Use of Geographic Information System Technology to Aid Health Department Decision Making about Childhood Lead Poisoning Prevention Activities

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The Centers for Disease Control and Prevention recommend that local public health agencies use local data to identify children at risk for lead exposure to ensure that they receive preventive services. The objective of this study was to demonstrate the usefulness of a geographic information system (GIS) in identifying children at risk for lead exposure. We conducted a descriptive study, using GIS technology, of the blood lead (BPb) levels and residential location of at-risk children screened for lead exposure. "At-risk children" were defined as those children living in housing built before 1950 or in an area with a high proportion of older housing. The study was conducted in Jefferson County, Kentucky, USA. Participants were the cohort of children born in 1995 and screened from 1996 through 1997, and children younger than age 7 years who were screened from 1994 through 1998. Outcome measures were the BPb level and residential location (address or target zone) of at-risk children screened from 1996 through 1997, and the number and location of homes where more than one child had been poisoned by lead from 1994 through 1998. The proportion of children screened who live within zones targeted for universal screening varied from 48% to 53%, while only 50% of the at-risk children in the entire county were screened. Between 1994 and 1998, 79 homes housed 35% of the 524 children with lead poisoning. These housing units were prioritized for lead-hazard remediation. Significant numbers of at-risk children throughout the county were not being tested for lead exposure, even in prioritized areas. GIS can be very useful to health departments in planning lead exposure screening strategies and measuring program performance. *Key words:* childhood, geographic information systems, lead poisoning, public health. *Environ Health Perspect* 109:89–94 (2001). [Online 21 December 2000]
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Recent data from phase 2 of the Third National Health and Nutrition Examination Survey (NHANES III) indicate that 4.4% of U.S. children younger than 6 years of age have blood lead (BPb) levels of at least 10 µg/dL, the level associated with cognitive impairment and behavior problems (*1*). NHANES III data demonstrate that residence in older housing is a strong, independent risk factor for lead poisoning. Deteriorating lead-based house paint remains the most important source of lead exposure for children in the United States (*2*). Before 1950, house paint contained up to 50% lead by weight, and currently children in 26 million households live in housing built before 1950 (*3*). The children most at risk for lead exposure are 6 months to 2 years of age, who are exposed primarily by ingestion of lead-contaminated dust on objects or hands placed in their mouths (*2*).

The U.S. Public Health Service has a strategic plan to eradicate childhood lead poisoning by the year 2011 (*4*). The plan requires that at-risk children be screened by blood tests for lead exposure. Children with mildly elevated BPb levels (e.g., 10–19 µg/dL) can then be protected from further lead exposure if parents are taught to reduce exposure. In addition, children with higher BPb levels (e.g., at least 20 µg/dL) can receive medical evaluation and treatment, if indicated. Because the risk for lead exposure is not distributed evenly throughout the population, the Centers for Disease Control and Prevention (CDC) recommended in 1997 that health departments use local data to identify children and neighborhoods at high risk in order to target screening efforts (*2*). For example, the CDC suggested that health departments could target children ages 6 months to 2 years who reside in geographic areas, such as zip codes or census tracts, where at least 27% of the housing stock was constructed before 1950.

This paper describes how a computerized geographic information system (GIS) can be used to help health department decision making and program evaluation about screening for childhood lead exposure when the main criterion used to assess a child's risk of lead exposure is residence in housing constructed before 1950 (*5*). We present data compiled and used by the Jefferson County, Kentucky, Childhood Lead Poisoning Prevention Program (Jefferson County CLPP).

Methods

Geographic Information Systems. GIS technology allows person-specific and location-specific data from different sources to be joined and mapped to display important geographic relationships. A GIS database comprises both tabular and geo-referenced (spatial) data. Tabular data in health department records, such as sex, age, date of birth, and laboratory test results, can be analyzed by geographic location, a GIS feature termed "spatial analysis." Spatial information can be constructed from a reference grid by assigning a "geocode," or coordinates (e.g., latitude, longitude), to each exact home address. This geocode corresponds to a mapping location. Larger areas such as counties, zip codes, census tracts, or land parcels are represented as polygons with geocoded boundaries.

