# Higher blood lead levels among children living in older homes in Evansville Indiana: associations between year house built, soil lead levels and blood lead levels among children aged 1-5 years -1998 to 2006

## *Niveles de plomo elevados en sangre de niños que vivían en casas antiguas de Evansville, Indiana: asociación entre año de construcción de la casa, niveles de plomo en suelo y niveles de plomo en sangre de niños de 1-5 años, entre 1998-2006*

## *Elevados níveis de chumbo no sangue de crianças que vivem em habitações antigas em Evansville, Indiana: associação entre o ano de construção da casa, níveis de chumbo no solo e níveis de chumbo no sangue de crianças de 1-5 anos, entre 1998 - 2006*

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## Abstract

A total of 18,218 blood lead levels (BLLs) were assessed. The samples from 11,719 children aged 1-5 years in Evansville, Indiana, were obtained on a volunteer basis between 1998 and 2006. In addition, soil lead levels were also evaluated from 35 residential yards that were matched to the addresses of 81 children.

During the study period, both average BLLs and the percentage of elevated BLLs declined. Even so, Evansville's BLLs still remained higher than national levels (median BLLs of 3.0 vs.1.5 µg/dL, respectively). From our analysis, living in older houses (presumably containing lead paint) was associated with higher BLLs in children. No clear association was found between higher BLLs and gender or residential soil lead levels.

**Keywords:** Children, lead, blood lead, leaded paint, environmental health, soil lead levels

## Resumen

En este estudio se evaluaron los niveles de plomo en 18.218 muestras de sangre. Las muestras de 11.719 niños de Evansville, Indiana, de edades comprendidas entre 1 y 5 años se obtuvieron de manera voluntaria entre los años 1998 y 2006. Se evaluaron además los niveles de plomo en el suelo de 35 jardines residenciales correspondientes al domicilio de 81 niños.

Durante el periodo de estudio, tanto los niveles de plomo en sangre como el porcentaje de valores elevados para dichos niveles fueron descendiendo. A pesar de ello, los valores de plomo en sangre en Evansville siguieron estando por encima de los nacionales (mediana de niveles de plomo en sangre 3,0 frente a 1,5 µg/dL, respectivamente). Nuestro análisis dio como resultado que vivir en casas antiguas (presumiblemente con pintura que contiene plomo) estaba asociado con niveles más elevados de plomo en sangre en los niños. No se encontró una asociación clara de los niveles elevados de plomo en sangre ni con el género ni con los niveles de plomo en el suelo de los jardines.

**Palabras Clave:** Niños, plomo, plomo en sangre, pintura que contiene plomo, salud ambiental, niveles de plomo en la tierra

## Resumo

Neste estudo avaliaram-se os níveis de chumbo em 18.218 amostra de sangue. As amostras de 11.719 crianças de Evansville, Indiana, de idades compreendidas entre 1 e 5 anos obtiveram-se de forma voluntária entre os anos de 1998 e 2006. Avaliaram-se também os níveis de chumbo na terra de 65 jardins residenciais correspondentes ao domicílio de 81 crianças.
Durante o período do estudo, tanto a média dos níveis de chumbo no sangue como a percentagem de valores elevados para este indicador foram descendo. No entanto, os níveis de chumbo no sangue em Evansville ficaram acima dos valores nacionais (mediana 3,0 vs 1,5, respetivamente). Da análise dos dados obtidos conclui-se que viver em casas mais antigas (presumivelmente contendo tintas com chumbo) está associado à presença de elevados níveis de chumbo no sangue de crianças. Não há uma associação clara entre os níveis elevados de chumbo no sangue e o sexo, a idade e os níveis de chumbo no solo dos jardins residenciais.


**Palavras-Chave**: crianças, chumbo, chumbo no sangue, tinta com chumbo, saúde ambiental, nível de chumbo no solo.

## INTRODUCTION

Although the use of leaded paint in housing was phased out from 1978, it still remains a major source of lead exposure in the United States (U.S.).[1,2] The main source of lead exposure for children in the U.S. is lead-based paint used in homes prior to that date. Lead contaminated dust and soil, resulting from lead that has settled from leaded paint, gasoline, and stationary sources (e.g., mining and smelting sites, battery manufacturers, and waste treatment plants) are other important sources.[1,3]

Exposure to lead can cause damage to the nervous, hematopoietic, and renal systems. Children, especially those under 6 years old, are at greater risk of adverse health effects from lead than adults. A child's lower body weight, higher absorption rate, and higher intake rate results in a greater dose of hazardous substance per unit of body weight. Moreover, the developing nervous system of young children is more sensitive to the neurotoxic effects of lead. As a result, a child suffers more damage than an adult exposed to the same amount of lead. Children are also more active. They crawl, play and basically live near the floor or ground where there is a higher chance of being exposed to lead. Children naturally have certain behaviors (e.g., often put toys, pacifiers and fingers in their mouths, eat lead paint chips, chew on toys, and wash hands less frequently) that will increase contact with contaminated soil/dust and soil/dust ingestion.[4,5]

The Centers for Disease Control and Prevention (CDC) created the Childhood Lead Poisoning Prevention Program (CLPPP) as a result of the Lead Contamination Control Act of 1988. The objectives of CLPPP are to reduce exposures to lead and to eliminate childhood lead poisoning in the U.S. CLPPP developed the Childhood Blood Lead Surveillance System to monitor BLLs in children less than 6 years old in the U.S. Forty-six states currently participate in the surveillance system and report data to the CDC.[6]

