THE RELATIONSHIP OF NEIGHBORHOOD SOCIOECONOMIC DIFFERENCES AND RACIAL RESIDENTIAL SEGREGATION TO CHILDHOOD BLOOD LEAD LEVELS IN METROPOLITAN DETROIT

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ABSTRACT

THE RELATIONSHIP OF NEIGHBORHOOD SOCIOECONOMIC DIFFERENCES AND RACIAL RESIDENTIAL SEGREGATION TO CHILDHOOD BLOOD LEAD LEVELS IN METROPOLITAN DETROIT

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Lead poisoning in children in the United States remains a persistent and prevalent environmental threat, especially for children living in central city neighborhoods. These neighborhoods typically contain disproportionately minority children of low-income families, older housing stock with a declining population, and are racially segregated. Further, recent evidence finds no safe level of lead exposure without doing irreparable neurological/ neurobehavioral and physiological damage. Pediatric blood lead level data from the Michigan Department of Community Health and socioeconomic indicators from the U.S. Census were obtained for this study. Quantitative methods were used to determine if average blood lead levels of the children in the Detroit Metropolitan Area were related to composite socioeconomic characteristics of the neighborhoods in which they live. In addition, this research estimated the effect racial residential segregation had on average blood lead levels in non-Hispanic black and non-Hispanic white children living in similar and different neighborhoods by socioeconomic characteristics. Results of bivariate regression analyses indicated that majority black neighborhoods with lower socioeconomic characteristics and high residential segregation from white neighborhoods were predictors of higher average blood lead levels of the children who lived there. Even more revealing, when black and white children resided in neighborhoods of similar socioeconomic characteristics, the black-white gap in blood lead levels disappeared. In a more in-depth difference of means investigation stratifying children by age and socioeconomic

characteristics, children living in the same neighborhood with the lowest socioeconomic characteristics negated this gap but the same was not true when children lived in neighborhoods with high socioeconomic characteristics (except for children greater than six years old). Also, when black children resided in neighborhoods of the highest socioeconomic characteristics and white children resided in neighborhoods of the lowest socioeconomic characteristics, white children's mean blood lead levels were greater than those of black children. These results have implications for public health policy.

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CHAPTER 1: INTRODUCTION

Regulations eliminating leaded gasoline, paint, and other lead-based products in the United States have reduced the prevalence of childhood lead poisoning (U.S. ATSDR, 2007). However, lead continues to be emitted from industrial processes and remains in paint and pipes of older non-rehabilitated housing. These sources of lead have caused major public health concerns especially for children who live in proximity to industrial sources and reside in older homes. Since older homes are typically located in central city neighborhoods that are racially segregated and disproportionately black or Latino and poor, minority children of low-income families are at greatest risk of lead exposure (CDC, 2005). For example, in the City of Detroit approximately 56 percent of all housing stock was built prior to 1950 (Detroit Department of Health and Wellness Promotion, 2005). The American Academy of Pediatrics (AAP) concluded in a 1998 study that although pediatric lead poisoning has declined (between 1976 and 1994), lead remains a preventable, common, but continued environmental threat especially for African American and urban children (American Academy of Pediatrics, 1998). In 1991, The Department of Health and Human Services' Strategic Plan called for the elimination of childhood lead poisoning by the year 2010 (CDC, 1991). In a nationwide 1999-2002 Center for Disease Control and Prevention (CDC) survey (CDC, 2005), children aged one to five years (n = 30,297) had the highest prevalence (1.6%) of lead poisoning (≥10 ug/dL) compared to children aged 6 to 19. They also estimated that an additional 310,000 children remained at risk for exposure to harmful lead levels in the United States. The latest 2010 national incidence of childhood lead exposure (CDC, 2012b), showed that of 4,003,420 children 0-72 months tested, 0.61 percent had lead poisoning (≥10 ug/dL) and 6.1 percent had blood lead levels (BLLs) of 5-9 ug/dL Yet, in 2012, this same population of children showed that greater than 200,000 were lead poisoned (≥10 ug/dL) nationally. This number is unquestionably much higher because generally only 15-35 percent of children <72 months are tested in the U.S. (from year to year Michigan tests approximately 30 percent of its children <72 months) and a majority (~61% in Michigan) of these children are on Medicaid. Further, the latest statement from the U.S. Environmental Protection Agency reads "….there is no demonstrated safe concentration of lead in blood…" for children ages 1-5 years (U.S. EPA, 2010; Michigan Childhood Lead Poisoning Prevention and Control Commission, 2007). At these levels any other childhood health dilemma, especially one causing permanent damage, would be treated as an urgent, national crisis. Many other recent studies have found no safe level of blood lead concentration without doing irreparable neurological/neurobehavioral and physiological damage (Schwartz, 1993; Lanphear et al., 2000; Schnaas et al., 2000; Lidsky and Schneider, 2003; Canfield et al., 2003; Chiodo, Jacobson, and Jacobson, 2004; Téllez-Rojo et al., 2006; Surkan et al., 2007; U.S. ATSDR, 2007; Miranda et al., 2007), demonstrating the importance of monitoring children's potential exposure especially among children on Medicaid and/or living in poor neighborhoods where the risk of lead exposure is greatest.

Lead exposure in children shows a pronounced linear dose-effect relationship (dosage increases yields a proportional physiological effect in the individual) between blood lead levels and this damage (Schwartz, 1993; Lanphear et al., 2000; Canfield et al,. 2003; Chiodo, Jacobson, and Jacobson, 2004; Téllez-Rojo et al., 2006; Surkan et al., 2007; and U.S. ATSDR, 2007). As a result, the CDC has changed the "level of concern" for lead poisoning several times (≥40 µg/dL in 1971, ≥30 µg/dL in 1975, ≥25 µg/dL in 1985, and ≥10 µg/dL in 1991) and as of January 2013, lowered the 10 ug/dL level of concern to ≥5 µg/dL. On January 4th, 2012, the CDC's Advisory Committee for Childhood Lead Poisoning Prevention (ACCLPP) submitted a report asking that the term “blood lead level of concern” be eliminated and that guidance be provided to respond to children with BLLs <10 ug/dL (ACCLPP, 2012). The ACCLPP recommended that a BLL reference value based on the 97.5th percentile of children 1-5 years old (5 ug/dL) be established and that children with BLLs ≥5 ug/dL be retested and provided follow-up services. The CDC stated that they would use the 5 ug/dL (1-5 year olds) level in recommendations that involve follow-up evaluations and services covered by Medicaid and all other primary health care providers (clinics/hospitals, private providers, etc.). They would not label the 5 ug/dL as the “lead poisoned” or “level of concern” reference value but as the “elevated blood lead level” (CDC, 2012a) because negative and irreversible health effects have been well established below this level. The CDC is under pressure to lower the ≥5 ug/dL level of concern and has agreed to seek additional research directed toward developing intervention capable of maintaining children’s BLLs lower than 5 ug/dL (CDC, 2012a).

Lead Poisoning and Spatial Justice

Exposure to lead poisoning is a critical environmental justice issue with racial and spatial overtones. Children most likely to be effected live in neighborhoods of very low socioeconomic status and in the oldest housing (Miranda, Dolinoy, and Galeano, 2002; Krieger et al., 2003; Bernard and McGeehin, 2003; Haley and Talbot, 2004; Oyana and Margai, 2010; Vivier et al., 2010; Kaplowitz, Perlstadt, and Post, 2010). Lead exposure is higher in blacks because of racial residential segregation in urban areas of the United States. For example, in New York State, African American children under age five were 8 times more likely to live in neighborhoods of “high risk” for lead paint hazards compared to white, non-minority children (Hanley, 2011). Further, racial residential segregation have led to one-third of African-American children to live within 36 ZIP codes identified as high risk for lead paint hazards in the state (Hanley, 2011).

These 36 ZIP codes (out of 1600) accounted for over 41 percent of children (n= 44,205) lead poisoned in the state outside of New York City (Hanely, 2011). Racial residential segregation, low socioeconomic status, older housing, and minority race are predictors of higher BLLs in children.

On two occasions, the Detroit Free Press dedicated feature news reports of the social injustice associated with lead poisoning on its central city children. The latest cover story and three-part series (Lam and Tanner-White, 2010) reported a joint study conducted by the Detroit Department of Health and Wellness Promotion and the Detroit Public Schools. The joint study, although not published, established a link between higher lead levels and poor academic performance (Lam and Tanner-White, 2010). This study reported that 60 percent of Detroit Public School students who performed below grade level on 2008 standardized tests had elevated lead levels during that same year (n = 7,255). On average, those with these higher lead levels had generally lower MEAP (Michigan Educational Assessment Program) scores and children receiving special education were more likely to be lead poisoned (>10 ug/dL) at that time.

Subsequently, Zhang et al. (2013) assessed the effect of early childhood lead exposure on long-term academic achievement of Detroit Public School children from 2008-2010. These authors linked individual blood lead surveillance data from the Detroit Department of Health and Wellness Promotion to each child's respective Detroit public school academic achievement test results in math, science, and reading (grades 3, 5, and 8). Using multivariate linear regression and controlling for grade level, gender, race, language, maternal education, and socioeconomic status, they found that children with blood lead levels >10 ug/dL before age six, were more than twice as likely (OR = 2.40, 95% CI math, 2.26 95% CI science, 2.69 95% CI reading 95% CI) to score "less than proficient" compared to those children with BLLs <1 ug/dL.

In 2003 a five-part series and cover story (Askari and Lam) run by the Detroit Free Press claimed that state and local officials mismanaged millions of dollars of lead abatement funds slated for renovation of homes containing lead paint and children. Instead the funds were allocated to renovate vacant apartments and/or one-bedroom apartments occupied by elderly people in Detroit and other Michigan cities (Askari and Lam, 2003). The series further investigated Master Metal, a battery smelter plant owned by NL Industries, who improperly operated pollution control equipment. This plant emitted illegal amounts of lead dust for two decades (Environmental Protection Agency (EPA) in Lam and Windsor, 2003) exposing 8 schools, sixteen parks, and 5,000 children under five years of age in Detroit's poor and minority east side to lead dust (Lam and Windsor, 2003) before ceasing operations in 1984. After minimal testing and cleanup by the EPA, the investigation was closed (Lam and Windsor, 2003). In response, the Detroit Free Press hired soil experts to test 97 samples up to 1.8 miles within the vacated smelter site in November of 2002 (Lam and Windsor, 2003). These experts found contamination in 10 neighborhood yard samples at levels as high as 5,811 ppm. These levels would require the EPA to initiate cleanup by its own standards of 400 ppm. These samples also exceeded many other EPA health standards (Lam and Windsor, 2003). Unfortunately, NL Industries declared bankruptcy and due to a lack of remediation funding, the neighborhoods remain contaminated today (Lam and Windsor, 2003). The Detroit Free Press also used soil technicians to test soils throughout the Metropolitan area and found dozens of soil samples containing lead levels that have triggered cleanups in many other U.S. communities (Wendland-Bowyer, 2003). However, since the national strategy for preventing lead poisoning in children is focused on lead-based paint, the soils in these communities remain contaminated (Wendland-Bowyer, 2003).

Conceptual and Theoretical Framework for Relating Neighborhood Characteristics to Childhood Blood Lead Levels

Research regarding "neighborhood effects" or the independent causal effect of a neighborhood on any number of health and social outcomes (Oakes, 2004), has a relatively long tradition. There are four basic research approaches to study neighborhood effects including concentrated poverty, social processes/mechanisms, social observation, and space-time analyses (Darden et al., 2010). This dissertation research will be conducted using the first approach within the conceptual and theoretical framework of neighborhood effects first conceptualized by Wilson's book, *The Truly Disadvantaged* of 1987. This approach studies the influence of concentrated neighborhood poverty (≥ 40 percent residents impoverished) on the creation and continued existence of a social underclass. This underclass is prevented from upward mobility because it is isolated from socioeconomic opportunities, a result of structural changes in the U.S. urban economy that undermined economic support of black communities leading to black male joblessness and fatherless families (Wilson, 1987). This phenomenon fosters increasing rates of unemployment and poverty in urban neighborhoods. Massey and Denton (1993) continued this research tradition in their book *American Apartheid* (1993). The objective of their research was to redirect the focus of the urban underclass from a culture of poverty to structural disarrange. Their supported hypothesis stated that racial residential segregation and the black ghetto are the key structural factors responsible for the perpetuation of black poverty in the U.S. More recently, Ross and Mirowsky (2008) investigated the relationship between concentrated poverty and adverse health outcomes. These authors demonstrated that within Illinois neighborhoods (n = 2,592 census tracts), socioeconomic status more significantly predicted adverse health outcomes in the form of physical impairment than individual or household socioeconomic status (regression coefficient = 0.036; $p = <0.001$). As neighborhood socioeconomic status increased, physical functioning improved (regression coefficient = 0.027; $p = <0.001$).

From 1994-1999, the U.S. Department of Housing and Urban Development enacted a program called Moving to Opportunity (MTO) partly to study what would happen to metropolitan residents living in concentrated poverty (≥40 percent in poverty) and concentrated minority race as they moved to better quality, integrated neighborhoods. A review article by Acevedo-Garcia and others (2004) evaluated housing mobility programs such as MTO and their impact on reduced health disparity. Mobility projects including the Gautreaux program (Rosenbaum and Popkin, 1990), Yonkers scattered-site public housing program (Briggs, Darden, and Aidala, 1999; Leventhal & Brooks-Gunn, 2000), Section 8 programs (U.S. Department of HUD, 2003), and the Cincinnati Spatial Mobility Program (Fischer, 1991) were also reviewed. Although none of the studies explicitly tested the mechanisms through which housing mobility programs impacted health only, their studies have found that relocation to better neighborhoods improved the residents' overall social and economic conditions as well as health.

Thus the social and economic characteristics of neighborhoods have a strong relationship between individual and neighborhood level health outcomes. The theoretical and conceptual approach summarized above will be used to capture racial and socioeconomic health disparities and more specifically disparities in average childhood BLLs by neighborhood socioeconomic position (defined below) and racial residential segregation in the Detroit Metropolitan Area (DMA). Following are this study's objectives, a review of health disparities research as it relates to neighborhood effects generally, and then a review of pediatric lead exposure research as it relates to neighborhood effects specifically.

Study Objectives and Hypotheses

The purpose of this dissertation study is twofold. The first aim is to determine if census tract average BLLs in children residing in the DMA are related to composite socioeconomic neighborhood characteristics (composite socioeconomic index). The DMA includes Wayne, Oakland, and Macomb counties. The second aim is to determine the extent of racial disparities in BLLs by census tract (herein referred to as neighborhoods) characteristics. This aim includes the estimation of the effect racial residential segregation has on mean BLLs in black and white children resulting in neighborhoods of *different* socioeconomic characteristics. In this study geometric mean (average) BLLs will be measured and reported. These aims will be explored via the following hypotheses:

1. Average pediatric BLLs will be higher in neighborhoods of lower socioeconomic characteristics and lower in neighborhoods of higher socioeconomic characteristics.

2. Non-Hispanic black children will have higher average BLLs than non-Hispanic white children in metropolitan Detroit because a higher percentage of non-Hispanic black children than non-Hispanic white children live in neighborhoods of very low neighborhood socioeconomic characteristics.

3. When non-Hispanic black and non-Hispanic white children reside in neighborhoods of similar socioeconomic characteristics, the black-white gap in geometric mean BLLs in those children decrease.

4. Where non-Hispanic black children reside in neighborhoods of very high socioeconomic characteristics and non-Hispanic white children reside in neighborhoods of very low socioeconomic characteristics, the non-Hispanic white children's mean BLLs will be greater than the mean BLLs for that of the non-Hispanic black children.

5. Depicted on maps of the DMA, higher average BLLs will be more prevalent in very low SEP neighborhoods which are located in the central city, followed by middle SEP neighborhoods which are most represented in the first suburbs (inner suburbs), and least prevalent in very high SEP neighborhoods of the outer suburbs.

CHAPTER 2: LITERATURE REVIEW

Neighborhood Effects and Health

The primary studies outlined below research health outcomes and neighborhood effect pathways as opposed to individual behaviors or genetic culpability.

Kawachi (2000) in the book *Social Epidemiology* by Berkman and Kawachi, states that area based socioeconomic inequalities research have well established the link between income inequality and health; i.e., statistically declining levels of income are directly related to declining levels of health. A fair number of cross-country studies have shown that equitable income distributions equate to reduced premature mortality and greater average life expectancies and vice versa controlling for individual level differences in those populations (Kawachi, 2000).

In the same vein, Krieger et al. (2001) compared the results of socioeconomic inequality on all cause mortality and cancer incidence. Their aim was to discover geographic inequalities of health in Massachusetts and Rhode Island. The respective Departments of Public Health provided mortality and cancer incidence data (n=370,196) within 2 years of the 1990 U.S. census. This data was geocoded to the census tract, block group, and ZIP code level. Measures of socioeconomic position (SEP) for each of these geographic areas including occupation, class, income, poverty, wealth, education, and crowding, were taken from the U.S. census. Some of these variables were combined to form indices of deprivation (Gini Coefficient, Townsend Index, Carstairs Index, and Index of Local Economic Resources). Age standardized average annual mortality rates and cancer incidence rates were stratified by area based socioeconomic measures at each level of geography. Changes in socioeconomic status for each outcome for each level of geography were calculated from 1989 to 1991 for Rhode Island and 1989 to 1992 for Massachusetts. Incidence rate ratios (IRR) were computed comparing rates for people living in areas with the least resources versus those with the most resources. The authors also calculated the relative index of inequality (RII) to compare socioeconomic change. Across all levels, the researchers found that IRR and RII were elevated in areas with lower economic resources, excluding the measure using the Gini Coefficient. Case-specific median incidence rate ratios for least versus greatest economic resources for Massachusetts at each geographic level showed that mortality due to heart disease (IRR = 1.31, 95% CI 1.32-1.35), diabetes (IRR = 1.57, 95% CI 1.54-1.67;), human immunodeficiency virus (HIV) (IRR = 3.05, 95% CI 3.25- 3.73), homicide/legal intervention (IRR = 9.26, 95% CI 10.63- 9.55), and malignant neoplasm (IRR = 1.16, 95% CI 1.12- 1.17) were associated with fewer economic resources. The findings for Rhode Island were similar to Massachusetts (Krieger et al., 2001).

A multilevel statistical analysis of neighborhood race/ethnicity and poverty heterogeneity in relationship to mortality was conducted by Subramanian et al. in 2005 in Massachusetts. The study asked what the mortality rate was like for different racial groups, the magnitude of rates for blacks versus whites, and if percent below poverty levels accounted for racial variation in mortality. Mortality, age, gender, and race data were obtained from the Massachusetts Department of Public Health from 1989-1991 and race data per census tract and block group were obtained from the 1990 U.S. Census. Mortality cases (n=142,836) were geocoded to the census tract (n = 1,307) and census block group (n = 5,532) levels. The dependent variable was the crude death rate at each level of geography. The independent variables in the multilevel models were percent deaths by gender, age, and race (white, black, and all others) for each level of geography. The percentage of the census tract or block group living below the poverty line was studied (level-2). Specifically, Model I included only the individual level characteristics of residents (level–1) of age, gender, and ethnicity nested within percent poverty at the block group level, nested within percent poverty census tracts to calculate mortality odds ratios. Model 2 was similar to Model 1 but permitted the fixed racial differential on mortality so that they varied across census tracts as the random portion to achieve differential census tract level variation in mortality for whites, blacks, and others controlling for gender and age. This was used to test the hypothesis of whether or not neighborhood level variation in mortality was different among different racial groups. Model 3, similar to Model 2, included a fixed cross level interaction among census tract level poverty and individual race controlling for gender and age. This allowed the study to determine the relationship between neighborhood poverty and individual race on mortality to an extent in which census tract level poverty could account for the census tract level racial variation in mortality, controlling for gender and race. All three level Models employed logit binomial and extrabinomial regression. Model 1 showed that mortality was greater for men than for women (OR = 1.25, 95% CI 1.11-1.41) and blacks versus whites (OR = 1.96, 95% CI 1.65-2.33); the OR for three, two-way interactions (age x race, gender x race/ethnicity, and age x gender mortality) yielded significant results between census tract variation in mortality. Model 2 found significant census tract level variation in the individual relationship between mortality and race (black versus white OR = 1.30, 95% CI 1.08-1.56). The between census tract variation in mortality was six times greater for blacks than for whites (OR = 0.52, 95% CI) suggesting that racial disparities are much greater in some neighborhoods than others. Model 3 found that census tract percent below poverty accounted for the racial heterogeneity in mortality at the census tract level. Between census tract variation in mortality from Model 2 to Model 3 (calculated using the standard error) was slightly less for whites (S.E. = 0.07, p = ≤0.001) but between census tract poverty accounted for 63 percent of the census tract level mortality variation for blacks (S.E. = 0.19, ≤0.001). The black versus white mortality odds ratio increased with increasing neighborhood percent below poverty (OR = 1.67, 95% CI 1.24 – 2.26) with 5-9.9% poverty, (OR = 2.34, 95% CI 1.76 – 3.12) with 10-19.9% poverty, (OR = 3.00, 95% CI 2.28 – 3.94) or with 20% or greater poverty (OR = 1.32, 95% CI 0.95-1.84). Subramanian et al. (2005) found that neighborhood variation in mortality was much greater for the black population than for the white population and that difference was largely due to increasing poverty rates.

To summarize, minorities, especially blacks, tend to live in impoverished, poor quality urban neighborhoods compared to whites. Thus, poverty contributes significantly to racial health disparities and declines in neighborhoods of low socioeconomic status. Poverty and low socioeconomic status are thus pathways to declines in health.

