Environmental Injustice and Lead (Pb) Contamination: Exploring Outcomes in Allegheny County, PA

by

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Abstract

Environmental injustice refers to the reality that certain individuals, particularly those from historically marginalized groups, and whose incomes are below the federal poverty threshold, bear a disproportionate burden of environmental risk in the population. This injustice has led to the continually growing Environmental Justice Movement which emphasizes the principle that every individual has a right to equal protection and enforcement of environmental regulations to promote their health and wellbeing, regardless of their place of residence. Landmark reports for this movement, such as the 1987 publication, "Toxic Wastes and Race in the United States: A National Report on the Racial and Socioeconomic Characteristics of Communities with Hazardous Waste Sites", have demonstrated environmental injustices across the United States.

Despite the environmental justice movement's rise in relevance throughout the past few decades, and the increase in research surrounding these injustices, largely avoidable tragedies continue to impact marginalized communities. One of the worst public health crises in recent history, and a stark example of environmental injustice, is the lead (Pb) contamination of drinking water in Flint, Michigan where over half of the population are people of color, with Black residents representing most of this percentage. The public health implications of the intersection between lead contamination and environmental injustice are also demonstrated locally in Allegheny County, where there are concerns surrounding Elevated Blood Lead Levels (EBLLs) in children residing in Environmental Justice Census tracts throughout the county. This review seeks to

explore the coupled history of Pb contamination and environmental injustice on national and local levels, provide original spatial analyses of predictors and health outcomes related to Pb in Allegheny County, and discuss individual and systemic factors involved in promoting the health of communities disproportionately affected by Pb and other environmental contamination events.

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Preface

The author acknowledges that language used in defining Environmental Justice Areas (e.g., "minority") often does not reflect the nuanced experiences of individuals from historically marginalized groups. Terms such as "minorities" will be used when directly referencing external definitions/classifications; more nuanced language regarding racial identities, such as "historically marginalized communities" or "communities of color," will be substituted wherever official phrasing is not critical. Cited definitions may also include "poor" as a classification; this term again does not fully encompass individual experiences, so the author will mindfully substitute, "lower socioeconomic status" wherever possible. Language differences also exist in the literature when referring to race/racial identity and ethnicity (e.g., "Black" and/or "African American"), this review will use the phrasing of the cited material, while acknowledging that the given terminology may not reflect the nuanced experiences of the people it aims to represent. This review will also reference the binary language of cited literature regarding health effects in people (e.g., "male" and "female"). The author acknowledges that these binary descriptors do not reflect important nuances surrounding the relationship between biological sex and gender for all people.

Original spatial analyses conducted by the author utilize open-source data that aim to represent the current state of Allegheny County, but it must be acknowledged that Census tract-level data are compiled from the last comprehensive Census in 2010. Additionally, it is important to acknowledge that the open-source data on elevated blood lead levels are from 2015-2020 and are calculated using the population of children who received a blood test during this time, not the entire Census tract. Therefore, the author acknowledges that portions of the current population in Allegheny County are likely excluded from these analyses.

1.0 Introduction

Exposure to Pb continues to be a major public health concern, particularly for children, as there is no known level that is considered safe[1]. The Centers for Disease Control and Prevention (CDC) report well-documented health effects caused by exposure to Pb including damage to the brain and nervous system, hearing and speech difficulties, learning and behavior problems, and slowed growth and development[1]. The CDC also claims that there is evidence to suggest that exposure to Pb during childhood can cause long-term harm to an individual's health[1].

There have been major public health victories in decreasing the amount of Pb to which individuals are exposed, such as phasing out the use of lead-based paint in new structures, introducing unleaded gasoline, and reducing the use of lead solder in pipes[2]. Despite these steps, Pb exposure is still a very real risk for many children across the United States. The Flint, Michigan Water Crisis that began in 2015 returned the issue of Pb contamination back to the forefront of the public's attention. Subsequently, there was an increase in research surrounding Elevated Blood Lead Levels (EBLLs) in children, including a recent publication in the *Proceedings of the National Academy of Sciences* which predicts that by 2030, over 43% of the United States population will have had BLLs higher than the CDC's Blood Lead Reference Value (BLRV) of 5µg/dL[3]. It is important to note that in this publication, BLLs were given an "elevated" designation if they were above this level, but in 2021 the BLRV was changed to 3.5ug/dL[4]. It is plausible that this decrease in reference level means that an even greater percentage of the United States' population now have BLLs that are given this "elevated" classification. Research on state-level EBLL trends from the Pennsylvania Department of Health's (PA DOH) 2019 Childhood Lead Surveillance Report shows that less than 1% of the total population of children aged 0-71 months in PA have confirmed EBLLs, but this equates to almost 6,000 children across the state who have relatively high levels of Pb circulating in their bodies[5]. If this value is reported as the percent of children with EBLLs among children that were tested, rather than the total PA childhood population, this value increases to nearly 3.5% with EBLLs[5]. Taking a more granular look at county-level data in the PA DOH report, researchers found about 2% of children tested in Allegheny County had confirmed EBLLs[5]. The report also provides EBLL data stratified by race/ethnicity, where the percentage of Non-Hispanic Black or African American children with EBLLs is almost four times greater than their Non-Hispanic White counterparts in Allegheny County[5]. It is also important to recontextualize these statistics with the fact that while some percentages of EBLLs may be smaller than others, there is still no known level of Pb that is safe, especially in children.

As with other environmental toxins, the risk of exposure to Pb also intersects with larger systemic issues involved with health and environmental justice, which poses an even greater risk to individuals who have been historically marginalized and/or are from a lower socioeconomic status. Across the United States, and locally in Allegheny County, risk of Pb exposure demonstrates a clear overlap between the environmental conditions in a community and other social determinants of health, including but not limited to, safe housing, job opportunities/income, racism, and access to nutritious food[6]. Based on the framework of the United States Department of Health and Human Services' Healthy People 2030 Initiative, the promotion of healthier, safer choices does not automatically create healthier communities; social determinants of health are also a major contributor to residents' health and wellbeing[6]. With this idea serving as the foundation of the work, three objectives of the present review are to (1) explore national and local histories of Pb contamination and environmental injustice, (2) conduct original geospatial analyses on predictors and health outcomes related to Pb in Allegheny County, and (3) discuss individual and systemic factors that governing bodies must consider when making policy decisions to better advocate for the health of community members who continue to be disproportionately affected by environmental contamination events.

2.0 Origins of Environmental Justice: Historical and Contextual Information

It is not clear when the environmental justice movement in the United States first began, as local groups have organized to push back against undesired land uses for decades, but it certainly has close ties to the Civil Rights Movement of the 1960s where people of color first sounded the alarm about the public health dangers threatening their communities[7]. Isolated environment-specific protests shifted in the early 1980s when communities across the nation galvanized to seek social justice and environmental protection[8]. Some landmark environmental justice events of the 1970s and 1980s include Houston, Texas communities pushing back against the Whispering Pines landfill and Native nations demonstrating against mineral mining[9]. An additional event that has been referred to as the initial spark of the modern environmental justice movement, is a 1982 protest in Warren County, North Carolina[8]. This small, predominately Black community was designated to host a landfill with toxic, polychlorinated biphenyl-containing waste, and with the help of the National Association for the Advancement of Colored People, the community staged a massive protest[8, 9]. Ultimately, this protest proved unsuccessful in blocking the hazardous waste disposal site in Warren County, but it provided a start to the environmental justice movement on a national scale and unfortunately, foreshadowed the uphill battle communities of color would continue to face for decades when advocating for environmental justice.

