Rural and Urban Ecologies of Early Childhood Toxic Lead Exposure: The State of Kansas, 2005 to 2012

Deniz Yeter, BSN, RN1,2, Deena Woodall, MSN, RN3, Matthew Dietrich, Ph.D.4, Barbara Polivka, Ph.D., RN, FAAN2
1University of Kansas Medical System, Kansas City, KS
Medical Telemetry
2University of Kansas Medical Center, Kansas City, KS
School of Nursing
3University of Kansas Medical Center, Salina, KS
School of Nursing
4Indiana University-Purdue University Indianapolis, Indianapolis, IN

Department of Earth Sciences

Received May 2, 2022; Accepted for publication June 1, 2022; Published online Aug. 22, 2022
https://doi.org/10.17161/kjm.vol15.17960

ABSTRACT

Introduction. No safe detectable level of lead (Pb) exists in the blood of children. Until recently, U.S. Centers for Disease Control and Prevention (CDC) guidelines designated a blood lead level (BLL) ≥5 μg/dL as an elevated BLL (EBLL). For the State of Kansas, early childhood blood lead burdens lack reporting in the literature.

Methods. Secondary analysis was conducted of passively reported EBLL rates ≥5 μg/dL among children ages 0–5 years at the zip code-level in Kansas during 2005 to 2012. Data weights using corresponding population estimates were applied to produce statewide outcomes.

Results. Statewide estimates of annual testing coverage in Kansas among children ages 0–5 years were low (97%). Approximately 17,000 children ages 0–5 years developed an EBLL ≥5 μg/dL each year in Kansas with a 6.9% statewide EBLL rate compared to the national rate of 3.2% for the corresponding years. Significant variations in EBLL rates were found between suburban zip codes compared to urban, urban cluster, or rural at 3.1%, 7.2%, 8.8%, and 10.0%, respectively. Among the worst outcomes in EBLL rates was observed for zip codes in southeast Kansas (13.5%) and rural areas with <500 persons (15.1%).

Conclusions. Young children in Kansas had twice the risk of developing an EBLL ≥5 μg/dL compared to the national rate, while higher rates consistently were seen outside of the suburbs and particularly in more rural and less populated areas. At-risk children and troubled areas of toxic lead exposure in the State of Kansas require increased recognition with improved targeting and interventions.

Kans J Med 2022:15:285-292

INTRODUCTION

Lead (Pb) is a soft, dull gray-colored metal that poses significant systemic and neurotoxic properties that particularly are pronounced among young children.1 Even at lower levels, exposure to lead during early childhood can result in a variety of negative outcomes to attention, behavior, cognition, decision-making, intellect, memory, and mental health.2,3,4 Lead-induced neurotoxicity in children primarily impacts the cerebellum, hippocampus, and prefrontal cerebral cortex.5 Decreased brain volume and lower structural brain integrity is found in adults with greater lead exposure during childhood.6–8 Developing infants are the most vulnerable to lead and suffer more exposure in part from their comparatively greater body surface area, higher heart and respiratory rates, ingestion and inhalation of contaminated dust or soil from greater hand-to-mouth activity, pica, floor-level sitting and crawling, and low stature to the ground where lead dust settles.9

There has been a significant reduction of the early childhood blood lead burden from an average 16 μg/dL during 1976 to 1980 to a historic low of 2 μg/dL during 2007 to 2010 as a result of public health policies and interventions.10–12 The CDC previously designated a blood lead level (BLL) ≥5 μg/dL as an elevated BLL (EBLL),20 which recently was revised down to 3.5 μg/dL.21 However, both the CDC and the American Academy of Pediatrics (AAP) officially recognize that there is no safe level of lead exposure or amount of lead in the blood of children.20,22 In particular, there is a measurable loss of grade school intelligence quotient (IQ) points even with BLLs beginning at 2 μg/dL during the first two years of life.22,23 Other negative outcomes associated with early childhood blood lead below the 5 μg/dL EBLL threshold include greater risk of attention-deficit/hyperactivity disorder (ADHD)-like symptoms,24 childhood anemia and decreasing iron status,25 and lower math and reading test scores in school.26 In the U.S., billions of dollars a year in costs are estimated just from lost IQ points alone from early childhood lead exposure and present with significant racial disparities that disproportionately impact Black children as a result of greater amounts of lead exposure.27