This dissertation study will build upon these neighborhood effect health studies by capturing a variety of neighborhood effect variables but within a unique composite socioeconomic index. This index will be studied in relation to a unique health outcome, average pediatric BLLs by neighborhoods in the DMA. This study will also examine changes in BLL by race and neighborhood socioeconomic index. The socioeconomic variables will be gathered from the U.S. Census at the census tract level and as mentioned previously, are surrogates for neighborhoods, common to the above referenced neighborhood effect health studies.

Residential Segregation Combined with Neighborhood Effects and Impact on Health Outcomes

Work by Polednak (1997) used literature reviews and statistical analyses to describe the epidemiology of the American apartheid. The purpose of this book, *Segregation, Poverty, and Mortality in Urban African Americans,* was to analyze the association between the degree of black-white segregation (due to discrimination in housing) and all-cause mortality rates of blacks in large urban areas. More specifically, the author used multiple regression analyses to study mortality in a selection of large metropolitan statistical areas from the late 1980s to early 1990s in the U.S. controlling for social class indicators. Polednak found a significant association between levels of residential segregation (index of dissimilarity) and black-white death rate ratios as well as black crude death rates and infant mortality rates. Data were obtained from the U.S. Census Bureau, Vital Statistics of the U.S., and the National Center of Health Statistics (Polednak, 1997).

Acevedo-Garcia and Lochner in *Neighborhoods and Health* by Berkman and Kawachi Berkman (2003) reviewed the literature on racial residential segregation and its impact on health. These authors showed that in the United States, race/ethnicity (especially African American) is more strongly correlated with residential segregation or hypersegregation than social class. Hypersegregation increased the negative effects of segregation. High poverty in these segregated cities led to lower quality/substandard housing, high unemployment, lower wages, teen pregnancy, joblessness, and higher crime rates (data not shown). Health consequence research of racially segregated areas found that urban areas with high levels of racial residential segregation experienced higher black mortality rates.

Investigating birth outcomes only, Grady (2006) sought to compare the relationship between NYC black women (n=96,882) in racially segregated neighborhoods versus racially mixed neighborhoods and the effect of these neighborhoods on low birth weight (LBW) (infants born <2,500 grams). Poverty and race data were obtained from the U.S. census for the year 2000 at the census tract level. The spatial index of isolation was used to calculate racial segregation. A value of 0 meant perfect interaction (no segregation) while 1 indicated no potential interaction (complete segregation). The dependent variable was LBW. Independent variables included individual characteristics of the mother, entered as dichotomous values (black/white, married/single, foreign/native born, college/no college, Medicaid/no Medicaid, smoke/no smoke, alcohol/no alcohol, substance abuse/non substance abuse). All of this information in addition to the mother's age was obtained from birth certificates of the NYC Department of Health and Mental Hygiene for the year 2000. Census tracts were identified to each birth/mother. In a multilevel approach, Grady's first hierarchical level of analysis used a Bernoulli binomial distribution model to estimate the effect of individual level variables on the incidence of low birth weight within and across census tracts. Results indicated that black, unmarried, no college, Medicaid, smoker, substance abuse, and native born mothers were at increased odds of having low birth weight babies. There were also statistically significant differences in low birth weights between census tracts of varying levels of racial isolation, controlling for these individual level risk factors demonstrating the importance of segregation in this study. The second Bernoulli model level measured the effect of increasing racial isolation on low birth weight, controlling for individual level risk factors and poverty. Results showed that residential isolation was significantly and positively associated with low birth weights when controlling for individual risk factors and neighborhood poverty. Residential isolation accounted for increased low birth weights across census tracts, not accounted for by neighborhood poverty alone. The third Bernoulli model level measured the effect of increasing racial isolation on the low birth weight intercept and level 1 predictor slopes. Results indicated increasing levels of racial isolation did not significantly reduce or increase individual risk factors for low birth weights. Comparing the same model to poverty, Grady found that increasing levels of neighborhood poverty significantly eliminated the black-white race effect and reduced the protective effect of being foreign born (on low birth weight incidence) controlling for local racial isolation. Overall, neighborhood poverty and racial isolation operated at different spatial scales, increasing the odds risk of low birth weight. At the neighborhood scale, racial isolation was positively significantly related to low birth weight, controlling for individual risk factors and neighborhood poverty however, at the individual level, increasing segregation did not significantly reduce the individual level risk of low birth weight. Grady's study, unlike others, demonstrated that ethnic density was not protective of low birth weights if neighborhoods were racially isolated. Racial isolation appears to induce stressors, thus lowering birth weight and offsetting advantages of ethnic density for mothers living in racially isolated neighborhoods (Grady, 2006).

Grady and Darden's purpose in a 2012 study was to elucidate the relationship between low birth weight infants and independent variables of segregation and socioeconomic position in the Detroit Metropolitan Area. Census tracts were used as surrogates for neighborhoods. These neighborhoods were reestablished and merged using automated zone matching to capture at least thirty contiguous low birth weight cases. A socioeconomic position (SEP) index (Darden-Kamel Composite Index) divided into quintiles was assigned to each zone (Darden et al., 2010). A spatial cluster index was also assigned to each zone to estimate segregation or racial clustering. A hierarchical linear regression model was used to predict the dependent variable, low birth weight via intrauterine growth restriction (IUGR) or preterm birth. Results showed low birth weight incidence to be predicted by black verses white race. This incidence decreased in both black and white infant groups with increasing SEP regardless of level of segregation. Zones of low SEP were located in highly segregated zones. The odds of IUGR and preterm births increased with black race (compared to white) controlling for individual factors such as maternal age education, and smoking. After adding high black segregation at the lowest SEP quintile, SEP was a better predictor for IUGR (OR = 1.97, 95% CI 1.85-2.10) than segregation. As SEP increased, the gap in IUGR lessoned between black and white infants (OR = 1.74, 95% CI 1.57-1.93). High black segregation and very low SEP both predicted preterm births (OR = 2.46, 95% CI 2.34-2.59). As segregation decreased and SEP increased, the gap in preterm births lessoned between black and white infants (OR = 2.12, 95% CI 1.94-2.33). The findings indicated that segregation had a stronger impact on preterm birth than SEP. Factors underlying this relationship appear to be due to institutional racism or unfair policies/practices in housing and other institutions (Grady and Darden, 2012).

The above findings suggest that black-white segregation exacerbates health disparities for blacks but that segregation alone does not sufficiently predict health disparities by race. Socioeconomic indicators of neighborhoods in which blacks and whites live are also important in determining health disparities. Many of the neighborhood effects studies summarized above found a census based approach useful in absence of individual socioeconomic data. Some of the studies found high agreement amongst indexes or composites of socioeconomic deprivation and statistical gradients in health. These composite indexes were successfully created to deal with covariance of neighborhood level variables and to supplant lacking socioeconomic data of U.S. medical records.

Race, Neighborhood Effects, and Lead Poisoning in Children

High rates of lead in children are one of the negative health effects/consequences of living in racially segregated and poor neighborhoods, also referred to as concentrated poverty. Black children living in concentrated poverty are more likely to be lead poisoned than whites, who are less likely to live in the same impoverished neighborhoods. Housing age, value, homeownership rates, and levels of rent have been shown to be significant predictors of high BLLs. In addition to race and class variables, the studies referenced below paint a broader picture of neighborhood effects. Most all of the following studies used either state or county Childhood Lead Poisoning Prevention Programs' (CLPPP) surveillance databases to obtain blood lead levels (BLLs) per child.

Haley and Talbot (2004) geographically combined and analyzed elevated BLLs (≥10 ug/dL) of New York State and New York City children born from 1994 to 1997 and less than two years of age. The sample data was obtained from New York State's Department of Public Health and included the child's ZIP code. The one time highest venous sample was used and if not available, the highest capillary sample (n = 677,112). Several socioeconomic variables were obtained by census block and census block groups from the U.S. Census and age of housing from a private demographic corporate database. Geographic information system (GIS) was used to apportion this data based on the population and location of the block centroids. The percentage of African-American children was calculated for each ZIP code using the mother's race as derived from birth certificates. ZIP codes with less than 100 children screened were merged with adjacent ZIP codes that had the closest expected percentage of elevated BLLs. The authors chose the percentage of children with elevated BLLs per ZIP code group as the dependent variable and then log transformed this variable to achieve a normal distribution and estimated the geometric mean BLL by Zip code. Independent socioeconomic variables were then applied using multiple linear regression. Results indicated that the age of housing (percent of units built before 1940), percent without high school diplomas, and percent African-American children (adjusting for mean level of education) explained an important amount of variance in elevated BLLs ($r^2 = 0.63$) in both New York city and in upstate New York. Simultaneous auto regression results indicated that the same variables were strong indicators of elevated BLLs ($r^2 = 0.52$).

In a nationwide study, Bernard and McGeehin (2003) analyzed socioeconomic and demographic characteristics of one to five year olds using BLL grouped gradients. BLL data was obtained from the Third National Health and Nutrition Examination Survey (NHANES III – 1985-1994). NHANES collected a stratified multistage sample survey of non-institutionalized children aged ≥2 months and analyzed by the CDC (National Center for Health Statistics, 1996). The sample population participated in a parent/guardian household interview including taking of a one-time venous blood sample. BLLs (n=2,529) were grouped into three categories, ≥5ug/dL to <10 ug/dL; ≥10 ug/dL to <20 ug/dL; and ≥20 ug/dL. Descriptive statistics of the study found that BLLs ≥5 ug/dL represented 46.8 percent of non-Hispanic black children, 27.9 percent of Mexican American children, and 18.7 percent of non-Hispanic white children. Non-Hispanic black children compared with non-Hispanic white children were three times more likely to have a BLL ≥5 and <10 ug/dL (OR = 13.5, 95% CI 4.7-38.5) more likely to have a BLL ≥20 ug-dL. Also 42.5 percent of children lived in pre-1946 housing, 38.9 percent of children in housing built from 1946-1973, and 14.1 percent of children in housing built after 1973 had BLLs ≥5 ug-dL demonstrating the increased odds of lead exposure with older housing. Multivariate logistic regression demonstrated that non-Hispanic black children were more likely to be in the highest BLL category (>20 ug/dL) compared to non-Hispanic white children (OR = 13.5, 95% CI 4.7-38.5). Mexican American children were more likely (OR = 2.4, 95% CI 1.4-4.2) to be in the 5-10 ug/dL group than in the <5 ug/dL but not more likely in the higher groups (i.e. BLLs >10 ug/dL) than non-Hispanic white children. Finally, children residing in housing built before 1946 were at significantly higher odds of elevated BLLs in all ethnic groups. Children residing in housing built between 1946 and 1973 were (OR = 2.2, 95% CI 1.3-3.8) more likely than children in newer housing to have BLLs ≥5ug/dL but not more likely to have BLLs ≥10 ug/dL (OR = 0.9, 95% CI 1.7-3.9).

As part of a broader *Public Health Disparities Geocoding Project*, Krieger et al. (2003) screened resident children 1-5 years in Rhode Island between 1994 and 1996 (n = 62,514). Pediatric BLLs were geocoded to the home of residence and spatially joined to the census tract, block group and ZIP code. Eight measures of SEP were used to establish and index of economic deprivation for each level of analysis from the 1990 U.S. Census. The proportion of children screened who had high lead concentrations (≥ 10 ug/dL) were calculated by individual SEP variables and quintiles of socioeconomic indices, all stratified into each level of geography. Calculating odds ratios, the authors found that impoverished (percent below poverty) children were at increased odds of elevated pediatric BLLs at both census tract (OR = 9.49, 95% CI 8.50-10.60) and block group (OR = 7.94, 95% CI 7.17-8.80) areal units, significantly more so than other socioeconomic measures (occupation, education, wealth) or indices. In other words, the authors showed that the "percentage of persons living below poverty" performed as well as a predictor of BLLs as more complex composite measures of economic deprivation. Finally, census tracts were just as predictive as block groups in revealing BLLs. Zip codes were not as predictive. Those living in census tracts (OR = 6.70, 95% CI 5.83-7.69), block groups (OR = 6.02, 95% CI 5.34-6.80), and ZIP codes (OR = 5.01, 95% CI 4.25-5.92) with ≥27 percent pre 1950 housing also had significantly increased odds of blood lead concentrations. Combined with poverty, the pre 1950 housing effect was more than additive (OR = 14.19, 95% CI 12.25-16.43).

Oyana and Margai (2010) obtained BLL data (n = 263,486) by address in the city of Chicago for the years 1997, 2000, and 2003. These addresses were aggregated by community area and neighborhoods (census tracts, census blocks, and census block groups). The authors calculated the predicted prevalence rates by census tract (number of children with elevated BLLs divided by either the sample population or population aged zero to 5) using optimal interpolation kriging with associated Best Linear Unbiased Estimator. A local indicator of spatial association (LISA) statistic was applied to the kriged prevalence rates to plot hotspot clusters of elevated BLLs (≥10ug/dL) of children. Also, profiles of high-risk census tracts were created based on U.S. Census housing age and socioeconomic composition factors via discriminant analysis. The LISA statistics identifying hot spots were superimposed onto this census geography of the county. Discriminant analysis of the housing age and socioeconomic factors for the hotspots found that median household income was the number one predictor of elevated BLLs followed by housing age (constructed before 1950) and minority race (black then Latino and then Asian) (Oyana and Margai, 2010). Although analyzing only "poisoned" lead reports, these researchers incorporated housing age, race, and income into their study and found significant relationships between these neighborhood characteristics and elevated pediatric BLLs.

A statewide study of Rhode Island pediatric BLLs was conducted in 2010 (Vivier et al.) for children up to 72 months from 1993-2005. Addresses were geocoded to residential addresses and spatially joined to census block groups. The study population was then reduced to the proportion of children who were lead poisoned (BLL ≥10 ug/dL) and organized in quintiles of census block groups by their sociodemographic characteristics of block groups (pre-1950 housing and percent of persons below poverty) were obtained from the 2000 Census and also organized into quintiles. A total of 204,746 children within 808 census block groups were included in a multivariate analysis. The relationship between lead poisoning was significantly associated with the highest quintile of poverty (OR = 5.05, 95% CI 4.84-5.26) and the highest quintile of pre-1950 housing (OR = 4.90, 95% CI 4.69-5.12) and decreased in a step wise manner from there.

Kaplowitz, Perlstadt, and Post (2010) assessed pediatric BLLs in relation to sociodemographic characteristics (from 1998-2001 and 2002-2005) for the State of Michigan. The highest venous or capillary BLL result from the MDCH's database (children 0-5) was analyzed. These BLLs were log transformed to achieve homogeneity of variance. Self reported race was missing for up to 36 percent of the cases. As a result, the authors used U.S. Census data to assume that children living in block groups with less than 10 percent African Americans were non-black and assumed that children living in block groups with more than 90 percent African Americans to be black (justified based on high segregation rates). The study employed hierarchical linear modeling to estimate lead poisoning risk, treated as a continuous variable, within the entire state. By comparing the proportion of variability of BLL explained by block group, census tract, and ZIP code (all nominal variables) the study found that census block groups explained more of the dependent variable (R^2 = 0.352 for 1998-2001 and R^2 = 0.278 for 2002-2005; $p<0.00$) BLL than did census tracts (0.300 and 0.236) and ZIP codes (0.302 and 0.242). Dichotomizing ZIP codes into high versus low risk did not explain as much of the BLL variance (0.107 and 0.076). For each block group, incomes were grouped as percentages below the federal poverty level (FPL) and those block groups with the lowest incomes (<185% FPL) had the greatest bivariate association with BLL (R^2 = 0.377 for 1998-2001 and R^2 = 0.212 for 2002-2005; $p<0.00$). Also, the proportion of houses built prior to 1940 (R^2 = 0.808 and 0.694; $p<0.00$) and black populations as calculated above (R^2 = 0.414 and 0.400; $p<0.00$) were significantly associated with higher BLLs. As age increased (1, 2, 3, 4, 5 years), predicted BLLs decreased with declining R^2 respectively. The proportion of rental housing did not explain a significant amount of variance with BLL ($R^2 = 0.05$; $p<0.00$) for both sets of years.

In an historical work, Markowitz and Rosner (2013) utilized over 200 scientific and historical pieces to expose the public health tragedy of childhood lead poisoning in the United States. The lead industry, complicit in knowledge of its many dangers as early as 1914, protected profits via marketing campaigns manufacturing doubt about the science of lead poisoning. The report summarizes that campaign contributions and political pressure were used at the expense of long term neurological damage to children. Poor minority neighborhoods consisting of older housing, had and have the highest lead poisoning risk. Throughout history the lead problem has led to civil disobedience in cities across the country especially in the 1970s. Once the lead industry faced the inevitable regulatory requirement to eliminate lead in paint (1978) and gasoline (1996), they successfully abrogated economic responsibility of a U.S. lead paint abatement plan; remediation costs of approximately 28 million dwelling units would cost them up to 35 billion dollars. Importantly, the lead industry marketed paint poisoning as a problem of the “slums” and “ignorant” “Negro and Puerto Rican families” demonstrating that racism was prevalent amongst these industrial leaders. Since lead poisoning is non-contagious and symptoms are not obvious and immediate, there would be no political constituency for reform. As a result, a public health epidemic by any definition of the word continues.

Summary and Significance of this Study in Understanding Pediatric BLLs

Past research suggests that childhood lead exposure is greater among black children than other racial and ethnic groups and also associated with poverty. Neighborhoods with higher median household incomes, newer housing, and greater housing values were significantly protective of elevated pediatric BLLs. These studies however, do not examine the relationship between lead poisoning and racial residential segregation to better understand the racial disparities in elevated blood lead among black children. Additionally, studying children of different races who live in similar socioeconomic neighborhoods to determine if the BLL gap still exists, has yet to be addressed and will be investigated in this dissertation study.

A majority of the lead studies relied upon state/county Childhood Lead Poisoning Prevention Programs' (CLPPP) databases as their source of BLL data. The CLPPP disproportionately tests those on Medicaid because this population historically has above average lead poisoning risk. This method introduces colinearity when measuring socioeconomic characteristics such as percent race, area-level income, and housing age and has been commented upon as a weakness in several studies. Although colinearity between race, segregation, and SEP may also be a weakness in this dissertation research, the problem will be addressed to some extent by using five years of BLL data, capturing an increased number of non-Medicaid children (and granted, more Medicaid children as well). However, Michigan tests BLLs of approximately 90 percent of all children by the time they turn the age of six, ensuring that non-Medicaid children are represented as well. Another weakness of previous studies is the lack of a longitudinal follow-up in children. However, pediatric BLLs peak at age two in which case, following children from one address to another may be counterproductive. This dissertation study will include BLL tests over five years, capturing all reported children tested in the DMA.

Finally, many of the lead studies compiled pediatric BLLs into percentiles, reducing possible fluctuation that may be gained from continuous values or means. This study will take continuous pediatric BLLs and convert them into geometric mean BLLs at the census tract level.

CHAPTER 3: STUDY AREA

In terms of academic research, the Detroit Metropolitan Area historically and most recently includes three counties; Macomb, Oakland and Wayne (Darden et al., 1987; Farley, Danzinger, and Holzer, 2000; Darden et al., 2010). This metropolitan area houses predominately poor blacks in the central city of Wayne County (Detroit) and more affluent whites in the suburbs of Macomb and Oakland counties (Darden et al., 1987; Farley, Danzinger, and Holzer, 2000; Darden et al., 2010) (Figure 7). Census tracts will be used as the level of analysis in this study because this areal unit was found to successfully capture sociodemographic characteristics of a neighborhood at a small scale (Krieger et al., 2003; Darden et al., 2010) while also consistently capturing socioeconomic gradients in health (Grady, 2006; Subramanian et al., 2005). Because medical records in the U.S. lack information on the socioeconomic status of patients, census tract socioeconomic data provides researchers a quantitative way to best represent these characteristics and their relationship to disparities in health (Krieger, 2006). They have also provided a stable estimate of health risk and social interactions compared to block groups because they contain on average 4,000 individuals (Krieger, 2006). The body of health disparity research suggests that ecological fallacy (making inferences about individuals at the ecological scale i.e. counties, cities) is overcome by estimating socioeconomic gradients to the census tract and have adequately represented individual-level socioeconomic measures in previous studies (Krieger, 2006). Other studies have found block groups to better capture social concentration effects of social characteristics although this has not been the case for cancer, mortality, and lead poisoning studies. Consensus has not been reached regarding which level of analysis to be used (block groups or tracts) so for these reasons, social scientists and epidemiologists have used census tracts as proxy for neighborhoods with quantitative success

(Krieger, 2006). For purpose of this research, census tracts were most useful because of the expanse of data available and the ability to map spatial distribution of socioeconomic characteristics.

CHAPTER 4: DATA

Pediatric Lead Data

The Michigan Department of Community Health's (MDCH) Childhood Lead Poisoning Prevention Program has established a statewide surveillance data warehouse (State of Michigan, 2004; Michigan Childhood Lead Poisoning Prevention and Control Commission, 2007). The MDCH's charge is to collect BLL tests from children who are at above-average risk for lead exposure; those enrolled in Medicaid. The MDCH also collects BLL tests from non-Medicaid children. All Michigan Medicaid enrolled children are required to be blood lead tested at 12 and 24 months of age or between 36 and 72 months of age if not previously tested at the earlier ages. In addition, any healthcare workers performing BLL tests on non-Medicaid children (~20% per given year) in the state must send the results to the MDCH (MDCH, 2013; State of Michigan 2004; Michigan Childhood Lead Poisoning Prevention and Control Commission, 2007). The MDCH collects these Medicaid and non-Medicaid BLL results and has maintained them in the Childhood Lead Poisoning Prevention Program Statewide Database since January of 1998 (Michigan Childhood Lead Poisoning Prevention and Control Commission, 2007; State of Michigan, 2004). This BLL data are individual records reported in ug/dL. If additional follow-up BLL tests were required of the same individual, only the highest value result was obtained for each case child. These data were assigned census tract identifiers along with other variables described below.