2.1 Environmental Justice at the Federal Level

The United States government appeared to begin prioritizing environmental health by establishing the Environmental Protection Agency in 1970, yet concerns raised by communities of color about disparate conditions were largely ignored[9]. However, on the heels of increased environmental justice activities throughout the United States in subsequent years, the federal government responded through a 1992 call to action from President George Bush Sr. to establish an Environmental Equity Working Group that fostered federally sponsored conversations on environmental justice with leaders of affected communities[8]. Over a decade after the Warren County protests, President Clinton introduced Executive Order 12898, entitled, "Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations", which sought to make environmental justice part of the federal decision-making process[8]. With a more intentional governmental response to environmental justice, definitions of environmental justice have gone through many iterations, including this current description from the CDC: "All people-regardless of race, color, national origin, or income- are entitled to equal protection from environmental and health hazards and equal access to the development, implementation, and enforcement of environmental laws, regulations, and policies[10]."

2.1.1 Advances in Federal Environmental Justice

With the increasing availability of data, and the need to apply these data in meaningful ways, tools such as the CDC's Environmental Justice Index have been developed to measure the cumulative impacts of environmental burdens on communities using a health equity framework[11]. By utilizing existing community data, this index generates a score for each community which allows public health officials to identify the most at-risk areas for adverse health effects of environmental burdens[11]. The index also considers key social factors such as race/ethnicity and poverty, as well as pre-existing conditions that may contribute to the adverse health outcomes in the area[11]. By delivering a single environmental justice score, as well as scores for three modules, social vulnerability, health vulnerability, and environmental burden, the Environmental Justice Index can assist public health officials in prioritizing interventions to serve the most vulnerable communities[11].

2.2 Local Environmental Justice: Pennsylvania and Allegheny County, PA

There are no unified, federally recognized criteria to define Environmental Justice Areas, but individual states have developed working definitions to help prioritize communities[12]. For example, for the purposes of the Pennsylvania Department of Environmental Protection's Environmental Justice Public Participation Policy, an Environmental Justice Area is defined as, "Any census tract where 20 percent or more individuals live at or below the federal poverty line, and/or 30 percent or more of the population identifies as a non-white minority, based on data from the U.S. Census Bureau and the federal guidelines for poverty[12]." Using this definition to focus on county-level information in Pennsylvania, specifically Allegheny County, there are 134 Census tracts that meet these criteria for Environmental Justice Areas (See Figure 1)[13]. This translates to over a third of the Census tracts in Allegheny County, as well as about 27% of the County's total population (based on 2010 Census data)[14]. It is important to recognize that these statistics and maps communicate the experiences of groups of real residents who are often disproportionately affected by environmental risks throughout Allegheny County. Another crucial acknowledgement is that the environmental justice area designation is merely for clusters of residents within Census tracts; it does not describe risk for individual citizens throughout the county that are part of marginalized communities and/or of lower socioeconomic status but may not reside in Census tracts given the environmental justice designation.

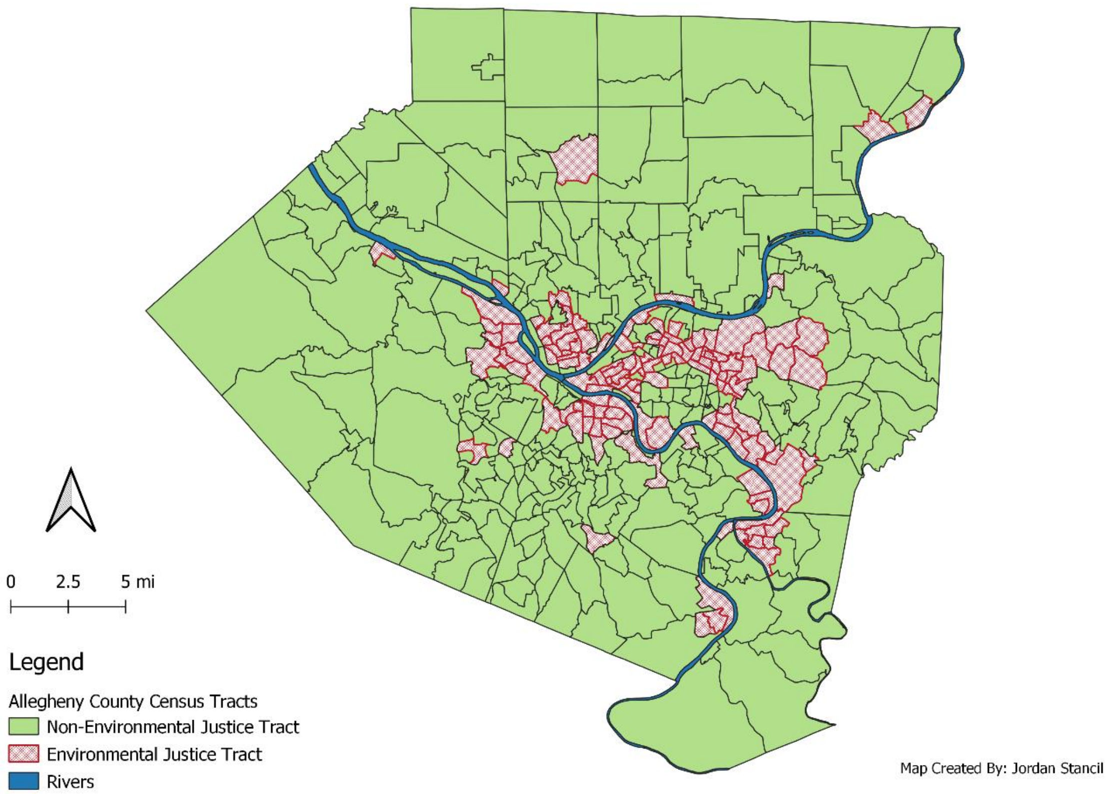

Figure 1. Map of Allegheny County Census Tracts

Census tracts shown in red communicate Environmental Justice Areas. Map created by the author using QGIS software and "Environmental Justice Areas 2010 Data" shapefile via the Western Pennsylvania Regional Data Center (WPRDC).

3.0 General Pb Information

Lead is a naturally occurring metal that does not degrade in the environment and can exist in various chemical forms[15]. This metal is continuously transferred between air, water, and soil by natural processes in the environment, which means each of these can be a media through which people are exposed to Pb[15]. Knowledge of the toxicological effects of Pb in humans can be traced back almost 2,000 years and is largely non-disputed[15]. The documented health effects of Pb are diverse, as exposure to this metal is associated with toxicity to every organ system in the body[15]. Lead also distributes widely throughout the entire body, and toxicity has been observed in each organ system at Pb concentrations in the blood of less than 10 µg/dL[15]. The existing body of research has not established an exposure threshold for effects on specific organ systems, which also means that no safe level of Pb exposure has been discovered[15]. Out of all affected systems, neurological effects of Pb are the most concerning, particularly in children[15]. The most robust and best substantiated effects are the cognitive deficits exhibited in children exposed to very low levels of Pb (i.e. Blood Lead Levels of less than or equal to 5 µg/dL)[15]. The United States Department of Health and Human Services considers Pb and Pb-compounds as, "reasonably anticipated to be human carcinogens", as well as "probable human carcinogen" based on criteria from the International Agency for Research on Cancer[15]. Table 1 catalogs the predominant health outcomes associated with Pb that are described in the "Toxicological Profile for Lead" compiled by the Agency for Toxic Substances and Disease Registry (ATSDR)[15].

