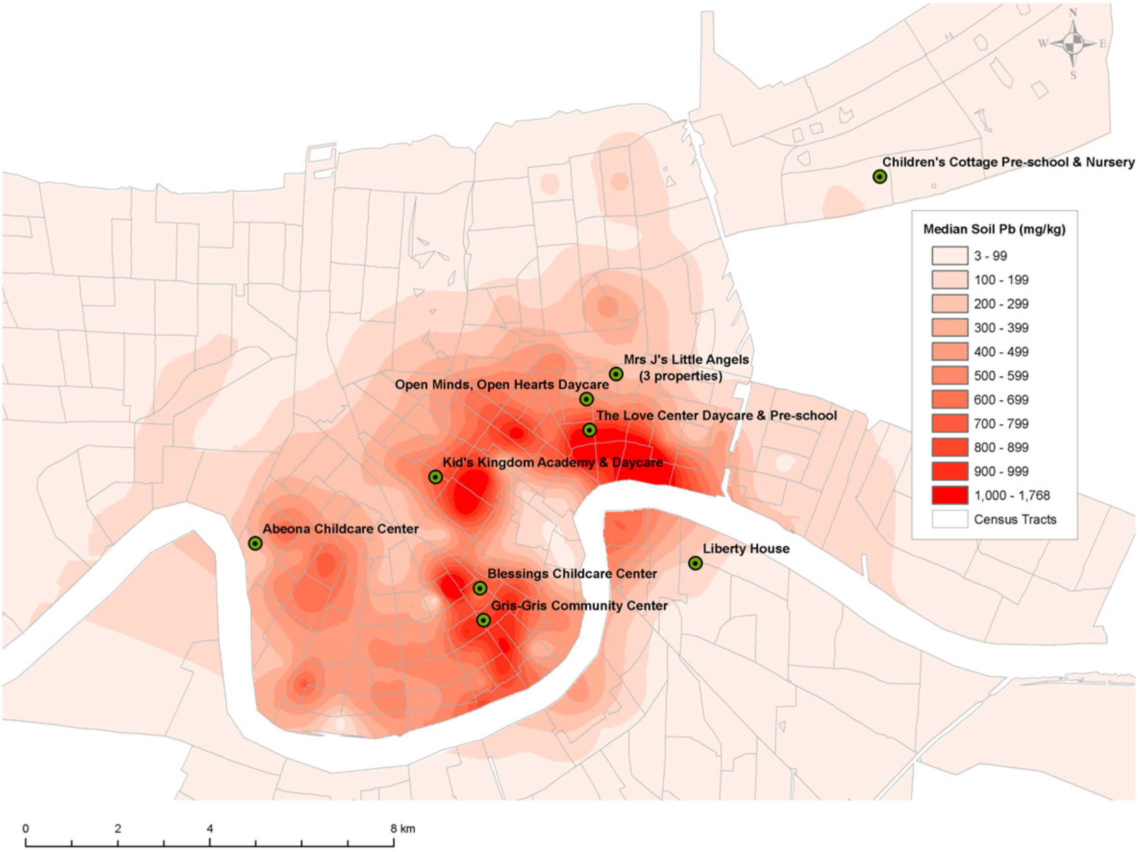

Fig. 1. Ten childcare centers and one community center in the context of the New Orleans soil Pb map (Mielke et al., 2005).

The PLOPS, or Pb loading samples were extracted in a similar manner to the soil samples with the exception that during collection the wipes were placed into 120 mL polypropylene specimen cups and 40 mL 1 mol/L HNO_3 were added to the specimen cups. Then, the PLOPS wipes and acid were shaken for 2 h for extraction and the solutes were filtered into 20 ml HDPE scintillation vials and analyzed in the same way as the soil extracts.