Between 2006 and 2010 there were 277,676 children, aged less than one month to 16 years, who were BLL tested in the DMA. The BLL samples and reports were submitted from clinics, hospitals, private providers, etc. to laboratories for analysis and then to the MDCH and made available to this study. Of these 277,676 case reports, 8,391 records did not have census tract identifiers leaving 269,285 records for subsequent analyses. Then an additional 53,184 records were eliminated from the dataset because they lacked appropriate composite socioeconomic index (CSI) values described below. This left a total of 216,101 records in which to test hypothesis one and five (See Figure 1)

From 2006-2010, the BLL tests were collected from a small number of portable blood lead test units that had detection limits of 3.3 ug/dL while most of the laboratory units were able to detect 1.0 ug/dL or less. (Given that detection limit information is not linked/available to the BLL report, a query of 3.0 ug/dL readings yielded 38,258 (14%) reports, a potential indication of the number of BLL reports obtained from this population of less accurate units). As a result, the health department coded all non-detect values (0.0 ug/dL) and any BLL value below 1.0 and up to 1.4 ug/dL, as 1.0 ug/dL. Otherwise, all other test results were rounded to the nearest whole number by the MDCH. The “level of concern” was 10 ug/dL (it has since been lowered to 5 ug/dL) for the entire data collection period.

The MDCH receives BLL tests from the laboratories identifying the case child by name and address, sex, birth date, Medicaid recipient status, and self-reported race/ethnicity. This data was obtained from the MDCH for the years 2006 to 2010. The child was assigned an ID and addresses were geocoded by the MDCH to the accompanying census year 2010 census tract.

Although not investigated in this dissertation, sex of the child could be important because it may determine the level of lead exposure risk due to differences in behavior such as chewing or playing outdoors (male (0), female (1), no-report (blank)). Of the 269,285 case BLL reports, 1,547 (0.06%) were missing a sex designation but were not removed from the analyses. These missing data are dispersed fairly evenly across census tracts of all three counties.

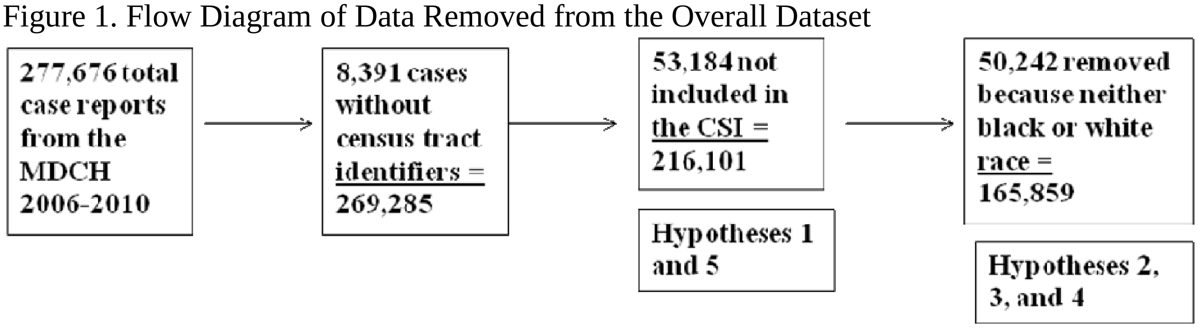
The birth date report rate was 100 percent and this date was converted to age in months as a continuous variable. Children ages 0-16 were entered into the database. A large majority were less than 6 years-old and by the time Michigan children are of age six, approximately 90 percent have been tested at least once and entered into the database, year dependent (MDCH, 2013). Controlling for age is important to this study as children typically produce the highest BLLs at age two as a result of hand-to-mouth behavior and playing on floors (U.S. ATSDR, 2007). Further, blood lead tests reveal fairly current exposure conditions at the time of testing because blood lead travels to the soft tissues and organs where it is stored only for a period of weeks. It is expelled later either though urine/feces or travels to teeth and bones for long-term storage (U.S. ATSDR, 2007).

Racial and ethnic groups included non-Hispanic black or African American (1), non-Hispanic white (2), Hispanic (3), Native Hawaiian or other Pacific Islander (4), Asian (5), Arab (6), American Indian or Native Alaskan (7), mixed race (8), and no-report (9). The MDCH finds that patients' parents report race approximately 50 percent of the time (MDCH, 2013) and most Arab parents do not report race, resulting in a "no-report" designation. If Hispanic and another race were both reported, the child was coded as Hispanic. Importantly, the MDCH linked the BLL reports on children with Medicaid to their Medicaid case records to achieve an 80-90 percent complete report on race in the database, year dependent. In total there were 34,984 cases (16.19%) entered as "no-report" on race. These no-reports were not eliminated from the dataset to test the first and fifth hypotheses. These 34,984 records with missing race data and an additional 15,258 cases that were Hispanic, Asian, etc. however, were removed from the dataset to test hypotheses two, three, and four. This left 165,859 records encompassing only non-Hispanic black and non-Hispanic white race designations.

The MDCH reports BLLs for both capillary (0) and venous (1) methods of blood draw, the later being more accurate because capillary tests may become more easily contaminated by fingertips. If an elevated BLL presented in the first capillary test (≥10 ug/dL during year of this study), the child was administered a second venous test and only this new venous BLL was entered, overriding the capillary result. If the test result was above the level of concern, follow-up tests were provided to the child on varying time tables depending on the blood lead concentration. The database manager provided only one test result for each child for the entire 2006-2010 period.

All of the proper non-disclosure data use agreement forms were approved to gain BLL data from the MDCH. Mr. Robert Scott of the MDCH BLL testing program is the database manager for the state and provided children's BLL information and the aforementioned variables in the DMA for the years 2006-2010. Michigan State University's Institutional Review Board has issued an exempt status, IRB# A41941039, for this work.

Figure 1. Flow Diagram of Data Removed from the Overall Dataset



Neighborhood Data

There were 1,162 DMA census tracts mapped and used in the initial analysis of this study while 1,046 DMA census tracts were used for later analyses. The census 2010 tract boundaries were used in this study. The U.S. Bureau of the Census, American Community Survey provides data per census tract on a variety of socioeconomic variables such as percent below poverty, unemployment rate, median household income, percent of occupied households with vehicle, percent management/business/science/arts occupations, percent of residents with bachelor degrees or higher, median value of occupied dwelling in dollars, median gross rent of occupied dwelling in dollars, and percent homeownership, female head of occupied household, housing age variables, etc. for the DMA (U.S. Bureau of the Census, 2010). The 5-year (2006-2010) estimate data of these variables was used in analyses with corresponding years of BLL data. Geographies of census tracts of the five years of blood lead data provided by the MDCH achieve a 100 percent match rate with the Census Bureau's census geography for the 5-year estimate data.

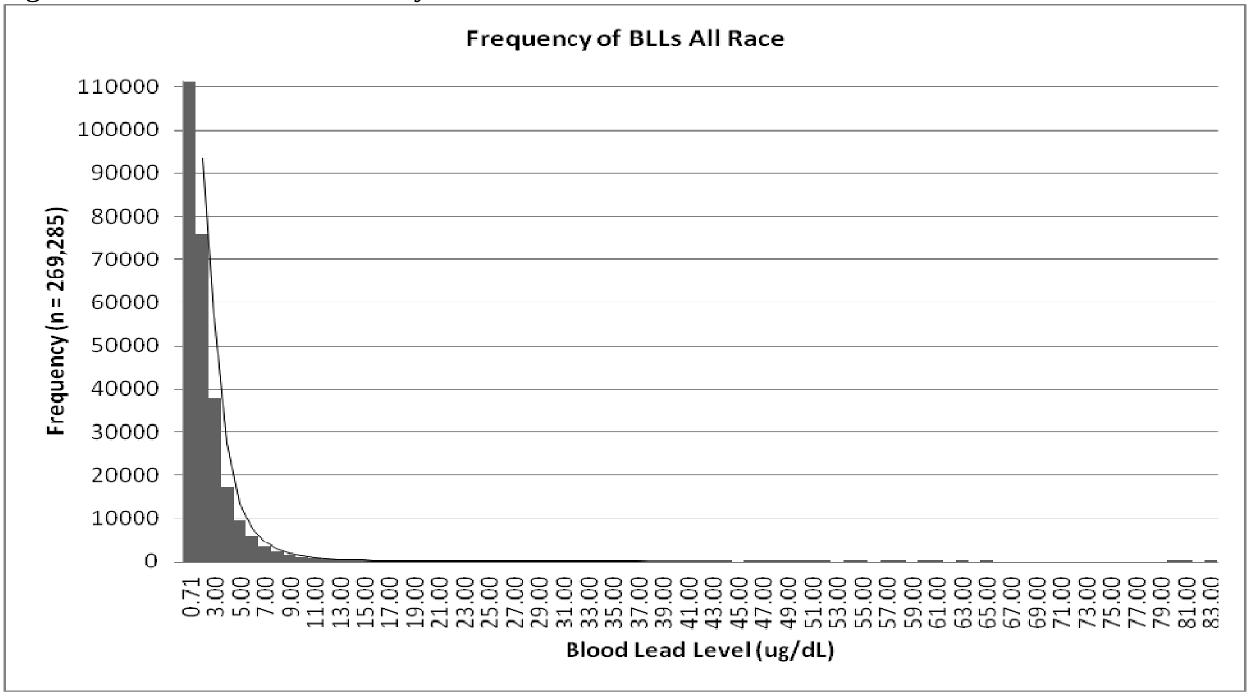
CHAPTER 5: METHODS

Blood Lead Level Data

Blood lead level testing prevalence by the MDCH was calculated for those children less than one month to two years old. Prevalence was calculated as the proportion of children blood lead tested divided by the 2010 5-year estimate census childhood population as a whole per census tract. The “In Households 0 to Less Than 3 Years Old” category (U.S. Bureau of the Census, 2010 (Table BO9001)) was used for the three counties during 2006-2010. This excluded group quarters (college residence halls, residential treatment centers, skilled nursing facilities, group homes, military barracks, correctional facilities, and workers’ dormitories) populations. This has little impact on the prevalence testing calculations because for the entire state of Michigan from 2006-2010, group quarters consisted of only one percent of the population of children less than 16 years old (U.S. Bureau of the Census, 2010 Table S2601A).

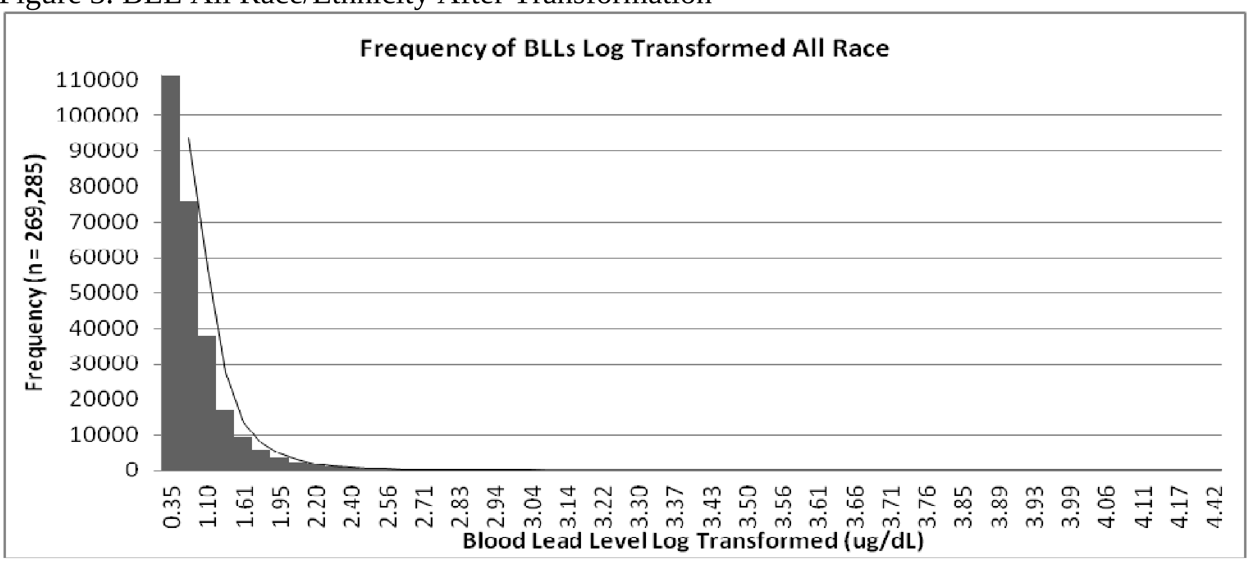
Blood lead levels obtained by the MDCH described above were first transformed. Methodological guidance by the Department of Health and Human Services, Centers for Disease Control and Prevention (2009) recommends dividing those concentrations that could be less than the limit of detection by the square root of two for eventual calculation of geometric means. In this study the detection limits were not available therefore, those records that did not meet the detection limit were coded as 1.0 ug/dL by the testing laboratories. To account for the large number of 1.0 ug/dL (n = 91,104; 42.16%) BLLs in the dataset, these 1.0 test results were first divided by the square root of two as recommended above and then log-transformed prior to performing subsequent analyses. All analyses required aggregation of the BLLs at the census tract level. As such, the arithmetic means of the transformed BLLs were first calculated and then they were exponentiated to provide a geometric mean for meaningful analyses. For example, a 1 ug/dL BLL result was divided by the square root of two to equal 0.707106781. These values along with all other BLL reports greater than one were log-transformed. The arithmetic means of these log-transformed values were calculated per census tract and then exponentiated, resulting in a geometric mean per census tract. Geometric means provide a better estimate of the central tendency of blood lead distribution, which tends to have a long upper end distribution and is influenced less by high values than is the arithmetic mean (Department of Health and Human Services, CDC, 2009). See Figures 2 and 3 below depicting histograms of the individual BLL data before and after log transformation. Log transformation yielded a slightly less skewed distribution of BLLs.

Figure 2. BLL All Race/Ethnicity Before Transformation



Source: MDCH 2006-2010

Figure 3. BLL All Race/Ethnicity After Transformation



Source: MDCH 2006-2010

Socioeconomic Position: The Darden-Kamel Composite Index of Area-Based Measures

This study utilized area-based indicators of socioeconomic position applied as proxy for individual level measures of socioeconomic position. The composite socioeconomic index (CSI) is defined based on the summation of nine census characteristics of neighborhoods of residence as follows:

1. Percent below poverty – the percent of all families whose income in the past 12 months is below the U.S. poverty level. The poverty thresholds vary depending on size of family, number of related children, and, for 1- and 2-person families, age of householder by the Bureau of the Census.
2. Unemployment rate – the percent of civilian sixteen years and older who were neither at work nor with a job but not at work during the reference week and who were actively seeking work during the last 4 weeks and available to start a job.
3. Median household income – the median income of all family members sixteen years and older including those without income.
4. Percent of households with vehicle – percent of occupied households with a vehicle available will be calculated.
5. Percent of residents with management, business, science, and arts occupations – percent of workers sixteen years and older that hold one of 194 positions codified by the U.S. Bureau of the Census for 2006-2010 five year estimates.

6. Percent of residents with bachelor degrees or higher – percent of the total population 25 years and older that holds at least a bachelor's degree (for example four or more years of schooling beyond a high school education).
7. Median value of dwelling in dollars – the median value of owner-occupied housing which is the respondent's estimate of how much the property would sell for.
8. Median gross rent of dwelling in dollars – the contract rent value plus the estimated average monthly cost of utilities.
9. Percent homeownership – percent of owner-occupied housing units regardless of mortgage status.

To standardize the contribution of each census variables included in the index, a Z-score was created for each of the nine census tract variables by subtracting the mean from the grand mean for the DMA and dividing by the standard deviation of the respective variables for the DMA as a whole. To insure that each variable contributed appropriately when calculating this index, the Z-scores for two depreciating variables, percent unemployment and percent of the population below poverty, were multiplied by -1 before they were added to the remainder variables so that they contributed appropriately to the area based socioeconomic characteristics (Darden et al., 2010). The formula for the index follows:

$$\mathrm{CSI_i} = \sum_{j=1}^{k} \frac{V_{ij} - V_{jDMA}}{S(V_{jDMA})}$$

$\mathrm{CSI_i}$ = the composite socioeconomic Z-score index for census tract *i*, is the sum of Z-scores for the socioeconomic status variables *j*, relative to the DMA's socioeconomic status.

DMA = three counties Wayne, Oakland, and Macomb.
k = the number of variables in the index
V_{ij} = the *j*th socioeconomic position variable (Z-score) for a given census tract *i*
V_{jDMA} = mean of the *j*th variable in the three county DMA
$S(V_{jDMA})$ = standard deviation of the jth variable in the three county DMA

For hypotheses two, three (part two and three), four, and five the resultant indexes were sorted and divided into quintiles of socioeconomic position (SEP) to create the Modified Darden-Kamel Composite Index for the DMA from 2006-2010 (Darden et al., 2010). This allowed for a division of DMA census tracts of residence into approximately equal proportions in each socioeconomic status, i.e. very high socioeconomic position (VHSEP), high socioeconomic position (HSEP), middle socioeconomic position (MSEP), low socioeconomic position (LSEP), or very low socioeconomic position (VLSEP).

Using the CSIs (summed Z-scores of each of the 9 above variables) and/or their subsequent SEP quintiles required removal of 116 census tracts from the population above, providing a total of 1046 (originally 1162) census tracts. Census tracts were excluded from the index if the Census Bureau's 5-year estimates yielded fewer than 100 people, housed only juvenile institutions, or had Arab or Hispanic populations consisting of more than 10 percent of the census tract population. In 2010, census tracts reporting more than 10 percent of the population as Arab or Hispanic race or ethnicity via the census were excluded from analyses because this study mainly compared non-Hispanic black and non-Hispanic white populations given that there were too few members of other groups available for analyses. This left an individual sample size of 216,101 children and their BLLs as described above and in Figure 1.

Because lead poisoning in children is due primarily to environmental conditions of the child's residence with the most significant source being chips, dust, and soil incorporated with lead based paint used in and on housing structures (U.S. ATSDR, 1988; U.S. ATSDR, 2007;

U.S. Department of HUD, 2003) and to ensure that the appropriate variables were used in predicting lead exposure to children, principle components analysis (PCA) was used not only to look within the Darden-Kamel index but also outside this index. An additional seventeen variables outside this index and suspected to inform lead exposure risk through direct exposure or an underlying socioeconomic condition, were added to the PCA analysis.

CHAPTER 6: DESCRIPTIVE STATISTICS AND PCA RESULTS

The MDCH census tract boundaries were derived from the 2010 census and all (100%) BLL reports with census tract identifiers were coded to those 2010 census boundaries (n = 1,162). There were 213 census tracts within Macomb County, 337 in Oakland County, and 612 in Wayne County. Frequencies were generated on demographic characteristics of the children tested and the characteristics of their BLL reports used to test the hypotheses. These frequencies are described below. Census tracts with a frequency of less than 20 cases tended to be the same across characteristics due to low numbers of children living there. Analyses were performed using SYSTAT 13.1 (Systat Software Inc., a subsidiary of Cranes Software International Ltd., 2009).

The BLL proportion prevalence range for Oakland county was 0 - 7.67 children (six census tracts equaled 0), Macomb 0 - 2.17 children (one census tract equaled 0), and Wayne 0.02 – 10.88 children. The following descriptive data were generated for this study. See Table 1 for a summary of these findings.

Sex

There were 110,788 (51.54%) male and 104,181 (48.46%) female case BLL reports. There were 8 (0.76%) and 9 (0.86%) census tracts with less than 20 males and females respectively.

Age

At the time of BLL testing, children’s birth dates were recorded and also rounded to age in months. Additional data management transferred these ages into years and age categories. The number of children aged less than one month to two years equaled 101,617 (47.02 %). Those aged over two and up to 6 years encompassed 88,260 (40.84%) children and those greater than 6 and up to 16 years consisted of 26,224 (12.14 %) children. The frequency of BLL tests in children aged less than one month to two years old yielded 7 census tracts (0.67%) with fewer than 20 reports compared to children 2.1 to 6 years, yielding 73 census tracts with fewer than 20 cases (6.98%). Those children greater than 6 years comprised 561 census tracts (53.63%) with fewer than 20 reports. (The MDCH's emphasis is to test children once and before the age of two). Children aged older than 6 and up to 16 years yielded 594 (51.12%) census tracts with fewer than 20 reports.

Race/Ethnicity

The following lists the MDCH's coded self-reported race for the children tested and provides the racial composition of the test population: Non-Hispanic black or African Americans 97,344 (53.75%) children, non-Hispanic whites 68,515 (37.83%) children, Hispanics 5,408 (2.99%) children, Native Hawaiian or other Pacific Islanders 99 (0.05%) children, Asians 4,701 (2.60%) children, Arabs 3,887 (2.15%) children, American Indian or Native Alaskans 569 (0.31%) children, and mixed races 594 (0.33%) children. Non-Hispanic black cases yielded 518 (49.52%) census tracts with fewer than 20 case reports and non-Hispanic whites had 303 (28.97%) census tracts with fewer than 20. All other tracts had 20 or greater case reports.

BLL Collection Method

There were 45,202 (21.07%) and 169,365 (78.93%) children who were BLL tested using the capillary and venous methods respectively. As stated above, if an elevated BLL presented in the first capillary test (≥10 ug/dL during the years covering this study), the child was administered a second venous test and only this new venous BLL was entered, overriding the capillary result. The frequency of the capillary blood collection method was less than the intravenous collection method. The capillary and venous methods yielded 221 (21.13%) and 21 (2.01%) census tracts housing fewer than 20 cases.