Indiana is one of those 46 states participating in the Childhood Blood Lead Surveillance System. The blood lead surveillance data for Evansville Indiana between 1998 and 2006 referring to children aged 1-5 years was used in this study. The surveillance data for Evansville includes information on the year the house was built, which is an indicator of the potential for lead paint to be present in the house. Most homes in Evansville were built before 1978 and probably contain lead-based paint.[7] However, another possible source of lead exposure in Evansville is widespread soil contamination.[8]

The contaminated soil was discovered in 2002, when the Indiana Department of Environmental Management (IDEM) investigated a former plating facility and found elevated lead concentrations in the soil in urban residential and commercial areas in Evansville. IDEM identified multiple former facilities that may have contributed to the soil contamination. IDEM and the U.S. Environmental Protection Agency (USEPA) now call the investigation, sampling and removal of contaminated soils, the *Jacobsville Neighborhood Soil Contamination (JNSC)* site (11 square miles),[8] which is 27% of the city of Evansville's land area (40.7 square miles).[9]

In this study, blood lead levels (BLLs) collected from children in Evansville, Indiana between 1998 and 2006 were evaluated to identify trends, while residential yard soil lead levels and year the house was built were examined to determine their association to BLLs.

## METHODS

### 1.- Data

### Blood lead data

The State of Indiana's Blood Lead Poisoning Prevention Program is administered through the Indiana State Department of Public Health and targets children less than 6 years old on a volunteer basis. The State of Indiana requires laboratories to report all results of blood lead tests.[10] After initial data management and analysis, the state health department submits test results annually to the CDC to be included in the Child Blood Lead Surveillance System (CBLS) database (CDC 2003). According to the CDC publication,[10] capillary or venous blood samples are analyzed by a Clinical Laboratory Improvement Amendments (CLIA)-certified facility or with an approved portable instrument. Sample results were measured in µg/dL and reported as whole numbers (0,1,2,3,…). The minimum BLL value in the dataset was zero.[6] Zeros in the dataset were substituted for non-detects or for detectable BLLs that were less than 1 µg/dL. BLL was defined as elevated if BLL was ≥10 µg/dL. Confirmed elevated BLL (EBLL) was defined as a child with one venous blood specimen ≥10 µg/dL, or any combination of two capillary and/or unknown blood specimens ≥10 µg/dL drawn within 12 weeks of each other. Detailed information on childhood lead poisoning prevention programs and surveillance activities can be found at < http://www.cdc.gov/nceh/lead/default.htm>.[6] Information on surveillance data specifications for the CDC Lead Database can be found at <ftp.cdc.gov/pub/environmental_surveillance/Lead/SURVSPEC.rtf>.

Blood-lead testing in Evansville is available free of charge at the Vanderburgh County Health Department clinic. The test is also available through private physicians and healthcare providers. The study examined the BLL data for Evansville, Indiana, for January 1 1998 to December 29 2006.

In the Child Blood Lead Surveillance System, some children were screened in multiple years or even multiple times within a given year. In this study, a child was counted only once for each year. Therefore, confirmed, venous but not confirmed, or the most recent capillary BLLs were all kept in the dataset.

### Yard soil lead data

Between 2001 and 2006, three tiers of sampling were performed during the remedial investigation (RI) to characterize the Jacobsville Neighborhood Soil Contamination site in the city of Evansville. The Indiana Department of Environmental Management (IDEM) conducted the first tier of sampling in 2001 to determine if the site should be listed on the National Priorities List (NPL). In years 2004 and 2005, the USEPA conducted the second tier of sampling to define the areal extent of contamination at the site.

For the second-tier sampling, a 250 meter or 500 meter grid sampling design was used to sample soil in either front or back yards of residential properties, parks, or recreational areas. Five-point composite soil samples were collected, with samples taken at four corners of the yard and one taken in the center. A four-point composite drip zone sample (one sample from the midpoint of each side of the house) was collected at some of the residential sample locations to determine if lead paint may be contributing to the high levels of lead in yard soils. The USEPA used a portable hand-held x-ray fluorescence (XRF) unit for in-field analysis of the samples, and 20% of the samples were sent to a laboratory for verification of the XRF results.

In 2006, after the areal extent of contamination was defined, the USEPA conducted third-tier sampling to define the depth of contamination to be used in the risk assessment. The residential yard soil samples (n=28) were collected at depths of 2, 6, 12, and 18 inches, and drip zone soil samples (n=26) at depths of 0 to 2 inches. Soil samples (n=75) were also collected at depths of 0 to 2 inches below ground surface from potentially high access properties (parks, playgrounds, schools, and day care facilities). The USEPA submitted a portion of the samples to the laboratory to verify the XRF results.[8]

The maximum soil lead concentrations from the third tier of sampling for residential properties were used for this study. Both soil lead concentrations and BLLs were available from 35 residential properties. As more than one child may reside at the same address, for the correlation analysis soil lead levels from 35 residential yards were matched to 81 BLLs from 81 children.