For the State of Kansas, there is a paucity of published literature examining historical and ongoing lead hazards in the environment, in addition to burdens of lead exposure among the population. Only two descriptive studies published in the state medical and nursing journals for Kansas in 1993 and 1994, respectively, have assessed the early childhood blood lead burden in the state.32,33 More recent research by the CDC in 2015 found that workers in Kansas ages 16 years and older have the second highest rate of an EBLL ≥10 μg/dL at 77.3 in 100,000 persons, followed by the State of Missouri with 106.7 in 100,000.34 Two other studies of lead exposure in Kansas published in 1999 and 2016 examined early childhood BLLs and observed positive associations with increasing concentrations of soil contamination or anthropogenic lead emissions resulting from industrial activity.35,36 Therefore, recent descriptions of the childhood blood lead burden in Kansas were lacking.

In 2016, the Reuters news agency reported that thousands of locales in the U.S. were experiencing early childhood EBLL rates that exceeded those which occurred in Flint, Michigan at the peak of its water crisis between 2014 and 2016.37 The following year, Reuters published data for the State of Kansas after it was disclosed to the news agency. Therefore, these data were utilized to conduct an investigation of Kansas for the years of 2005 to 2012.

METHODS

Study Sample. Data of blood lead testing provided to Reuters were retrieved in their national reporting,37 which originally were obtained from various state health departments and the CDC. For the State of Kansas, this included an eight year survey period between 2005 and 2012 of children ages 0–5 years. Tests for blood lead were reported
passively by providers to the Kansas Department of Health and Environment (KDHE), which discloses the data for the total number of overall tests and the total number of EBLL cases at the zip code-level. The KDHE uses CDC guidelines to identify an EBLL ≥ 5 µg/dL by rounding to the first decimal place and using values 4.5 µg/dL or higher. However, the KDHE suppressed data for zip codes reporting > 0 but < 5 total tests or EBLL cases as a result of privacy concerns. Similar to other states, early childhood blood lead testing primarily involves an initial capillary blood test that typically is followed by a subsequent whole blood venous to confirm an EBLL identified via capillary testing. When multiple blood lead tests exist for an individual case in a given year, the highest blood lead value is identified, while other results are removed to prevent multiple entries in reporting. Lastly, nationwide reporting was retrieved for children ages 1 - 5 years from the 2005 to 2012 National Health and Nutrition Examination Survey (NHANES), which is a nationally-representative cross-sectional survey (www.cdc.gov/nchs/nhanes.htm).

Geographic Designations. Zip codes in Kansas were categorized by their most populous city. Individual zip codes within multiple counties were designated to the county where the largest proportion of their population resided. Zip codes were categorized as either suburban, urban, urban cluster, or rural. As shown in Figure 1, urbanized metropolitan areas and urban clusters were defined using official designations from the 2010 census for the State of Kansas. Urban zip codes included the three major urban cities of Kansas City, Topeka, or Wichita. Suburban designation was reserved for all other remaining zip codes within urbanized areas, in addition to the cities of Lawrence and Manhattan. Urban cluster cities are smaller urbanized capitals throughout the rest of Kansas that serve as the county seats for their respective counties, although not every county in the state has an urban cluster. Rural zip codes were designated as any other remaining zip codes that did not match one of the three aforementioned criteria. Lastly, the KDHE defines six different regions within the state along county lines. Zip codes were assigned to each region corresponding to their designated county.

Figure 1. Urbanized metropolitan areas (dark blue) and urban cluster cities (green triangles) in the State of Kansas, 2010 census (US Census Bureau, 2012).

Statistical Design and Analysis. Early childhood EBLL rates were derived by dividing the total number of EBLL-positive cases by the total number of overall tests for each zip code. To produce statewide estimates, EBLL rates were weighted by total population estimates of children 0 - 5 years of age. Population weights were constructed by using five year estimates of the total population (all ages) for each zip code from the American Community Survey (ACS), which involved the survey years of 2015 to 2019 as a result of limited data availability. To construct childhood population weights, total population estimates were multiplied by the percentage of the population accounted for by children ages 0 - 5 years within each county corresponding to the zip code as reported from the 2010 census. As previously mentioned, the KDHE suppressed the reporting of data when a zip code has > 0 but < 5 blood lead tests and/or EBLL cases over privacy concerns. To address this issue, data imputation was performed using a uniform distribution of values {1, 2, 3, 4} that conferred equal probability to each number being retrieved for suppressed data. Suppressed EBLL cases were not imputed for zip codes in which the total number of blood lead tests also had been suppressed, which were treated as unavailable data. Annual blood lead testing coverage was determined from multiplying estimated population totals for children 0 - 5 years of age by the eight survey years and dividing total BLL tests by that figure, while three zip codes were set to 100% as a result of exceeding that value. Simple regression analysis was used to assess linear trends while statistical significance was determined by a p value ≤ 0.05 for all testing.