Insurance Coverage

Medicaid tested cases equaled 153,890 (71.21%) and non-Medicaid cases 62,211 (28.79%) children. All cases (100%) were coded as either having Medicaid (1) or some other non-Medicaid insurance type (0). There were 46 (4.40%) non-Medicaid and 66 (6.31%) Medicaid cases with fewer than 20 cases per census tract.

BLL Test Dates

During the five year period from 2006-2010, the greatest frequency of tests occurred during the month of August (n = 26,699; 12.35%) and least during the month of December (n = 12,578; 5.82%). Tests were administered throughout all four seasons.

PCA

Results indicated that eight of the nine Darden-Kamel Index variables had the highest degree of shared and orthogonal shared variance, confirming the strength of this index and its component variables.[1]

[1]Median household income, median dwelling value, percent households with a vehicle, percent with a bachelor's degree or higher, percent in management, business, science, or art, and percent homeownership exhibited shared variance and orthogonal to equally weighted variables of percent below poverty and unemployment rate. Percent renter, not included in the Darden-Kamel Index, was exactly opposite to percent owner (included in the index). Proportion female head of household and percent housing lacking complete plumbing were the tenth and eleventh ranked variables not included in the index. Female head of household, an indicator of poverty in the social science literature, and percent housing lacking complete plumbing, a potential sign of old, lead-based piping and/or lack of dwelling renovation were considered for integration in the Darden-Kamel Index. Then again, female head of household and percent below poverty variables are likely redundant and component loadings of the latter more strongly varied with the other index variables. Similarly, risk of lead exposure that may be captured by the lack of complete plumbing variable is likely encompassed within the other socioeconomic variables that associate to a greater degree. Median gross rent, included in the Darden-Kamel index, followed this progression weighted close in value to the plumbing variable. The remaining variables such as children on Medicaid, race, housing age by rental or owner designation, etc. shared even less variance with the socioeconomic indicator variables of the Darden-Kamel Index. In all, this analysis confirmed the strength of the socioeconomic variables used in the Darden-Kamel Index.

Table 1. Demographic Characteristics of Children BLL Tested and the Characteristics of their BLL[†] Reports Across CSIs

Variables	n	% of Reported	n Census Tracts <20 Case Reports	Mean of Reported	Standard Deviation of Reported
Sex				0.49	0.50
Male (0)	110,788	51.54	8 (0.76%)		
Female (1)	104,181	48.46	9 (0.86%)		
No Report	1,132				
Total	216,101		17 (1.63%)		
Age*				38.89 months	34.31 months
0 – 2	101,617	47.02	7 (0.67%)		
2.1 – 6	88,260	40.84	73 (6.98%)		
>6	26,224	12.14	561 (53.63%)		
Total	216,101		641 (61.28%)		
Race/Ethnicity					2.88
Non-Hispanic Black	97,344	53.75	518 (49.52%)		
Non-Hispanic White	68,515	37.83	303 (28.97%)		
Hispanic	5,408	2.99			
Native Hawaiian or other Pacific Islander	99	0.05			
Asian	4,701	2.60			
Arab	3,887	2.15			
American Indian or Native Alaskan	569	0.31			
Mixed Race	594	0.33			
No Report	34,984				
Total	216,101				
Blood Collection Method				0.79	0.41
Capillary (0)	45,202	21.07	221 (21.13%)		
Intravenous (1)	169,365	78.93	21 (2.01%)		
No Report	1,534				
Total	216,101		242 (23.14%)		
1.0 ug/dL Reports	91,104	42.16			
Reports > 1.0 ug/dL	124,997	57.84			
Total	216,101				
Insurance Coverage				0.71	0.45
Non-Medicaid	62,211	28.79	46 (4.40%)		
Medicaid	153,890	71.21	66 (6.31%)		
Total	216,101		112 (10.71%)		

Table 1. (cont'd)

BLL Test Month 2006 -2010					
January	16,848	7.80			
February	14,773	6.84			
March	17,971	8.32			
April	16,864	7.80			
May	16,750	7.75			
June	16,785	7.78			
July	18,083	8.37			
August	26,699	12.35			
September	24,425	11.30			
October	19,256	8.91			
November	15,069	6.97			
December	12,578	5.82			
Total	216,101				

†Geometric Mean BLL = 1.0 *Range = 191 months

Source: MDCH 2006-2010

In subsequent analyses and the second aim of this dissertation (hypotheses 2, 3, and 4), removal of all children of a race/ethnicity other than non-Hispanic white or non-Hispanic black, left a total individual sample size of 165,859 children, their census tracts, and BLLs (see Figure 1). Frequencies were generated of the non-Hispanic black and white children tested across these five quintiles as depicted in Table 2 below. Of the 1046 census tracts, 209 to 210 fell into each of one of the five SEP quintiles. Across all quintiles there was a range of 4 to 1036, mean of 159, and standard deviation of 121 children per census tract. Eighteen tracts had less than 20 children. In general there were a mean 207 children (range 6 to 1169) and standard deviation equal to 140 children per census tract. Only one tract included in this analysis had less than 20 children.

Table 2. Demographic Characteristics of non-Hispanic Black and non-Hispanic White DMA Children Tested and the Characteristics of their BLL† Reports Across SEP Quintiles

Variables	n (%)					n Census Tracts <20 Case Reports (% of total, all census tracts)				
Quintile	1	2	3	4	5	1	2	3	4	5
Sex										
Male	30,656 (50.76)	21,676 (51.32)	14,287 (51.67)	10,870 (52.20)	7,277 (52.18)	1 (0.00)	4 (0.02)	7 (0.05)	12 (0.11)	51 (0.70)
Female	29,740 (49.24)	20,561 (48.68)	13,366 (48.33)	9,953 (47.80)	6,668 (47.82)	0 (0.00)	4 (0.02)	8 (0.06)	19 (0.19)	62 (0.93)
Total	60,396	42,237	27,653	20,823	13,945	1 (0.00)	9 (0.02)	15 (0.05)	31 (0.15)	113 (0.81)
Age										
0 – 2	24,411 (40.14)	19.401 (45.69)	14,251 (51.49)	11,217 (53.73)	7,598 (54.34)	1 (0.00)	1 (0.00)	6 (0.04)	6 (0.05)	43 (0.57)
2.1 – 6	27,531 (45.27)	18,019 (42.44)	10,723 (38.68)	7,690 (36.83)	4,928 (35.25)	3 (0.01)	3 (0.02)	22 (0.21)	22 (0.29)	111 (2.25)
>6	8,872 (14.59)	5,041 (11.87)	2,751 (9.92)	1,970 (9.44)	1,456 (10.41)	31 (0.35)	30 (0.60)	170 (6.18)	170 (8.63)	194 (13.32)
Total	60,814	42,461	27,725	20,877	13,982					
Race/Ethnicity										
Non-Hispanic Black	56,863 (93.50)	26,397 (62.17)	7,670 (27.66)	4,167 (19.96)	2,247 (16.07)	1 (0.00)	46 (0.17)	114 (1.49)	155 (3.72)	177 (7.88)
Non-Hispanic White	3,951 (6.50)	16,064 (37.83)	20,056 (72.34)	16,710 (80.04)	11,735 (83.93)	173 (4.38)	72 (0.45)	10 (0.05)	15 (0.09)	23 (0.20)
Total	60,814	42,461	27,725	20,877	13,982					
Blood Collection Method										
Capillary	7,758 (12.79)	8,241 (19.54)	7,175 (26.12)	5,779 (28.02)	4,053 (29.27)	60 (0.77)	44 (0.53)	61 (0.85)	91 1.57)(	97 (2.39)
Intravenous	52,913 (87.21)	33,935 (80.46)	20,290 (73.88)	14,844 (71.98)	9,793 (70.73)	0 (0.00)	3 (0.00)	2 (0.01)	9 (0.06)	9 (0.09)
Total	60,671	42,176	27,465	20,623	13,846					
1.0 ug/dL Reports	13,620 (20.13)	17,781 (26.28)	15,372 (22.72)	12,371 (18.28)	8,514 (12.58)					
Insurance Coverage										
Non-Medicaid	2,222 (3.65)	4,416 (10.40)	6,101 (22.01)	6,696 (32.07)	6,604 (47.23)	60 (2.70)	44 (1.00)	61 (1.00)	96 (1.43)	124 (1.88)
Medicaid	58,592 (96.35)	38,045 (89.60)	21,624 (78.00)	14,181 (67.93)	7,378 (52.77)	0 (0.00)	3 (0.01)	2 (0.01)	9 (0.06)	35 (0.47)
Total	60,814	42,461	27,725	20,877	13,982					
BLL Test Month 2006 - 2010										
January	5,093 (8.37)	3,215 (7.57)	2,081 (7.51)	1,559 (7.47)	1,076 (7.70)					
February	4,233 (6.96)	3,051 (7.19)	1,835 (6.62)	1,458 (6.98)	915 (6.54)					
March	5,337 (8.78)	3,517 (8.28)	2,233 (8.05)	1,727 (8.27)	1,137 (8.13)					
April	4,720 (7.76)	3,251 (7.66)	2,200 (7.94)	1,621 (7.76)	1,128 (8.07)					
May	4,697 (7.72)	3,228 (7.60)	2,154 (7.77)	1,707 (8.18)	1,024 (7.32)					
June	4,321 (7.11)	3,256 (7.67)	2,278 (8.22)	1,670 (8.00)	1,180 (8.44)					
July	4,694 (7.72)	3,531 (8.32)	2,413 (8.70)	1,785 (8.55)	1,221 (8.73)					
August	7,271 (11.96)	5,357 (12.62)	3,512 (12.67)	2,534 (12.14)	1,733 (12.39)					
September	7,418 (12.20)	4,921 (11.59)	2,997 (10.81)	2,202 (10.55)	1,489 (10.65)					
October	5,584 (9.18)	3,765 (8.87)	2,426 (8.75)	1,830 (8.77)	1,149 (8.22)					
November	4,142 (6.81)	2,945 (6.94)	1,971 (7.11)	1,497 (7.17)	1,005 (7.19)					
December	3,304 (5.43)	2,424 (5.71)	1,625 (5.86)	1,287 (6.16)	925 (6.62)					
Total	60,814	42,461	27,725	20,877	13,982					

n=165,859

Source: MDCH 2006-2010

CHAPTER 7: HYPOTHESES RESULTS

Hypothesis 1. All Race BLL and CSI Results

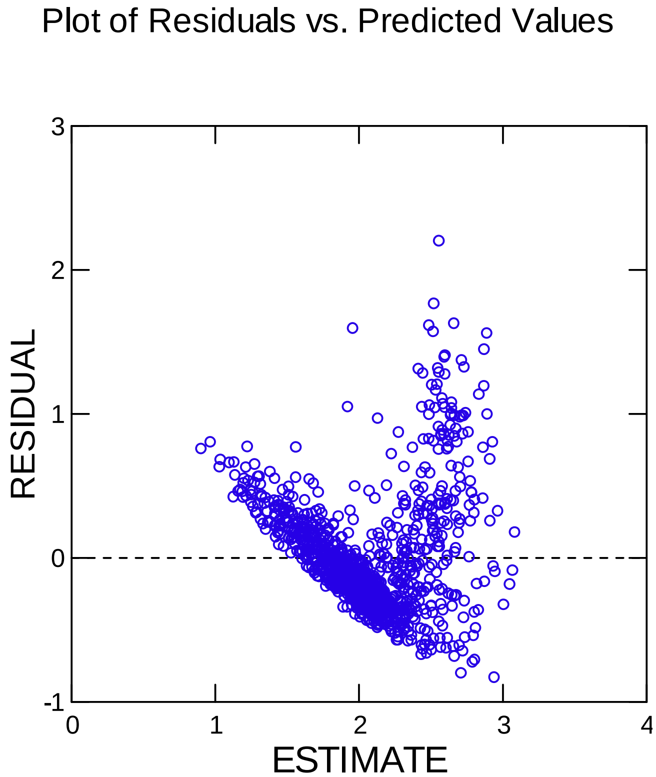
Average pediatric BLLs will be higher in neighborhoods of lower socioeconomic characteristics and lower in neighborhoods of higher socioeconomic characteristics.

Bivariate regression analysis was used to test if the association between very low socioeconomic position and geometric mean pediatric BLLs were significantly different from zero by census tracts of the DMA. The geometric mean BLLs were associated with CSI values.

$$\text{Geometric Mean BLL by Census Tract} = \underset{(0.012)}{2.06} + \underset{(0.002)}{-0.05 * \text{CSI}}$$

A regression slope coefficient estimate of -0.05 (p = 0.000; S.E. = 0.002) indicates that for every unit increase in CSI, mean BLL decreases by 0.05 units across the DMA. In other words, those children living in neighborhoods of decreasing quality are at significantly higher risk of elevated BLLs. The y-intercept estimate from the analysis was 2.06 with a correlation coefficient of -0.68. Plots of residual frequency by estimated BLLs indicate a skewed pattern of errors around the model intercept of 2.06 (see Figure 4). Therefore, unexplained variation between neighborhood geometric mean BLL remains, after controlling for CSI. Importantly, upon mapping the positive and negative extreme residuals, their spatial patterns appear to be associated with average housing age by census tract and are explored in more detail in hypothesis five.

Figure 4. Plot of Residual Versus Predicted Values. Geometric Mean BLLs, 2006-2010



Source: U.S. Bureau of the Census, 2010 and MDCH 2006-2010

Hypothesis 2. Racial Residential Segregation and BLLs Results

Non-Hispanic black children will have higher average BLLs than non-Hispanic white children in metropolitan Detroit because a higher percentage of non-Hispanic black children than non-Hispanic white children live in neighborhoods of very low neighborhood socioeconomic characteristics.

The index of dissimilarity was used to compute the level of racial unevenness by SEP between non-Hispanic black and non-Hispanic white children of dissimilar neighborhood characteristics. The five quintiles of SEP clustered census tracts and their children as depicted in the following equation:

$$D = \left(1/2\sum_{i=1}^{k}[x_i - y_i]\right)$$

k = 1 of 5 quintiles of SEP as clustered census tracts within the DMA
x_i = percent of DMA's total reported non-Hispanic black children in the *i*th SEP
y_i = percent of the DMA's total reported non-Hispanic white children in the same SEP
D = half of the sum of the absolute differences between the proportional distribution of the black and white children within the DMA.

The resultant values represented the minimum percentage of children from either non-Hispanic black or non-Hispanic white race/ethnicity that would have to move from one SEP cluster to another to achieve an even spatial distribution across the DMA (Darden, Tabachneck, and Raine, 1980).

The Darden-Kamel Index assigns a higher score to tracts with higher SEP. The mean socioeconomic characteristics within SEP quintiles are presented in Table 3. Frequencies were generated of the children tested across the 9 CSI characteristics per census tract. Neighborhoods of very low SEP had the highest unemployment rates and those living below poverty. Median household income was only $23,999, average dwelling value $79,621, and median gross rent

$730. Homeownership, vehicle ownership, professional/managerial occupations, and education levels were the lowest values. Conversely, neighborhoods of very high SEP had the lowest unemployment rates and those living below poverty. Median household income was $98,228, average dwelling value $290,870, and median gross rent $1,294. Homeownership, vehicle ownership, professional/managerial occupations, and education levels were the highest values.

Table 3. The Mean Social Structure of DMA's Census Tracts from 2006-2010 Based on the Modified Darden-Kamel Composite Socioeconomic Index

Neighborhood SEP Quintile	% Below Poverty	% Unemployment Rate	Median Household Income ($)	% Households with a Vehicle	% Residents with Mgmt., Business, Science, Arts, Occupations	% Residents with Bachelor Degrees or Higher	Median Dwelling Value ($)	Median Gross Rent ($)	% Homeownership
Very Low SEP (Quintile 1)	37.06	29.01	23,999	72.58	17.59	8.75	79,621	730	46.23
Low SEP (Quintile 2)	14.63	16.42	40,013	89.46	25.51	15.10	108,309	782	64.36
Middle SEP (Quintile 3)	7.00	11.45	52,244	94.40	31.56	22.15	146,355	838	76.63
High SEP (Quintile 4)	4.18	8.97	65,582	95.93	41.52	32.86	182,102	748	81.69
Very High SEP (Quintile 5)	2.33	7.05	98,228	97.86	54.80	53.77	290,870	1,294	89.26
All Tracts	13.03	14.57	56,054	90.05	34.22	26.55	160,927	914	71.65

n = 165,859 children c.t.n. = 1046 census tracts (209 to 210 each for each level of SEP)
Source: Computed by author from data obtained from the U.S. Bureau of the Census, 2010

To provide perspective on the disparity between black and white children's BLLs, Table 4 displays their respective geometric mean BLLs, standard deviations, and percent populations at each level of SEP. A difference of means test between black and white children's BLLs at each level of SEP will be performed in hypothesis three below. In all levels of socioeconomic position, black children had higher average BLLs than white children. Black children BLL reports were greater and over represented in the very low and low SEP neighborhoods and white children BLL reports were lesser and overrepresented in the middle, high, and very high SEP neighborhoods. Importantly, children of black race had higher predicted geometric mean BLLs across all neighborhood SEP levels. Considering the DMA as a whole, D = 56.32 demonstrating that 56.32 percent of either black or white children with reported BLLs would have to move from one SEP cluster to another to achieve an even spatial distribution across census tracts in the DMA. The higher BLLs presented in children was related to the neighborhoods in which they lived. If black children lived in higher SEP neighborhoods, their collective BLLs were lower. Black children residing in very high SEP neighborhoods had lower geometric mean BLLs than white children residing in very low SEP neighborhoods. Regardless of the socioeconomic position quintile employed, black and white children were extremely segregated i.e. unevenly distributed across neighborhood SEP levels.

Table 4. Descriptive Characteristics of Children by Geometric Mean BLLs and Total Population and the Darden-Kamel Index of SEP in Metropolitan Detroit, 2006-2010

SEP Quintiles	Non-Hispanic White and non-Hispanic Black Children's Geometric Mean BLLs (ug/dL) and Standard Deviation per SEP Quintile				Percent of Tested Population	Difference in Percent of Total Population x-y
Very Low SEP (Quintile 1)		n (%)	Mean	S.D.		52.65 [52.65]
	White	3,951 (6.50)	2.74	1.32	5.77	
	Black	56,863 (93.50)	2.95	0.69	58.41	
Low SEP (Quintile 2)		n (%)	Mean	S.D.		3.67 [3.67]
	White	16,064 (37.83)	1.95	0.35	23.45	
	Black	26,397 (62.17)	2.10	0.31	27.11	
Middle SEP (Quintile 3)		n (%)	Mean	S.D.		-21.39 [21.39]
	White	20,055 (72.34)	1.80	0.25	29.27	
	Black	7,670 (27.66)	2.00	0.69	7.88	
High SEP (Quintile 4)		n (%)	Mean	S.D.		-20.11 [20.11]
	White	16,710 (80.04)	1.78	0.26	24.39	
	Black	4,167 (19.96)	1.92	0.41	4.28	
Very High SEP (Quintile 5)		n (%)	Mean	S.D.		-14.82 [14.82]
	White	11,735 (83.93)	1.73	0.15	17.13	
	Black	2,247 (16.07)	1.94	0.49	2.31	
All SEP		n (%)	Mean	S.D.		Index of Dissimilarity 56.32
	White	68,515 (41.31)	1.94	0.58	41.31	
	Black	97,344 (58.69)	2.11	0.53	58.69	

n = 165,859 children c.t.n. = 1,046 census tracts (209 to 210 each for each SEP)

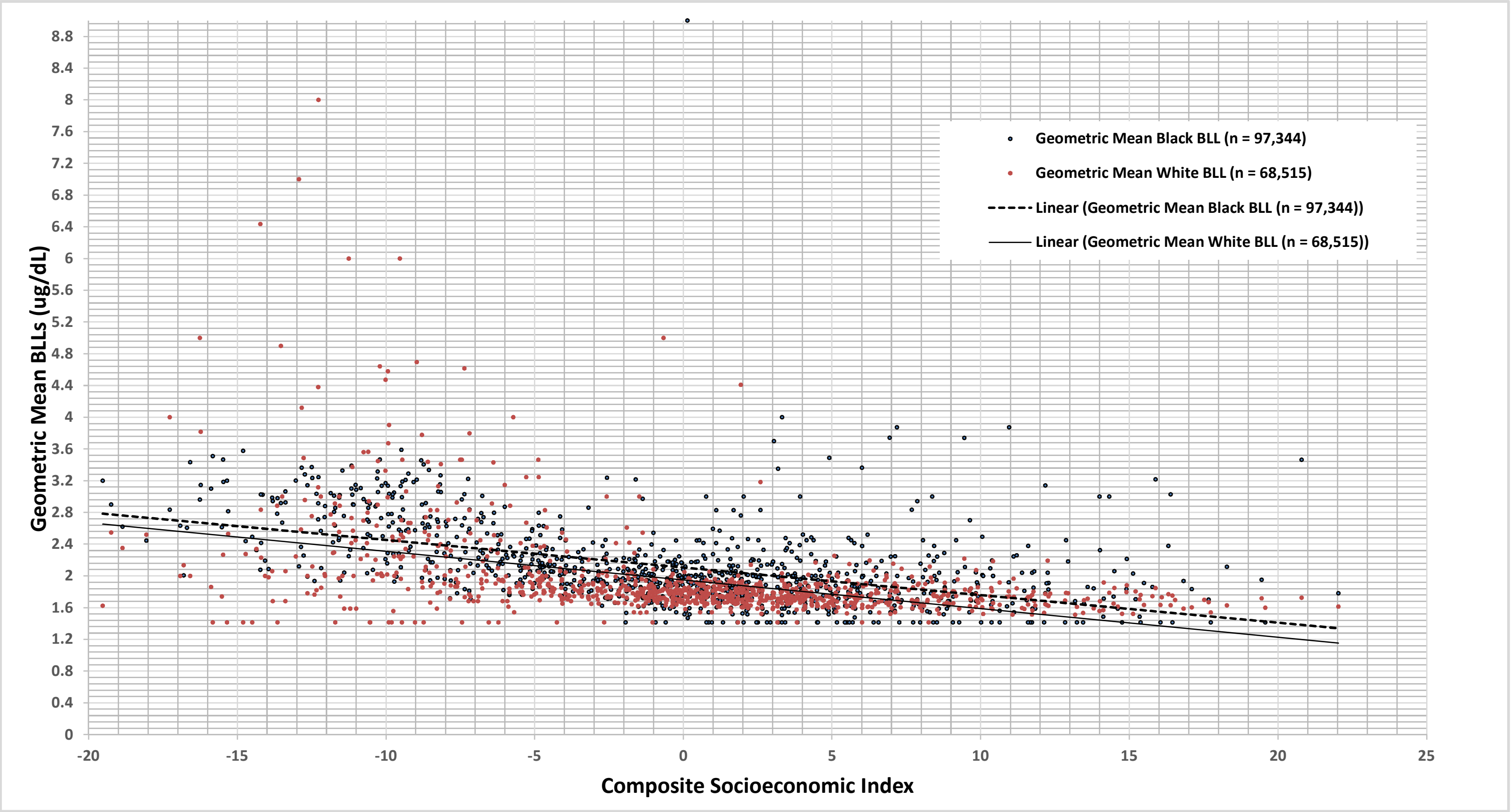
Source: Computed by author from data obtained from the U.S. Bureau of the Census, 2010 and MDCH 2006-2010

Hypothesis 3. Black-White BLL and CSI Part One Results

When non-Hispanic black and non-Hispanic white children reside in neighborhoods of similar socioeconomic characteristics, the black-white gap in geometric mean BLLs in those children decrease.