Table 1. Predominant Health Effects Associated with Pb

Information Source: "Toxicological Profile for Lead" (ATSDR)[15]

Note: This list does not reflect the health outcomes resulting from a combination of these physiological effects, or those combined with existing comorbid conditions seen throughout the population, particularly in historically marginalized communities and/or those of lower socioeconomic status.

Physiological Effect Category	**Example Health Outcome(s)** ***(Not an exhaustive list)***
Neurological	Decreased cognitive function and learning deficits; Altered neuromotor/sensory function; Altered mood/behavior; Peripheral neuropathy; Encephalopathy *(Particular susceptibility in children)*
Renal	Proteinuria; Histopathological damage; Impaired tubular transport
Cardiovascular	Increased risk of hypertension, atherosclerosis, heart disease, and cardiovascular-related mortality
Hematological	Decreased hemoglobin content; Anemia
Immunological	Perturbation of cell-mediated and humoral immune systems
Reproductive	*Males:* Alterations in semen/sperm quality; Decreased fertility *Females:* Spontaneous abortion; Early-onset menopause; Preterm birth; Decreased fertility
Developmental	Delayed onset of puberty; Decreased birth weight and size; Decreased anthropometric measures in children

3.1 Routes of Exposure

Exposure to Pb in the general population primarily occurs via the oral route, with some contribution from inhalation[15]. Therefore, people are mainly exposed to Pb from food, soil, drinking water, dust, and ambient air. Pb is also a component of many consumer/commercial products including, but not limited to, cosmetics, jewelry, ammunition, pottery glazes, and solders used in plumbing fixtures that deliver drinking water[15]. Exposure varies between adults and children, as adult exposures to Pb that are greater than background levels are generally associated with occupational activities[15]. However, the primary source of Pb exposure in children is from surface dusts/soil that contain Pb from sources such as deteriorated Pb-based paint[15]. This Pb-containing dust in the environment is especially accessible to children because of the proximity of their breathing zone to the dust source and their considerable hand-to-mouth activity[15].

3.2 Blood Lead Levels

Since Pb is distributed widely throughout the body, Blood Lead Levels (BLLs) are the most common biomarker of Pb exposure[15]. It is important to note that BLLs reflect acute exposure to Pb and do not represent the potential cumulative, long-term exposures where Pb is sequestered in places in the body such as bone[15]. Research involving BLLs has largely focused on low blood Pb concentrations (less than or equal to 5 µg/dL) where health effects are generally observed, which strengthens the claim that there is no safe level of Pb[15]. Additionally, the CDC recently decreased the Blood Lead Reference Value from 5 µg/dL to 3.5 µg/dL in October 2021[16]. This reference value is used to identify children aged one to five years with levels of Pb in their blood greater than or equal to this value[16]. Using this value, children in the top 2.5% of BLLs among all children tested in the National Health and Nutrition Examination Survey are then classified as having elevated blood Pb levels[16].

4.0 History of Pb Contamination

The recent decrease in Blood Lead Reference Value represents a culmination of major public health successes in the past 50 years to combat the longstanding history of Pb contamination in the United States. The Industrial Revolution introduced the widespread extraction of Pb, which exposed people to levels of Pb not previously encountered in human history[2]. Additionally, the use of Pb in paint was routine during the early 1900s, as the paint industry saw major expansions with the capability of producing pigments on a large commercial scale[2]. The use of Pb in residential paint was unregulated until 1955 when the paint industry reportedly adopted a voluntary standard where paints with more than 1% Pb by weight were no longer allowed for interior use[2]. For reference, interior paints used prior to 1940 contained, on average, about 50% Pb by weight[2]. Another one of the largest historical sources of Pb was the exhaust from leaded gasoline used in motor vehicles[2]. This is demonstrated by data released in the late 1970s from the CDC that revealed the close correlation between BLLs in the general population, and the concentration of Pb in gasoline[2]. An additional manner of Pb exposure with historical significance is drinking water, primarily through the corrosion of Pb-containing plumbing fixtures[2]. During the late 1800s and early 1900s, Pb pipes were commonly used in the construction of main service lines for drinking water because of their pliability and relatively good resistance to corrosion compared to iron and steel[2]. These individual types of Pb exposures, and often their combined effects, were associated with extreme BLLs during this time[2]. Decreases in exposures to Pb in the population are evidenced by substantial and sustained decreases in BLLs in the United States over the past 40 years, with a direct link to public health-based policy efforts[2].

4.1 Pb Legislation

Historic legislation enacted to reduce the public's exposure to Pb has resulted in an overall reduction in BLLs since the 1970s[2]. Some landmark policy efforts include the Lead-Based Paint Poisoning Prevention Act of 1971 (the ban officially took effect in 1978), the removal of Pb from gasoline in 1972, and the Safe Drinking Water Act of 1974[2]. There have been multiple amendments to each of these pieces of legislation as well, reflecting the continued prioritization of Pb as a public health concern. The United States government routinely sets goals involving Pb reduction, such as those outlined in the CDC's "Healthy People 2020" objective, and has met these 2020 goals, but the benefits are not uniformly distributed[2]. Significant disparities still exist based on Pb exposure by race/ethnicity and income across the United States[2].

4.2 Pb in Drinking Water

Drinking water can be contaminated with Pb on its journey from water treatment facilities into homes through pipes that contain Pb, or traveling within the home through Pb-containing plumbing fixtures[17]. While the Safe Drinking Water Act of 1986 included stipulations to reduce the amount of Pb used in commercial and residential plumbing, fixtures made of Pb can still be found in older homes, and many public water systems still utilize their existing Pb pipes[17]. Therefore, to control Pb in drinking water from public water systems, the United States Environmental Protection Agency passed the Lead and Copper Rule (LCR) in 1991[18]. This regulation requires public water systems to monitor drinking water at customer taps for both Pb and copper (Cu) concentrations[18]. If Pb concentrations exceed the action level of 15 parts per billion (ppb), or Cu concentrations exceed the action level of 1.3 parts per million (ppm), in more than 10% of the customer taps sampled, the water system must take multiple steps to control the corrosion in their system, including the possible replacement of service lines under their control[18]. If an action level for either Pb or Cu is exceeded, the water system must also provide the public with information about steps they should take to protect their health[18]. Recent revisions to the LCR in 2020 prioritized the following areas: identifying areas most impacted, strengthening treatment requirements, replacing Pb service lines, increasing sampling reliability, and improving risk communication[19]. A key feature introduced in the revised LCR is a "trigger level" of 10 ppb of Pb in drinking water, where systems that do not currently treat for corrosion are required to re-optimize their existing treatment plans to mitigate the increased Pb levels[19]. However, criticism surrounding the revisions focuses on the fact that the action level for Pb still remains at 15 ppb, as well as the decrease in the amount of lead service lines required to be replaced from 7% to 3% in each city per year; this means it will take several decades longer to replace existing Pb pipes in communities across the United States[20]. These Pb-containing fixtures and pipes can be particularly problematic in areas with a larger population of historically marginalized groups and/or families from a lower socioeconomic status, as these environmental justice communities are unlikely to have access to the same resources to replace Pb fixtures as more affluent areas.