2.3. Data analysis: Multi-Response Permutation Procedures (MRPP) statistical tests and rationalization

In most investigations, the population distribution will never be known, and assuming an inappropriate distributional model will most likely result in invalid statistical inferences. Thus, the normal distribution is an inappropriate model for many ecological data, which most often are skewed, discontinuous, and multimodal. When sample sizes are small, large sample approximate methods are often questionable. Permutation procedures make efficient use of small sample sets, because probabilities can be calculated exactly by complete enumeration of all possible combinations under the null hypothesis, otherwise, resampling or Pearson type III approximations are needed; the latter are used here because very small probability values (*P*-values) are encountered. Of greater importance, the permutation testing framework allows the use of exceedingly robust statistical tests based on distance functions such as Euclidean distance. Euclidean distances yield the ordinary geometrical interpretation of distance by investigators in any applied field of science. Most conventional parametric and nonparametric methods are based on squared Euclidean distances as a consequence of statistical analyses based on least squares (Mielke and Berry, 2007). Statistics based on squared Euclidean distances are non-metric because they violate the triangle inequality property of a metric and consequently they have no simple geometrical interpretation for the *r* response variables associated with the *r*-dimensional Euclidean distance data space in question. The results are given as *P*-values, i.e., the probability of having the same or a more extreme outcome by chance alone. Thus a very small *P*-value (near 0) suggests that the outcome is most likely not attributed to chance alone. In contrast, a large *P*-value (e.g. from 0.1 to 1) suggests the outcome could easily be attributed to chance alone. More information about MRPP statistics and software can be obtained from the following sources (Mielke and Berry, 2007; Blossom, 2008).

For this project MRPP are used to compare *g* sets of cases where each case involves multivariate responses and are described in detail by Mielke and Berry (2007). A version of MRPP was applied to the first study of urban soil metals conducted in Baltimore in the mid-1970s (Mielke et al., 1983). The version of MRPP used here is confined to univariate data and g = 2. While MRPP are a family of statistical tests based on various distance functions, the simple Euclidian distance used here is the intuitive choice of distance functions for evaluating the relationships of these data sets. The distance function between the *r* multivariate values of the Ith and Jth cases, i.e., $(x_{1,I},\ldots,x_{r,I})$ and $(x_{1,J},\ldots,x_{r,J})$, is given by

$$\Delta_{I,J} = \left[\sum_{h=1}^{r}\left(x_{h,I} - x_{h,J}\right)^2\right]^{1/2}$$

For completeness, if m_i is the number of cases in ith of g data sets (i = 1,…,g), then the efficient MRPP weight function is given by $c_i = m_i/(m_1+\ldots+m_g)$. Euclidean distance has the property of being a metric that yields an analysis space that is congruent with the data space in question (Mielke and Berry, 2007).

3. Results and discussion

3.1. Soil Pb content, soil Pb loading and feasibility

Table 1 shows soil Pb results for the 10 childcare centers and one community center before and after intervention. Before emplacement of Pb-safe soil, the median soil Pb for all of the play areas was 558 mg/kg. After emplacement of Bonnet Carré Spillway soil, the median Pb was 4.1 mg/kg, or a decrease in median soil Pb by a factor of 135. The span of Pb for the initial soil was 3678 mg/kg and the span for the Pb-safe soil was 24 mg/kg.

The feasibility of intervention results from the fact that low Pb alluvial soil is readily available for conducting this type of project. In fact, the median soil Pb background in the U.S. is 16.5 mg/kg (range from 10.3 to 30.1 mg/kg), and thus low Pb soil is available to cities everywhere in the nation for similar intervention projects (Gustavsson et al., 2001).

Table 1
Before and after treatment results of lead found in the top 2.5 cm of soil within play areas at 10 childcare centers and one community center in New Orleans. Results are in mg/kg.

	Min	5%	10%	25%	Median	75%	90%	95%	Max	*n*
Before	14.1	28	40	140	558	1520	2720	3122	3692	50
After	2.2	2.3	2.5	2.8	4.1	7.1	9	11.9	26.1	30

Table 1 shows that the soils collected from many childcare centers are below the 400 mg/kg EPA standard. However, at 400 mg/kg for areas where children play, or 1200 mg/kg for non-play areas in the yard, the soil Pb standards in the U.S. are high compared to the high sensitivity found by empirical BPb responses of children to soil Pb in New Orleans (Mielke et al., 1999; Mielke et al., 2007a) and Syracuse, NY (Johnson and Bretsch, 2002). Empirical research on BPb and soil Pb in New Orleans indicates that to protect children from exceeding a BPb exposure ≥10 μg/dL, the soil Pb standard should be no more than 80 mg/kg (Mielke et al., 1999).