The following methods were employed to test this hypothesis. First, in a descriptive analysis, geometric mean BLLs of black and white children were plotted separately against the CSI for each census tract of residence in the DMA. Interestingly, Figure 5 below clearly displays the similar slopes of the two regression lines for both races as the hypothesis predicts. An increase in CSI yields similar decreases in BLLs for black and white children. The difference in these slopes will be tested for statistical significance in part two. However more interestingly, mean BLLs for black children are at least approximately 0.2 units higher than mean BLLs for white children across all CSI levels and this difference (in y-intercepts) appears to be magnified as the slopes approach greater levels of SEP (greater CSI). This second phenomenon will be quantified in part three of this hypothesis and summarized on Table 5.

Figure 5. CSI and Geometric Mean BLLs, 2006-2010



Source: U.S. Bureau of the Census, 2010 and MDCH 2006-2010

Hypothesis 3. Black-White BLL and CSI Part Two Results

Bivariate regression analysis was used to quantitatively estimate the effect of CSI of residence, stratified by black and white children's geometric mean BLLs. Geometric mean BLLs for black and white children in the DMA for years 2006-2010 were estimated by census tract and CSI levels.

$$\text{Geometric Mean BLL Black Race by Census Tract} = \underset{(0.015)}{2.11} + \underset{(0.002)}{-0.035*CSI}$$

$$\text{Geometric Mean BLL White Race by Census Tract} = \underset{(0.016)}{1.95} + \underset{(0.002)}{-0.036*CSI}$$

$$S_{\bar{x}_1} \text{-} S_{\bar{x}_2} = \sqrt{S_{\bar{x}_1}^2 + S_{\bar{x}_2}^2 - 2rS_{\bar{x}_1}S_{\bar{x}_2}}$$

S = standard error
$\bar{x}_1$= non-Hispanic black group
$\bar{x}_2$= non-Hispanic white group
r = correlation between the two samples

The regression coefficients derived from this analysis showed the predicted mean BLLs for black and white children by CSI census tract level. Regression slope coefficient estimates of -0.035 (p = 0.000; S.E. = 0.002) and -0.036 (p = 0.000; S.E. = 0.002) indicates that CSI explains a small but significant and similar variation between black children's and white children's geometric mean BLLs in neighborhoods across the DMA. For every unit increase in CSI, mean BLLs decrease by 0.035 units for black and 0.036 for white children. The y-intercept estimates for the above equations were 2.11 and 1.95 respectively. Subsequently, in an attempt to test the hypothesis and verify the similar slope appearance of Figure 5, the standard error of the difference between means was measured (Runyon and Harber, 1980). This method was used to test the hypothesis and examine the slopes of Figure 5 by examining the difference in the two significant regression coefficients of the bivariate analysis outlined above. The standard error of correlated samples was 0.0028 which did not indicate a significant difference between mean BLLs for black and white children ($z = 0.35$; $p = 0.72$). This demonstrates that increasing CSI levels in neighborhoods have similar effects on reducing the BLLs of black and white children alike while also confirming the appearance of the black and white slopes of Figure 5, part one above.

Hypothesis 3. Black-White BLL and CSI Part Three Results

In addition, differences of means tests were utilized to examine black-white BLLs within neighborhoods of each level of SEP and to further investigate the apparent increasing gap in BLLs of black and white children within increasing CSI depicted in Figure 5, part one. In this analysis, black and white differences of geometric mean BLLs were measured within the very high, high, middle, low, and very low SEP neighborhoods. All analyses stratified children by age group as a control measure.

$$t=[(\bar{x}_1 - \bar{x}_2) - d]/SE$$

t = the difference between black and white mean BLL two sample t-test
$\bar{x}_1$ = the geometric mean BLL for white children in the *i*th SEP
$\bar{x}_2$ = the geometric mean BLL for black children in the *i*th SEP
d = null hypothesized difference between child means in the *i*th SEP
SE = standard error in the *i*th SEP

Table 5 displays the differences in mean BLLs for black and white children at each SEP level. For children 0-2 years old, the black-white differences in mean BLL were significantly different in low, medium, high, and very high SEP neighborhoods versus neighborhoods of very low SEP; these differences in mean BLL were not significantly different from each other. Similarly, for children 2.1-6 years old, the black-white differences in mean BLL were significantly different in low, medium, high, and very high SEP neighborhoods versus neighborhoods of very low SEP; these differences in mean BLL were not significantly different. For children greater than 6 years old, the black-white differences in mean BLLs were significantly different in low, medium, and high SEP neighborhoods versus neighborhoods of very low and very high SEP; these differences in mean BLL were not significantly different. To summarize, black and white children in all age groups living in the very low SEP had the same mean BLLs ($t = 0.91$; $p = 0.36$ and $t = 0.85$; $p = 0.39$ and $t=0.83$; $p = 0.41$). Black and white children greater than 6 years old living very high SEP neighborhoods also had the same mean BLLs ($t = 1.92$; $p = 0.06$). Black children living in all other levels of SEP (low, medium, and high), regardless of age, had significantly greater mean BLLs than white children. The mean differences in black-white BLLs for children aged 0–2 and 2.1-6 years increased as SEP levels improved. Black-white BLL disparity in children greater than 6 years old increased from SEP one to SEP two but then decreased from there. Younger children are more likely to inhale and ingest lead because they play on floors and exhibit hand-to-mouth behavior, breathing and eating more lead laden dust than adults or older children (U.S. ATSDR, 2007). Perhaps the oldest age group is showing a reduced gap in black-white mean BLLs because the older children are no longer exhibiting these behaviors, reducing their exposure to lead laden dust.

Table 5. Differences Between Mean BLLs for Black and White Children by SEP Quintile Stratified by Age Group, Detroit Metropolitan Area 2006-2010

Group	Census Tract n	Children n	BLL Mean	S.D.	t-test	p-value
SEP 1 Age 0-2						
Black	208	22,610	2.90	0.69	0.91	0.362
White	168	1,801	2.76	1.79		
SEP 2 Age 0-2						
Black	207	11,219	2.13	0.40	2.40	0.017
White	204	8,182	1.99	0.73		
SEP 3 Age 0-2						
Black	200	3,469	2.00	0.64	3.23	0.001
White	208	10,782	1.83	0.33		
SEP 4 Age 0-2						
Black	189	1,977	1.94	0.48	4.49	0.000
White	208	9,240	1.77	0.20		
SEP 5 Age 0-2						
Black	170	1,011	1.98	0.75	4.10	0.000
White	209	6,587	1.74	0.16		
SEP 1 Age 2.1-6						
Black	209	25,589	3.23	0.86	0.85	0.394
White	163	1,687	3.07	2.25		
SEP 2 Age 2.1-6						
Black	208	11,756	2.20	0.69	2.62	0.009
White	193	6,142	2.02	0.64		
SEP 3 Age 2.1-6						
Black	196	3,242	2.10	1.30	3.42	0.001
White	206	7,398	1.79	0.15		
SEP 4 Age 2.1-6						
Black	175	1,720	2.03	0.81	3.74	0.000
White	205	5,894	1.79	0.29		
SEP 5 Age 2.1-6						
Black	169	956	2.07	0.68	5.61	0.000
White	210	3,923	1.76	0.23		
SEP 1 Age >6						
Black	209	8,664	2.42	0.47	0.83	0.41
White	113	463	2.55	1.64		
SEP 2 Age >6						
Black	189	3,422	1.93	0.43	4.91	0.000
White	167	1,740	1.74	0.29		
SEP 3 Age >6						
Black	154	959	1.85	0.62	3.02	0.003
White	203	1,875	1.69	0.25		
SEP 4 Age >6						
Black	117	470	1.93	0.93	2.12	0.036
White	203	1,576	1.73	0.43		
SEP 5 Age >6						
Black	931	280	1.85	0.82	1.92	0.057
White	96	1,225	1.68	0.34		

n = 165,859 children c.t.n. = 1046 census tracts

Source: Computed by author from data obtained from the U.S. Bureau of the Census, 2010 and MDCH 2006-2010

In an attempt to explain greater disparity in black-white BLLs of younger children (0-2 and 2.1 – 6 years) in high and very high SEP neighborhoods, two of the greatest ranked positive residual values of black children's BLLs in both SEP four and five neighborhoods were examined. The greatest SEP four black BLL residual was located in Livonia City, Wayne County (census tract 557200). Aerial examination of this tract indicates a lack of industry, roadways, etc. that may pose an external environmental lead risk for houses in this neighborhood. There are older farmhouses intermixed with newer subdivision housing. Overall, 82 percent of all housing in this census tract was built before 1969, posing potential exposure to lead paint (banned in 1978). This housing stock is on average older than the typical high SEP neighborhood housing stock and the oldest housing may be resident to the only two black children BLL tested in this neighborhood (n = 30). Confirmation of this hypothesis via census data would be ideal but this information is not available at the census tract level and to draw any conclusions based on this sample size would be erroneous.

The second greatest SEP four black BLL residual is located in Trenton City, Wayne County (census tract #594300). Upon aerial examination of this census tract, one mile to the southeast is the Detroit Edison coal burning plant, a definite contributor to atmospheric lead. Perhaps the six black children's homes are located closer to this facility (n = 89). Also, 69 percent of this subdivision's housing was built from 1950-1959.

The greatest SEP five black BLL residual is located in Troy City, Oakland County (census tract #196300). Bordering this census tract to the southwest is highway 75, a possible legacy contributor of roadside lead dust (leaded gasoline was not banned until 1996). This tract contains mainly new housing but four percent of the housing stock was built in 1939 or earlier. Again, small four percent may be resident to the only two black children tested in this neighborhood (n = 33) but again, this sample size is too small to make any conclusions about residual causes.

The second greatest black BLL residual value lies in Birmingham City of Oakland County (census tract #152600) but again only two black children BLL tested resided here (n = 54). Bordering this tract to the east is Woodward Avenue (State Highway 1) another possible roadside lead contributor. Also, most of its housing was built before 1939 (34%) and much of it before 1969 (75%). This is just a sampling of residuals and possible explanations to the black-white BLL disparity that increases with SEP four and five neighborhoods but inconclusive without further investigation and larger sample sizes. The next hypothesis compares mean BLLs across race and levels of SEP.

Hypothesis 4. Black-White BLLs across CSI Results

Where non-Hispanic black children reside in neighborhoods of very high socioeconomic characteristics and non-Hispanic white children reside in neighborhoods of very low socioeconomic characteristics, the non-Hispanic white children's mean BLLs will be greater than the mean BLLs for that of the non-Hispanic black children.

Differences of means tests were utilized to examine black-white BLLs across different levels of neighborhood SEP. In this analysis, differences of geometric mean BLLs of black children living in very high SEP neighborhoods were compared to white children living in very low SEP neighborhoods of the DMA, stratified for age.

Table 6 presents the differences of mean BLLs for black children living in very high SEP neighborhoods and white children living in the very low SEP neighborhoods. For all children, the mean BLLs were significantly different from each other with whites having the greater mean BLLs across all age groups. Those white children aged 2.1-6 years old experienced the greatest disparity in mean BLLs compared to black children ($t = -5.48$; $p = 0.00$). The results indicate that the socioeconomic position of neighborhoods matter in addition to race.

Table 6. Differences Between Mean BLLs for Black and White Children Across SEP Quintile Stratified by Age Groups, Detroit Metropolitan Area, 2006-2010

Group	Census Tract n	Children n	BLL Mean	S.D.	t-test	p-value
Age 0-2						
Black Children SEP 5	168	1,011	1.97	0.76	-5.28	0.000
White Children SEP 1	168	1,801	2.76	1.79		
Age 2.1-6						
Black Children SEP 5	169	956	2.07	0.68	-5.48	0.000
White Children SEP 1	163	1,687	3.07	2.25		
Age >6						
Black Children SEP 5	92	280	1.82	0.79	-4.21	0.000
White Children SEP 1	112	463	2.56	1.64		

Source: Computed by author from data obtained from the U.S. Bureau of the Census, 2010 and MDCH 2006-2010

Given all of these results, housing age was investigated in hypothesis five as a possible contributing factor to unexplained variation and residual BLL results. Generally, housing age is related to SEP of neighborhoods with the oldest housing stock concentrated in the poorest (very low SEP) neighborhoods of the central city. For decades and in most part today, a duel model of development within the DMA between the central city and suburbs has transpired. Increasing population, tax base, economic development, jobs and housing investment dollars and loans have been made available to the inner and outer suburban ring. At the same time, public policy allowed the central city to decline in population, tax base, economic development, jobs, and property valuation with increasing housing loan restrictions and discrimination even for renovation (Darden et al, 1987). Aside from historically renovated homes located within wealthy suburban neighborhoods (SEP 4 and 5), greatest pediatric mean BLLs may be related to this pattern of concentrated aging housing stock of the central city. Housing age is captured in part by measures of median value of dwelling, median gross rent, and percent homeownership embedded within the Darden-Kamel Index, but more thorough examination of this variable is presented below.

Hypothesis 5. Map Results

Depicted on maps of the DMA, higher average BLLs will be more prevalent in very low SEP neighborhoods which are located in the central city, followed by middle SEP neighborhoods which are most represented in the first suburbs (inner suburbs), and least prevalent in very high SEP neighborhoods of the outer suburbs.

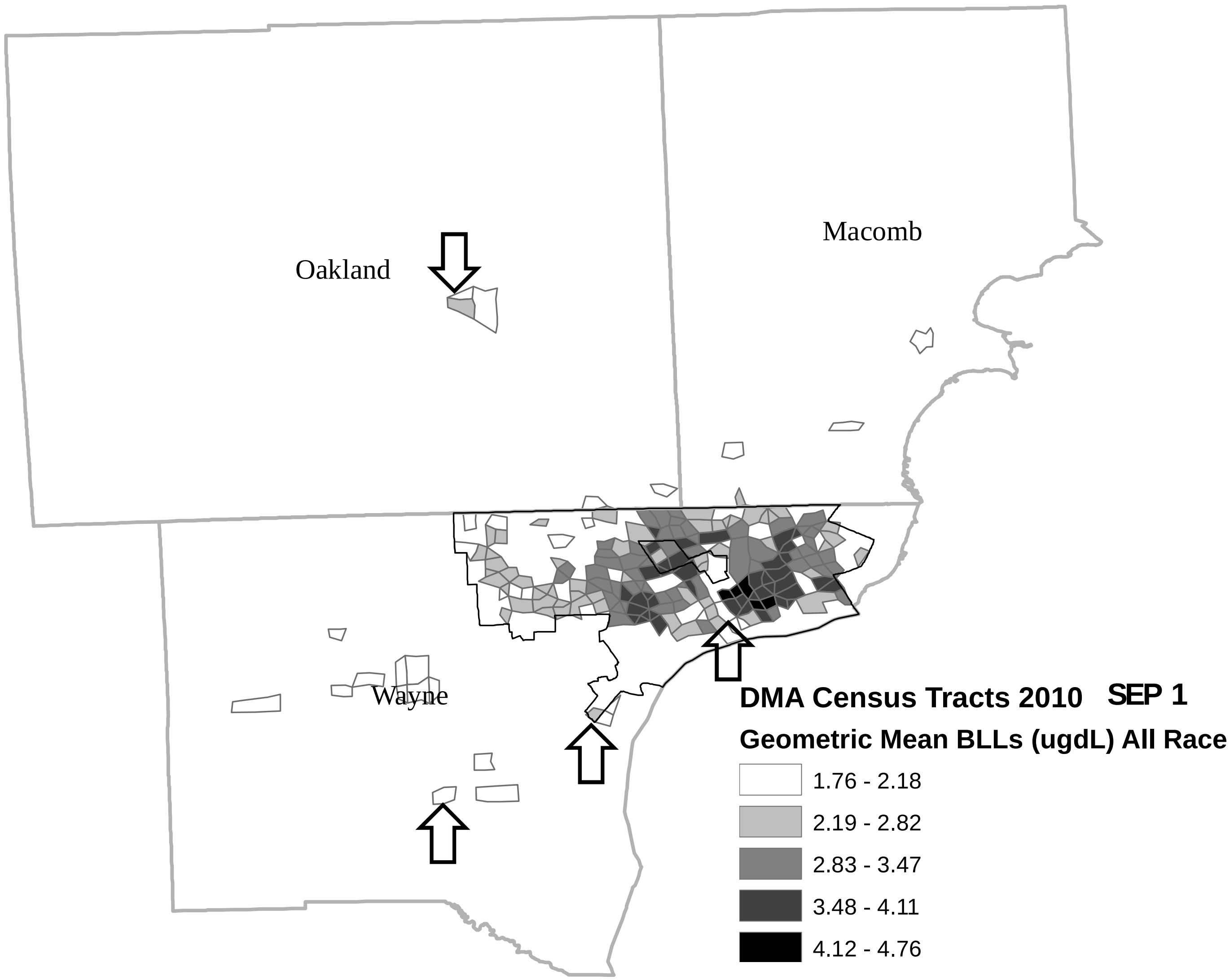
Maps (Figures 6, 7, 8, 9, 10) of geometric mean BLLs for all race/ethnicity groups were reported by census tract at each SEP level. Another map (Figure 11) displays the DMA's incorporated cities (U.S. Bureau of the Census, 2013; verified by *Incorporated Cities* list from the Michigan Office of the Great Seal, Secretary of State).and their designated inner or outer suburban status. Included on this map is percent change in population values derived from census 2000 and 2010 data. Additional maps of housing age (Figures 12, 13, 14, 15) at the census tract level were generated. Figure 12 was created to display percent occupied housing built before 1939 or earlier, the oldest designation available at the Census Bureau. Figure 13 was created to display percent occupied housing built in 1969 or before, important to inner suburb designations of social science research detailed below. Figure 14 displays the percent occupied housing built in 1979 or before, chosen to encompass the ban of lead based paint in 1978. Figure 15 was created to display percent occupied housing built in 2005 or later, the most recent categorical designation available at the Census Bureau (U.S. Bureau of the Census, 2010).

Traditional suburbs of the 1950s are considered the first (inner) suburbs of today and are experiencing a filtering process. As this housing stock aged, it filtered to low-income families while higher income families moved into new housing on the suburban fringe (Bier, 2001; Voinovich and Darden, 2013). First or inner suburbs are defined as those with more than 50 percent of their housing stock built before 1969 and are experiencing the negative effects of deindustrialization. Newer, outer suburbs are defined as those where more than 50 percent of the housing stock was built after 1969. Between 1980 and 2000, racial and ethnic minorities became one-third the population of U.S. inner suburbs as white populations moved out. Nationally, blacks and Hispanics are two and three times more likely to be poorer than whites but this racial divide is increasingly true of inner suburbs (Hanlon, 2008). This information is important because housing age may explain a portion of the residual outliers described above; older housing stock is likely to harbor lead-based paint and expose children living in these homes.

Within the DMA, suburbs were defined by the three county area (Wayne, Oakland, and Macomb) as excluding census tracts of the central city of Detroit. Inner suburbs of middle aged housing stock border the central city of Detroit (containing the oldest housing stock) and/or are less than five miles from the city. Outer suburbs of the newest housing stock include disproportionately professional, middle, and upper-class populations of incorporated places located five or more miles away from the City of Detroit.