4.2.1 Flint, Michigan

Likely the most prominent example of Pb-contaminated drinking water in recent history is the Flint, Michigan water crisis which began in 2014, where residents continue to deal with the fallout nearly a decade later. This public health crisis was a direct result of the city's cost-cutting decision to switch its municipal water supply from Lake Huron to the Flint River[21]. This switch was not accompanied with appropriate treatment of the new water source, resulting in chemical changes in the municipal water system piping, which caused Pb from these pipes to leach into the drinking water delivered to the nearly 100,000 residents of Flint, more than half of whom racially identify as African American[21, 22]. This improperly treated, Pb-contaminated water was supplied to residents for nearly a year and a half until elevated Pb levels in tap water and samples of residents' blood were discovered, and the original water source was reinstated in October 2015[21]. Pb concentrations in the Flint tap water during and following this corrosion event often exceeded the LCR action level of 15 ppb, and in some cases, exceeded hazardous waste levels (greater than 5000 ppb)[21]. A Community Assessment for Public Health Emergency Response was conducted in 2016 to evaluate the health outcomes of the Flint residents, and the results demonstrate that 66% of households reported one or more adult members experiencing at least one behavioral health issue "more than usual" after the water crisis, as well as 54% of households reported this same experience in children[23]. Over half of households also reported they felt that the physical health of at least one member had worsened due to the water crisis[23]. These behavioral results are compelling, as the most serious and well-documented health outcomes from Pb are neurological effects, especially in children.

4.2.2 Allegheny County, Pennsylvania

On a local level, Allegheny County has also had its share of challenges with Pb in its municipal drinking water systems. With increasing water quality concerns across the county, an analysis was conducted on the quality and transparency in Allegheny County community water systems, aptly titled, "Something's in the Water[20]." Published in 2021, this report by local nonprofit organization, Women for a Healthy Environment (WHE), found that in 2019, 80% of the community water systems sampled in Allegheny County had detectable levels of Pb in the drinking water delivered to residents across the county[20]. Contextualizing these results with the EPA's Lead and Copper Rule, WHE discovered that over 17% of these water systems exceeded the 10 ppb "trigger level" for Pb, with 3% exceeding the 15 ppb LCR action level for Pb. Despite these statistics, the report highlights that only 36% of the Allegheny County water systems sampled had Pb hazard information available to residents on their websites[20].

4.3 Pb in Older Homes: Allegheny County, PA

In addition to potential exposure to Pb in drinking water, a significant threat is posed to residents with older homes, as flaking or peeling Pb paint, and Pb-containing household dust, accounts for up to 80% of EBLLs in children across the United States[17]. While the residential use of Pb paint was banned in 1978, this regulation inherently does not apply to existing homes in which Pb paint was used. This is a critical distinction with local importance, as over 80% of homes in Allegheny County were built before 1978, with over 40% of those built before 1950[17]. Additionally, in one of the most populated areas in the county, the City of Pittsburgh, over 85% of homes were built before 1978, with over 60% of those built prior to 1950[17]. While any of the homes constructed before 1978 could contain Pb paint, those built before 1950 are likely to contain the most Pb paint[17].

5.0 Case Study: Spatial Analysis of Allegheny County EBLLs, Older Housing, and Environmental Justice Communities

To better understand the childhood elevated blood lead levels in Allegheny County and their relationship with Environmental Justice communities and older housing, the author of the present review created maps and conducted spatial analyses of these variables in QGIS and GeoDa software packages. These analyses involve open-source data about Allegheny County from the Western Pennsylvania Regional Data Center including Environmental Justice Census tract designations from 2010, percent of Census tract childhood population with EBLLs between 2015-2020, and percent of pre-1950 housing between 2010-2014[13].

5.1 Mapping

Figure 2 depicts Allegheny County Environmental Justice Areas and the percentage of the childhood population with EBLLs in each Census tract, as well as an inset map for a closer look at these patterns in the City of Pittsburgh. In this map, the EBLLs are illustrated with a graduated point, which means the higher the percentage of childhood population with EBLLs, the larger the point appears in each Census tract. Visually, the largest points appear to occur within Environmental Justice Census tracts, consistent with the idea that Pb exposure in Allegheny County is an Environmental Justice concern. Then in Figure 3, to visualize areas of higher Pb exposure, the percentage of housing in each Census tract built before 1950 was added to the variables mapped in Figure 2. This is an important factor, as housing built before 1950 generally confers a higher Pb exposure if the home still contains Pb paint[17]. In Figure 3, this additional information about the percentage of older housing is shown as a graduated layer, where darker shaded Census tracts indicate areas with a higher percentage of pre-1950 housing. The EBLLs are again shown as a graduated point, but now with darker colored points indicating a higher percentage of childhood population with EBLLs in a given Census tract, rather than the size of the point. The resulting maps visually describe the pattern that Census tracts with the highest percentage of childhood population with EBLLs are also, in general, Census tracts with the highest percentage of pre-1950 housing. Higher percentages in both metrics, EBLLs and pre-1950 housing, also appear to coincide with Environmental Justice Census tracts. These maps provide visual evidence to support the idea that higher Pb exposures in Allegheny County, and therefore higher prevalence of EBLLs in children, tend to occur in Census tracts with a greater population of historically marginalized residents and/or residents of lower socioeconomic status. The combination of these trends supports the claim that Pb remains a compelling environmental justice issue in Allegheny County.

