Predictive Risk Mapping and Recommendations to Mitigate Childhood Lead Poisoning in North Carolina

by

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Abstract

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Background: Research shows that exposure to lead is linked to a number of health impacts, including behavioral problems, attention deficit/hyperactivity disorder, reduced IQ, and learning disabilities. In July 2012, the Centers for Disease Control and Prevention (CDC) updated the reference level from 10 µg/dL to 5 µg/dL because studies were identifying health impacts from exposure to lead at lower levels. In light of this, North Carolina followed suit in July 2017 by lowering the state action level to match the CDC’s reference level, yet childhood lead poisoning still remains an issue.

Methods: In North Carolina, more than 140,000 children under six years old are tested for lead each year and focusing resources and outreach to the most highly impacted areas is a challenge. Utilizing blood lead data from the North Carolina Division of Public Health (DPH) and a number of data sets encompassing lead poisoning risk factors from the US Census Bureau, preventative risk maps were created in ArcGIS.

Results: A handful of counties in North Carolina were identified as high risk, using the following factors with varying weights: pre-1950 housing, 1950-1978 housing, poverty status, renter-occupied housing, education level, percent African American and/or Hispanic, and population under six years old. The majority of counties identified as high risk for childhood lead poisoning, also show higher percentages of children, ages 6 to 35 months, with confirmed elevated blood lead levels from 2013 to 2017.

Conclusions: The risk maps discussed in this paper will help inform local health departments and organizations that work to mitigate childhood lead poisoning in North Carolina. With this information, the North Carolina Childhood Lead Poisoning Prevention Program (NC CLPPP) outreach team can begin formulating plans to deposit resources and educational materials in the counties identified as high risk. Likewise, preventative methods and strategies used in counties with lower percentages of children with confirmed elevated blood lead levels can be shared with high risk counties.
Biography

Megan Rodgers grew up in Raleigh, North Carolina and graduated from North Carolina State University in 2014 with a bachelor’s degree in environmental science and a minor in nonprofit studies. After graduating, she began working as an environmental research assistant at UNC’s Institute for the Environment in the Environmental Resource Program (ERP). The ERP connects UNC’s environmental community with local communities, classrooms, government agencies and businesses across the state through outreach, engagement, and research translation. As part of her position in ERP, Megan is a member of the outreach team on the NC DHHS contracted North Carolina Childhood Lead Poisoning Prevention Program (NC CLPPP) grant and a member of the Community Outreach and Engagement Core for the Center for Environmental Health and Susceptibility in the UNC Gilling’s School of Global Public Health. In order to declare a research focus in the environmental field, Megan began pursuing her master’s degree in environmental assessment with a certificate in Geographic Information Systems (GIS), while continuing to work at the Institute.
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Introduction

Lead poisoning causes health impacts, especially for children. Studies show that exposure to lead is linked with behavioral problems, attention deficit/hyperactivity disorder, reduced IQ, learning disabilities, and other health problems (Hood, 2002; Brown, 2008; Kessler, 2009; Betts, 2012; CDC, 2012). The U.S. Centers for Disease Control recently updated guidelines for childhood lead exposure, due to research now linking health impacts from exposure to lower levels of lead (Betts 2012; CDC, 2012). In a 2005 study involving 1,581 children divided into seven cohorts, intelligence decreases were found in association with lead levels below 10ug/dL (Lanphear et al., 2005; Betts 2012).

In North Carolina, more than 140,000 children under six years old are tested for lead each year and focusing resources and outreach to the most highly impacted areas is a challenge. The North Carolina Department of Health and Human Services, Division of Public Health (DPH) has more than 20 years of data, including blood lead test results and addresses for all counties in the state. It is important to utilize these data to initiate a shift from mitigative to preventive intervention programs to protect children from lead exposure. Studies show that age of housing, urban/rural status, race/ethnicity, and socioeconomic status are all important factors contributing to lead exposure in children (Wartenberg, 1992; Miranda et al., 2002; Gaitens et al., 2009; Kessler, 2009; Akkus & Ozdenerol, 2014). While health impacts of lead poisoning have been studied in children and adults, the risk factors for lead poisoning have not been analyzed statewide in North Carolina using geospatial data to identify the areas of highest risk.