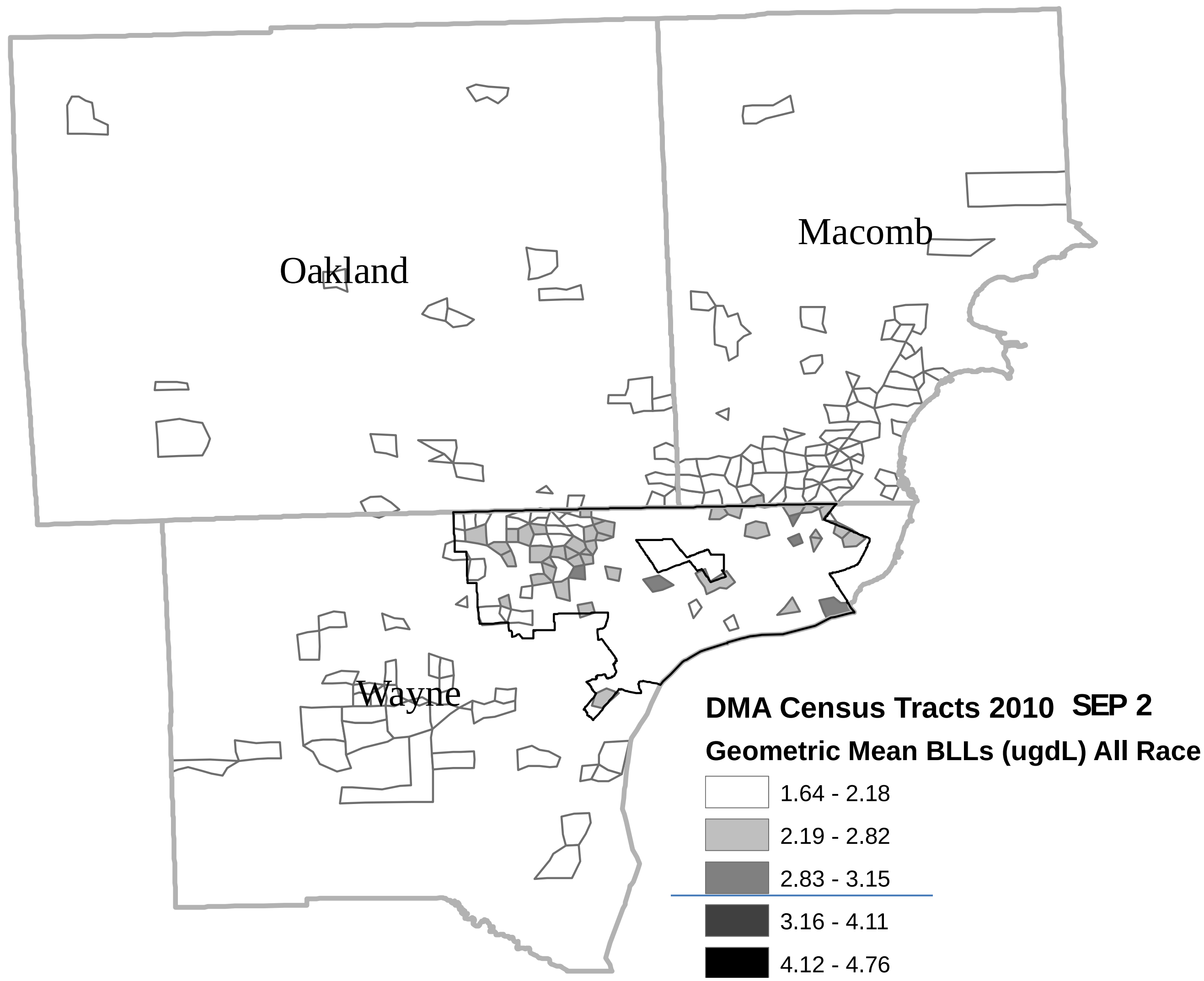
Census tracts' mean BLLs and SEP quintiles are displayed on Figures 6, 7, 8, 9, and 10. As hypothesized, the highest mean BLLs are found in very low SEP neighborhoods which are located in the central city of Detroit, followed by lower mean BLLs in middle SEP neighborhoods, which are mostly located in the first suburbs (inner suburbs), and the lowest mean BLLs are located in very high SEP neighborhoods of the outer suburbs. These maps can be compared to the defined central, inner, and outer suburban rings of the DMA, Figure 11, demonstrating that the greatest mean BLLs occur within the central city of Detroit followed by the inner suburban ring. The least mean BLLs were located in the outermost suburbs predominately of the highest SEP neighborhoods.

Figure 6. Geometric Mean BLLs (ug/dL) all Race in Census Tracts of SEP 1 of the DMA



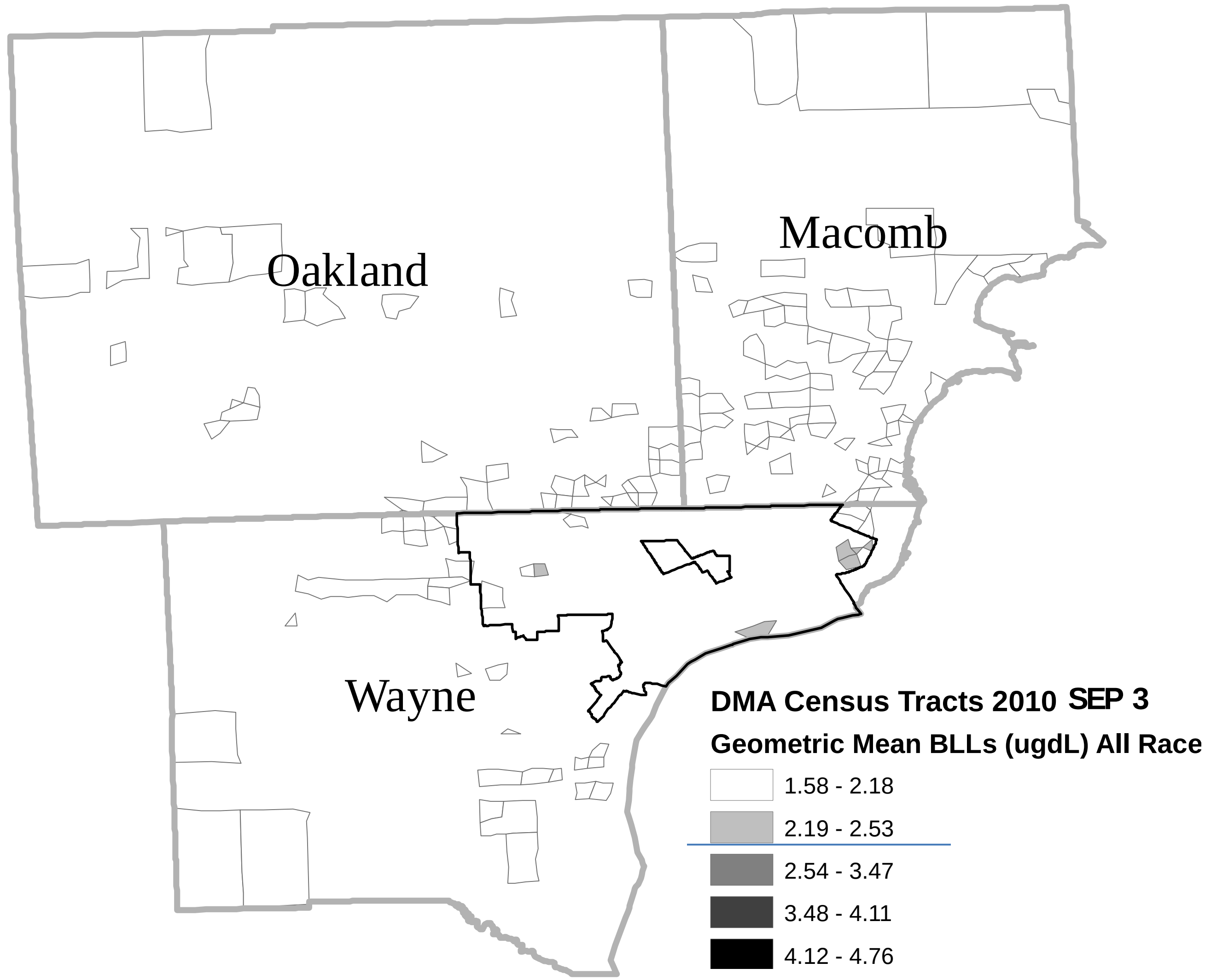
Source: MDCH, 2006-2010

Figure 7. Geometric Mean BLLs (ug/dL) all Race in Census Tracts of SEP 2 of the DMA



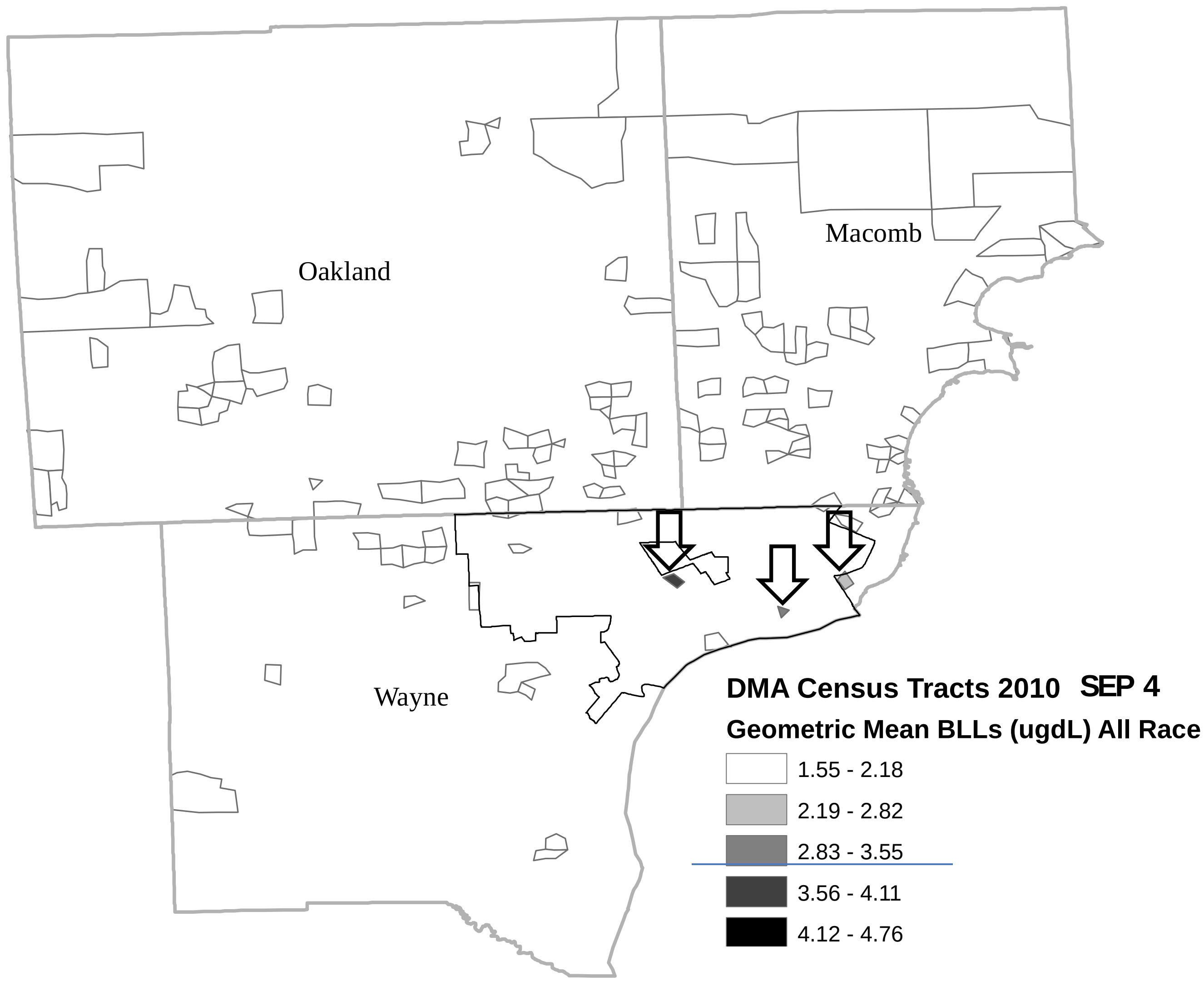
Source: MDCH, 2006-2010

Figure 8. Geometric Mean BLLs (ug/dL) all Race in Census Tracts of SEP 3 of the DMA



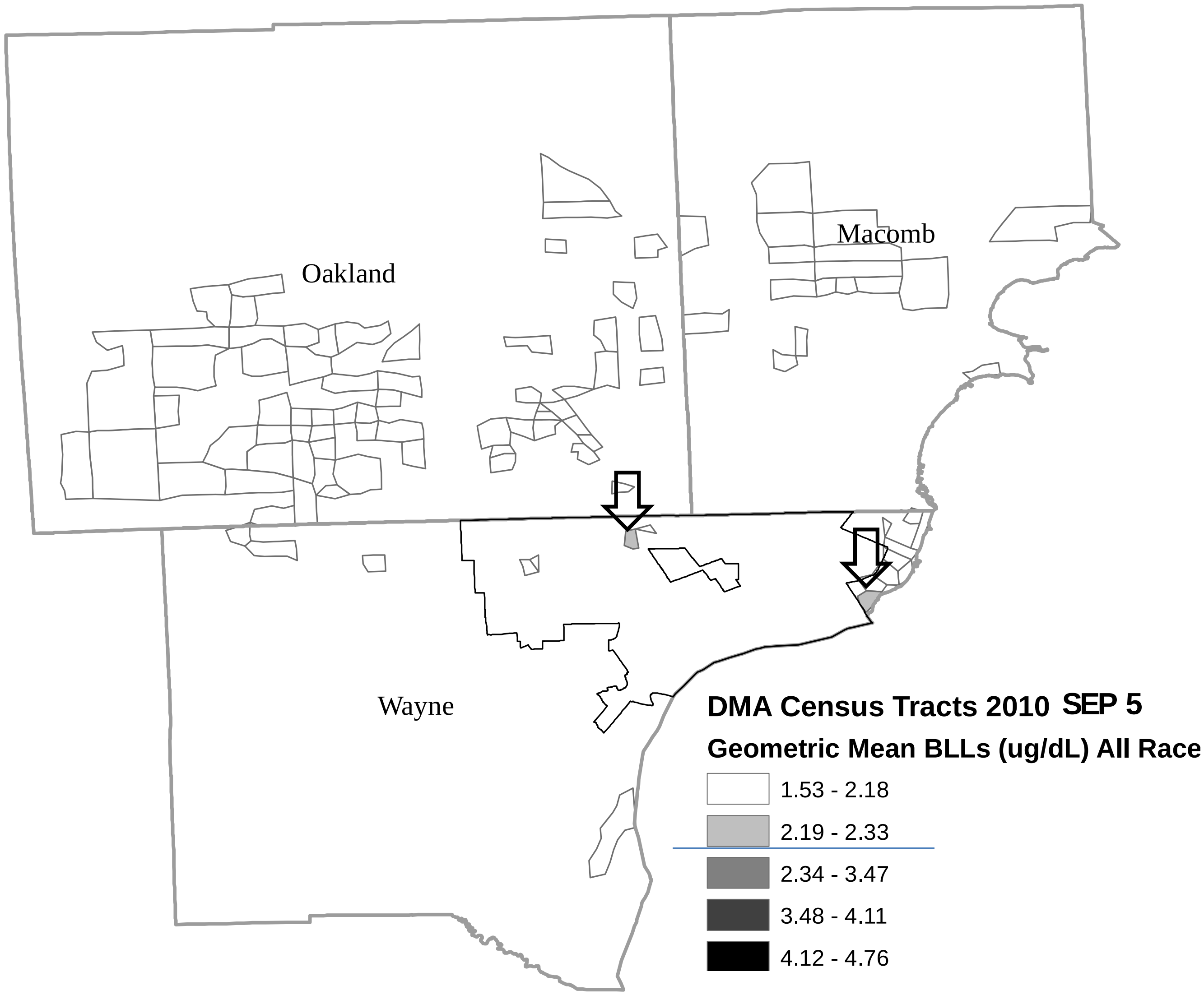
Source: MDCH, 2006-2010

Figure 9. Geometric Mean BLLs (ug/dL) all Race in Census Tracts of SEP 4 of the DMA



Source: MDCH, 2006-2010

Figure 10. Geometric Mean BLLs (ug/dL) all Race in Census Tracts of SEP 5 of the DMA



Source: MDCH, 2006-20

Table 7 below defines the incorporated cities fully within the three counties of the DMA and provides their percent change in population from 2000-2010 (U.S. Bureau of the Census, 2000, 2010, 2013). Only incorporated cities were included in this summary as unincorporated places hold little control over the acquisition of new housing. All bordering suburbs had 50 percent of their housing stock built before 1969. Non-bordering inner suburbs less than five files from the city also had greater than 50 percent of their housing stock built before 1969 with the exception of three places; Flat Rock City, Woodhaven City, and Farmington Hills City (U.S. Bureau of the Census, 2010). These inner suburbs were as a whole, declining in population while the outer suburbs were generally growing in population (U.S. Bureau of the Census, 2000 and 2010).

Table 7. Growth and Decline of Detroit and Inner and Outer Suburbs from 2000-2010

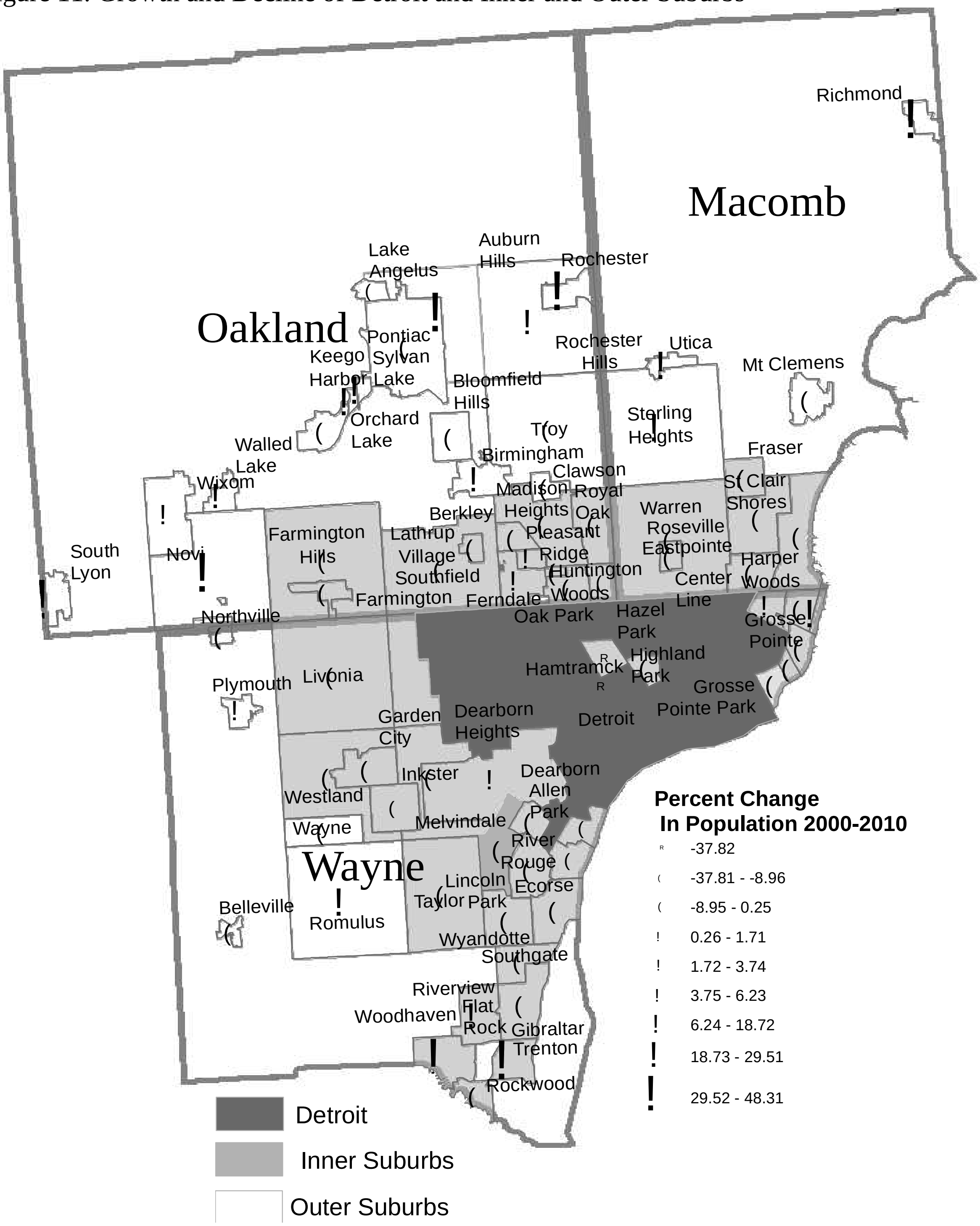
DMA Place	Total Population 2000	Total Population 2006-2010 5-Year Estimate	Percent Change
City of Detroit	951270	713777	-25.00
INNER SUBURBS			
Allen Park City	29376	28542	-2.84
Berkley City	15531	15063	-3.01
Center Line City	8531	8374	-1.84
Dearborn City	97775	98392	0.63
Dearborn Heights City	58264	58066	-0.34
Eastpointe City	34077	32944	-3.32
Ecorse City	11229	9845	-12.33
Farmington City	10423	10380	-0.41
Farmington Hills City	82111	80191	-2.34
Ferndale City	22105	20286	-8.23
Flat Rock City	8488	9666	13.88
Fraser City	15297	14739	-3.65
Garden City City	30047	28199	-6.15
Gibraltar City	4264	4601	7.90
Grosse Pointe City	5670	5478	-3.39
Grosse Pointe Farms City	9764	9561	-2.08
Grosse Pointe Park City	12443	11755	-5.53
Grosse Pointe Woods City	17080	16357	-4.23
Hamtramck City	22976	22594	-1.66
Harper Woods City	14254	14296	0.29
Hazel Park City	18963	16876	-11.01
Highland Park City	16746	12714	-24.08
Huntington Woods City	6151	6209	0.94
Inkster City	30115	26311	-12.63
Lathrup Village City	4236	4101	-3.19
Lincoln Park City	40008	38595	-3.53
Livonia City	100545	97915	-2.62
Madison Heights City	31101	29954	-3.69
Melvindale City	10735	10759	0.22
Oak Park City	29793	29892	0.33
Pleasant Ridge City	2594	2556	-1.46
River Rouge City	9917	8299	-16.32
Riverview City	13272	12640	-4.76
Rockwood City	3442	3323	-3.46
Roseville City	48129	47830	-0.62
Royal Oak City	60062	57741	-3.86
St. Clair Shores City	63096	60776	-3.68