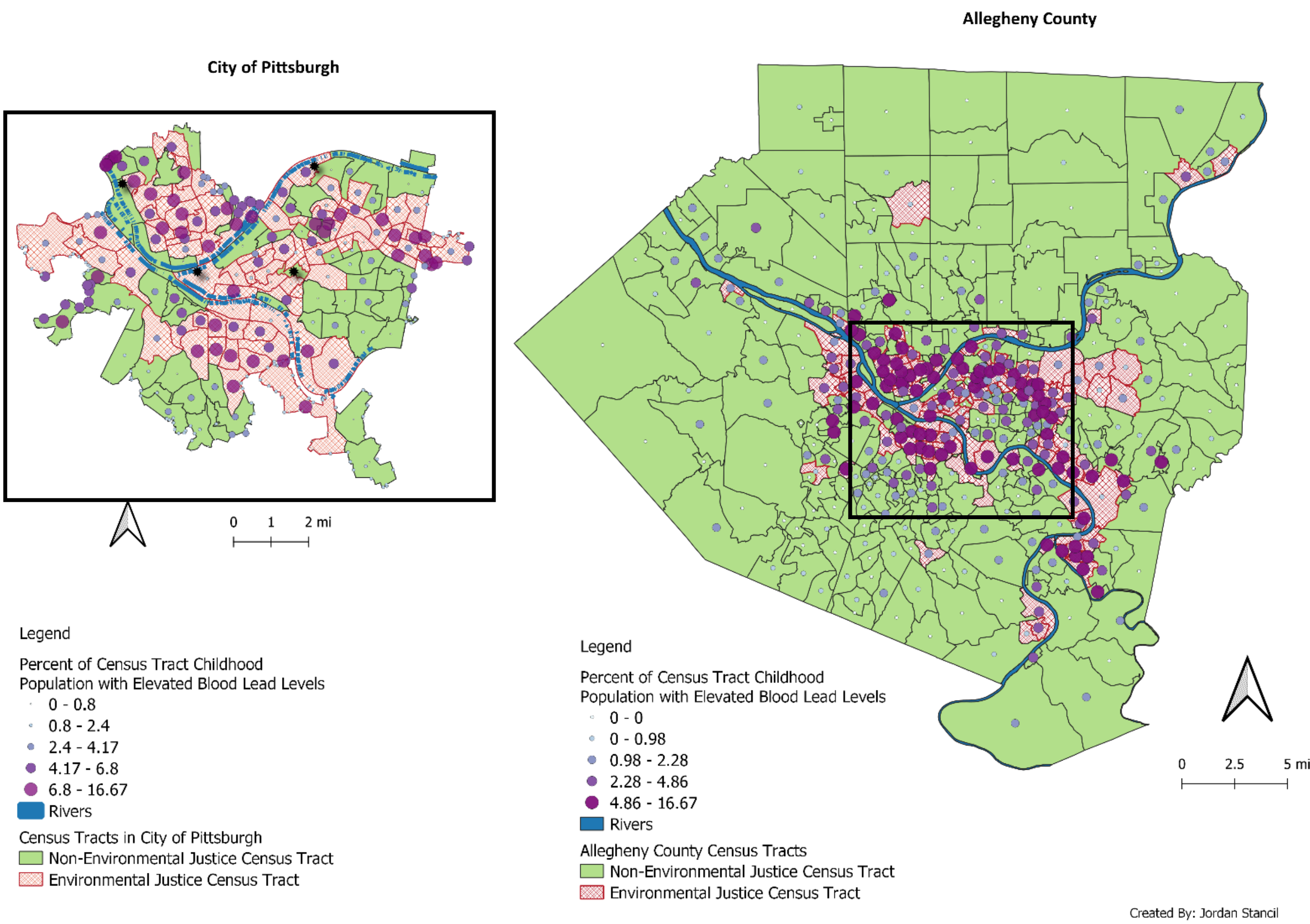

Figure 2. Map of Childhood Elevated Blood Lead Levels and Environmental Justice Census Tracts in Allegheny County and the City of Pittsburgh

Maps created by the author with data from the Western Pennsylvania Regional Data Center including "Allegheny County Department of Health 2010 Census Tract Data" and "Allegheny County Elevated Blood Lead Level Rates" shapefiles.

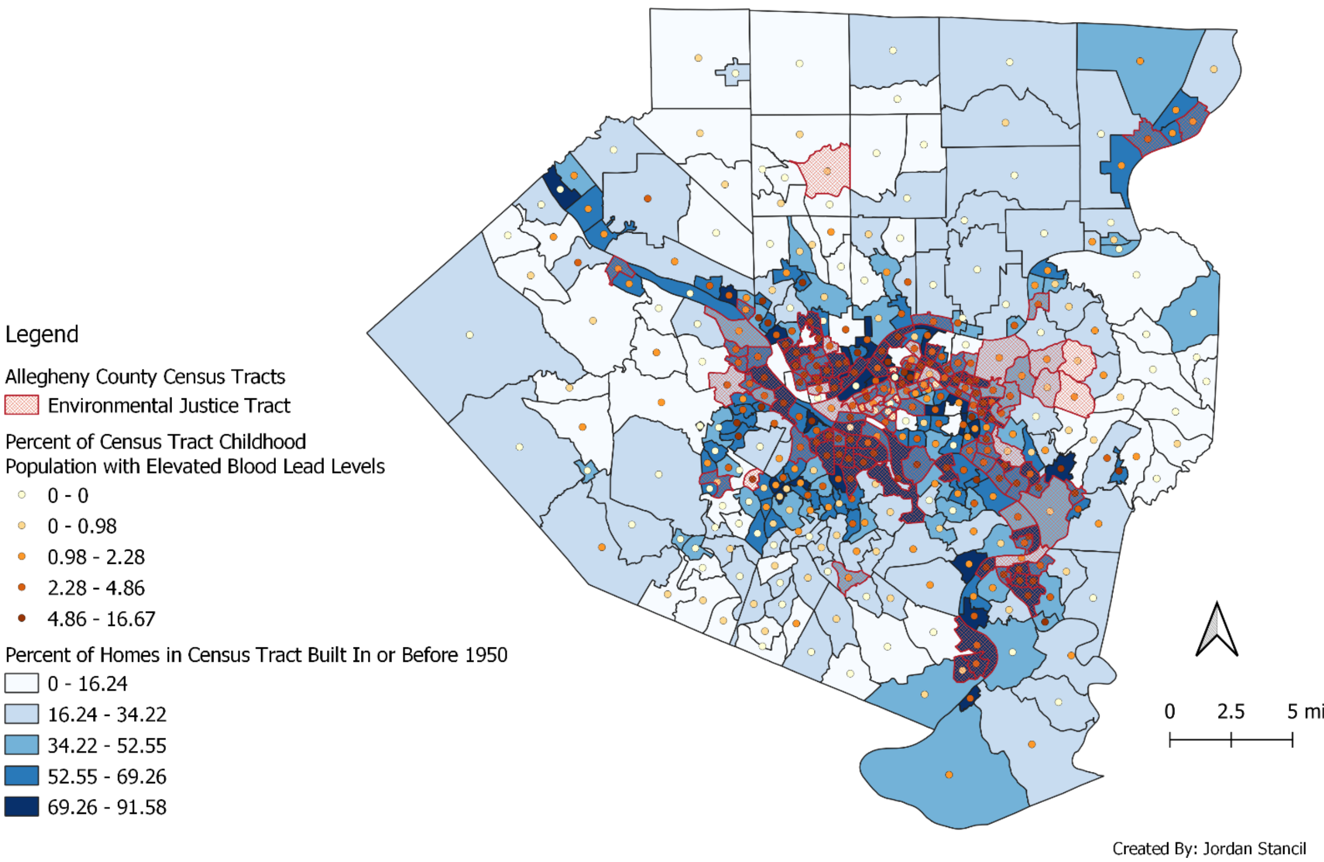

Figure 3. Map of Housing Built Before 1950, Childhood Elevated Blood Lead Levels, and Environmental Justice Communities in Allegheny County

Map created by the author with data from the Western Pennsylvania Regional Data Center including "Allegheny County Department of Health 2010 Census Tract Data", "Allegheny County Elevated Blood Lead Level Rates", and "Pre-1950 Housing Data" shapefiles.

5.2 Spatial Analysis

In addition to visually illustrating the relationship between the three variables of interest, spatial analyses were also conducted to provide additional information about the childhood EBLLs variable. Table 2 outlines the spatial analysis methods performed in GeoDa and their corresponding output(s). Exploratory Spatial Data Analysis results are demonstrated in the box map, shown in Figure 4, of the percentage of childhood population with EBLLs in each Allegheny County Census tract. As depicted in this box map, there are 12 Census tracts (shown in dark red) considered “upper outliers,” which means that the percentages of children with EBLLs in these 12 Census tracts are more than 1.5 times the inner quartile range higher than the 75th percentile (i.e., third quartile) of EBLL percentages across the county. Additionally, this box map communicates that nearly half of the Census tracts in Allegheny County report the percentage of childhood population with EBLLs in at least the 50th percentile, many of which are greater than the 75th percentile. The majority of these outlying and high-percentile Census tracts appear to correspond with the Environmental Justice Census tracts depicted in the constructed maps shown in Figures 1, 2 and 3.