A major strength and advantage of GIS technology is the dynamic linkage between tabular and spatial data. For example, when tabular records are selected, corresponding features in a linked map view are also selected and vice versa, enabling easy identification of records or features of interest. "Spatial overlay," another GIS capability, allows map layers drawn from different GIS databases to be superimposed and displayed as a composite map image. Information contained within different GIS databases can be spatially joined by merging information contained in each database with its geographic area or location. For example, a specific home address can be assigned to its corresponding land parcel, census tract, or zip code.

Operational research questions. The initial study cohort comprised children born in 1995 in Jefferson County, Kentucky, USA. We used health department records to determine which children in this cohort were screened for lead exposure from 1 January 1996 through 31 December 1997 to assess the effectiveness of the Jefferson County CLPP in reaching at-risk children. "At-risk"

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was defined as being 6 to 35 months of age and living in a home built before 1950 or in a target zone (i.e., an area where at least 27% of the homes were built before 1950). We created GIS databases for tabular and spatial queries to address the following research questions: *a*) Of children born in 1995 and screened for lead exposure in 1996–1997, what percentage lived in housing built before 1950? *b*) What percentage of children born in 1995 and residing in housing built before 1950 was screened in 1996–1997? *c*) What percentage of children born in 1995 and living within target zones was screened in 1996–1997?

We then expanded the study cohort to include all children younger than 7 years of age who were screened by the Jefferson County CLPP from 1994 through 1998 to assess the ability of GIS to identify neighborhoods and specific housing units in need of special attention for remediation. We posed the following research questions to assess this ability: *a*) What is the geographic distribution of children younger than 7 years of age whose BPb levels were at least 20 µg/dL at any time from 1 January 1994 through 31 December 1998? *b*) Which housing units pose an extraordinary risk to child residents, as evidenced by the units containing more than one child younger than 7 years of age from 1994 through 1998 whose BPb levels were at least 20 µg/dL?

Sources of data. This project required tabular data on births, children screened for lead exposure, and individual housing construction dates, as well as home construction dates aggregated by census tract and zip code. Birth records containing home address data of all newborns within Jefferson County were extracted from the Commonwealth of Kentucky's 1995 birth registry. Child-specific BPb testing records containing the home address and BPb test results for children born in 1995 and screened at 6–35 months of age from 1 January 1996 through 31 December 1997 were extracted from the Jefferson County CLPP lead-screening registry. We performed a separate data extraction from the lead-screening registry to capture data on children younger than 7 years of age who had confirmed blood test results of 20 µg/dL or greater from 1 January 1994 through 31 December 1998. In Jefferson County, screening tests for lead exposure are done by the fingerstick (capillary sampling) method. When the BPb is less than 20 µg/dL, repeat testing is done by fingerstick; confirmatory testing is done by venipuncture when the BPb is at least 20 µg/dL. The methods of obtaining BPb levels and the purpose for testing (screening, follow-up, or confirmation of elevated BPb) are designated in the health department record.

To maintain confidentiality, children's names were not extracted from the birth and screening registries. In addition, because there was a chance that families would move after their child was born, we could not assume that the same home address indicated the same child. Therefore, we could not match individual screening records to birth records. So we assumed a steady-state population and calculated screening rates by aggregating the number of children within a specific geographic area (zip code, census tract, or target zone) rather than matching by individual child or street address. The year of construction for individual residences was extracted by land parcel (property) from the Jefferson County property valuation (tax assessor) database and merged with corresponding home addresses in the birth registry and the lead-screening registry. The proportion of housing constructed before 1950 was extracted from the 1990 U.S. Census Survey (*6*) for census tracts and zip codes within Jefferson County, Kentucky.

The spatial data comprised geo-referenced databases for individual residential addresses, land parcels, census tracts, zip codes, and county boundaries. These databases are updated and maintained within ArcInfo 7.0 (Environmental Systems Research Institute, Redlands, CA) libraries by the Louisville and Jefferson County Information Consortium (LOJIC). As members of the LOJIC, the Jefferson County CLPP and the Jefferson County Property Valuation Administration also share data.