Table 7. (cont'd)

Southfield City	78296	72949	-6.83
Southgate City	30136	30160	0.08
Taylor City	65868	63833	-3.09
Trenton City	19584	19051	-2.72
Village of Grosse Pointe Shores City	2823	2976	5.42
Warren City	138247	135791	-1.78
Westland City	86602	84832	-2.04
Woodhaven City	12530	12862	2.65
Wyandotte City	28006	26368	-5.85
TOTAL	1585173	1544329	-2.58
OUTER SUBURBS			
Auburn Hills City	19837	21162	6.68
Belleville City	3997	4000	0.08
Birmingham City	19291	19962	3.48
Bloomfield Hills City	3940	3879	-1.55
Clawson City	12732	11995	-5.79
Keego Harbor City	2769	2929	5.78
Lake Angelus City	326	294	-9.82
Memphis City	1129	1132	0.27
Mount Clemens City	17312	16616	-4.02
Northville City	6459	6063	-6.13
Novi City	47386	53823	13.58
Orchard Lake Village City	2215	2127	-3.97
Plymouth City	9022	9136	1.26
Pontiac City	66337	60982	-8.07
Richmond City	4897	5630	14.97
Rochester City	10467	12312	17.63
Rochester Hills City	68825	70606	2.59
Romulus City	22979	23874	3.89
South Lyon City	10036	11072	10.32
Sterling Heights City	124471	129687	4.19
Sylvan Lake City	1735	1803	3.92
Troy City	80959	80987	0.03
Utica City	4577	4757	3.93
Walled Lake City	6713	6941	3.40
Wayne City	19051	17924	-5.92
Wixom City	13263	13456	1.46
TOTAL	580725	593149	2.14

Source: U.S. Census Bureau, 2000 and 2010

Figure 11. Growth and Decline of Detroit and Inner and Outer Suburbs



Source: U.S. Bureau of the Census, 2000 and 2010

Table 7 and Figure 11 indicate that the City of Detroit had a 25 percent decrease in population from 2000 to 2010. The inner suburbs experienced a total decline of 2.58 percent and the outer suburbs experienced a total growth of 2.14 percent. Comparing this map with the housing age maps of Figures 12, 13, 14, and 15, the inner suburbs and especially the city of Detroit, had declining populations with some of the oldest housing stock. Remembering that the most significant exposure to childhood lead is from lead based paint, and that older homes are typically located in inner cities that are also more racially segregated, poor, and minority (CDC, 2005), it is important to compare these housing age maps with the BLL maps. Hypothesis three results found that the gap in black-white BLLs were not significantly different in the very low SEP neighborhoods, controlling for age. The maps indicate heterogeneity in housing age of the central city (see Figure 12), the lowest SEP neighborhoods. As indicated by the population decline and housing age statistics, the city and inner suburbs were not likely to have experienced significant renovation and thus childhood exposure to lead may have became more of a risk geographically in these areas. By comparing Figure 8 to Figures 12 and 14, one can see that little renovation has taken place since 1939 and especially since 1979 within the city and many inner suburbs, corresponding to the highest mean BLLs. The outer suburb's younger housing stock (Figure 15) has benefitted from increased population growth and presumably subsequent renovation and new house construction, posing less of a lead exposure risk to the children living there (predominately SEPs 3, 4, and 5 of Figure 8, 9, and 10). Housing age is much more variable in the outer suburbs and possibly the upward mobility of black families into better SEP neighborhoods does not completely translate into the safest and newer lead free housing, explaining higher BLLs of younger black children in especially the very high SEP areas.

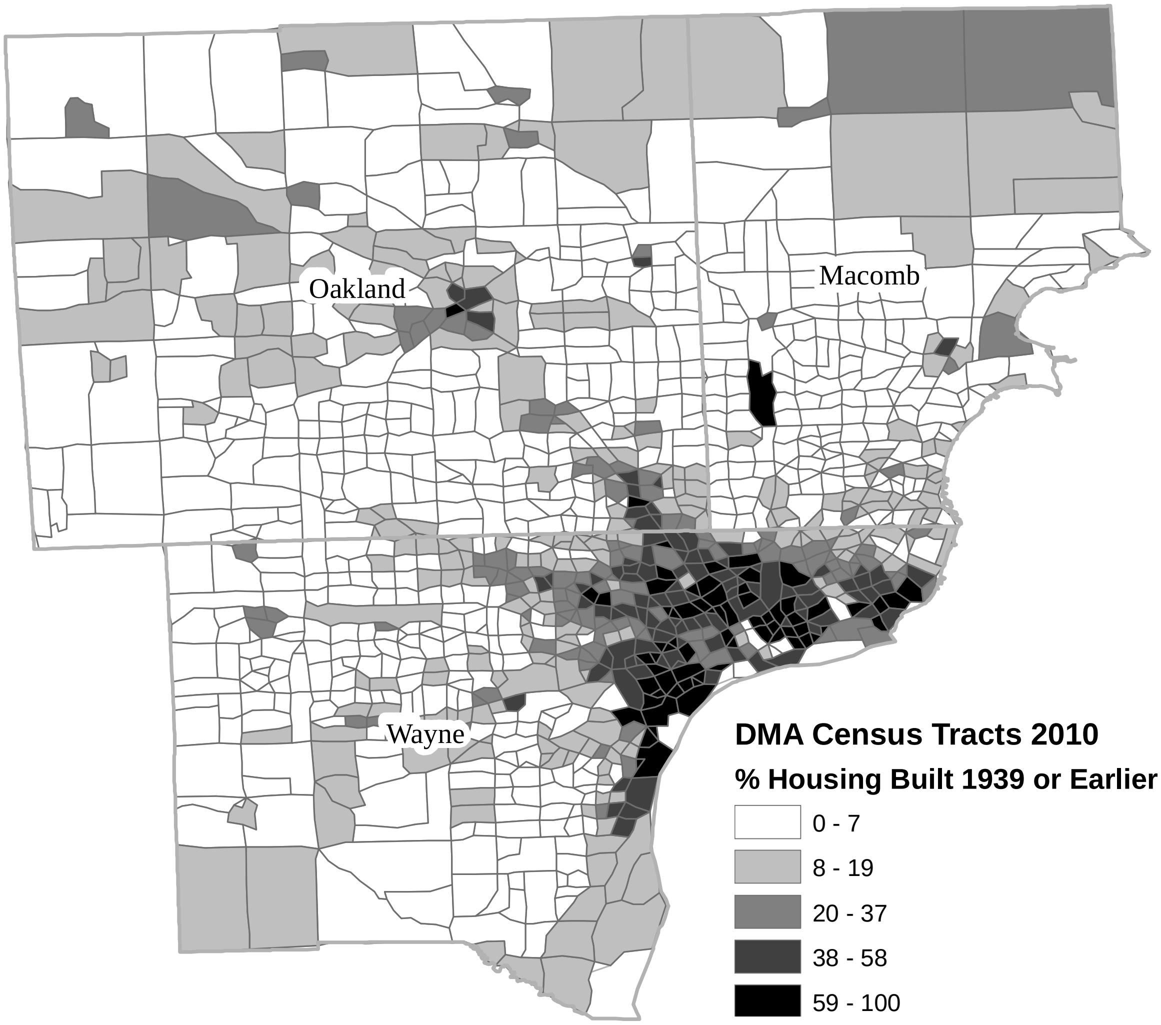
Although the highest mean BLLs exist in the central city, there appear to be two areas of high mean BLLs (see Figure 6) on the outskirts or outside the city center that can be explained by geographic location in the very low SEP neighborhoods. For example the arrow pointing to the census tract in Oakland County (#142400) is located in Pontiac City and has children with mean BLLs of 2.26 ug/dL. This census tract had zero percent housing built during the year 2005 or later, 18.4 percent built in 1939 or before, and 98.7 built before 1969/1979 (see Figures 12, 13, 14, and 15). Its annual median household income was $28,169 and percent below poverty 30.1 based on the 5-year 2006-2010 estimates from the census (U.S. Bureau of the Census, 2010). The second location in Wayne County is actually within the city of Detroit (census tract #524800) with a very similar childhood mean BLLs of 2.27 ug/dL. It had the same housing age statistics as the Pontiac census tract, its median household income was $26,962 and percent below poverty 33.2 (U.S. Bureau of the Census, 2010). This further evidences the fact that neighborhoods matter in determining health outcomes in lead exposure. Also, most of the housing stock in these two census tracts was built before lead paint was banned. Population declines (Pontiac -8.07 and Detroit -25.0) likely contributed to the lack of new housing from 2000 to 2010. Conversely, there are two census tracts with lower than average mean BLLs that also rank as the first and second most negative residuals from the bivariate regression results of hypothesis one. These residuals may be attributed to the newer than average housing age atypical of these very low SEP neighborhoods. The first is in Wayne County within the city of Detroit near the city center (census tract #518900) with mean BLLs of 2.11 ug/dL (75.00% non-Hispanic black; 20.28% no report on race; 3.30% non-Hispanic white; 0.47% Hispanic; 0.47% Arab). This census tract had over one percent of its housing built during the year 2005 or later, only 3.9 percent built in 1939 or before, 18.6 built before 1969/1979 and most of it built from 1990-1999.

Its annual median household income was $14,336 and percent below poverty 64.7, based on the 5-year 2006-2010 estimates from the census (U.S. Bureau of the Census, 2010). The cluster of census tracts, also with lower mean BLLs contiguous and to the north, consists of industrial areas and parking lots. The second and southern most designated census tract (#584800) with a lower than average mean BLL of 1.91 ug/dL (67.32% non-Hispanic black; 21.30% non-Hispanic white; 4.63% no report on race; 3.45% Arab; 0.34% Hispanic; 0.35% Native Hawaiian or other Pacific Islander; 0.17% American Indian or Native Alaskan) is also located in Wayne County. This census tract had over five percent of its housing built during the year 2005 or later, only 1.4 percent built in 1939 or before, and 42.6 percent before 1979. Its annual median household income was $19,141 and percent below poverty 53.2 based on the 5-year 2006-2010 estimates from the census (U.S. Bureau of the Census, 2010). Of course, discussion of these residuals could be improved if census data were available on the racial composition of children living in relatively younger versus older housing.

There are other census tracts of high mean BLLs in the high and very high SEP neighborhoods (Figures 9 and 10) that cannot be explained by lower SEP but partially explained by housing stock age. Again, these higher than average mean BLL outliers were top ranked amongst the positive residuals resulting from hypothesis one's bivariate regression. For example, Figure 9 has three noteworthy census tracts in Wayne County. The far northeast tract (#550200) is located in Grosse Pointe Park, a high SEP neighborhood with childhood mean BLLs of 2.27 ug/dL. This tract had zero percent housing built during the year 2005 or later, 71.8 percent built in 1939 or before, and 91.2 built before 1969/1979. Its annual median household income was $58,722 and percent below poverty 8.9 (U.S. Bureau of the Census, 2010). This community had older housing stock than the communities in the very low SEP neighborhoods of Pontiac and

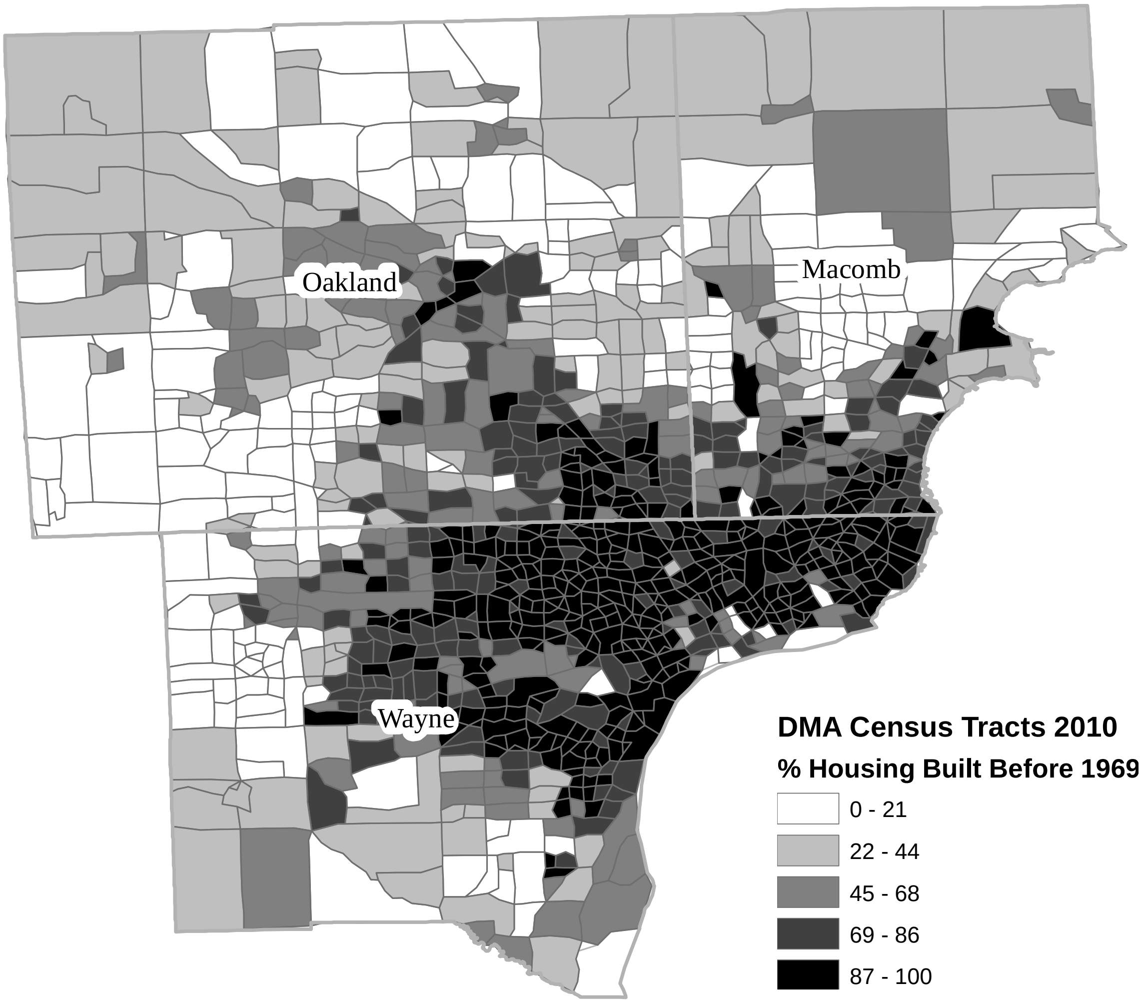
Detroit above, possibly historic homes that had not undergone lead paint removal. Just to the south, two remaining high mean BLL census tracts (#532300 and #515400) are located in the city of Detroit. The southeastern most neighborhood had children with mean BLLs of 3.55 ug/dL, zero percent housing built during the year 2005 or later, 77.1 percent built in 1939 or before, and 100 percent built before 1969/1979. Its annual median household income was $48,534 and its percent below poverty was zero. The western most neighborhood (census tract #515400) had children with mean BLLs of 2.97 ug/dL, zero percent housing built during the year 2005 or later, 76.8 percent built in 1939 or before, and 98.6 percent built before 1969/1979. Its annual median household income was $63,889 and percent below poverty 15.9 (U.S. Bureau of the Census, 2010). Grosse Pointe Park (-5.53) and Detroit (-25.00) had experienced a negative percent change in population from 2000-2010. Two other examples can be found in very high SEP neighborhoods (see Figure 10). To the east is another community in Grosse Pointe Park (census tract #550100) almost double the annual median income of $109,073 and with less poverty (4.8 percent below poverty) than the community described above. Their children had comparable 2.32 ug/dL mean BLL values and comparable housing stock ages (0% built 2005 or later, 49.3% built in 1939 or earlier, and 93.8 percent built before 1969/1979). To the west is a very high SEP neighborhood in the city of Detroit (census tract #538400) whose children had mean BLLs of 2.20 ug/dL. Zero percent of the housing stock was built in 2005 or later, 53.8 percent built in 1939 or earlier, and 98.4 percent built before 1969/1979. They had a median household income of $74,987 and percent below poverty of 2.2 (U.S. Bureau of the Census, 2010). These few neighborhood BLL anomalies may be better explained by the older housing stock and declining populations rather than SEP of the neighborhoods.