RESULTS

Descriptive Statistics. As shown in Figure 2, unsuppressed data for blood lead testing rates were available from 662 zip codes (95.4%) and demonstrated a low average rate of testing statewide at 11.8%. Data including imputation for rates of an EBLL ≥ 5 µg/dL were available from 655 zip codes (94.4%) that included 45 suburban, 50 urban, 82 urban cluster, and 478 rural areas. As shown in Table 1, these examined zip codes represented an estimated 247,320 children 0 - 5 years of age (99.7%) residing in the State of Kansas in a given year. Within these zip codes, there was a total of 192,474 individual blood lead tests passively reported to the KDHE over the eight year survey period. Among the included blood lead tests, there were a total of 15,937 EBLL-positive cases at an 8.3% EBLL rate. A total of 635 EBLL-positive cases were imputed for 261 zip codes with suppressed data involving an estimated 22,449 children ages 0 - 5 years. There were seven zip codes with no blood lead testing involving an estimated 135 children ages 0 - 5 years, in addition to 32 zip codes with unavailable data as a result of suppressed data for both blood lead tests and EBLL-positive cases involving an estimated 628 children ages 0 - 5 years.

Weighted Outcomes. Weighted estimates for children ages 0 - 5 years were produced for blood lead outcomes among zip codes. As shown in Table 2, an estimated 16,928 EBLL-positive cases occurred each year in Kansas with an early childhood EBLL rate at 69% compared to the national rate at 32% produced from the NHANES data for the corresponding years of 2005 to 2012. Therefore, young children in the State of Kansas had more than twice the risk of developing an early childhood EBLL than their peers at the national level.
in areas that were more rural and isolated suffered from higher EBLL

0.60 [S.E. 0.01]; p < 0.001). Associations also were observed with log10 county-level population
densities (R² = 0.069; β = -0.262; B = -3.62 [S.E. 0.52]; p < 0.001) and
county-level rural population percentages (R² = 0.040; β = 0.200; B = 0.60 [S.E. 0.001]; p < 0.001).

As shown in Table 2, population estimates and total EBLL cases for zip codes in different categories for EBLL rates were examined. Based upon these categories, a visual illustration of varying EBLL rates across the state is displayed in Figure 4. This revealed that more than 1 in 5 young children in Kansas (21.7%) lived in zip codes with an EBLL rate at least three times higher than the national average of 3.2% at the time, which accounted for nearly half of all EBLL cases (44.7%) across the state.

Lastly, as shown in Table 4, estimates for statewide blood lead testing coverage among children ages 0–5 years residing in the State of Kansas were low at 9.7% with the lowest testing in zip codes that were suburban (5.6%) compared to zip codes that were urban (11.5%) or urban clusters (12.3%) that had the greatest testing coverage. Furthermore, rural areas had lower testing rates (9.7%) despite having the highest rates of developing an early childhood EBLL.

**DISCUSSION**

Although our findings were somewhat dated, the current study involved the first descriptive examination of the early childhood lead burden for Kansas in nearly three decades. Compared to the national rate produced from NHANES data, young children in Kansas experienced twice the risk of developing an EBLL. This current study examined the early childhood lead burden in more detail and found that consistently higher rates of elevated blood lead were seen outside of the suburbs and particularly in areas that were more isolated or rural. Higher EBLL rates were correlated with lower population sizes and densities along with greater rural populations. Recently, another study of the national blood lead burden among young children found numerous zip codes in Kansas had the worst risks of developing an EBLL, which were primarily located in rural areas of the state. This strongly suggested far greater early childhood lead exposure was occurring in rural Kansas.