Database preparation. Data from the Jefferson County CLPP and the Commonwealth of Kentucky's birth registry had numerous errors with respect to the street address information. These errors included improper spelling or spacing, invalid street numbers, invalid zip codes, and addresses that were not within Jefferson County. We verified and corrected address information from these databases on the basis of a comparison with a commercial reference (*7*) by using Excel 97 (Microsoft, Seattle, WA) and the LOJIC reference library. Address data in the LOJIC library had been corrected previously by LOJIC's routine maintenance procedures. Records were excluded from mapping and GIS analysis if the address was out of the target county, missing essential components, or indicated a post office box or rural delivery route.

We used ArcView 3.0a software (Environmental Systems Research Institute) to manipulate the GIS databases. We geocoded home addresses in the lead-screening and birth registry databases via the address-matching function of ArcView 3.0a on the basis of the geo-referenced databases maintained by LOJIC through standard procedures for verification.

The property valuation (tax assessor) database did not contain the year of construction for a large percentage of the home addresses in the geo-referenced lead-screening and birth registries. Specifically, 30% (2,507 of 8,361) of the geo-referenced birth registry and 45% (1,238 of 2,740) of the geo-referenced cumulative lead-screening cohort from 1996 through 1997 were missing data on year of construction. We assigned records to a pre-1950 housing age category when their year of construction was omitted from the tax assessor record if the address was present in the 1949 city phone directory for Louisville; otherwise, the record was assigned to the 1950-or-more-recent housing age category (*8*). Thus we were able to assign 491 (20%) of the 2,507 births and 364 (29%) of the 1,238 children screened during the 1996–1997 time period to the pre-1950 housing age category.

The proportions of Jefferson County housing built before 1950 by census tract or by zip code were spatially joined to the corresponding geo-referenced census tract and zip code databases in the LOJIC library. A tabular query of these joined GIS databases produced map layers highlighting either census tracts or zip codes that contained at least 27% of the housing built before 1950 within Jefferson County. These highlighted census tracts and zip codes comprised the target zones for universal lead exposure screening. Home addresses from the lead-screening and birth registries were spatially joined with their corresponding geo-referenced census tract and zip code databases in the LOJIC library.

Results

Following are findings for each of the five research questions we posed. We first asked, of children born in 1995 and screened for lead exposure in 1996–1997, what percentage was living in housing built before 1950 when screened? A total of 9,439 children were born in Jefferson County in 1995. Of these, 17% were screened in 1996 and 21% were screened in 1997, whereas 6% of the cohort was screened in both years. Cumulatively, only 32% of the 1995 county birth cohort was screened at least once from 1 January 1996 through 31 December 1997.

Of children in the initial databases, 11% (1,078 of 9,439) of the addresses in the 1995 county birth cohort and 9% (284 of 3,024) of the addresses in the cumulative lead-screening cohort for 1996–1997 could not be geocoded and were excluded from further analysis. Of the children whose addresses could be geocoded, 31% (2,569 of 8,361) of the children in the 1995 county birth cohort and 47% (1,283 of 2,740) of the cumulative lead-screening cohort resided in housing built before 1950.

For children in the cumulative lead-screening cohort, 27% (351 of 1,283) of those living in housing built before 1950 and 9% (131 of 1,457) of those living in newer housing had BPb levels of at least 10 µg/dL. Figure 1 shows the home address and housing-age category (i.e., housing built before 1950, home built in 1950 or more recently) for each child in the cumulative lead-screening cohort for 1996–1997. Mapping this information revealed that most of the screened children residing in housing built before 1950 lived in the northwestern section of the county.