To determine if there is spatial clustering of EBLLs in the county, a Global Moran’s I test was performed which resulted in a value of 0.422 with an associated p-value close to zero. This means there is statistically significant evidence of positive global spatial autocorrelation in percentage of childhood EBLLs in Allegheny County Census tracts. In other words, the spatial distribution of high or low percentage of EBLL in Allegheny County is more spatially clustered than would be expected if the underlying spatial processes were random. Since this global test produced significant results, a local cluster detection test was also performed to investigate where hot spots of percentage of EBLLs appeared within Allegheny County. Results from this test are shown in Figure 5 in the form of a Gi* Cluster Map of EBLL percentages. As demonstrated in this cluster map, there are 53 Census tracts (shown in red) that, along with their immediate neighboring Census tracts, have higher percentages of childhood EBLL values when compared to the rest of the Census tracts in Allegheny County. This cluster map provides evidence of local spatial clustering of high percentages of childhood EBLLs in Allegheny County, which again, appear to follow a similar pattern as the Environmental Justice Census tracts across the county.

In addition to mapping and cluster detection, spatial regression was also conducted to gain a better understanding of the quantitative relationship EBLLs have with Environmental Justice areas and Pre-1950 Housing. After producing Ordinary Least Squares, Spatial Error, and Spatial Lag regression models of EBLLs on Environmental Justice areas and percentage of pre-1950 housing, the Spatial Lag model was chosen to represent this relationship. The concept of spatial lag suggests a potential diffusion process in the geospatial data[24]. In other words, spatial lag suggests that events (e.g., EBLLs) in one place predict an increased likelihood of similar events in neighboring places[24]. As shown in the selected regression model output summary in Table 3, Environmental Justice area status and percentage of pre-1950 housing are both statistically significant predictors of childhood EBLLs in Allegheny County. This type of regression model includes a spatial lag term that is also statistically significant with a positive coefficient, which communicates that percentage of EBLLs in a given Census tract are positively associated with percentage of EBLLs in neighboring Census tracts. For example, in a given Census tract “A,” if a neighboring Census tract “B” has a high percentage of childhood EBLLs, this likely indicates a high percentage of childhood EBLLs in Census tract “A” (Note: this general relationship is the same for Census tracts where low percentages of EBLLs appear clustered as well). This model also has a corresponding R-squared value of about 0.55 which means that approximately 55% of the variance in percentage of childhood EBLLs can be explained by Environmental Justice Census tract status and percentage of pre-1950 housing in Allegheny County Census tracts. This is not a particularly strong R-squared value, in terms of predicting specific childhood EBLL percentages from Environmental Justice area status and percentages of pre-1950 housing, but the general relationships between EBLLs and predictors are still statistically significant. These original spatial analyses provide quantitative evidence that EBLLs in Allegheny County children are significantly associated with Environmental Justice areas and percentage of pre-1950 housing. When paired with the constructed maps, these analyses also demonstrate that higher percentages of both childhood EBLLs and pre-1950 housing disproportionately cluster in Environmental Justice areas.

Table 2. Spatial Analysis Methods Used to Analyze Elevated Blood Lead Levels Variable

Method	Output
Exploratory Spatial Data Analysis (ESDA)	Box maps for outliers
Global Test for Spatial Autocorrelation	Moran’s I test ($p<0.05$)
Local Test for Spatial Autocorrelation	Cluster test via Gi* ($p<0.05$)
Spatial Regression (Spatial Lag Model)	EBLL regressed on Environmental Justice status and percentage of pre-1950 housing ($p<0.05$)

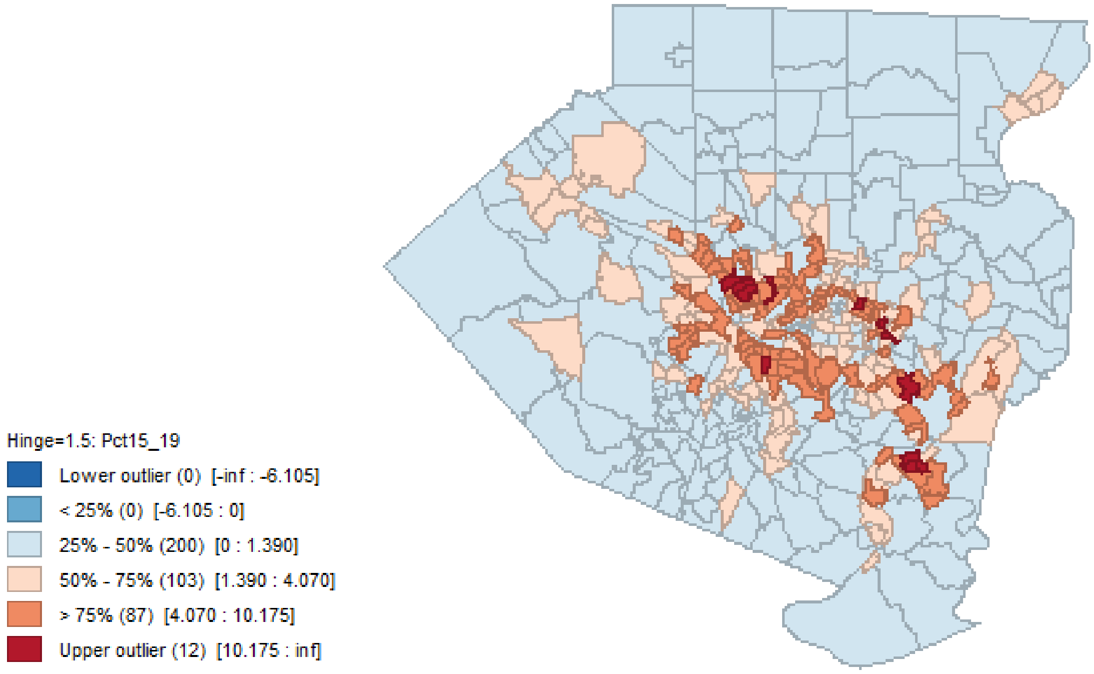

Figure 4. Box Map for Outliers in Percent of Childhood Elevated Blood Lead Levels

Map created by the author in GeoDa software with data from the Western Pennsylvania Regional Data Center including "Allegheny County Elevated Blood Lead Level Rates" shapefile. Hinge=1.5 communicates outliers that are more than 1.5 times the inner quartile range higher than the third quartile (upper outliers) or below the first quartile (lower outliers).