In contrast to other states, higher EBLL rates were found in less urbanized and more rural areas in Kansas. Rural areas typically experience lower EBLL rates than urban cities, although similar EBLL rates were found between rural and urban newborns in Iowa. This may be unique to Kansas in part from a greater rural population, major urban cities that are comparatively smaller than others, much older and substandard housing, rural healthcare disparities related to access and affordability, and higher rates of soil contamination and industrial emissions as found in previous studies. There also may be a lack of

Figure 2. Passive reporting of blood lead levels among children ages 0–5 years to the Kansas Department of Health and Environment (KDHE), the State of Kansas, 2005 to 2012.
Table 1. Blood lead testing and population characteristics in the State of Kansas, 2005 to 2012.

| Setting         | Variable                                      | Summary Statistics          |
|-----------------|-----------------------------------------------|-----------------------------|
|                 |                                               | Sum | Mean ± S.E. | S.D. | Min-Max |
| Zip code        | % BLL testing coverage                        | -   | 11.8 ± 0.4 | 11.00 | 0 to 100 |
| Zip code        | % EBLL-positive tests (≥ 5 µg/dL)             | -   | 11.4 ± 0.4 | 10.2  | 0 to 66.7 |
| County          | % Rural population                            | -   | 56.8 ± 1.3 | 34.0  | 4 to 100  |
| Zip code        | N = BLL tests                                 | 192,396 | 294 ± 27 | 689  | 5 to 7,046 |
| Zip code        | N = EBLL-positive tests (≥ 5 µg/dL)           | 15,937 | 24 ± 2   | 60   | 0 to 632  |
| County          | N = Population density (persons/sq. mile)     | 137 ± 11 | 289     | 2 to 1,150 |
| Zip code        | N = Population estimates (all ages)          | 2,898,982 | 4,426 ±325 | 8,307 | 29 to 80,489 |
| Zip code        | N = Population estimates (ages 0-5 years)     | 247,320 | 378 ± 29 | 741  | 1 to 6,954 |

Table 2. Weighted outcomes of elevated blood lead in the State of Kansas, 2005 to 2012.

| Setting                        | Studied Sample | Population Estimate Ages 0-5 Years | Blood Lead ≥ 5 µg/dL Annual Incidence |
|-------------------------------|----------------|-----------------------------------|--------------------------------------|
|                               | Zip Codes N    | Ages 0-5 Years N                   | Rate N                                |
| Nationwide (NHANES)           | -              | 6,673,044                          | 3.2% 214,551                          |
| Statewide                     | 655            | 247,320                            | 6.9% 16,928                           |
|                               | ≥ 10,000 persons | 176,377                            | 6.0% 10,583                           |
|                               | 1,000 to 9,999 persons | 60,442                       | 8.2% 4,956                            |
|                               | < 1,000 persons | 10,501                             | 13.0% 1,365                           |
| Suburban                      | 45             | 74,265                             | 3.1% 2,311                            |
|                               | ≥ 30,000 persons | 20,863                            | 2.4% 505                              |
|                               | 15,000 to 29,999 persons | 32,972                     | 3.1% 1,021                            |
|                               | < 15,000 persons | 10,501                            | 3.8% 785                              |
| Urban                         | 50             | 65,001                             | 7.2% 4,693                            |
|                               | Topeka, KS     | 17                                | 6.5% 894                              |
|                               | Kansas City, KS | 9                              | 7.1% 1,142                            |
|                               | Wichita, KS    | 24                                | 7.6% 2,657                            |
| Urban cluster                 | 82             | 72,072                             | 8.8% 6,315                            |
|                               | ≥ 15,000 persons | 39,176                           | 7.8% 3,035                            |
|                               | 5,000 to 14,999 persons | 25,557                        | 9.4% 2,398                            |
|                               | < 5,000 persons | 7,339                             | 12.0% 882                             |
| Rural                         | 478            | 35,982                             | 10.0% 3,608                           |
|                               | ≥ 1,500 persons | 20,498                            | 8.3% 1,697                            |
|                               | 500 to 1,499 persons | 11,430                       | 11.4% 1,298                           |
|                               | < 500 persons  | 4,054                             | 15.1% 613                             |
| County rural population       |                |                                    |                                      |
|                               | < 20%          | 138                                | 5.1% 8,387                            |
|                               | 20 to 39%      | 94                                 | 8.8% 2,829                            |
|                               | ≥ 40%          | 423                                | 11.1% 5,630                           |
Table 2. Weighted outcomes of elevated blood lead in the State of Kansas, 2005 to 2012, continued.