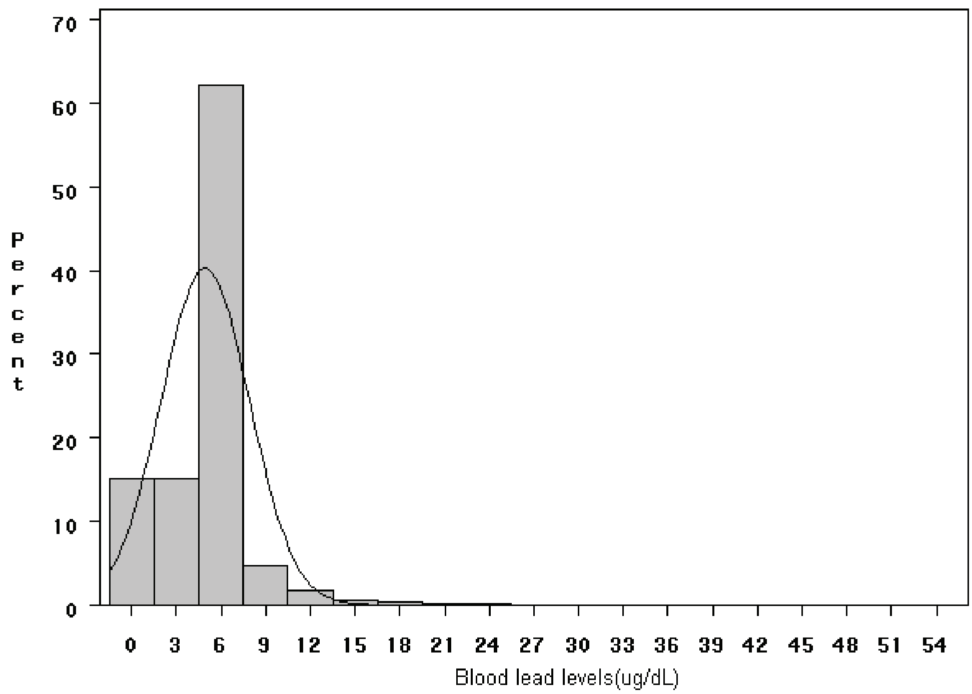
### 2.- Analysis

SAS statistical software (SAS institute, Inc, release 9.1, Cary, NC) and SAS-callable SUDAAN (Research Triangle Institute, release 9.0, Research Triangle Park, NC) were used for the analysis.

As the data were not normally distributed and the natural log transformation did not normalize the distribution, frequency and percentiles were calculated with asymmetric, distribution free 95% confidence intervals for BLLs and soil lead levels. The distribution of BLLs was compared to the results of the U.S. population aged 1-5 years (NHANES 2001-2002).[11] The chi-square test was calculated for equal proportions. Statistical significance was determined by a P-value less than 0.05 or a non-overlapping confidence interval (CI) (i.e., 95%). A non-parametric correlation coefficient (Spearman) was used to examine the association between BLLs and soil lead levels.

Among those with multiple blood lead samples, there was no consistency in the test year and the time interval

Figure 1. Histogram for blood lead levels in children aged 1-5 years. Evansville, Indiana, 1998–2006




between blood lead samples. Therefore, in the analysis, BLLs were assumed to be independent observations, even though some children might have had more than one BLL from 1998 to 2006. Proportional odds models were used to examine the effects of year house built and BLL test years on BLLs. To be used as an outcome variable, BLLs were grouped into three categories, BLL ≥10 µg/dL; 5<BLL<10; and BLL≤5, based on the natural breaks in the data (Figure 1). Sex, year house built, and BLL test year were used as explanatory variables in the models. Soil lead levels were not included in the model, because the small number of soil lead levels would have limited the number of data points in the model. In addition, a separate proportional odds model was used for those who had BLLs in multiple years to account for the repeated measure effects (Generalized Estimating Equations [GEE] for repeated measures), so as to examine if the association altered. BLL was defined as elevated if BLL was ≥10 µg/dL. Confirmed elevated BLL (EBLL) was defined as a child with one venous blood specimen ≥10 µg/dL, or any combination of two capillary and/or unknown blood specimens ≥10 µg/dL drawn within 12 weeks of each other.[6] BLLs were also categorized on the basis of confirmation status. The categories were: BLL elevated (≥10 µg/dL) and confirmed; BLL elevated but unconfirmed; and BLL not elevated (<10 µg/dL).

Although 23.6 % of the data on "Year (house) Built" were missing, the percentage of older houses (i.e., those built before 1978) was similar to the U.S. Census data for Evansville. According to the Census 2000 Summary File 3 (SF 3), 85% of the structures in Evansville were built before 1979 (U.S. Census Bureau 2000a), whereas 85.9% of the structures in this data set were built before 1978.