The first step in initiating preventative intervention programs is recognizing the sources of lead exposure creating the most risk. Lead-based paint, found in houses built before 1978, is the largest contributing source of lead exposure for children (Bellinger et al., 1986; CDC, 1991; Clark, 1992; Lanphear et al., 1996; Brown, 2008; Levin et al., 2008; Tehranifar et al., 2008; Hanchette 2008). Lead-based paint, while “safe” when undisturbed, deteriorates as a house ages and lead dust is emitted when friction is applied. Therefore, lead dust is typically found inside and outside the house on window sills, door jams, porches, and in the dirt around the outside of the house. Other sources of lead can include imported candy, folk medicine, solder, spices, toy jewelry, toys, and water, yet lead-based paint remains the most widespread (CDC, 2015; Angelon-Gaetz et al., 2018). Research shows that addressing lead-based paint hazards in housing units with children identified to have an elevated blood lead (EBL) significantly reduces the risk
of identifying a second child with an EBL (Levin et al., 2008). Likewise, studies show that children with EBLs are more common in communities with many households below the federal poverty level (Sargent et al., 1995; Bernard & McGeehin, 2003; Levin et al., 2008) and residents of these households are less likely to undertake the extensive process of lead removal. Appropriate measures, such as the EPA’s 2008 Renovation, Repair and Painting (RRP) Rule (amended in 2010 and 2011), is required when disturbing lead-based paint in pre-1978 housing. The RRP Rule requires workers to be certified and trained in the use of lead-safe work practices, and requires renovation, repair, and painting firms to be EPA-certified (CDC, 2012). Although the RRP is important from an environmental health and safety standpoint, hiring a lead-safe professional can be prohibitive for some families due to the expense.

According to Jacobs and Nevin (2006), in 2000 approximately 38 million homes contained lead-based paint. Furthermore, in a statistical analysis on data from the Third National Health and Nutrition Examination Survey (NHANES III, 1988-1994), 42% of children living in housing built before 1946, and 39% of children in housing built between 1946 and 1973 had blood lead levels (BLL) greater than or equal to 5ug/dL, compared to the 14% of children in housing built post-1973 (Bernard & McGeehin, 2003; Levin et al., 2008). That said, risk maps displaying housing build date in correlation with blood lead tests, socioeconomic status, percent African American and/or Hispanic, and renter-occupied housing would be beneficial for initiating preventative intervention programs in North Carolina. Furthermore, research shows that GIS and spatial analysis are beneficial in identifying areas of highest risk for health effects and directing outreach activities and intervention tools to those areas (Wartenberg, 1992; Miranda & Edwards, 2011; Akkus & Ozdenerol, 2014).

Several other states have tried mapping lead exposure risk to determine statewide trends. For example, in a 2001 study in Jefferson County, Kentucky, researchers mapped blood lead level and residential location of at-risk children, defined as living in a house built before 1950 or in an area with a high proportion of older housing. As a result, researchers found that identifying at-risk children was useful to health departments in planning lead exposure screening strategies (Reissman et al., 2001). Similarly, in a New York City study in 2008, researchers investigated the association between childhood lead poisoning and foreign birthplace. Using blood lead and housing data, researchers matched children on age, date of blood lead test, and residential area, and found that both foreign birthplace and time since most recent foreign residence had strong
associations with lead poisoning status (Tehranifar et al., 2008). Furthermore, a study in Marion County, Indianapolis, Indiana evaluated the spatial relationship between soil lead sources and children’s blood lead levels among 16,232 records from January 1999 – December 2008 and found that soil lead is correlated with interior lead accumulation (Morrison et al., 2013). In addition, Morrison et al. (2013) found that soil lead levels shared a high degree of variability at the neighborhood level, once again confirming the importance of spatial analysis for determining the areas of highest risk for childhood lead poisoning.