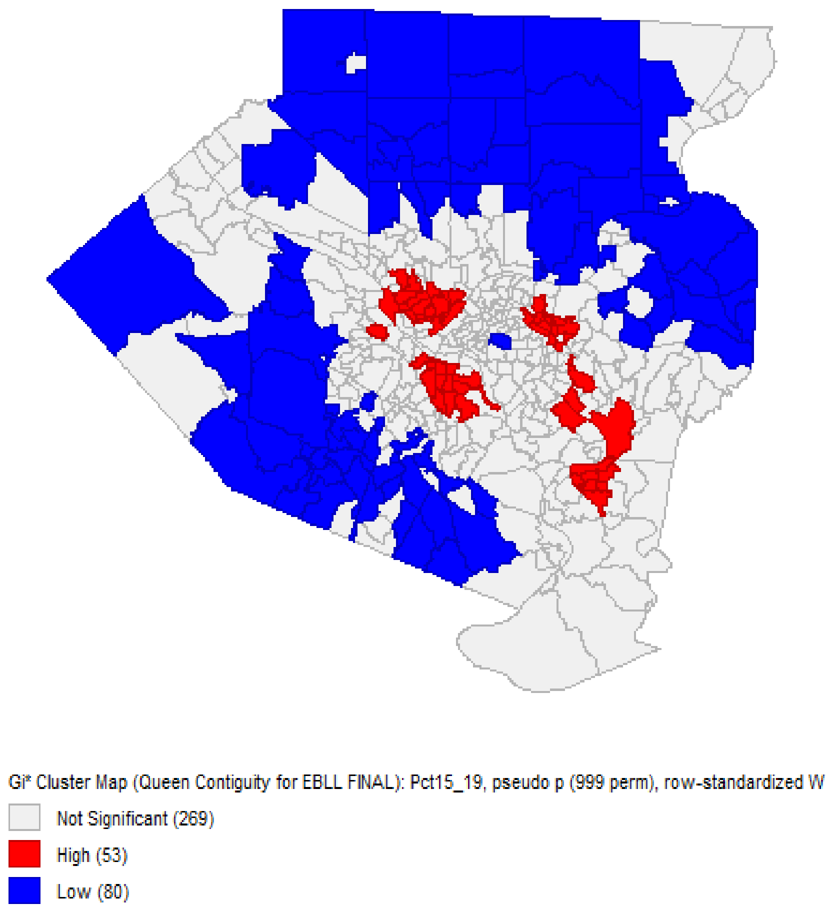

Figure 5. Gi* Cluster Map for Detection of Local Spatial Autocorrelation in Percent of Childhood Elevated Blood Lead Levels

Map created by the author in GeoDa software with "Allegheny County Elevated Blood lead Level Rates" shapefile from the Western Pennsylvania Regional Data Center. Red areas indicate Census tracts where high percentages of childhood EBLLs are clustered. Blue areas indicate Census tracts where low percentages of childhood EBLLs are clustered.

Table 3. Output Summary for the Spatial Lag Regression of Percent of Childhood Elevated Blood Lead Levels on Environmental Justice Area Status and Percent of Pre-1950 Housing in Each Census Tract

Spatial regression performed by the author in GeoDa software with data from the Western Pennsylvania Regional Data Center including: "Allegheny County Department of Health 2010 Census Tract Data", "Allegheny County Elevated Blood Lead Level Rates", and "Pre-1950 Housing Data" shapefiles. (Note: There is evidence that spatial dependence and heteroskedasticity exist in this model, and the normality assumption was also violated)

Covariate	Coefficient (β)	Standard Error	p-value
Spatial Lag Term	0.384848	0.0528646	<0.000001*
Constant	-1.01305	0.216805	<0.000001*
Environmental Justice Area Status (This is an indicator variable where 1=EJ Area, 0=Non-EJ Area)	1.69552	0.259417	<0.000001*
Pre-1950 Housing (This variable is represented as a percent of existing housing built before 1950)	4.70922	0.502728	<0.000001*

**Asterisk indicates statistically significant results*

6.0 Policy Implications

This case study in Allegheny County is likely just one of many similar scenarios in areas across the United States which demonstrate the disproportionate effect of Pb on residents within Environmental Justice communities. With decades of existing evidence that has not determined a safe level of Pb, mitigation efforts have been recommended to the public, particularly to families with small children since they are most vulnerable to Pb. Official recommendations are generally directed towards the individual level, especially to parents of children that have already been exposed to Pb. However, it is important to keep in mind that these Pb exposures often result from larger structural/systemic factors that allow Pb to remain in homes, or in the water that is delivered to homes, not from the actions of individual families. Making recommendations to parents of children exposed to Pb is crucial in supporting the health of those children, but this is inherently a reactive approach, not one that aims to solve or prevent the problem of Pb exposures altogether. Additionally, these recommendations for Pb, and other environmental hazards, generally do not address the historical policy decisions that perpetuate the disproportionate hazards for residents of environmental justice communities across the United States.

6.1 Existing Individual-Level Recommendations for Pb

For parents of children with elevated blood lead levels, the CDC published a list entitled, "5 Things You Can Do to Help Lower Your Child's Lead Level[25]." These five things include making a plan with the family doctor, finding the source of Pb in the home, cleaning up Pb dust in the home, giving the child healthy foods, and learning more/getting additional support[25]. These are necessary and important recommendations, but they make bold assumptions about the resources families readily have at their disposal, especially for residents of Environmental Justice communities where health outcomes are significantly impacted by many intersecting systemic factors. For example, it is important to recognize that while it is true families likely have access to a primary care physician for their children through personal means, or state-sponsored programs like the Children's Health Insurance Program in Pennsylvania, the CDC's recommendation to families about making a plan with their doctor depends on many other factors than just access to physicians in the area. These factors include, but are not limited to, reliable/safe transportation, time constraints, childcare, and distrust of health professionals, which can all be significant barriers to care for families in Environmental Justice communities[26]. Additionally, the recommendation for parents to give their children healthy foods is an incredibly nuanced issue for families from historically marginalized groups or those of lower socioeconomic status. For families living in Environmental Justice communities, this represents another potential obstacle in following official Pb exposure reduction recommendations, as consumption of healthy foods is a multidimensional issue that depends on factors such as access to stores with healthy food, cultural frameworks, safe/reliable transportation, and financial constraints among many others[27].

Other common recommendations made to families, specifically to prevent Pb exposure from drinking water are, "obtain a National Science Foundation-approved water filter that removes lead" and/or "consider using bottled water for infant formula and as drinking water for pregnant women[28]." These suggestions are helpful in many situations, but they again make assumptions about the financial position of families to be able to obtain additional resources (filters, bottled water, etc.) to try to mitigate a chemical hazard that was pumped into their homes from a public resource. Many of these recommendations also assume that residents are even aware of a Pb problem in their community, which could be unlikely if there are not significant transparency efforts by the public water systems. Recommendations like these from the CDC, or other local public health entities, are critical to promoting the health of children in the community, but they cannot be the only response to Pb contamination, particularly for families in Environmental Justice communities; systemic efforts must also exist.

6.2 Existing Systemic/Governmental Efforts for Pb

On a national level, the CDC has established the Childhood Lead Poisoning Prevention Program, which supports state and local public health departments with funds for prevention of Pb exposure and surveillance efforts, with the overall goal of preventing childhood Pb exposure before harm occurs[29]. On a local level in Allegheny County, a universal Pb testing regulation went into effect in 2018 that requires all children be tested for Pb exposure at approximately 9-12 months after birth and then again at about age two[30]. This type of secondary prevention measure allows the health department to monitor for childhood EBLLs across the county and is an essential safety net for children already exposed to Pb[29].