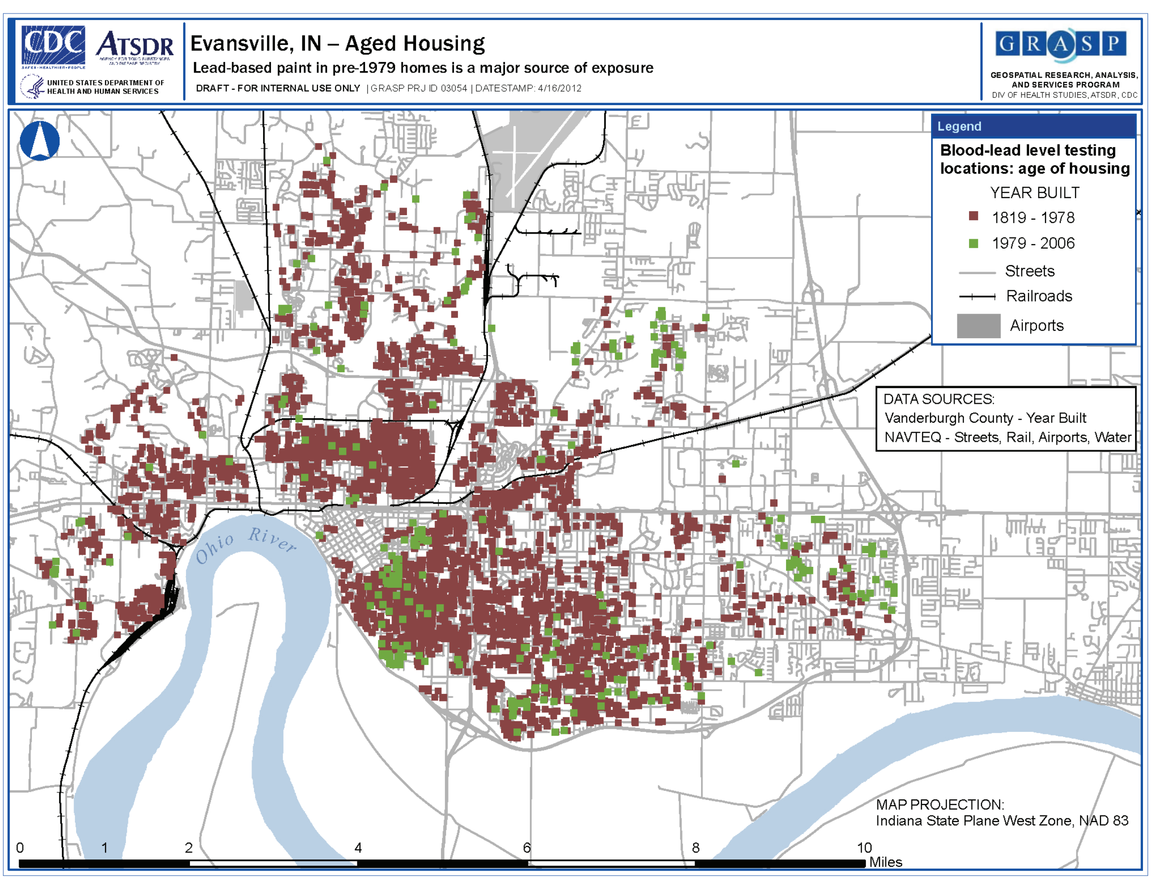
## RESULTS

A total of 18,218 BLLs were obtained from 11,719 children aged 1-5 years in Evansville, Indiana; 49.4% of those were girls (Table 1). No association was found between BLLs and gender (Chi-Square: 2.6870; P-value: 0.1012). Of these 11,719 children, 7,720 (65.9%) were tested one time and 3,999 (34.1%) were tested in multiple years. Of these 3,999 children, 2,329 (19.9%) children were tested two times and 1,670 (14.2%) were tested between three to six times (data are not shown in the tables). A total of 18,218 BLLs were in the data set because children who were tested in multiple years would be counted more than once. Due to inconsistent reporting, it was not possible to assess the race/ethnicity distribution of the children tested.

Table 1. Sample characteristics- Evansville, Indiana, 1998–2006

| | Number of sample | Percentage | Chi-square test for equal proportions | P-value |
|---|---|---|---|---|
| **Sex** | | | 2.6870 | 0.1012 |
| Boys | 9199 | 50.6 | | |
| Girls | 8978 | 49.4 | | |
| **Year house built** | | | 7170.3579 | <.0001 |
| Built before 1978 | 11958 | 85.9 | | |
| Built 1978 or later | 1966 | 14.1 | | |
| **BLL test year** | | | 443.4946 | <.0001 |
| 1998 | 2269 | 12.5 | | |
| 1999 | 2367 | 13.0 | | |
| 2000 | 2286 | 12.6 | | |
| 2001 | 2409 | 13.2 | | |
| 2002 | 1947 | 10.7 | | |
| 2003 | 2033 | 11.2 | | |
| 2004 | 1717 | 9.4 | | |
| 2005 | 1727 | 9.5 | | |
| 2006 | 1463 | 8.0 | | |

Figure 2. Relative Age of the Children's Homes



Information on the year the house was built was available for 76.4% of the 18,218 BLLs and a large percentage (85.9%) of the 11,719 children lived in houses built before 1978. The relative age of the homes of the children from whom blood samples were collected is presented in Figure 2.

The number of children tested declined during the study period. Although the estimated population (ages 0-5 years) for Evansville remained stable, the number of children tested dropped from 12.5% in 1998 to 8.0% in 2006. The differences were statistically significant (Table 1).

## Blood lead trends

Overall, BLLs for the children tested in Evansville were higher than BLLs for the same age group in the U.S. population (2001-2002). Median BLLs (2004-2006) in Evansville (3.0 µg/dL; 95% CI: 3.0-3.0) were twice the median BLLs for the U.S. children aged 1-5 years (1.5 µg/dL; 95% CI: 1.4-1.7) (Table 2).

The majority (96.1%) of the Evansville BLLs were not elevated (< 10 µg/dL). At least half of the BLLs (52.8%) were between 6 and 10 µg/dL; 28.5% were between 1 and 5 µg/dL; 14.8% were less than Limit of Detection (LOD); and 3.9% were ≥10 µg/dL (Table 3). Location of BLLs ≥10 µg/dL (elevated) vs. BLLs <10 µg/dL are shown in Figure 3. Statistical associations are detailed below.

Overall, BLLs declined during the study period. The percentage of elevated BLLs was lower during the later years (2000-2006, range: 1.6-3.6%) than during the earlier years (1998, 1999, range: 6.3-8.0%). The percentage of BLLs ≤5 was higher during the later years (2004-2006, range: 89.2-91.2%) than during the earlier years (1998-2003, range: 1.3-74.0%). The percentage of BLLs greater than 5 and less than 10 µg/dL was significantly lower during the later years (2004-2006, range: 5.7-8.2%) than during the earlier years (1998- 2003, range: 18.0-95.1%) (Table 4 and Figure 4).