Our second question was, what percentage of children born in 1995 and residing in housing built before 1950 was screened in 1996–1997? In the county as a whole, 50% (1,283 of 2,570) of the children in the 1995 birth cohort who resided in older housing were screened at least once from 1 January 1996 through 31 December 1997. Figure 2 demonstrates the percentage of children in the 1995 birth cohort that were screened during this time period (1996–1997). The intensity of color in the maps corresponds to the screening percentage. This percentage corresponds to the number of children screened divided by the number of children in the 1995 birth cohort for that specific geographic unit, and therefore corrects for population density among the children at risk by virtue of residence in older housing. Different geographic units of analysis, either census tracts (Figure 2A) or zip codes (Figure 2B), yielded a somewhat different graphic pattern of screening rates, but both indicate that screening efforts were more focused in the northwestern region of the county.

We next asked, what percentage of children born in 1995 and living within target zones were screened in 1996–1997? The target zone defined by census tracts had a screening rate of 53% (1,525 screened children of 2,906 births), and the target zone defined by zip codes had a screening rate of 48% (1,782 screened children of 3,727 births). Figure 3 demonstrates the target zone defined by census tracts (Figure 3A) and zip codes (Figure 3B).

The fourth question was, what is the geographic distribution of children younger than 7 years of age whose BPb was at least 20 µg/dL from 1994 through 1998? There were 539 newly reported cases of lead poisoning (confirmed BPb at least 20 µg/dL) from 1994 through 1998, representing 524 different children. Case managers created a "new case" category if a child's current BPb was at least 10 µg/dL and their previous BPb had fallen below 10 µg/dL on two sequential measurements. Figure 4 demonstrates a clustering of these case children within the northwest region of the county. The census-tract target zone (Figure 4A) includes 94% (491 of 524) of these case children, whereas the zip-code target zone (Figure 4B) includes 97% (509 of 524).

Finally, which housing units pose an extraordinary risk to child residents, as evidenced by containing more than one child younger than 7 years of age whose BPb levels were at least 20 µg/dL at any time from 1 January 1994 through 31 December 1998? Seventy-nine different housing units accounted for 35% (187 of 524) of these children. Figure 5 demonstrates a clustering of these priority housing units within the northwest region of the county. The census tract target zone (Figure 5A) includes 90% (71 of 79) of these housing units, while the zip code target zone (Figure 5B) includes 95% (75 of 79).

Discussion

The CDC recommends that state health officials develop locally appropriate recommendations for childhood lead screening

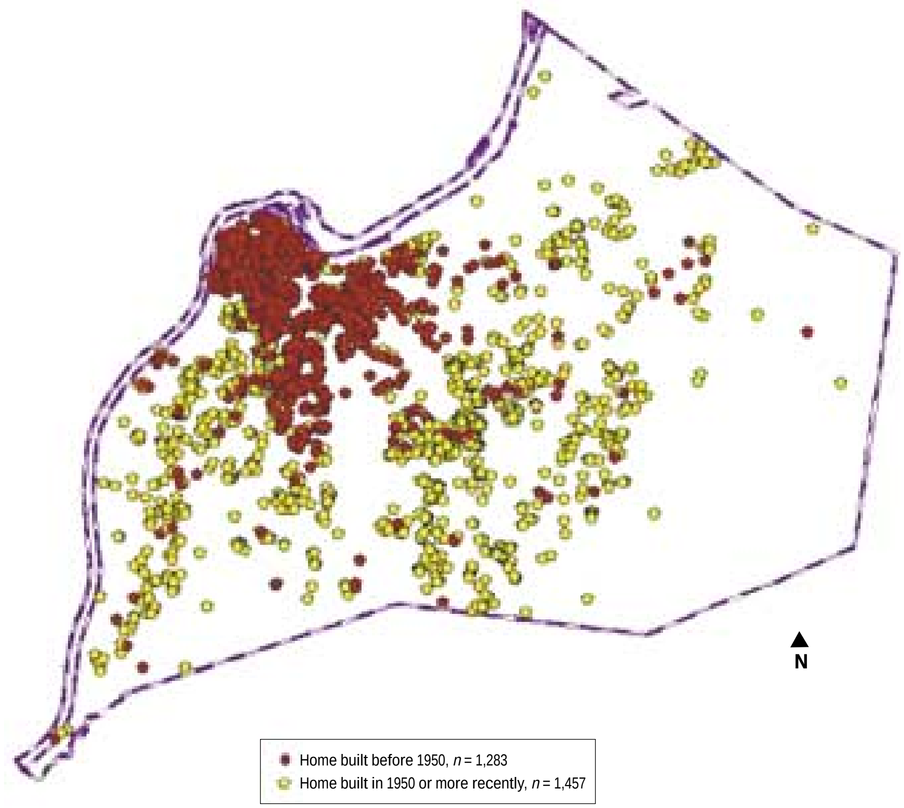

Figure 1. Residential location and age of home for children born in 1995 and screened in 1996–1997 for lead poisoning in Jefferson County, Kentucky. Each symbol represents one child.