| Setting                        | Studied Sample Zip Codes | Population Estimate Ages 0 - 5 Years | Blood Lead ≥ 5 µg/dL Annual Incidence |
|--------------------------------|--------------------------|-------------------------------------|--------------------------------------|
|                                | N                        | N                                   | Rate                  | N         |
| County population density      |                          |                                      |                        |           |
| ≥ 1,000 persons/sq. mile       | 42                       | 68,208                              | 3.6%                   | 2,445     |
| 100 to 999 persons/sq. mile    | 86                       | 83,520                              | 6.3%                   | 5,219     |
| 10 to 99 persons/sq. mile      | 308                      | 80,398                              | 9.5%                   | 7,596     |
| < 10 persons/sq. mile          | 219                      | 15,194                              | 11.0%                  | 1,668     |
| Region                         |                          |                                      |                        |           |
| Northeast                      | 175                      | 112,731                             | 4.9%                   | 5,497     |
| North Central                  | 106                      | 23,110                              | 7.0%                   | 1,606     |
| Southwest                      | 71                       | 17,979                              | 7.5%                   | 1,340     |
| South Central                  | 106                      | 66,499                              | 7.7%                   | 5,124     |
| Northwest                      | 93                       | 9,158                               | 10.3%                  | 945       |
| Southeast                      | 104                      | 17,843                              | 13.5%                  | 2,416     |

Figure 3. Scatterplots of zip codes with linear trends and 95% confidence intervals for elevated blood lead level (EBLL) rates ≥ 5 µg/dL among children ages 0 - 5 years in the State of Kansas, 2005 to 2012.

Table 3. Weighted outcomes of blood lead testing coverage in the State of Kansas, 2005 to 2012.

| Setting                        | Studied Sample Zip Codes | Population Estimate Ages 0 - 5 Years | Blood Lead ≥ 5 µg/dL Annual Incidence |
|--------------------------------|--------------------------|-------------------------------------|--------------------------------------|
|                                | N                        | N                                   | Percent                             | N         | Percent |
| Statewide                      |                          |                                      |                                     |           |
| Total                          | 655                      | 247,320                             | –                                   | 16,928    | –       |
| 0%                             | 50                       | 2,482                               | 1.0%                                | 0         | 0%      |
| >0 to 5%                       | 130                      | 106,426                             | 43.0%                               | 3,147     | 18.6%   |
| 5 to 10%                       | 178                      | 84,896                              | 34.3%                               | 6,209     | 36.7%   |
| 10 to 15%                      | 121                      | 35,600                              | 14.4%                               | 4,143     | 24.5%   |
| 15 to 20%                      | 74                       | 13,769                              | 5.6%                                | 2,275     | 13.4%   |
| 20% or higher                  | 102                      | 4,147                               | 1.7%                                | 1,154     | 6.8%    |
awareness among the public and healthcare providers in rural areas with significant problems related to lead exposure and contamination. Underfunded public health institutions, hospital closures, and a low number of pediatricians and other clinicians in rural areas likely further compound these issues. Lastly, rural children with EBLLs ≥ 10 µg/dL were less likely to have a follow-up blood test,46 while rural residents have been shown to be less knowledgeable about the prevention of lead exposure.47

However, while our findings for rural areas were unique, the findings for urban compared to suburban areas of the state were in agreement with those from other states. Higher early childhood lead burdens in urban areas are well-known and documented in states across the country, which were characterized by significant socio-economic and particularly racial/ethnic disparities that disproportionately impact Black children who are predominately African-American.31,48 Sources of lead exposure in urban areas included industrial lead emissions,49,50 soil contamination by industry and automobile traffic that can occur from both historical and ongoing sources of emissions,51 and older housing containing higher rates of leaded paint and dust. Higher rates of industrial emissions, soil contamination, and household lead hazards still requiring cost-prohibitive remediation disproportionately impacted marginalized Black communities.49-53 In contrast, suburban areas that typically are more affluent and predominately White were found to have much lower lead burdens compared to other areas outside of the suburbs.33,44