Table 2. Selected percentiles of blood lead levels (BLLs) (µg/dL) among children aged 1-5 years — Evansville, Indiana, 1998–2006

| | Sample size | Minimum-Maximum (µg/dL) | 25th (95% CI) (µg/dL) | 50th (95% CI) (µg/dL) | 75th (95% CI) (µg/dL) | 90th (95% CI) (µg/dL) | 95th (95% CI) (µg/dL) |
|---|---|---|---|---|---|---|---|
| **BLLs in Evansville (1998-2006)** | 18,218 | 0.0-55.0 | 3.0 (3.0-3.0) | 6.0 (6.0-6.0) | 6.0 (6.0-6.0) | 7.0 (7.0-7.0) | 9.0 (9.0-9.0) |
| **BLLs in Evansville (2004-2006*)** | 4907 | 0.0-38.0 | 0.0 (0.0-0.0) | 3.0 (3.0-3.0) | 3.0 (3.0-3.0) | 5.0 (5.0-6.0) | 8.0 (7.0-8.0) |
| **BLLs in the U.S. (NHANES 2001-2002)** | 898 | — | — | 1.5 (1.4-1.7) | 2.5 (2.2-2.8) | 4.1 (3.4-5.0) | 5.8 (4.7-6.9) |

* time period with low BLLs.

Table 3. BLL percentages by category among children tested aged 1-5 years - Evansville, Indiana, 1998–2006

| | Sample size | Percentage (%) | Chi-Square | P-value |
|---|---|---|---|---|
| BLLs (µg/dL) | | | 9725.7747 | <0.0001 |
| BLL ≥10 (elevated) | 710 | 3.9 | | |
| 6 ≤ BLL <10 | 9619 | 52.8 | | |
| 1≤ BLL ≤5 | 5194 | 28.5 | | |
| BLL= LOD | 2695 | 14.8 | | |
| BLL <10 | 17508 | 96.1 | | |
| BLL≥10 vs. BLL<10 | | | 32585.4337 | <0.0001 |
| Confirmation status | | | 2.4845 | 0.1150 |
| Elevated BLL, confirmed | 334 | 1.8 | | |
| Elevated BLL, unconfirmed | 376 | 2.1 | | |

Figure 3. Location of Homes of Children's Blood Lead Samples and BLL ≥10 µg/dL

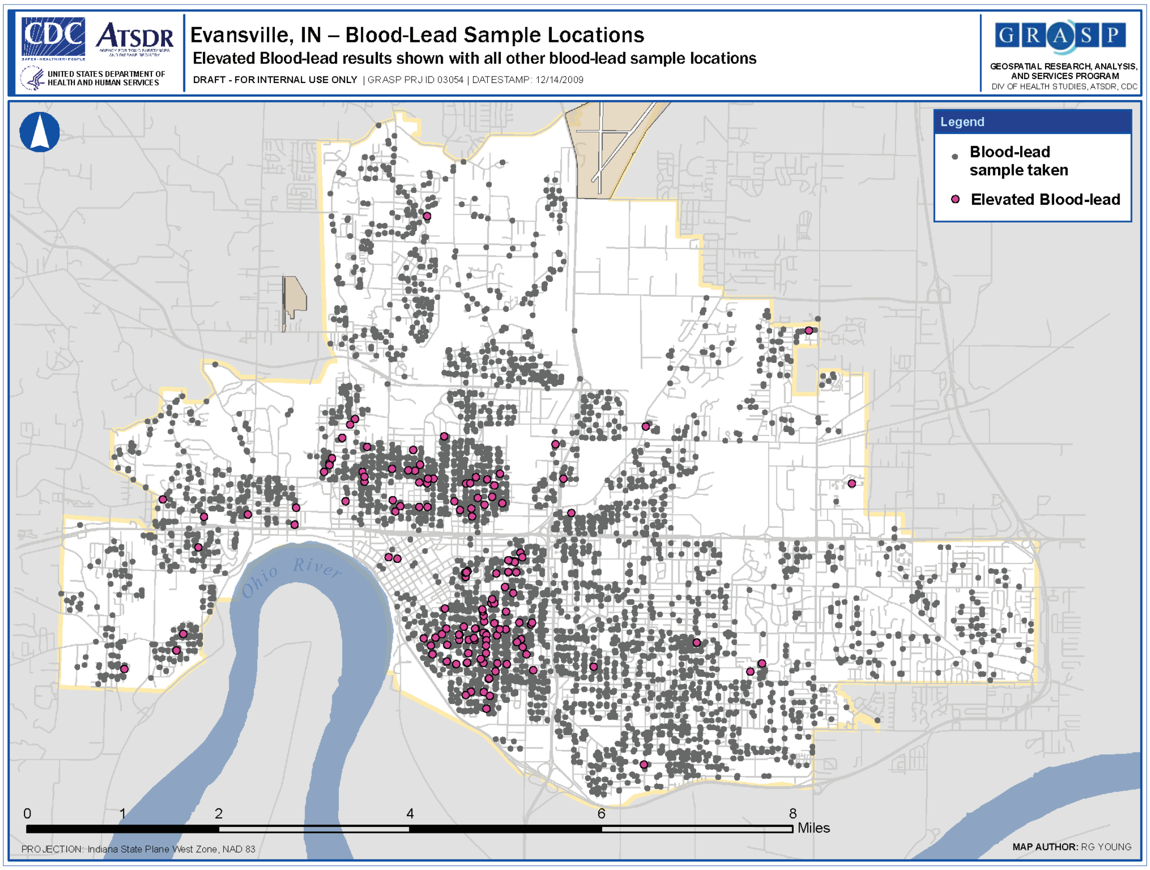



Table 4. BLL percentages by category, confirmation status, and year among children tested aged 1-5 years — Evansville, Indiana, 1998–2006