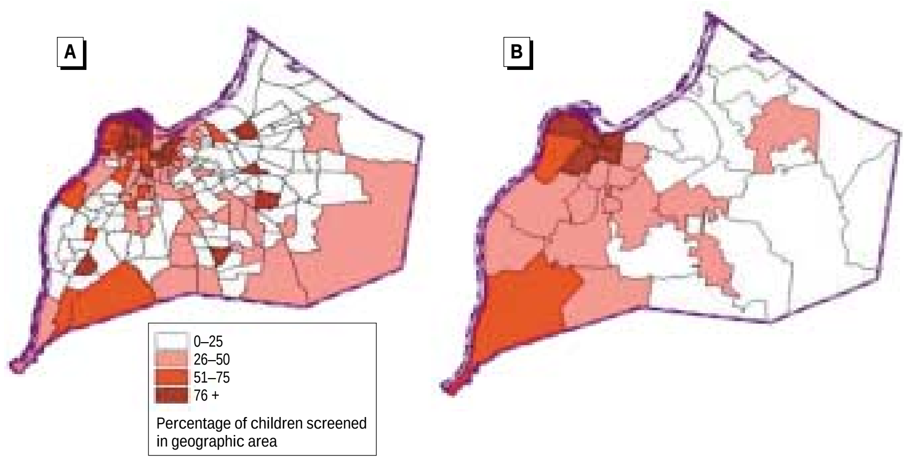

Figure 2. Lead exposure screening percentages of children born in 1995 and residing in pre-1950 housing within Jefferson County, Kentucky, aggregated by geographic unit and screened for lead exposure at least once within 1996–1997. (*A*) Screening rate by census tracts. (*B*) Screening rate by zip code.

based on the prevalence of older housing within specified geographic areas (*2*). The guidelines recommend lead-exposure screening for children 1 and 2 years of age or children between 36 and 72 months of age who have not previously been screened and who reside in a geographic area (zip code or census tract) where at least 27% of the housing was built before 1950. In the absence of such a plan, the CDC recommends that all children younger than 72 months of age be screened. The policy of the Jefferson County CLPP recommends that all children 6 months to 3 years of age be screened for lead exposure every 6 months and that children 3–5 years of age be screened yearly (*9*).

This study used GIS technology to assess how effectively the Jefferson County CLPP was able to identify and screen at-risk children for lead exposure. We used the individual lead-screening record as the unit of analysis to answer some questions, whereas to answer other questions we aggregated screening records by geographic areas (census tracts, zip codes, or target zones). We compared the different geographic aggregates to evaluate the effectiveness of current screening practices in reaching at-risk children.

Analysis of the tabular data from the cumulative lead-screening cohort of 1996–1997 demonstrated that the proportion of children with elevated BPb levels was much higher for children residing in homes built before 1950 (27%) than for those in newer homes (9%). This finding is consistent with those of other studies demonstrating that residing in older housing is an important risk factor for excessive childhood lead exposure (*1*,*10*–*13*). Sociodemographic and housing data aggregated by community in Massachusetts (*11*) showed that children living in communities with high rates of poverty, single-parent families, housing built before 1950, and low rates of home ownership were at greater risk for lead poisoning. Socioeconomic and demographic variables aggregated by census tract from the 1990 U.S. Census for Rhode Island (*12*) showed that older homes and vacant housing were significant predictors of excessive lead exposure among children.