By region, the highest EBLL rates were found in Southeast Kansas, which is part of the Midwestern “lead belt” primarily located in Southwest Missouri and also includes Northeast Oklahoma. This region of Kansas has long been impacted by historical and ongoing issues of lead pollution largely resulting from mining and smelting operations centered around the urban cluster city of Galena, Kansas. Previously, two studies on industrial emissions in Kansas found a positive association between higher rates of lead exposure and greater amounts of lead in the blood of children,35,36 in which a disproportionate share of these industries were located in Southeast Kansas. Workers in Kansas also suffered from the second highest rates of EBLLs ≥ 10 µg/dL in the U.S.,34 which likely stemmed from greater employment in lead-related industries and can result in take-home contamination that results in childhood lead exposure.54 Furthermore, many rural areas in Kansas have higher rates of older housing stock and substandard housing.55 Lastly, the lack of investigations highlighted the need for further study.

Table 4. Weighted outcomes of blood lead testing coverage in the State of Kansas, 2005 to 2012.

| Setting         | Studied Sample | Population Estimate | Blood Lead ≥ 5 µg/dL | Annual Incidence |
|-----------------|----------------|---------------------|----------------------|-----------------|
|                 | Zip Codes N   | Ages 0 - 5 Years N | Rate (%)             | N               |
| Statewide       |               |                     |                      |                 |
| Total           | 694           | 248,083             | 9.7%                 | 192,474         |
| Suburban        | 46            | 74,529              | 5.6%                 | 33,475          |
| Urban           | 52            | 65,067              | 11.5%                | 60,008          |
| Urban cluster   | 82            | 72,072              | 12.3%                | 70,635          |
| Rural           | 514           | 36,415              | 9.7%                 | 28,356          |

Figure 4. Zip code-level rates of an elevated blood lead level (EBLL) ≥ 5 µg/dL among children ages 0 - 5 years in the State of Kansas, 2005 to 2012.
Very low testing rates were observed for early childhood blood lead exposure so that the proper preventative and mitigative interventions may take place. Low testing rates in Kansas could be improved through the promotion of both public and provider education along with greater availability of point-of-care testing. This may identify more EBL cases among at-risk children while giving a clearer picture of troubled areas in the State of Kansas.