| Year | BLL ≤5 µg/dL % (95% CI) | 5.0<BLL<10 µg/dL % (95% CI) | BLL≥10 µg/dL (Elevated) % (95% CI) | Confirmed elevated BLL % (95% CI) | Unconfirmed elevated BLL % (95% CI) |
|---|---|---|---|---|---|
| Total | 43.3 (42.6-44.0) | 52.8 (52.1-53.5) | 3.9 (3.6-4.2) | 1.8 (1.7-2.0) | 2.1 (1.9-2.3) |
| 1998 | 74.0 (72.2-75.8) | 18.0 (16.5-19.6) | 8.0 (6.9-9.2) | 2.6 (2.0-3.3) | 5.4 (4.5-6.4) |
| 1999 | 21.4 (19.8-23.1) | 72.2 (70.4-74.0) | 6.3 (5.4-7.4) | 2.4 (1.9-3.1) | 3.9 (3.2-4.8) |
| 2000 | 1.3 (0.9-1.8) | 95.1 (94.2-96.0) | 3.6 (2.9-4.4) | 1.5 (1.1-2.1) | 2.1 (1.6-2.7) |
| 2001 | 4.2 (3.5-5.1) | 92.6 (91.5-93.6) | 3.2 (2.6-4.0) | 1.5 (1.1-2.1) | 1.7 (1.2-2.3) |
| 2002 | 2.7 (2.0-3.5) | 95.0 (94.0-95.9) | 2.3 (1.7-3.1) | 1.7 (1.2-2.4) | 0.6 (0.4-1.1) |
| 2003 | 53.8 (51.6-56.0) | 43.4 (41.2-45.6) | 2.8 (2.2-3.6) | 1.7 (1.2-2.4) | 1.1 (0.7-1.6) |
| 2004 | 90.4 (88.9-91.7) | 8.0 (6.8-9.4) | 1.6 (1.1-2.3) | 1.3 (0.9-1.9) | 0.3 (0.1-0.7) |
| 2005 | 89.2 (87.6-90.6) | 8.2 (7.0-9.6) | 2.6 (2.0-3.5) | 1.7 (1.2-2.5) | 0.9 (0.5-1.4) |
| 2006 | 91.2 (89.6-92.5) | 5.7 (4.6-7.0) | 3.1 (2.4-4.2) | 1.8 (1.2-2.6) | 1.4 (0.9-2.1) |

Figure 4. Percentage of BLL >5 µg/dL in children aged 1-5 years — Evansville, Indiana, 1998–2006

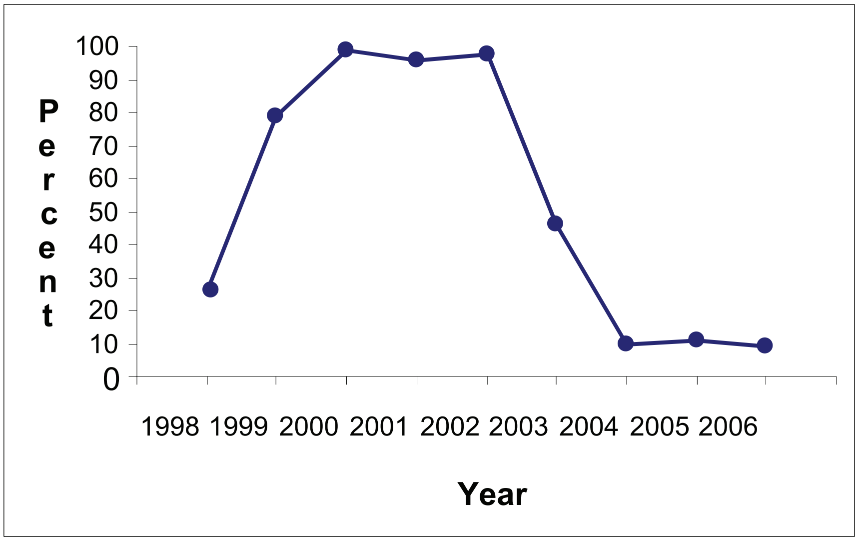



Table 5. Multivariate analysis of the association between BLLs and BLL-related factors among children tested aged 1-5 years — Evansville, Indiana, 1998–2006

| | Model I* Adjusted Odds Ratio (95% CI) | Model II† Adjusted Odds Ratio (95% CI) | Model III§ Adjusted Odds Ratio (95% CI) |
|---|---|---|---|
| **Sex** | | | |
| Boys¶ | 1.0 | 1.0 | 1.0 |
| Girls | 0.9 (0.8-1.0) | 1.0 (0.8-1.4) | 0.8 (0.7-1.1) |
| **Year house built** | | | |
| Built before 1978 | 5.5 (3.4-8.9) §§ | 4.7 (2.2-10.1) §§ | 4.0 (2.3-6.8) §§ |
| Built 1978 or later¶ | 1.0 | 1.0 | 1.0 |
| **BLL test year** | | | |
| 1998¶ | 1.0 | 1.0 | 1.0 |
| 1999 | 0.9 (0.7-1.1) | 0.7 (0.5-1.1) | 0.9 (0.7-1.1) |
| 2000 | 0.5 (0.4-0.7) §§ | 0.4 (0.2-0.7) †† | 0.5 (0.4-0.7) §§ |
| 2001 | 0.4 (0.3-0.6) §§ | 0.3 (0.1-0.5) §§ | 0.5 (0.3-0.7) §§ |
| 2002 | 0.3 (0.2-0.5) §§ | 0.1 (0.0-0.3) §§ | 0.4 (0.2-0.6) §§ |
| 2003 | 0.4 (0.3-0.5) §§ | 0.2 (0.1-0.4) §§ | 0.4 (0.2-0.6) §§ |
| 2004 | 0.2 (0.1-0.3) §§ | 0.1 (0.0-0.2) §§ | 0.2 (0.1-0.4) §§ |
| 2005 | 0.3 (0.2-0.5) §§ | 0.2 (0.1-0.3) §§ | 0.4 (0.2-0.6) †† |
| 2006 | 0.4 (0.3-0.6) §§ | 0.3 (0.2-0.6) §§ | (0.3-0.9) †† |

*a proportional odds model (generalized estimating equations [GEE]), under the assumption of independent working correlations and using a robust variance estimator (Zeger method). Data: all data points, ignoring the effects of multiple measurement (n=18,218 BLLs).