Allegheny County also supports primary prevention efforts for Pb exposure, including the Allegheny Lead Safe Homes Program, which offers qualifying homeowners/renters in the county free home Pb paint testing and hires certified Pb abatement contractors to eliminate or stabilize Pb paint in homes[31]. The qualifications for this program include that the home was built prior to 1978, a child under six or a pregnant woman lives in the home, and the household is under 80% of the area median income[31]. This program could be helpful for many families in Environmental

Justice communities, as the criteria appear to try to qualify many of the households that would be most affected, but it is still the resident's responsibility to initiate this process. Therefore, knowledge of Pb in the home, awareness of the program itself, and resources necessary to initiate the process are certainly limiting factors in its utilization, and therefore impacts its effectiveness in preventing Pb exposures. However, this program in Allegheny County represents a significant effort by local government to reduce exposure to Pb at the source, rather than just responding to its effects.

6.3 Policy Recommendations: Pb

Based on estimates made in 2019, about 23 million housing units across the United States contain significant Pb-based paint hazards, as well as 6.1 million housing units that contain Pb water service lines, representing a large amount of people vulnerable to Pb exposure[2]. Low-income and poorly maintained rental properties should likely be the first priority to eliminate or control these Pb hazards, as residents of these properties likely have the least control over the maintenance of their rented property and are often most vulnerable[2]. In addition to Pb in homes, a key focus for policy initiatives should be to prioritize full replacements of Pb services lines throughout Allegheny County, the Commonwealth of Pennsylvania, and ultimately the United States. To actualize this widespread full replacement of existing Pb service lines, increased financial investments in public infrastructure are needed at the federal, state, and local levels. Increasing investments in public infrastructure is critical for promoting health equity in environmental justice communities, as removing the potential for Pb exposures in a fundamental resource such as water should not be a privilege; Pb-free water should be considered a right for all people.

It must be acknowledged that eliminating Pb from all sources may not be realistic in every case. Therefore, policies and practices that institutionalize control measures and maintenance are critical to prevent recurrence of Pb hazards in properties that have not yet been made free of Pb[2]. Additionally, an essential tactic in combating Pb is the integration of federal, state, and local primary prevention plans to help eliminate Pb exposures[2]. The current body of research suggests that diverse public-private partnerships are essential elements for developing, promoting, and monitoring evidence-based, comprehensive public health interventions to control and eliminate lead hazards from the environment[2]. Blood Pb surveillance programs, such as the universal testing efforts in Allegheny County, should continue operating at full capacity, as these are proven practices of monitoring Pb exposure particularly in children, which allows medical intervention for the most vulnerable. However, the emphasis should not solely be on these secondary prevention efforts. These programs are essential fixtures of a sound public health response to Pb, but they must be accompanied by adequate primary prevention efforts that seek to eliminate sources of Pb wherever possible.

6.4 Policy Recommendations: Environmental Justice

Continuing to reduce Pb exposures in the population, and ideally preventing them altogether, would be an incredible milestone in promoting the health of all people in the United States. However, the reality for Environmental Justice communities is that residents are not solely impacted by one type of hazard, such as Pb. The existing body of research surrounding environmental health has demonstrated the health impacts of these individual pollutants, like Pb, but there is increasing evidence to suggest that environmental hazards/stressors often have synergistic effects on the health of communities[9]. The American Public Health Association refers to this synergistic relationship as “cumulative impact”, a concept they define as, “the combined, incremental effects of human activity and their consequences for human health[9].” Addressing the cumulative impact on Environmental Justice communities first requires an acknowledgment of the historic policy decisions that have permitted/encouraged environmental inequities to continue today[9]. In addition to the federal government’s minimal, and slow, regulatory response to the initial environmental concerns of communities of color in the 1970s, structural and systemic racism/discrimination in planning measures have historically contributed to environmental injustices, leading to public health concerns in communities that are now given the Environmental Justice designation[9]. Examples of practices that have contributed to inequitable development include discriminatory housing policies, segregation, suburbanization, massive highway construction, deindustrialization, and biased zoning (“Jim Crow Laws”, exclusionary zoning, redlining, etc.)[9]. Gentrification is also a significant issue for urban Environmental Justice communities, as residents are often displaced due to inflated costs of living within their communities[9]. For families in Environmental Justice communities, these historic systemic factors often give way to, or are combined with existing poverty, crime, unemployment, decreased access to nutritious food options (i.e., “food deserts”), poor quality infrastructure, limited access to green spaces, and reduced access to transportation[9]. All of these factors can have adverse effects on human health, so an important aspect that must be factored into the cumulative impact on Environmental Justice communities is the increased prevalence/incidence of comorbid conditions such as obesity, diabetes, neurological and psychiatric disorders, cardiovascular disease, and adverse maternal and child health[9]. To adequately address the needs of Environmental Justice communities, a more holistic approach must be adopted.

Cumulative impact analyses, which incorporate social determinants of health in communities have been used to begin understanding the full scope of stressors in Environmental Justice communities and the impact of the existing policies in these areas[9]. A concept known as "health in all policies", must be adopted in the policymaking process, as it attempts to address these cumulative impacts by including considerations of health impacts into all policy decisions[9]. For example, public health departments at all levels, as well as public health advocates, should work across sectors to develop and promote policies that translate analyses, such as the case study presented in this review, or more robust cumulative impact analyses, to inform concrete actions about zoning policies, monitoring, compliance/enforcement, resource allocation, and mitigation programs[9]. For the new/modified policies to have the most meaningful impact on Environmental Justice communities, the quantitative data collected in these analyses should also be supplemented with qualitative data that acknowledges the lived experiences of residents in these communities. An intentionally holistic approach to advocating for environmental health is required to move towards a healthier, more equitable future for residents of Environmental Justice communities.

7.0 Conclusion

Decades of research have resulted in a robust body of evidence that demonstrates the harmful effects of Pb at any level, specifically in children. Interventions to decrease Pb exposures have allowed for a great reduction in overall blood Pb levels across the United States, but disparities in exposures remain. This represents a significant Environmental Justice issue, as residents from historically marginalized groups, and those in areas with lower socioeconomic status, continue to be disproportionately impacted by exposures to Pb, as shown in the case study of this review, as well as other environmental contamination events. The onus of protecting communities from environmental contaminants cannot solely be on residents to protect their families from problems caused by current and historic policymaking that failed to consider the health of their community. Policy decisions must prioritize the health of all residents, especially those from historically marginalized groups, lower socioeconomic status, and other vulnerable populations. Individuals should not have to worry that fundamental resources, such as the water supplied to their homes or the air they breathe in their communities, are contaminated because of decisions made at their expense by governing bodies and corporations to cut costs. Additionally, residents of Environmental Justice communities should be afforded the same level of protection against environmental hazards as their neighbors in surrounding areas, and their health should be advocated for when they cannot advocate for themselves. With mounting research showing the cumulative, disproportionate burden of environmental hazards that residents of Environmental Justice communities bear throughout the United States, and locally in Allegheny County, it is unacceptable to allow this pattern to continue. While there are effective strategies and public health interventions that can be readily implemented to combat Pb contamination, and other environmental hazards, the most impactful step towards Environmental Justice is likely one that involves an ideological shift in policymaking where health is considered throughout the entire process. The historic harm done to residents of Environmental Justice communities, and the cumulative impacts, must be acknowledged and used to inform a healthier, more equitable future for all. The policymaking process, and the resulting decisions made on behalf of communities, must prioritize the health, wellbeing, and safety of all residents with continued effort to protect the most vulnerable.

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