Research and mapping have also been conducted in North Carolina, but risk factors have not been evaluated statewide. In a 2002 study, median household income, percentage of children in poverty, percentage of persons in poverty, percentage of renter-occupied households, percentage of single-parent households, percentage of African Americans, and number of Hispanics from the 1990 Census were evaluated and mapped in four geographic sectors: Buncombe county, Durham and Orange county, Wilson and Edgecombe counties, and New Hanover county (Miranda et al., 2002). While this model was successful in determining areas of highest risk, it is not statewide, and it is based on data that is almost 30 years old. Likewise, in a 2008 study, pockets of higher lead poisoning rates were found in several eastern North Carolina counties (Hanchett, 2008). According to Hanchette (2008), understanding this cluster requires knowledge of the political ecology of the area and cannot be explained by poverty and housing characteristics alone. Therefore, historical, social, political, and economic processes should not be ignored when analyzing lead poisoning trends in North Carolina.

Finally, in Durham, North Carolina, Miranda et al. (2013) used geographic health information systems (GHIS) to link health systems and social and environmental data, with the ultimate goal of supporting the Institute for Healthcare Improvement’s Triple Aim Initiative, a framework developed to improve the US health care system. Using different subsets of data embedded into the larger GHIS framework, the researchers evaluated three different scenarios, one of which pertained to childhood lead poisoning. For the relevant scenario, the model combined county tax assessor data, blood lead, screening data from clinic visits, and census data to determine lead risk levels at the individual tax-parcel level in Durham, North Carolina. While this is a critical tool for understanding childhood lead poisoning, it only encompassed one county in North Carolina. Therefore, learning from previous studies helped inform this project and will
help local health departments in North Carolina to provide targeted screening, education, and outreach for preventative intervention programs.

**Objective Statement**

The purpose of this project is to inform local health departments and organizations in North Carolina that work to mitigate childhood lead poisoning. Ultimately, the risk maps described in this paper identify areas of highest risk in North Carolina so preventative intervention programs can be implemented where they are needed most. In order to determine which areas assume the highest risk, a number of risk factors were evaluated, including poverty status, housing build date, population under six, African American and/or Hispanic population, foreign-born population, population receiving food stamps or Supplemental Nutrition Assistance Program (SNAP) benefits, educational attainment, and renter-occupied properties in North Carolina by county, in conjunction with confirmed elevated blood lead test data. Further analysis of these maps can initiate questions regarding lead testing frequency and availability in North Carolina, and can result in targeted outreach, education, and testing recommendations for the most highly impacted counties in the state.

**Methods**

GIS and spatial analysis can offer comprehensive avenues for data, especially when many factors are involved. The key to spatial analysis is determining a geographical commonality, such as county, zip code, or census tract among the data sets to be analyzed. Spatial analysis enables the user to overlay multiple data sets by location and explore the relationships that are almost impossible to identify in spreadsheets. Furthermore, GIS allows the user to create accessible maps that can be used by researchers and community members alike. The risk maps described in this paper were created using ArcGIS and data from NC DPH and the US Census Bureau to determine counties of highest risk for lead exposure in North Carolina.

**Data collection**

The initial study plan rationale was submitted to the University of North Carolina at Chapel Hill’s Office of Human Research Ethics/Institutional Review Board and was deemed exempt from further review. Following this exemption, a data use agreement was submitted to the NC DPH and approved by North Carolina State University. The blood lead data sets were retrieved from NC DPH and organized using Microsoft Excel before beginning analysis. Pivot
tables were used to categorize the blood lead level data points from lowest to highest by identifier, county, and year, and duplicates were omitted per NC DPH recommendations. Since the discrete testing dates were not listed in the data set supplied by NC DPH, it was important to use only one blood lead test result from each identifier in order to avoid an inaccurate portrayal and analysis of the data.

Meanwhile, additional data sets were downloaded from the US Census Bureau using the American Fact Finder, including socioeconomic status, rental/owner-occupied housing, housing build date, race and ethnicity demographics, educational attainment, foreign-born populations, food stamps and Supplemental Nutrition Assistance Program (SNAP) recipients, and population under six years of age in North Carolina (Table 1). Before utilizing this data to create layers in GIS, the files were organized in Microsoft Excel. Each data set was categorized by county and necessary headings and subsequent data were included for spatial analysis purposes. All data sets required identical heading nomenclature in order to perform spatial joining in GIS. For each variable, county percentages were determined based on total population or total housing structures, determined by the data set.