†a proportional odds model (generalized estimating equations [GEE]), under the assumption of independent working correlations and using a robust variance estimator (Zeger method). Data: children with a single BLL (n=7720 BLLs).

§a proportional odds model (generalized estimating equations [GEE]) for repeated measures, using a robust variance estimator (Zeger method). Data: 3999 children who had BLLs in multiple years (n=10,498 BLLs).

¶Reference levels.

**p<0.05; ††p<0.01; §§p<0.0001 for t-test regression coefficient=0.

Examining the confirmation status, overall, 1.8% of BLLs were elevated and confirmed, and 2.1% were elevated but not confirmed (Table 4). The difference between elevated/confirmed and unconfirmed was not statistically significant (Chi Square 2.4845; P-value 0.1150). Although the differences were not statistically significant, confirmation of elevated BLLs in Evansville has improved over time and the percentage of unconfirmed elevated BLLs significantly decreased from 5.4% (4.5-6.4) in 1998 to 1.4% (0.9-2.1) in 2006 (Table 4).

Qualitatively, similar results were obtained from the multivariate logistic regression analysis, irrespective of assumption of independent observations (Model I-III). The proportional odds of increasing BLLs in later years were significantly lower than for the earlier years (Table 5).

## BLLs versus yard soil lead concentrations and year house was built

The association between soil lead levels and BLLs was examined on a subset of the BLL data. Soil lead levels from 35 residential yards were matched to 81 BLLs from 81 children. The yard soil concentrations ranged from 0 to 10,527 parts per million (ppm). No association was observed between BLLs and soil lead levels (Spearman correlation coefficients: 0.05792; P-value: 0.6075) (Table 6).

No statistically significant difference was found between the distributions of soil lead levels where BLLs were elevated (≥10 µg/dL) and soil lead levels where BLLs were not elevated. Where BLLs were elevated, 95% coverage was not obtained for the 90th and 95th percentiles, due to insufficient soil lead data (Table 7).

Finally, examining the association between the year the house was built and BLLs on 13,924 observations, living in older houses was associated with elevated BLLs. The result from all three models indicates that children living in houses built before 1978 were at least 4.0 times as likely to have high BLLs than those children living in houses built in 1978 or later (95%CI=2.3-6.8) (Table 5). Overall, 85.9% of the children tested in Evansville lived in housing built before 1978, while 14.1% lived in newer housing. In addition, 97.1% of the children with elevated BLLs lived in housing built before 1978, while only 2.9% lived in newer housing (Odds Ratio (OR)=5.7; 95% CI: 3.5-9.2) (data are not shown in the tables).

Table 6. Correlation between blood lead levels (BLL) and yard soil lead levels (ppm), where both soil and blood lead levels were available — Evansville, Indiana

| Year | Number of observations in the analysis | Spearman correlation coefficient (r) | P-value (r) |
|---|---|---|---|
| 1998-2006 | 81 | 0.05792 | 0.6075 |
| 2005-2006* | 14 | -0.14060 | 0.6316 |
| 2006† | 7 | 0.40825 | 0.3632 |

*Data from the two most recent years were used to increase statistical power (number of soil lead levels in correlation analysis). † Soil lead levels were obtained in 2006.

Table 7. Selected percentiles of soil lead concentrations (ppm), where BLLs were available — Evansville, Indiana

| | Sample size | Minimum-Maximum | 25th (95% CI) | 50th (95% CI) | 75th (95% CI) | 90th (95% CI) | 95th (95% CI) |
|---|---|---|---|---|---|---|---|
| Soil lead levels | 81 | 0- 10,527 | 422 (83-705) | 1391 (764-1864) | 2198 (2046-2394) | 3037 (2394-7004) | 7004 (3037-10527) |
| Where BBLs ≥10 µg/dL | 10 | 0-2,394 | 791 (0-2394) | 2046 (448-2394) | 2046 (0-2394) | 2394 (0-2394)[a] | 2394 (0-2394)[b] |
| Where BBLs <10 µg/dL | 71 | 0-10,527 | 273 (83-705) | 1076 (764-1827) | 2336 (1864-2394) | 4854 (2394-7004) | 7004 (3037-10527) |

[a] 65.1% confidence interval. 95% CI could not be calculated because of small sample size.
[b] 40.1% confidence interval. 95% CI could not be calculated because of small sample size.