Table 2 shows the PLOPS results before and after intervention. Mielke et al. (2007b) developed the PLOPS as a method for measuring the amount of Pb loading on the soil surface (μg/area). Table 2 indicates that the initial median Pb loading on the initial play area surfaces was 4887 μg/m^2 (454 μg/ft^2). The span of Pb loading for the initial soil at childcare centers was 56,650 μg/m^2 (5207 μg/ft^2). The median Pb loading on the Pb-safe soil decreased to 398 μg/m^2 (37 μg/ft^2), or over a 10 fold reduction from the initial results. Furthermore, the span of the Pb loading on the emplaced Bonnet Carré alluvial soil decreases to 893 μg/m^2 (83 μg/ft^2).

Based on the logic of causality and the available evidence concerning the plausibility of the connection of soil Pb to children's exposure, our research indicated that soil Pb was at least as important as paint as a risk to children (Mielke and Reagan, 1998). Furthermore, research conducted in New Orleans indicated that the soil surface is an exceptionally large reservoir of Pb dust compared to interior floor surfaces (Mielke et al., 2007b). The Pb surface loading of soil containing 400 mg/kg (the current U.S. standard) is about 16,146 μg/m^2 (1500 μg Pb/ft^2), or more than 37 times the current indoor floor surface standard of 431 μg/m^2 (40 μg Pb/ft^2) (Mielke et al., 2007b). The importance of this finding is that by merely touching the soil surface children at play may get a hazardous amount of Pb on their hands.

Sayre et al. (1974) described the importance of Pb on hands as a route of exposure. A study of Pb on children's hands at New Orleans childcare centers demonstrated an increase of Pb on hands after outdoor play compared with the hands of the same children after indoor play (Viverette et al., 1996). A Danish hand Pb study further demonstrated that when soil Pb at kindergartens was decreased from 100–200 mg/kg to <10 mg/kg, there was a corresponding reduction of Pb adhering to children's hands (Nielsen and Kristiansen, 2005). The associations between the paired soil Pb and PLOPS samples ($n = 54$) from this study provides additional empirical perspective on the variation issue. The Pearson Product Moment Correlation coefficient for soil Pb and PLOPS is 0.378 (*P*-value < 0.005) indicating a large amount of variation between the paired soil Pb and PLOPS results. As shown in Tables 1 and 2, the combination of soil Pb and PLOPS data indicates that the initial soils at the play areas of these 10 childcare centers and 1 community center play area presented a Pb hazard. The Bonnet Carré soil cover provides a margin of safety in these environments.

3.2. Comparison of childcare center soils and Survey II results

Fig. 2 shows the locations of the childcare centers and the data points for soil samples collected for Survey II, including samples collected within a 1 km radius of each childcare center. The childcare center soil samples ($n = 44$) within the inner core of New Orleans and the soil samples within 1 km of each childcare center collected for Survey II ($n = 669$) did not differ significantly

Table 2
Before and after results of lead loading by the PLOPS sampler on the soil surfaces of plays areas at 10 childcare centers and one community center. Results are shown in μg/m^2 and μg/ft^2 in parentheses.

	Min	5%	10%	25%	Median	75%	90%	95%	Max	*n*
Before	603 (56)	(111)	1841 (171)	2745 (255)	4887 (454)	9688 (900)	28,632 (2660)	37,071 (3444)	56,650 (5263)	24
After	86 (8)	97 (9)	140 (13)	205 (19)	398 (37)	570 (53)	710 (66)	818 (76)	980 (91)	30

(P-value = 0.231). Likewise, the soil samples collected at the childcare centers (n = 6) in the outer areas of New Orleans versus soil samples collected for Survey II within 1 km of the childcare centers (n = 54) did not differ significantly (P-value = 0.170).