Table 1. US Census Bureau data set download details.

<table>
<thead>
<tr>
<th>US Census Bureau Data Set</th>
<th>Data Variable</th>
<th>Census Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Years of Age and Sex: 2010</td>
<td>Population under six years old</td>
<td>2010</td>
</tr>
<tr>
<td>ACS 5-Year Estimates: 2012-2016</td>
<td>Poverty status</td>
<td>2012-2016</td>
</tr>
<tr>
<td>ACS 5-Year Estimates: 2012-2016</td>
<td>Race and ethnicity demographics</td>
<td>2012-2016</td>
</tr>
<tr>
<td>ACS 5-Year Estimates:2012-2016</td>
<td>Renter occupied housing units</td>
<td>2012-2016</td>
</tr>
<tr>
<td>ACS 5-Year Estimates: 2012-2016</td>
<td>Year structure built</td>
<td>2012-2016</td>
</tr>
<tr>
<td>ACS 5-Year Estimates: 2012-2016</td>
<td>Selected characteristics of the native and foreign-born populations</td>
<td>2012-2016</td>
</tr>
<tr>
<td>ACS 1-Year Estimates: 2017</td>
<td>Food Stamps/Supplemental Nutrition Assistance Program (SNAP)</td>
<td>2017</td>
</tr>
</tbody>
</table>
Data Analysis

Each data set was configured as a GIS layer using the join feature to connect the data geographically to the North Carolina counties, and graduated color symbology was used (Figures 1-3) to aid visual analysis. At this point, layers were kept for continued use or eliminated based on their merit in displaying meaningful trends in childhood lead poisoning.

Figure 1. Aggregate percentage of confirmed elevated blood lead levels among children ages 6-35 months old by county in North Carolina from 2013-2017.

Figure 2. Percent of pre-1978 housing by county in North Carolina.
Eventually, all data sets were converted into raster files using the polygon to raster tool and reclassified into five categories using the reclassify tool. With all of the data sets classified into five categories, it was possible to rank the factors for analysis using the weighted sum overlay tool. The contributing factors were ranked using information from NC DPH and the literature (Miranda et al., 2002; Miranda et al., 2013), and the tool was run multiple times with varying scenarios. Analyzing the factors with equal weight applied, the first weighted sum overlay scenario combined the initially determined factors for childhood lead poisoning, including pre-1978 housing, poverty status, population under six years old, and renter-occupied housing (Figure 4).

In the scenarios that followed, additional factors were included, such as foreign-born populations, food stamps and SNAP recipients, and education level. Data regarding foreign-born populations and food stamps or SNAP recipients were integrated secondarily because data was not available for all counties in North Carolina. While the standalone maps are interesting for these data sets (Figures 5-6), their addition to the overall analysis could skew the results due to incomplete data. Furthermore, the food stamp and SNAP recipient data is likely also represented in the poverty data set and is therefore redundant. Viewing the standalone maps in additional to the final risk map outlined in this paper, will help NC DPH and the North Carolina Childhood Lead Poisoning Prevention Program (NC CLPPP) outreach team formulate recommendations for local health departments with high combinations of risk factors. Furthermore, the standalone maps can help answer questions about specific populations in North Carolina.
Figure 4. Weighted sum overlay with preliminary factors (poverty status, population under six years old, renter-occupied housing, and pre-1978 housing) represented with equal weight.

Figure 5. Percent of population that is foreign born by county in North Carolina. Data not available for some counties.

Figure 6. Percent of population receiving food stamps or SNAP benefits by county in North Carolina. Data not available for some counties.
After conducting the first weighted sum overlay using the initial four factors with equal weighting, it became clear that this mapping would require multiple iterations to determine how different combinations of risk factors with varying weights would impact the map outputs and the resulting analysis of risk. The second iteration of weighted sum overlay included the additional factor of education level with the initial four factors and equal weighting (Figure 7) and the third iteration included the same five factors using unequal weighting (Figure 8).