## DISCUSSION

BLLs declined during the study period. This was similar to the decline in BLLs throughout the U.S.[10,11] The decline in BLLs in the U.S. population, as well as in this study population, probably resulted from the banning, since the late 1970s, of the use of lead in gasoline, household paint, food and drink cans, and plumbing systems. In addition, the coordinated efforts by state, local, and non-governmental organizations may have contributed to this decline (e.g., childhood lead poisoning-prevention programs and lead paint-abatement programs). Despite the overall decline in BLLs in recent years (2004-2006), half of the BLLs in this study were 3.0 µg/dL or above, which is higher than median BLLs for U.S. population aged 1-5 years (1.5 µg/dL; NHANES 2001-2002) (CDC 2005). About 3.9% of the children tested in Evansville had elevated levels (BLL ≥10 µg/dL) compared to an estimated 2.2% of the U.S. population.[10]

BLL testing in Evansville has declined during the study period. Voluntary testing has dropped by about 5% over this nine-year period, although the population (ages 0-5 years) for Evansville, Indiana, has remained stable. This is a concern for an area that needs further monitoring, because the BLLs are higher than the national average, and there is no known threshold for adverse health effects from exposure to lead.[10-14]

The results of this study indicate that most BLLs were higher than the national average. This may indicate a common lead source among the study population. The main source of lead exposure for children in the U.S. is lead-based paint. Other important sources include lead contaminated soil resulting from deteriorating or disturbed lead-based paint or due to lead that has settled from leaded paint, gasoline, and stationary sources (e.g., mining and smelting sites, battery manufacturers, and waste treatment plants).[1] A review of the environmental lead sources for Evansville indicated that lead paint is probably present in the majority of Evansville's housing, as 85.9% of the structures were built before leaded-paint was banned in 1978.[7] Lead exposure was evaluated from soil, groundwater, surface water, and sediment samples by the USEPA for the Jacobsville Neighborhood Soil Contamination (JNSC) site in the city of Evansville, Indiana. The USEPA established that only the soil posed a health risk.[8] Between 2005 and 2007, lead in Vanderburgh County's ambient air was much lower (0.01 µg/m$^3$) than the primary standards established in the National Ambient Air Quality Standards (NAAQS) (1.5 µg/m$^3$).[15] No information was available on lead in indoor dusts.

The findings from this study indicate a strong association between BLLs and the year the house was built (i.e., possible exposure to leaded paint). Children living in older housing (i.e., built before 1978) in Evansville were almost six times as likely to have elevated BLLs (≥10 µg/dL) than children living in newer housing (OR=5.7; 95% CI: 3.5-9.2). This finding is comparable with previously published studies.[16,17] Lead remains a hazard in homes built before 1978, especially for children aged 1-5 years, because of their physiological characteristics (e.g., better absorption, having relative large surface area to body weight resulting in a greater dose of hazardous substance per unit of body weight) and behavioral characteristics (e.g., children often put toys, pacifiers and fingers in their mouths, eat lead paint chips, chew on toys, and wash their hands less frequently).

Contrary to the findings from previously published studies,[18,19] in this study, residential soil lead levels were not associated with BLLs. According to the USEPA reports, the likely sources for the lead in soil from the Jacobsville Neighborhood Soil Contamination (JNSC) site came from industries closed in the 1940s and 1950s: Blount Plow Works (operated from the 1880s to about the 1940s), Advance Stove Works (operated from approximately the 1900s to the 1950s), Newton-Kelsay (operated from approximately the 1900s to the 1950s), and Sharpes Shot Works (operated from 1878 to an unknown date).[8] The lack of association between BLLs and soil lead levels might be due to lead becoming less bioavailable as it gets more bound to the soil matrix over time (ATSDR 2007). Lead that is highly bound to the soil can be remobilized if the soils are unusually disturbed or undergo a chemical reaction (e.g., an acid or solvent spill) and, therefore, can still present an exposure hazard.[20] Another reason for the lack of association between BLLs and soil lead levels might be the community's awareness of the soil lead contamination because of USEPA's remedial intervention activities in the study area. As a result, parents may adopt behaviors to reduce indoor dust that originates from outside and, also, may not allow their children to play in the yard. All these factors would reduce the lead exposure from soil.

Indoor dust sampling may be key to determining the source for Evansville's higher BLLs. As lead dust can be generated from both deterioration of leaded paint and contaminated soils blown or tracked indoors on shoes or pets, sampling dust and determining the primary lead source may help to provide meaningful information for reducing BLLs in Evansville. The findings from this study indicate that there is an association between living in older houses and elevated BLLs, and that no association was found between soil lead levels and BLLs. If most of the lead exposure is from indoor paint, removal of lead contaminated soils alone will not help to reduce Evansville's BLLs.

The strength of this study is that it is based on a large BLL data set collected over several years, and that it included the variables yard soil lead levels and the year the house was built. This allowed BLL trends to be reviewed, while examining the residential yard soil lead levels, year the house was built, and their association to BLLs.

However, the findings in this study are subject to at least three limitations. First, the BLLs were collected on a volunteer basis, which makes this a convenience sample vs. a sample with a known survey design (e.g., probability sampling). Because this study is not based on a known sampling design, its findings may not be generalized to all of the children aged 1 to 5 years in Evansville. Second, while a large percentage (85.9%) of the children in the study lived in houses built before 1978 and age of home had a significant association with BLLs, other lead sources outside the focus of the study, such as lead in the diet and consumer goods might also account for the differences between the levels in Evansville and those reported nationally. Finally, other factors not studied, such as the time between the blood sample taken and recent contact with soil in the yard, indoor dust levels and knowledge about the possible exposure to lead from lead contaminated soil might have affected the association between BLLs and soil lead levels.

## CONCLUSION

BLLs for the children tested in Evansville, Indiana were higher than BLLs for the same age group in the U.S. population. In our analysis, living in older houses, which presumably have lead-containing paint, was associated with higher BLLs in children. No clear association was found between higher BLLs and gender or residential soil lead levels. However, given the limitations of the study, it cannot be ruled out that the lead contaminated soil may present an exposure hazard.

The decline in the number of children tested each year indicates the need for continued targeted outreach. Local health agencies should promote activities to prevent lead exposure, such as informing the public on the identification and proper removal of lead paint. Health officials can also emphasize the need for a well balanced diet, including foods rich in iron, calcium, zinc, and L-ascorbate (vitamin C) to help to reduce the amount of lead absorbed.

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