The childcare centers located in the inner city of New Orleans were also compared with the centers located in the outer areas of New Orleans. The differences were significant (P-value = 0.673×10^{-2}) between the initial soil samples (n = 44) collected at childcare centers within the inner city core and the initial soil samples (n = 6) collected at childcare centers located in the outer areas of the city. Likewise, the differences were significant (P-value = 0.364×10^{-8}) between the Survey II samples (n = 669) collected within 1 km of the childcare center in the inner city core compared with the Survey II soil samples (n = 54) collected within 1 km of childcare centers in the outer areas of the city. The similarities of soil Pb of childcare centers and soil collected from their surrounding community, as well as the differences between childcare centers located in the inner city and outer city areas of the city are in full agreement with earlier results for inner city and outer city public and private housing and nearby community Pb footprint in New Orleans (Mielke et al., 2008).

3.3. *Research in other cities*

Soil Pb research in other cities has called attention to the soil Pb problems present at childcare centers and public parks. Haugland et al. (2008) describe the highly Pb contaminated soil at childcare facilities in the central parts of Bergen, Norway compared with the low Pb contamination in the outlying areas. Button (2008) studied soil Pb contamination at childcare centers in greater Cincinnati and found that locations near pre-1980 construction as well as distance from the nearest interstate highway were significant variables affecting the amount of Pb accumulation in the soil. LaBelle (1986) described the soil Pb content of play areas in parks of urban and rural areas of Illinois and concluded that degree of urbanization was related to traffic density; given the fact that painted buildings were not generally located within the parks LaBelle concluded that Pb in gasoline was more likely the major contributor of Pb to the soil than Pb-based paint in these public spaces. Filippelli and Laidlaw (2010) describe Pb in soils of play areas as so commonplace that they characterize the situation as the "elephant in the playground".