**Figure 7.** Weighted sum overlay with the following factors represented with equal weight (poverty status, population under six years old, renter-occupied housing, pre-1978 housing, and education level).

**Figure 8.** Weighted sum overlay with the following factors represented with unequal weight (poverty status, population under six years old, renter-occupied housing, pre-1978 housing, and education level).
For this iteration, pre-1978 housing was given the most weight followed by poverty status and renter-occupied units, and finally population under six years old and education level, based on recommendations from NC DPH and the literature (Miranda et al., 2002; Miranda et al., 2013). While the differences between these two maps are subtle, it is apparent that weighing the factors is necessary for accurate analysis.

With this in mind, the next iteration was completed with factor weighting and the inclusion of relevant race and ethnicity data, specifically percent African American and percent Hispanic. Including the addition of these factors, the data was weighted in the following order, with the first factor weighted heaviest: 1) pre-1978 housing, 2) poverty status and renter-occupied housing, and then 3) population under six years old, education level, percent African American, and percent Hispanic (Figure 9). Once again, these additions produced subtle changes in the map and suggest that these factors contribute to the potential for childhood lead poisoning.

Figure 9. Weighted sum overlay with the following factors represented with unequal weight (poverty status, population under six years old, renter-occupied housing, pre-1978 housing, education level, percent African American, and percent Hispanic).

In the last weighted sum overlay, the pre-1978 housing data was divided into two categories, pre-1950 housing and 1950-1978 housing. This addition was initiated due to research showing that houses built pre-1950 are more than three times likely to contain lead-based paint compared to houses built between 1950 and 1978 (Reissman et al., 2001; Bernard & McGeehin, 2003; Levin et al., 2008; EPA, 2017). In the final iteration, the risk factors were weighted as follows, with the first factor weighted heaviest: 1) pre-1950 housing, 2) 1950-1978 housing,
poverty status and renter-occupied housing, and 3) population under six years old, education level, percent African American, and percent Hispanic (Figure 10). As expected, this map showed some subtle differences from the previous iterations but many of the designated high-risk counties, displayed in dark red, stayed continuous throughout the trial and error process.

**Figure 10.** Weighted sum overlay with the following factors represented with unequal weight (poverty status, population under six years old, renter-occupied housing, education level, pre-1950 housing, 1950-1978 housing, percent African American, and percent Hispanic).

**Discussion**

In assessing the final risk map output (Figure 10), the counties with highest risk for childhood lead poisoning, using the factors outlined in this paper, include Anson, Edgecombe, Halifax, Lenoir, Richmond, Scotland, Vance, and Wilson. This outcome aligns with the standalone maps, in that many of the risk factors are also prevalent in these counties when displayed individually. With the exception of Hispanic populations, the counties listed above tended to display higher percentages when looking at the defined lead risk factors. Likewise, while most of the listed counties displayed a higher percentage of confirmed EBLs from 2013-2017, but Anson county does not (Figure 1). This could be a result of undertesting for lead or, on a positive note, efficient education and outreach that has helped mitigate childhood lead poisoning despite the many risk factors.

As a quick validation mechanism, the results were compared with the CDC’s Social Vulnerability Index (2016) which depicts a county’s social vulnerability based on four
categories: socioeconomic status, household composition/disability, race/ethnicity/language, and housing/transportation. Based on the composition of each of these categories, socioeconomic status (poverty, unemployment, per capita income, and no high school diploma) aligned best with the factors discussed in this paper and was therefore used for brief validation. Of the eight counties designated as high risk in this paper, six were ranked in the highest vulnerability category for socioeconomic status and two were in the second highest vulnerability category. Therefore, if this project progresses using zip-code or census tract, this tool will be essential in validating and contributing additional factors.