REFERENCES

1. Mayans L. Lead poisoning in children. Am Fam Physician 2019; 100(1):24-30. PMID: 31259498.
2. Dietrich KN, Succop PA, Berger OG, Hammond PB, Bornschein RL. Lead exposure and the cognitive development of urban preschool children: The Cincinnati Lead Study cohort at age 4 years. Neurotoxicol Teratol 1991; 13(2):203-210. PMID: 1710765.
3. Lampe CB, Dietrich K, Auinger P, Cox C. Cognitive deficits associated with blood lead concentrations ≥10 microg/dL in US children and adolescents. Public Health Rep 2000; 115(6):521-529. PMID: 11354334.
4. Lampe CB, Hornung R, Khoury J, et al. Low-level environmental lead exposure and children’s intellectual function: An international pooled analysis. Environ Health Perspect 2005; 113(7):894-899. PMID: 16002379.
5. Arnold OM, Liu J. Blood lead levels ≤10 micrograms/dL and executive functioning across childhood development: A systematic review. Neurotoxicol Teratol 2020; 80:106888. PMID: 32878736.
6. Bao QS, Lu CY, Song H, et al. Behavioural development of school-aged children who live around a multi-metal sulphide mine in Guangdong province, China: A cross-sectional study. BMC Public Health 2009; 9:217. PMID: 19573251.
7. Bellinger DC. Very low lead exposures and children’s neurodevelopment. Curr Opin Pediatr 2018; 30(2):172-177. PMID: 18332714.
8. Chiado LM, Covington C, Sokol RJ, et al. Blood lead levels and specific attention effects in young children. Neurotoxicol Teratol 2007; 29(5):538-546. PMID: 17553667.
9. Banks EC, Ferretti LE, Shucard DW. Effects of low level lead exposure on cognitive function in children: A review of behavioral, neuropsychological and biological evidence. Neurotoxicology 1997; 18:237-281. PMID: 9216005.
10. Searle AK, Baghurst PA, van Hooff M, et al. Tracing the long-term legacy of childhood lead exposure: A review of three decades of the Port Pirie cohort study. Neurotoxicology 2014; 43:46-56. PMID: 24785378.
11. Senut MC, Cingolani P, Sen A, et al. Epigenetics of early-life lead exposure and effects on brain development. Epigenomics 2012; 4(6):665-674. PMID: 23244311.
12. Shah-Kulkarni S, Ha M, Kim BM, et al. Neurodevelopment in early childhood affected by prenatal lead exposure and iron intake. Medicine (Baltimore) 2016; 95(4):e2508. PMID: 26825887.
13. Vorvolakos T, Arsenio S, Samakouri M. There is no safe threshold for lead exposure: A literature review. Psychiatrir 2016; 27(3):204-214. PMID: 27837574.
14. Crump KS, Van Landingham C, Bowers TS, Cahoy D, Chandalia JK. A statistical reevaluation of the data used in the Lampehart et al. (2005) pooled analysis that related low levels of blood lead to intellectual deficits in children. Crit Rev Toxicol 2013; 43(9):785-799. PMID: 24040996.
15. Sanders T, Liu Y, Buchner V, Tchoumouw PB. Neurotoxic effects and biomarkers of lead exposure: A review. Rev Environ Health 2009; 24(1):15-45. PMID: 19476290.
16. Cecil KM, Brubaker CJ, Adler CM, et al. Decreased brain volume in adults with childhood lead exposure. PLoS Med 2008; 5(5):e112. PMID: 18307499.
17. Reuben A, Elliott ML, Abraham WC, et al. Association of childhood lead exposure with MRI measurements of structural brain integrity in midlife. JAMA 2020; 324(19):1970-1979. PMID: 33281203.
18. Beckwith TJ, Dietrich KN, Wright JP, Altaye M, Cecil KM. Criminal arrests associated with reduced regional brain volumes in an adult population with documented childhood lead exposure. Environ Res 2021; 201:111559. PMID: 34181918.
19. Mielke HW, Reagan PL. Soil is an important pathway of human lead exposure. Environ Health Perspect 1998; 106(Suppl 1):217-229. PMID: 9539015.
20. Centers for Disease Control and Prevention (CDC). Blood lead levels in children aged 1-5 years - United States, 1999-2010. MMWR Morb Mortal Wkly Rep 2013; 62(33):245-248. PMID: 23552225.
continued.

21. Jones RL, Homa DM, Meyer PA, et al. Trends in blood lead levels and blood lead testing among US children aged 1 to 5 years, 1988-2004. Pediatrics 2009; 123(6):E769-73. PMID: 19254973.

22. Mahaffey KR, Amnest JL, Roberts J, Murphy BS. National estimates of blood lead levels: United States, 1976-1980. Association with selected demographic and socioeconomic factors. N Engl J Med 1982; 307(10):573-579. PMID: 7110203.

23. Meyer PA, Pivetz T, Dignam TA, Homa DM, Schoonover J, Brody D. Surveillance for elevated blood lead levels among children—United States, 1997-2001. MMWR Surveill Summ 2003; 52(10):1-21. PMID: 14532866.

24. Pirkle JL, Brody DM, Gunter EW, et al. The decline in blood lead levels in the United States. The National Health and Nutrition Examination Surveys (NHANES). JAMA 1994; 272(4):284-291. PMID: 8041056.

25. Guo Y, Deng YH, Ke HJ, Wu JL. Iron status in relation to low-level lead exposure and the persistence of educational consequences into adolescence. Environ Sci Pollut Res Int 2019; 26(18):17875-17884. PMID: 28780688.

26. Boyd J, Yeter D, Aschner M, Wheeler DC. Estimated IQ points and lifetime earnings lost to early childhood blood lead levels in the United States. Sci Total Environ 2021; 784:139430. PMID: 34030555.

27. [No authors] Pediatric blood lead testing in Kansas, 1993; Kans Med 1994; 95(4):98. PMID: 8041056.

28. Shadbegian R, Guignet D, Klemick H, Bui L. Early childhood lead exposure and the persistence of educational consequences into adolescence. Environ Res 2019; 176:108643. PMID: 31475304.

29. Shadbegian R, Guignet D, Klemick H, Bui L. Early childhood lead exposure and the persistence of educational consequences into adolescence. Environ Res 2019; 176:108643. PMID: 31475304.