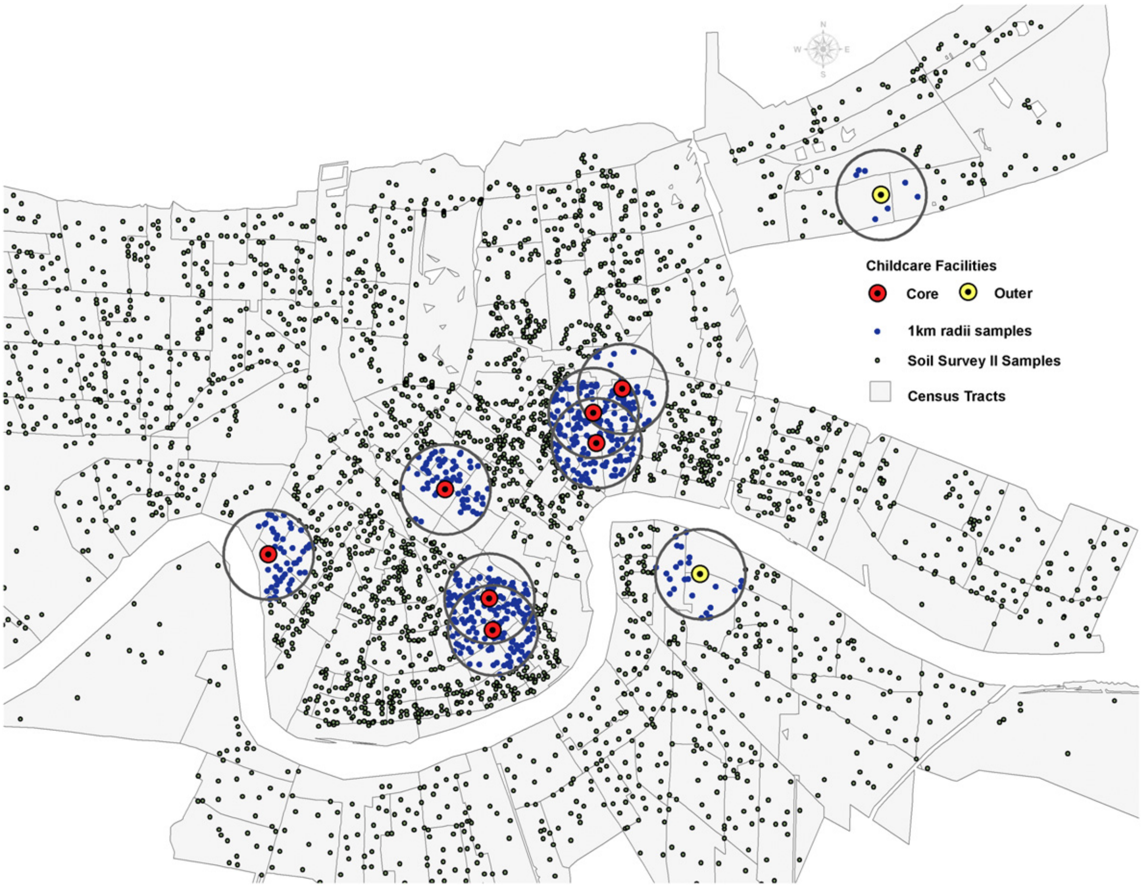

Fig. 2. Location of childcare centers and a community center, with sampling locations for Survey II, including samples collected within 1 km radius (large circles) from each of the childcare centers.

3.4. Societal consequences of elevated blood Pb

The human geography of soil Pb provides an indication of racial disparities between inner city high Pb soils and outer area low Pb soils of New Orleans (Campanella and Mielke, 2008). Exposure to Pb can result in damage to a number of organ systems most notably the central nervous system. The effect is most often manifested as cognitive impairment which can persist despite intervention. Even low level exposure to Pb has been associated with lower IQ scores in children (Pocock et al., 1994; Jusko et al., 2008; Lanphear et al., 2005). Learning achievement in pre-Katrina New Orleans elementary school districts has been linked with blood Pb of children in the same districts (Zahran et al., 2009). Elevated blood Pb is strongly associated with behavior, hyperactivity and attention problems. Dietrich et al. (2001) and Wright et al. (2008) found that exposure to lead, including prenatal exposure, was associated with antisocial behavior. Needleman et al. (2002) and more recently economist Nevins (2007) found a relationship between elevated BPb during childhood and future violence and criminal activity. Studies in adults have found an association between elevated BPb and chronic diseases including hypertension, heart disease, diabetes and renal insufficiency supporting a cumulative and persistent effect on health (Hu, 2002; Lustberg and Silbergeld, 2002; Needleman, 1998; Woolf et al., 2007). During pregnancy, mobilization of Pb from bone stores, resulting from chronic Pb exposure beginning in childhood, crosses the placenta and places the fetus at risk (Cleveland et al., 2008).

3.5. Costs and benefits of upstream and downstream approaches

Primary prevention of poisoning by intervention of environmental Pb actualizes Butterfield's (2006) concept of thinking upstream, an approach considered preferable to the traditional secondary prevention strategy of screening through BPb. The latter represents a less desirable downstream approach associated with higher individual and societal costs (Butterfield, 2006).

3.5.1. Monetary costs of traditional childhood surveillance

The estimated number of young children (less than 5 years old) living in metropolitan New Orleans is approximately 74,000 (Plyer and Ortiz, 2009). On average 9259 children in metropolitan New Orleans have blood drawn by phlebotomists and/or physicians for BPb determination as part of the Louisiana Childhood Lead Poisoning Prevention Program (LACLPPP) $71 each; for a total cost of $657,000. Research by Mielke et al. (2007a) suggests that in New Orleans, nearly 11.8% of children (1093) screened had elevated BPb ($\geq$10 μg/dL) necessitating retesting for an additional cost of $77,603. If the repeat test is elevated, additional services (physician visit [$105] and environmental risk assessments [$220]) are performed on each child for an additional cost of $355,225 (Gould, 2009). The total estimated amount spent is approximately $1.2 million annually and the estimated surveillance costs per child are about U.S. $1070. These costs underestimate the cost of childhood Pb exposure because they do not include other continuing costs such as special education and chronic health costs associated with Pb poisoning.