In this study, mapping the spatial data (Figure 1) demonstrated that the screening program focused its efforts in the northwest region of the county, which contains most of the older and deteriorated housing units (76% of housing stock is pre-1950, vs. 29% in the rest of the county) as well as the poorer families. The choice of screening in this region appears to be supported by a clustering of cases of children with elevated BPb levels (Figure 4) and priority housing units (Figure 5). However, cases will be detected only where appropriate screening occurs. Despite the number of cases detected in the northwest region, the screening rates aggregated by census tract (Figure 2A) and zip code (Figure 2B) reveal that a significant number of at-risk children throughout the county were not tested for lead exposure. In Jefferson County, lead screening by capillary sampling (fingerstick) is a requirement for the Women, Infants, and Children Program recertification (every 6 months) and Head Start physicals. From 1994 through 1998, the children who received these services were the ones seen at health department clinics and two additional community health service provider agencies for well-child visits. However, in November 1997 Medicaid-managed care was implemented in Jefferson County and reimbursed lead screening only by the primary care provider.

Since 1998, the Jefferson County Childhood Lead Poisoning Prevention Program has made additional efforts to educate physicians who are now seeing many of the Medicaid patients who used to be seen in the health department clinics. Based on these analyses, the Jefferson County CLPP intervened to improve screening rates among the children living in older housing. A high-risk designation was given to the zip codes currently containing young children living in pre-1950 housing stock where few of these children received lead-screening tests in 1997. According to the local work permit agency, at least 10% of houses in these areas were being remodeled at any one time. Health alerts were sent to the parents of these children and pediatricians practicing in these high-risk zip code regions. The letter encouraged parents to discuss blood lead screening with their pediatrician. The Jefferson County CLPP posted the blood lead-screening rates by zip code on the medical society web page (Internet) and visited pediatric practices located within the high-risk zip codes to encourage awareness of the risk of lead poisoning in their practice areas. In addition, health risk information was placed in retail hardware and home remodeling centers. An evaluation of the impact of these initiatives is under way.

The designation "priority housing" was given by the Jefferson County CLPP to the 79 units associated with 35% of all of the

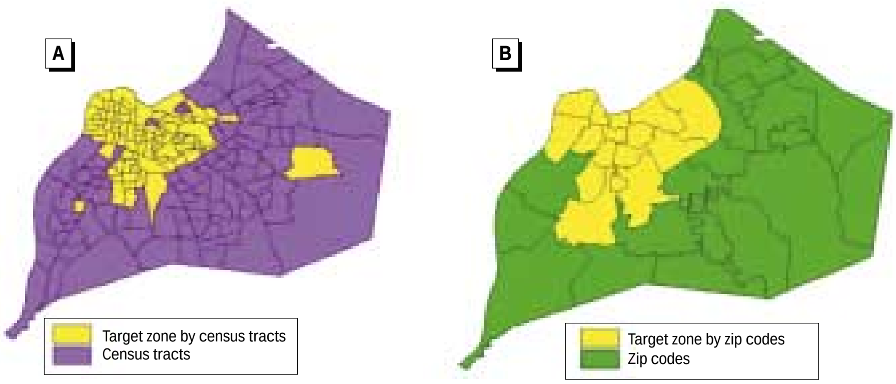

Figure 3. Residential location of children born in 1995 and screened for lead exposure within Jefferson County, Kentucky, during 1997. (*A*) Target zone by census tracts. (*B*) Target zone by zip codes.