30. Boyd J, Yeter D, Aschner M, Wheeler DC. Estimated IQ points and lifetime earnings lost to early childhood blood lead levels in the United States. Sci Total Environ 2021; 784:139430. PMID: 34030555.

31. [No authors] Pediatric blood lead testing in Kansas, 1993; Kans Med 1994; 95(4):98. PMID: 8041056.

32. Shadbegian R, Guignet D, Klemick H, Bui L. Early childhood lead exposure and the persistence of educational consequences into adolescence. Environ Res 2019; 176:108643. PMID: 31475304.

33. Shadbegian R, Guignet D, Klemick H, Bui L. Early childhood lead exposure and the persistence of educational consequences into adolescence. Environ Res 2019; 176:108643. PMID: 31475304.

34. Alarcon WA. Summary of notifiable noninfectious conditions and disease outbreaks: Elevated blood lead levels among employed adults—United States, 1994-2012. MMWR Mortal Mortal Wkly Rep 2015; 62(54):52-75. PMID: 26572072.

35. Levin MD, Sarasua S, Jones PA. A multivariate linear regression model for predicting children's blood lead levels based on soil lead levels: A study at four superfund sites. Environ Res 1999; 81(1):52-61. PMID: 10361026.

36. Brink LA, Talbott EO, Marsh GM, et al. Revisiting nonresidential environmental exposures and childhood lead poisoning in the US: Findings from Kansas, 2000-2005. J Environ Public Health 2016; 2016:2798-2805. PMID: 27042184.

37. Pell M, Schneyer J. Off the Charts: The thousands of U.S. locales where lead poisoning is worse than in Flint. December 19, 2016. www.reuters.com/investigates/special-report/us-lead-testing. Accessed December 19, 2016.

38. Centers for Disease Control and Prevention. Lead and childhood blood lead levels in urban areas. City Environ Interact 2020; 6:100042. PMID: 34589652.

39. Dietrich M. Using historical atmospheric pollution data to prioritize environmental sampling in urban areas. City Environ Interact 2020; 6:100042. PMID: 34589652.

40. Lamphear BP, Weitzman M, Winter NL, et al. Lead-contaminated house dust and urban children's blood lead levels. Am J Public Health 1966; 86(10):1416-1421. PMID: 8876511.

41. Jacobs DE, Clickner RP, Zhou JY, et al. The prevalence of lead-based paint hazards in U.S. housing. Environ Health Perspect 2002; 110(10):A599-606. PMID: 12361941.

42. Newman N, Jones C, Page E, Ceballos D, Oza A. Investigation of childhood lead poisoning from parental take-home exposure from an electronic scrap recycling facility - Ohio, 2012. MMWR Mortal Mortal Wkly Rep 2013; 62(27):743-745. PMID: 26182192.

43. Kansas State Data Center. KU Institute for Policy & Social Research. Housing. Available online: https://ipsr.ku.edu/sdc/region.php?area=Kansas. Accessed May 31, 2022.

44. Carnahan B, Schaefer EW, Fogel BN, Point-of-care testing improves lead screening rates at 1- and 2-year well visits. J Pediatr 2021; 243:206-211.e202. PMID: 33675816.

45. Gettens GC, Drouin BR. Successfully changing a state’s climate to increase blood lead testing. J Public Health Manag Pract 2019; 25(Suppl 1, Lead Poisoning Prevention):S31-S36. PMID: 30507767.

46. Davidson JR, Karas DR, Bigham MT. Improving lead screening rates in a large pediatric primary care network. Pediatr Qual Saf 2021; 6(5):e478. PMID: 34589652.

47. Knighton AJ, Payne NR, Speedie S. Lead testing in a pediatric population: Underscreening and problematic repeated tests. J Public Health Manag Pract 2016; 22(4):331-337. PMID: 26483037.

48. Christensen K, Coons M, Walsh RO, Meiman JG, Neary E. Childhood lead poisoning in Wisconsin, WMI 2019; 118(1):1-20. PMID: 31083828.

49. Roberts EM, Madrigal D, Valle J, King G, Kite L. Assessing child lead poisoning case ascertainment in the US, 1999-2010. Pediatrics 2017; 139(5):e20164266. PMID: 28557759.

Keywords: lead poisoning, adverse childhood experiences, epidemiology, public health, rural health