Figure 12. Percent of Housing Built 1939 or Earlier in Census Tracts of the DMA



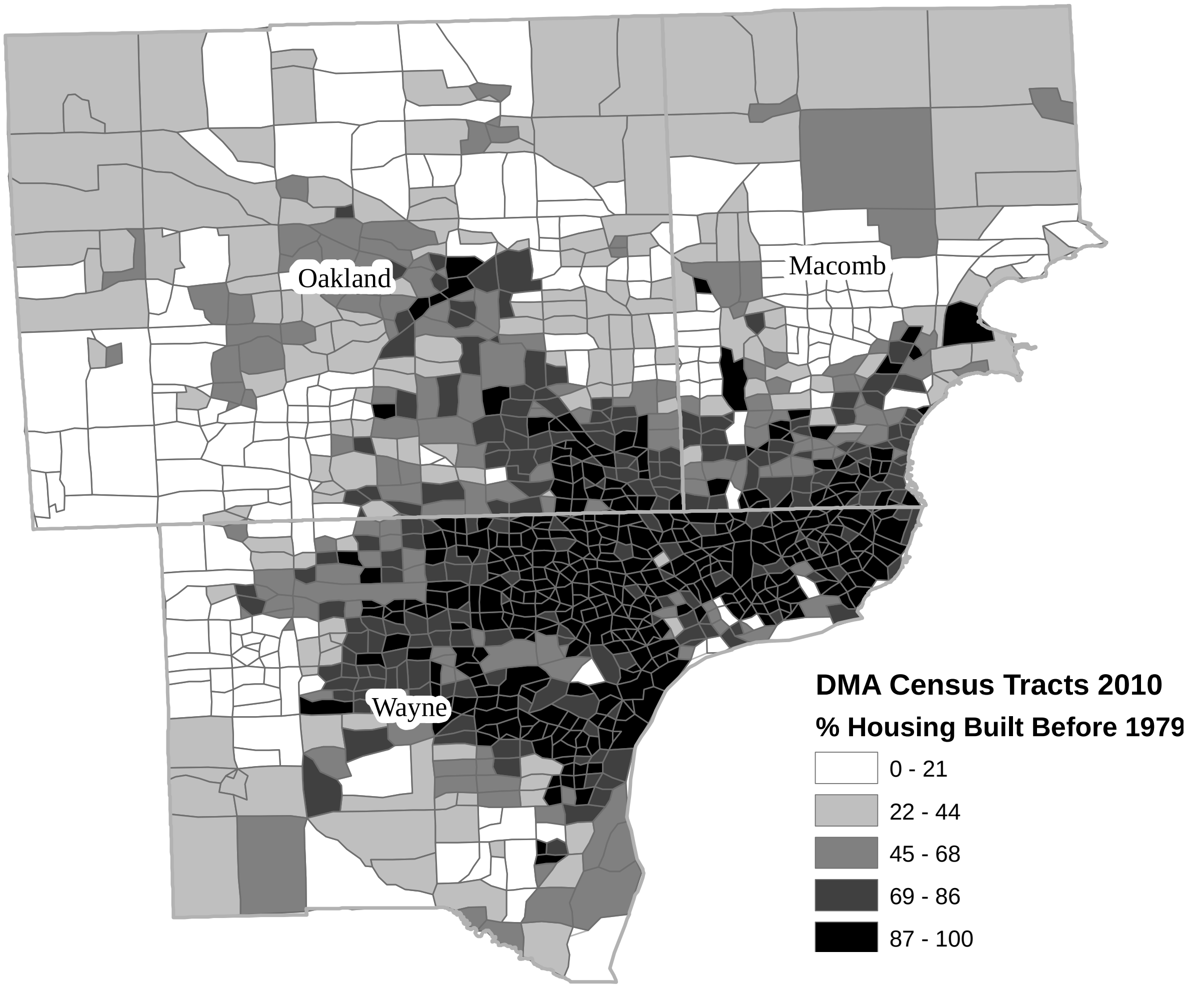
Source: U.S. Bureau of the Census, 2010

Figure 13. Percent of Housing Built Before 1969 in Census Tracts of the DMA



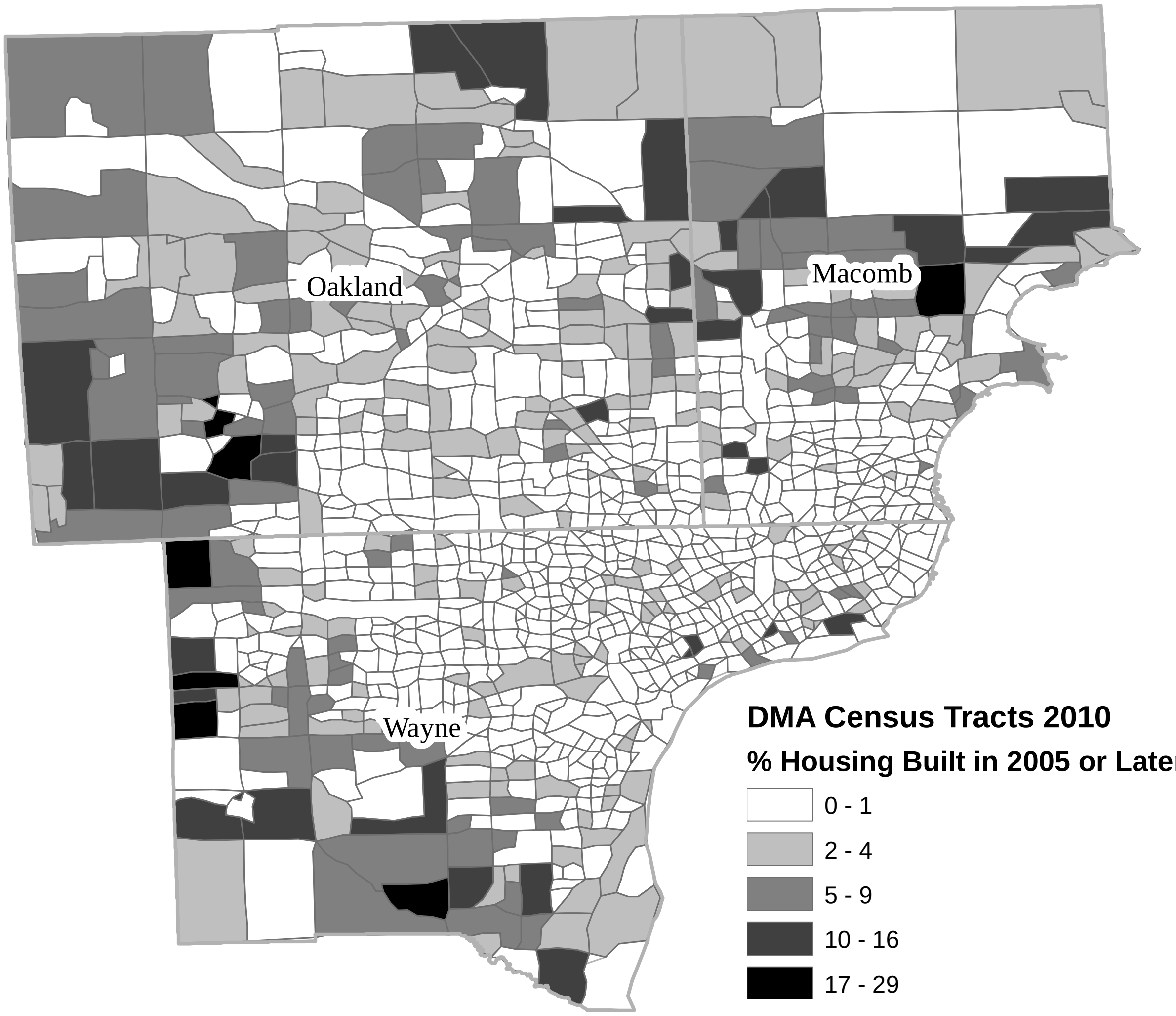
Source: U.S. Bureau of the Census, 2010

Figure 14. Percent of Housing Built Before 1979 in Census Tracts of the DMA



Source: U.S. Bureau of the Census, 2010

Figure 15. Percent of Housing Built 2005 or Later in Census Tracts of the DMA



Source: U.S. Bureau of the Census, 2010

CHAPTER 8: SUMMARY AND CONLCUSIONS

The purpose of this dissertation was twofold. The first aim was to determine if average BLLs in children in the Detroit Metropolitan Area were related to composite socioeconomic neighborhood characteristics where they live. The second was to determine the extent of racial disparities in BLLs by neighborhood characteristics. Part of this aim was to estimate the effect residential segregation of black and white children over neighborhoods of *different* socioeconomic characteristics had on exposing black and white children to different levels of lead.

Well defined racial and socioeconomic inequality in metropolitan Detroit exists. In an environment where exposure to lead were not dependant on socioeconomic status, one would expect to find equal mean BLLs across all SEPs. An environment where race was not a factor, researchers would find equal mean BLLs between black and white children.

Unfortunately, the level of neighborhood SEP in which children lived was a factor in predicting mean BLLs. Hypothesis one, a*verage pediatric BLLs will be higher in neighborhoods of lower socioeconomic characteristics and lower in neighborhoods of higher socioeconomic characteristics* was accepted using bivariate regression analysis. There was a significant amount of variation between mean BLLs in neighborhoods across the DMA. As neighborhood CSI declined, mean BLLs increased significantly for all races.

Unfortunately too, race was a factor as evidenced by the greater mean BLLs of black children as opposed to white children residing in the same SEP neighborhoods. The acceptance of hypothesis two, *non-Hispanic black children will have higher average BLLs than non-Hispanic white children in metropolitan Detroit because a higher percentage of non-Hispanic black children than non-Hispanic white children live in neighborhoods of very low neighborhood* *socioeconomic characteristics* was tested by comparing mean BLLs of black-white race across all levels of SEP. Not only did black children have higher mean BLLs in all quintiles of SEP, but black children were over represented in the lowest quality neighborhoods of SEP; white children were over represented in the middle to very high SEP neighborhoods. The uneven distribution (segregation) of black and white children across the DMA and their mean BLLs was confirmed using the index of dissimilarity. Being a black child predicted higher mean BLLs across all neighborhood SEPs. High black-white segregation and very low SEP neighborhoods predicted the greatest geometric mean BLLs for both races.

Race alone is insufficient to explain health disparities in BLLs as revealed using area based methods to test black-white childhood mean BLLs within and across neighborhood SEP. Hypothesis three, *when non-Hispanic black and non-Hispanic white children reside in neighborhoods of similar socioeconomic characteristics, the black-white gap in geometric mean BLLs in those children decrease,* was supported. Geometric mean BLLs of black and white children per census tract in the DMA for years 2006-2010 were associated and stratified across neighborhood SEP. As neighborhood quality (CSI) improved, mean black and white BLLs decreased significantly. Using the standard error of correlated samples, the estimated difference between the two regression lines were not significantly different from each other indicating that decreasing neighborhood CSI levels have similar effects on increasing the BLLs of black and white children. Importantly, using differences of means tests stratified across age, living in the same very low SEP neighborhoods lessoned the black-white BLL disparity gap but not significantly so in the medium, very high, and high SEP neighborhoods (except children >6 living in very high SEP tracts). Being black was a predictor of greater mean BLLs compared to white children but being black and living in better SEP neighborhoods exacerbated the racial divide in mean BLLs. This phenomenon will be explored in more depth in the conclusion chapter below.

Where non-Hispanic black children reside in neighborhoods of very high socioeconomic characteristics and non-Hispanic white children reside in neighborhoods of very low socioeconomic characteristics, the non-Hispanic white children's mean BLLs will be greater than the mean BLLs for that of the non-Hispanic black children. This fourth hypothesis was accepted after comparing the geometric mean BLLs of black children living in very high SEP neighborhoods with that of white children living in the very low SEP neighborhoods; white children had significantly greater mean BLLs than blacks. The socioeconomic positions of neighborhoods mattered in addition to race.

Hypothesis five, *depicted on maps of the DMA, higher average BLLs will be more prevalent in very low SEP neighborhoods which are located in the central city, followed by middle SEP neighborhoods which are most represented in the first suburbs (inner suburbs), and least prevalent in very high SEP neighborhoods of the outer suburbs* was tested using ArcGIS. Geographic analysis of mean BLL data and census data from the U.S. Bureau of the Census revealed that the highest mean BLLs existed in the central city with the oldest housing and declining population. This scenario was true of the inner suburbs but to a lesser extent. The outer suburbs housed the lowest mean BLLs, youngest housing stock, and a growing population.

Contributions to the Field

This research built upon neighborhood effects health literature by capturing a variety of neighborhood effect variables within a unique composite socioeconomic index to study a unique health outcome, mean pediatric BLLs of neighborhoods in the DMA. Building upon the social science lead literature, the index incorporated established predictors of higher BLLs (poverty, income, home value, etc.) providing results that were more predictive than any one variable alone as attempted by Krieger et al. (2003). Authors who found that socioeconomic position of the neighborhoods in which children lived was a factor in predicting health outcomes were the following: Krieger et al. (2001) found higher mortality for a variety of illnesses as neighborhood economic resources decreased in Massachusetts and Rhode Island. Ross and Mirowsky (2008) determined that Illinois neighborhood socioeconomic status significantly caused adverse health outcomes controlling for individual measures. Of all socioeconomic variables, Krieger et al. (2003) found that childhood poverty was most predictive of elevated BLLs (≥10 ug/dL) at the census tract level in Rhode Island. Median household income was the number one socioeconomic predictor of elevated BLLs (≥10 ug/dL) by hot spots in Chicago (Oyana and Margai (2010). In Rhode Island, Vivier et al. (2010) grouped lead poisoned children (≥10 ug/dL) into quintiles and found poisoning to be significantly correlated with the highest quintile of poverty. Kaplowitz, Peristadt, and Post (2010) found in Michigan that block groups with the lowest incomes had the greatest significant bivariate correlation with BLLs.

This dissertation was the first study to use five years of BLL data and to focus on the Detroit Metropolitan Area to examine changes in the neighborhood SEP associated with changes in mean pediatric BLLs by race. A collection of studies found too that race was a factor in health no matter the quality of neighborhood in which they lived. Subramanian et al. (2005) found in Massachusetts, mortality odds ratios were much greater for blacks than for whites. Haley and Talbot (2004) found an important amount of variance in census tract BLLs (≥10 ug/dL) as the African-American children population increased in NYC and upstate New York. Bernard et al. (2003) similarly found an increase in individual BLLs nationwide with an increase in non-Hispanic black children.

This dissertation study exclusively examined the uneven distribution of mean BLLs of black and white children living in lower quality, segregated neighborhoods. Also using the index of dissimilarity, Polednak (1997) found spatial unevenness between levels of residential segregation and black-white death rate ratios and infant mortality rates in the U.S. Acevedo-Garcia and Lochner's review article (2003) found mortality rates to be greater for blacks with greater racial residential segregation. Grady and Darden (2012) found that high black segregation and very low SEP significantly predicted preterm birth. Likewise, this dissertation study found that high black-white segregation and very low SEP predicted greater mean BLLs.

Interpretation and Comparison to Previous Research

This research filled a methodological void in lead studies by comparing race, quality of place, and mean values of pediatric BLLs by neighborhood. The *gap* in black-white mean pediatric BLLs was tested within and over different SEP neighborhoods where these children lived. This exposed new associations between neighborhood childhood BLLs, socioeconomic status, and residential segregation between black and white children who were lead tested in the DMA. Other neighborhood socioeconomic health disparity research exposes the DMA as racially and socioeconomically disparate. Grady and Darden (2012) found that low birth weight incidence was increased by black versus white race and this incidence decreased in both groups with increasing socioeconomic position in the DMA. In addition, as SEP increased, also using the Darden-Kamel Composite Index, the gap in intrauterine growth restriction (leading to low birth weights) lessoned between black and white infants. In agreement, Subramanian et al., 2005 found that black versus white mortality odds ratios increased with neighborhood poverty.

These results are contrary to a more detailed analysis of the BLL outcomes of this study. Overall, when black and white children lived in similar SEP neighborhoods, the black-white gap in mean

BLLs ceased to exist. But when these children were stratified by age group and SEP, significant findings were revealed; as neighborhoods improved beyond the very low SEP, mean BLL differences increased between black and white children aged zero to two and two to six years old. Then again, Grady (2006) found that increasing levels of neighborhood poverty significantly eliminated the black-white race effect on low birth weight incidence in NYC. The same was true for the gap in black-white BLLs of this dissertation study; the lowest socioeconomic position neighborhoods eliminated the black-white mean BLL gap. This may be partly explained by the homogeneity of older housing stock (likely containing lead based paint) of very low SEP neighborhoods, equally increasing exposure to children living there, especially the youngest playing on floors. Examination of housing stock age in census tracts of high and very high SEP neighborhoods and each with the two greatest black BLL residual values, produced a hodgepodge of housing ages atypical of SEP four and five. This may explain in part why the black-white mean BLL gap is greater in younger children as SEP improves; black families may not be able translate their increased socioeconomic standing into newer/renovated housing. It may also explain why this disparity lessons in children greater than six years old; regardless of housing age, when no longer playing on floors the BLLs of black and white children become more similar.

Review of other lead studies find poverty type variables to be most predictive of BLLs or lead poisoning, more so than housing age. Housing age may not be a detectable independent variable at the census tract or block group level as Kaplowitz, Peristadt, and Post, 2010 confirmed. Regressing a variety of housing age variables alone or in combination with CSI was not predictive in determining mean BLLs in this dissertation study. A likely explanation is the historic older homes of SEP four and five neighborhoods investigated above and the rare new construction of housing in SEP one and two neighborhoods, diluting the effect of this variable. This invites further, more localized analysis at the individual level scale to capture the linear relationship between housing age and pediatric BLLs. As example, Troy City, an SEP four census tract examined in hypothesis three, has the second largest black mean BLL residual and contains just four percent of its housing built before 1939. Greater mean black BLLs would not be detected as related to exposure to lead-based paint in older housing without individual level analysis. Another explanation may be living more closely to outside environmental contributors such as lead laden dust of old, historic freeways, or next to coal burning plants and other lead emitting industries. Other contributors may lie in older/un-renovated structures of public schools/day care centers within very high SEP neighborhoods. Perhaps wealthier, white children are commuted to newer schools or day care centers outside the census tract. For example, the Cranbrook Institute of Science, a private pre-kindergarten through high school institution, is located in an adjacent census tract of the very high SEP neighborhood of Birmingham City. This census tract was examined in hypothesis three as having the second largest black mean BLL residual. Regardless of the contributors to the black-white BLL gap, it seems that segregation into lower quality housing, environments, etc. occurs even in the wealthiest neighborhoods and at geographic levels as fine as census tracts.

This dissertation study's novel geographic analyses of metropolitan Detroit revealed that the highest mean BLLs existed in the central city with the oldest housing and declining population. This scenario was true of the inner suburbs but to a lesser extent. The outer suburbs of the DMA housed the lowest mean BLLs, youngest housing stock, and a growing population. Similarly but in New York State, Hanley (2011) found African American children under age five were 8 times more likely to live in neighborhoods of "high risk" for lead paint hazards compared to white, non-minority children. Followed by income, housing built before 1950 was the second best predictor of elevated BLLs (≥10 ug/dL) in BLL hot spots of Chicago (Oyana and Margai, 2010).

Indeed research regarding lead poisoning in Metropolitan Detroit has been limited even though Metropolitan Detroit was tied with Metropolitan Milwaukee as the most residentially segregated metropolitan area in the United States by race in 2010 (Darden and Thomas, 2013). Detroit has also continued to experience extreme class segregation (Darden et al., 2010). Although childhood lead poisoning is a preventable disease, these factors have led to a ranking of 10^{th} in the nation for the highest percentage of elevated BLL children (CDC, 2012b).

Future Research

Limitations of this study include using the CLPPP lead surveillance database. As illuminated by Kemper et al. in 2005, the authors used this database to calculate the overall rates of blood lead testing in children in Michigan. They noted that in urban areas, testing protocol is biased toward minorities who are Medicaid enrolled. Further, Kaplowitz, Perlstadt, and Post (2010) claim that Michigan was not fully compliant with testing protocol as required by Centers for Medicare and Medicaid Services (Michigan Childhood Lead Poisoning Prevention and Control Commission, 2007) resulting in an incomplete database sample. This study relied on the MDCH's 50 percent report rate on race for both non-Medicaid and Medicaid children. The Medicaid children were cross-listed to Medicaid records yielding an approximately 90 percent report rate to provide a greater number of observations. However, this presented another problem; patients reporting race were over-represented by Medicaid recipients, exacerbating the sampling protocol preference of Medicaid children by the MDCH. These weaknesses were addressed to some extent by gathering five years of BLL surveillance data and thus capturing more non-Medicaid children as well. Also, as of the year 2012, approximately 33 percent of children less than six years old were tested in the DMA for any given year and Michigan tests BLLs of approximately 90 percent of all children by the age of six, ensuring that a large number of non-Medicaid children were represented in this study (MDCH, 2013). By running sample size and power calculations of the populations tested, this study ensured there were sufficient numbers of children per census tract, even in very high SEP neighborhoods. The large sampling sets increased precision and margins of errors.

Other limitations of the BLL data dealing with validity are that only the highest venous blood lead level was entered into the database even if immediate re-tests or chelation therapy (a medical lead extraction procedure that elevates blood lead for a time) had been conducted. If a venous result was unavailable, the highest capillary value was entered. And as discussed in the methods section above, detection limits of the analytical equipment varied (although most of the laboratory units had detection limits of 1 ug/dL or less) and values were rounded to the nearest integer from 1 to 164 ug/dL. A BLL test of zero was entered as a 1.0 ug/dL and to account for the large number of 1.0 ug/dL results, the latest guidance methodology from the U.S. Department of Health and Human Services was used. These 1.0 ug/dL BLL values were divided by the square root of two and all of the BLLs were log-transformed to achieve a less skewed BLL distribution prior to performing any of the analyses.

Another limitation of the data was discovered when attempting to perform multiple linear regression models and controlling for age to test hypothesis three. Many of the children were BLL tested on or near their birthdates. As a result and in combination with value BLL rounding, a clumping of ages (12, 24, 36, months etc.) and clumping of BLLs (1, 2, 3, ug/dL etc.) resulted in a pattern of errors that were not normally distributed. Instead, differences of means tests were conducted and provided meaningful results to hypothesis three.

Also, because the MDCH BLL records lack information on the socioeconomic status of the children's parents, census tract socioeconomic data provided a quantitative way to best represent these characteristics as relates to disparities in BLLs. The ecological fallacy was overcome by estimating socioeconomic position at the census tract while obtaining individual level BLLs, race, gender, and age variables. Despite these limitations, this surveillance data is the only source available to determine disparities in mean BLLs.

Finally, a finer geographic level of analyses, ideally at the individual level, may uncover explanation of the highest and lowest BLL outliers atypical of the SEP neighborhoods in which they reside. Investigation of housing age, renovation status, external environmental contributors, etc. may capture some of these imperfect associations between pediatric BLLs and neighborhood socioeconomic position.

Implications of this Research for Public Policy and Future Study

I have argued that the effects of black concentration in very low SEP neighborhoods and racial residential segregation have contributed to the gap in childhood black-white mean BLLs in metropolitan Detroit. An examination of this study and a body of previous research conducted across the country has demonstrated the importance of the childhood lead problem.

Even though lead poisoning is a preventable environmental threat that has long term effects, federal agencies responsible for its elimination lack congressional will or budgets to eliminate this hazard. The Department of Health and Human Services' CDC was charged with elimination of childhood lead paint hazards by the year 2010 during the Clinton Administration (CDC, 2000). Under this program, the U.S. Department of Housing and Urban Development

(HUD) provided Lead Hazard Grants to cities most in need. (The City of Detroit received such a grant but State/local officials mismanaged the 3 million dollars slated for children's lead laden homes and instead renovated vacant and/or one-bedroom apartments (Askari and Lam, 2003)). This funding was cut so badly under the Obama administration in 2012 that the grants have virtually been eliminated (Markowitz and Rosner, 2013). A second national effort is the CDC's Healthy Homes and Lead Poisoning Prevention program that supports state and local lead screening, inspection of homes, and removal of lead sources in addition to maintaining the national BLL surveillance system. Annual funding is typically precarious. Fortunately it received 15 million dollars this year, a drastic increase from last year's appropriation of 2.45 million. (The prior year's funding was 29 million dollars). Expectantly this increase will resume support for local lead identification and abatement efforts (CDC, 2014). A third federal agency, the U.S. Environmental Protection Agency, has been stifled from regulating environmental dangers of thousands of chemicals including lead from a variety of indoor and outdoor sources (Markowitz and Rosner, 2013). National policy ought to re-instate the HUD Lead Hazard Grants, allocate increased and consistent funding for healthy homes, and provide the EPA with necessary regulatory and enforcement power to ensure children are protected from outdoor emissions of lead. On a broader scale, future research should be translated into national health policies, mandating the abatement of lead contaminated housing, especially in disparate low income and segregated communities

Locally, a Detroit city ordinance requires that children with a BLL test result of ≥10 ug/dL (as reported by the MDCH) have their homes inspected for lead. Inspectors may cite a homeowner/landlord for peeling lead paint. Those who do not comply may be issued a fine however, these penalties are rarely enforced and there are few staff members (1-2) to inspect these homes. Surrounding counties have similar ordinances and staffing/enforcement issues. (Askari and Lam, 2003). Stricter housing regulations, ordinances, and penalties should be promulgated and enforced under Michigan law, requiring landlords and homeowners to abate lead based sources before a child becomes lead poisoned.

This information invites research investigating ordinance enforcement action per neighborhood or county and a comparison with childhood BLLs. Changing BLLs may also be associated with the housing market crises and a decline in housing values/housing investment. In combination, transience, a predictor of poverty and poor housing conditions, might also be compared to BLLs. Immigrant children's environments may be another variable correlated with higher or lower BLLs.

This dissertation may be translated to affected communities using the spatial maps developed and fostering intervention strategies as well as eventual abatement of pockets of lead contamination, as the CDC's Healthy Homes and Lead Poisoning Prevention program is aimed to do. I have agreed to present the results of this research to the MDCH's Michigan Childhood Lead Poisoning Prevention and Control Commission.

Such a national public health threat and educational crisis would normally be treated as an epidemic. However, because the epidemic is non-contagious and the children most affected are minority and live in segregated and poor socioeconomic neighborhoods, little has been done on a national scale. As lead exposure is related to race through place of residence and neighborhood characteristics, it has become a critical spatial justice and environmental racism issue.

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