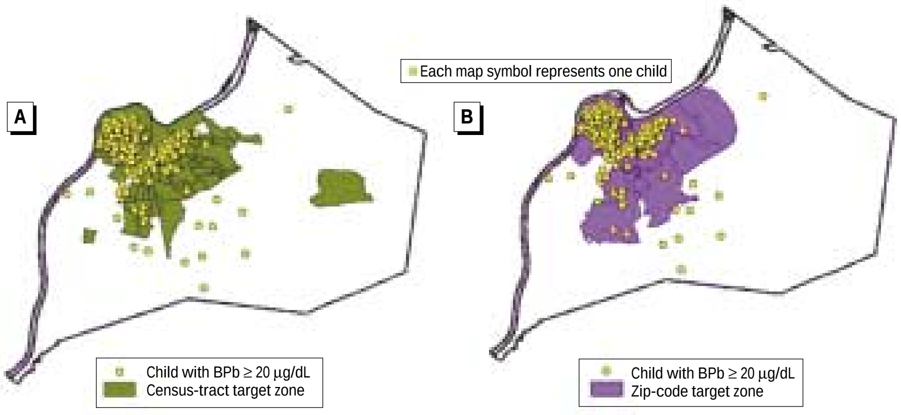

Figure 4. Residential location of children under 7 years of age with confirmed BPb ≥ 20 µg/dL between 1994–1998 in Jefferson County, Kentucky (n = 524). Lead poisoning cases within (*A*) census-tract target zone (n = 491) and (*B*) zip-code target zone (n = 509). Each symbol represents one child.

children who had lead poisoning (BPb at least 20 µg/dL) over the past 5 years. This designation is intended to promote remediation of the residential lead hazards. In addition, Jefferson County was able to use this information to successfully compete for grant funds from the U.S. Department of Housing and Urban Development for housing remediation (*9*). Remediation is often costly and requires coordination between limited resources located in disparate public sectors—departments of public health, housing, and the environment. This kind of analysis provides evidence of the public health burden imposed by lead-contaminated housing that is not remediated promptly. Public health authorities may be able to use such evidence to pursue legal action to impose fines or loss of federal subsidies for landlords of public housing.

To our knowledge, this is the first study published to target the individual housing unit on the basis of its year of construction as shown in the county tax-assessor database. Previous published studies (*5,10–14*) have only evaluated screening strategies that use the percentage of older housing within a defined geographic area but would miss the at-risk children not living within defined target areas. By identifying the spatial distribution of housing built before 1950, public health departments can devise strategies to screen all children living in older homes. Future research might uncover other variables in the tax-assessor database that could indicate the likelihood that lead-based paint remains on the premises and could pose a threat to child occupants if the housing condition deteriorated or if the old paint was exposed by renovation or remodeling.

In this study, we found that more children were designated to receive screening tests when zip codes (3,727) rather than census tracts (2,906) were used to define the target zones. However, when percentages are used to select target zones, census tracts would be more sensitive than zip codes in locating a greater number of older housing units. Socioeconomic factors are also more similar within a census tract than within the larger area of a zip code. However, health department guidelines are implemented more easily by pediatricians when using targeted zip codes because people usually know their residential zip code but not their respective census tract. In Jefferson County, Kentucky, the target zone defined by census tracts (Figure 3A) closely resembled the spatial distribution of the target zone defined by zip codes (Figure 3B). A study in Syracuse, New York, also found that a similar location and geographic pattern of elevated BPb levels persisted when data aggregated by either census tracts or zip codes were compared (*14*).

Study Limitations

A lead-exposure hazard can arise from the disturbance of any housing surface covered with lead-based paint. Such hazards include renovation, remodeling, repair, or simply deterioration of older housing units (*15*). We evaluated only the age of housing construction as a risk factor and not the condition of the housing or any previous remediation. In addition, this method may not be able to evaluate screening practices in areas that have not been adequately geo-referenced, which is a common problem in rural settings.

We aggregated information from the birth and lead-screening registries geographically by census tract, zip code, and screening target zones by using a steady-state assumption about residential mobility. If this assumption was not correct, then the screening rates estimated among at-risk children will have been too high for some geographic areas and too low for others. Because no shared unique child identifiers (other than address) were released to the CDC to preserve confidentiality, limiting the follow-up to 2 years from birth minimized the likelihood that the children had moved (*14,16*). In addition, the childhood immunization program staff in Jefferson County noted that residential mobility among impoverished families was confined to specific geographic areas captured by the zip-code target zone.