3.5.2. Monetary costs and benefits of intervention

Making outdoor play areas Pb-safe represents a primary prevention approach to environmental health and results in significant individual and societal cost savings. Based on results of this study outdoor play area soil Pb intervention including the addition of assessing of interior environments for risk at the 145 remaining childcare centers in New Orleans will involve a onetime cost estimated at $700,500 with an estimated cost per child of less than U.S. $100, representing a significant savings over the downstream secondary prevention strategy. When completed, with a median of 48 children per center, the project will have administered primary prevention measures for an annual total of about 7440 children (or, assuming the soil Pb remains low, prevention for 74,400 children over ten years at a cost of ~$10 per child).

Other costs associated with this study's soil emplacement strategy include liability insurance carried by the non-profit Lead Lab, Inc., post-intervention analysis of the soil and PLOPS samples, the geotextile cover, and transporting and spreading Bonnet Carré alluvial soil on the properties. Another cost includes educational materials in the form of coloring books plus a box of crayons delivered to each child. The purpose of these materials were to assist parents with developing a better understanding about Pb and the importance of providing safer interior and exterior play environments for children. Based on a summary of the before and after results of the project, framed certificates were presented to each of the 10 childcare centers indicating the summary results and precautions about maintaining the soil quality of the play areas.

Placing emphasis on primary prevention is not a new idea; it was proposed in 1909 by Turner, a physician from Queensland, Australia, who advocated primary prevention as essential for protecting children from Pb poisoning (Taylor et al., 2010). There are many benefits for ensuring children play in Pb-safe soils at childcare centers. The Pb-safe soil, containing around 5 mg/kg Pb significantly reduces the potential of direct exposure to Pb from hand-to-mouth behavior by children playing in the soil (Nielsen and Kristiansen, 2005). In addition, the low Pb soil curtails track-in of Pb dust into each childcare center (Clark et al., 2004; Hunt et al., 2006; von Lindern et al., 2003). Ultimately this should result in a significant decrease in the Pb burden among children who attend New Orleans childcare centers. Soil Pb intervention at childcare centers is especially cost effective because it targets areas where younger, more vulnerable children gather in large numbers during the greater portion of their waking hours. Ideally, once intervention of the childcare centers is completed, Pb-safe soil emplacement should be expanded to other environments where children congregate (kindergartens, elementary schools, and city playgrounds), an approach analogous to the Norwegian government action plan for primary prevention to contaminated soils (Ottesen et al., 2008).

4. Conclusions

Lead-safe soil emplacement advances an upstream and preferable primary Pb prevention intervention for children. In this study, the 10 childcare centers (and 1 community center) initially had soil with a median soil Pb content of 558 mg/kg (range 14–3692 mg/kg) in their playgrounds. This means that according to current U.S. EPA soil Pb standards over half of the soil samples from the play areas contain hazardous amounts of Pb. Relatively simple soil Pb intervention through emplacement resulted in a post-intervention median soil Pb concentration of 4.1 mg/kg (range 2.2–26.1 mg/kg). The Pb loading of the surface soil underwent a correspondingly large decrease from a median of 454 μg/ft^2 (range 56–5263 μg/ft^2) to a median of 37 μg/ft^2 (range 8–91 μg/ft^2).

These results also indicate that the high density residential-based soil Pb map of New Orleans, completed in 2001, remains applicable for predicting soil Pb on play areas of childcare centers in 2009. Survey II can therefore be used to develop a logical, evidence-based remediation plan for New Orleans. Childcare centers in New Orleans are generally developed within former residential properties, and the childcare centers follow the same trend of soil Pb as found in other residential soils of the city. The soils within childcare center play areas of the inner city of New Orleans present high hazard environments for children. In contrast, the childcare centers in outer areas of New Orleans, like the residential properties of the same communities, tend to present relatively smaller soil Pb hazards to children at play in their playgrounds.

This project indicates that within hours, at a cost of about U.S. $100 (2010) per child, exterior play areas at childcare centers can be transformed from Pb contaminated to Pb-safe with a margin of safety. This is a miniscule cost when compared to the costs associated with secondary prevention and treatment of Pb poisoned children, costs of learning and behavioral disorders, and subsequent costs to society of lifelong chronic health problems.

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Human subjects

This study focused only on environmental characteristics. No identifiable information was collected on human subjects during the conduct of this study.

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