Fortunately, all North Carolina counties are covered under the NC CLPPP, and following a brief web search, it was confirmed that all of the counties identified as high-risk for lead poisoning in this paper have active lead poisoning prevention programs. Furthermore, some counties have formed regional health departments, like the Granville-Vance District Health Department for example, to pool their resources and staff. While the regional environmental health specialists from the NC Department of Health and Human Services conduct lead investigations for all counties, some local health departments, typically in the less populous areas, may not have a dedicated lead nurse or environmental health specialist authorized in lead. In fact, there seems to be a shortage of staff on the clinical side of lead at the county level. For a child with an elevated blood lead level, a county health department lead nurse would typically provide nutritional advice, follow-up with the child’s physician, and monitor follow-up testing, yet since most counties do not have a lead designated nurse, these steps may be falling to the wayside. Likewise, follow-up after an environmental investigation conducted by the state is often conducted at the local level, and if an environmental health specialist authorized in lead in not present, this step might not be completed. Unfortunately, this is likely the case for many of the poorer and/or less populous counties in the state.

After learning about the many factors that contribute to childhood lead poisoning and experimenting with risk mapping models, a possible next step would be to do a model building exercise with GIS to add the potential risk factors one at a time to determine goodness of fit statistically. This step will help decide which factors contribute the most to the risk mapping overall. Another possible next step would be to use similar methods, as the ones described in this paper, to create risk maps at the zip-code and census tract level. As a member of the outreach team for the NC CLPPP, the author intends to continue this mapping project at the zip-code
and/or census tract level after the completion of her graduate degree. Furthermore, additional research should be conducted to determine what strategies are being used in counties that have a low percentage of confirmed elevated blood lead levels. If the local health departments in these areas are implementing effective strategies, it would be worthwhile to communicate these strategies and methods to the counties that are suffering from high percentages of elevated blood lead levels and/or high vulnerability for risk factors.

Limitations

Several limitations were encountered while completing this project. As to be expected, a data use agreement was required to retrieve the BLL data from NC DPH, including data security and storage requirements. When the data use agreement was submitted to NC DPH, it was likely that the data was available, but it was uncertain that it could be retrieved for this project until it was approved, and the process was lengthier than expected. Likewise, since the data is referencing children’s medical data, the public version of the map cannot display housing level detail, for anonymity. Finally, the mapping goal that was proposed was extensive for a semester of work and, as mentioned in the discussion section, it is likely that the project will continue in phases past the completion of the author’s graduate degree. Given more time and resources, the author would like to include data regarding distance to Superfund and/or Brownfield sites, as well as information from the EPA Toxic Release Inventory.

Conclusion

The process that was used to create the predictive risk maps outlined in this paper provided valuable for information regarding the details needed to address childhood lead poisoning. There are many different factors that come into play when identifying areas of highest risk and it is important to take note of the interaction among the factors discussed. Using GIS and spatial analysis offers comprehensive avenues for data, especially when many factors are involved. This is because spatial analysis enables the user to overlay multiple data sets by location and explore the relationships in a visual way, while also creating an accessible map that can be used by researchers and community members. Since spatial analysis for identifying lead poisoning risk is fairly new, it is necessary to test the predictions of the GIS model by comparing the areas identified as high risk with the low risk areas.
It is also worth noting that there are additional factors that contribute to lead exposure but cannot be included in GIS mapping, for example lead tainted spices, toys, and/or medicines (Angelon-Gaetz et al., 2018). Due to the portability and uncertainty around these lead sources, their locations or even access cannot be listed in a geographical data set at this time. Therefore, while these maps can help identify areas of higher risk for lead poisoning, additional factors and resources must be considered. By identifying the vulnerable areas in North Carolina, the NC CLPPP outreach team can now provide targeted resources and efforts for prevention. Likewise, highlighting areas with higher percentages of children with confirmed elevated blood lead levels will inform the NC CLPPP on where to focus education on follow-up steps and advocate for clinical staff. In conclusion, the maps and methodology discussed in this paper will contribute to the efforts of moving to a preventative model for childhood lead poisoning, and to the reduction in the number of children with lead poisoning in North Carolina.
References


Disclaimer: The NC Department of Public Health and Human Services (DPH) does not take responsibility for the scientific validity or accuracy of methodology, results, statistical analyses, or conclusions presented.