Recommendations

This GIS analysis revealed that substantial numbers of at-risk children throughout Jefferson County, even those residing within prioritized screening areas, were not being tested for lead exposure. These findings may reflect the attitude or knowledge deficit of health care providers and parents toward the value and need for lead-exposure screening in the county. To increase the percentage of at-risk children screened, educational mailings could be sent to all older housing units identified in the tax assessor database and addressed to the resident's name to alert parents of younger children about the potential for lead exposure hazards. Sending a flyer addressed to "occupant" may not be an effective method of informing residents because this type of mailing is often ignored. However, when addressing mailings by name, care must be taken to avoid increasing public concern about government intrusion into an individual's home and suggesting that there may be lead hazards. Screening campaigns conducted door-to-door in at-risk neighborhoods or via a mobile screening van may also improve the chances of reaching at-risk children.

We hope that health departments will use this methodology to analyze their screening data to assess one aspect of program effectiveness and to evaluate how well their programs are reaching children residing in older housing where there is an increased likelihood that old layers of lead-based paint are present and place them at risk for lead exposure. We are not suggesting that this should be the only method implemented for evaluating screening strategies. This kind of analysis provides data for decision making rather than data for theoretical model construction. Additional factors that can affect lead exposure risk include other locations where a child spends significant time (e.g., school, day care, play, and visitation sites) and other sociodemographic risk factors (e.g., race/ethnicity, poverty, use of public assistance funds, and population density) (*1,2*). These other factors were not evaluated in this analysis, but geographically based information on these variables could be obtained from the U.S. Census Bureau and used to refine definitions of "at risk" in future GIS evaluations. Environmental concentrations of lead in the

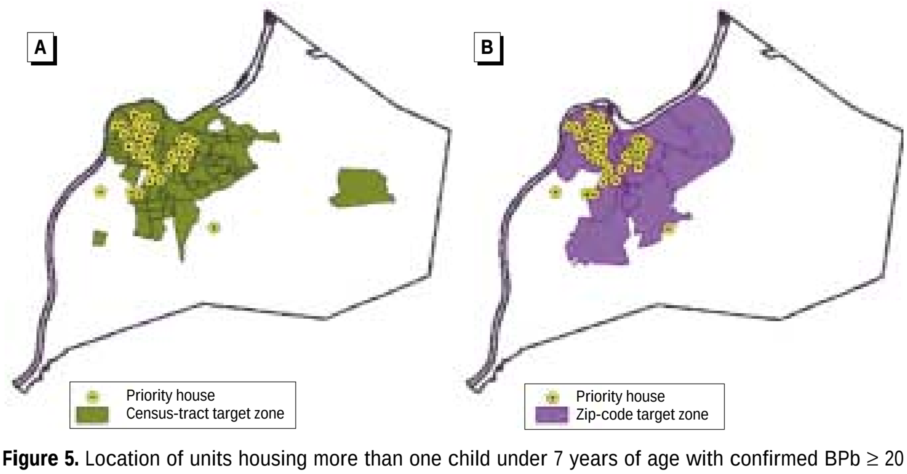

Figure 5. Location of units housing more than one child under 7 years of age with confirmed BPb ≥ 20 µg/dL between 1994–1998 in Jefferson County, Kentucky (*n* = 79). Priority housing within (*A*) census-tract target zone (*n* = 71) and (*B*) zip-code target zone (*n* = 75).

air, water, and soil can also be integrated by mathematical modeling using GIS and advanced spatial analysis (*17*).

Housing age categories could be evaluated by GIS methodologies to choose the cut-point that best serves the public health department's lead-screening strategy, especially given the disparities in housing age cut-points used in lead exposure guidelines published by different federal agencies (i.e., Housing and Urban Development, Environmental Protection Agency, Centers for Disease Control and Prevention). Georeferenced "neighborhoods" might be better geographic reference areas for GIS analyses because census tracts are created each decade to take the national census, and zip codes are sometimes redesignated for mail delivery. These neighborhoods could be defined on the basis of local information about socioeconomic and cultural issues influencing patterns of residential migration and mobility. The use of a neighborhood strategy might help health departments raise awareness among both parents and pediatricians about the need for lead-exposure screening. In keeping with the practice of disease prevention, pediatricians should follow their local health department recommendations for childhood lead exposure screening and screen their patients accordingly.

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