HUMN HEALTH EFFECTS OF LEAD IN THE ENVIRONMENT: A MULTI-SOURCE APPROACH OF ELEVATED LEAD EXPOSURE AMONG AT-RISK POPULATIONS IN PITT COUNTY, NORTH CAROLINA, USA

By

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ABSTRACT

Despite lead (Pb) in public drinking water has been studied extensively, Pb in homes has received less attention. Elevated Pb level in homes is a growing public health concern as Pb exposure in children is known to cause a multitude of health outcomes, including impaired brain function, behavioral disorders, reduced attention span, memory loss, lower IQ, antisocial behavior, and mood disorders. Most of the homes with higher Pb levels are considered low-income, older, or outdated apartment buildings, where at-risk populations (low-income, minority populations that rely on government assistance to assist with daily needs) typically live and may be unaware of Pb exposure risks. Using secondary data from multiple databases, this ecological study was aimed to: (1) identify potential environmental sources of Pb in different areas of homes in Pitt County, North Carolina, and (2) explore the association between children blood lead level (BLL) and age, gender, race, and sampled years (2018, 2019, 2020) using General Linear Model (GLM). Further, the distribution of minority populations, education level, Pb in homes, and age of homes were mapped using ArcGIS and EPA EJScreen for the United States to determine potential trend. Our GLM results showed a significant positive association between BLL and age of the child (p=0.022); however, there were no significant racial or gender differences in BLL (p>0.05), and that sampled years (2018, 2019, 2020) did not differ

significantly in BLL (p>0.05). On average, White children had higher average BLL compared to Black or Other races; while White females, Black males and Other males had higher average BLL compared to their opposite gender. ArcGIS and/or EJScreen mapping showed a general clustering of minority populations and low-income status with the distribution of homes with Pb-based paint in the United States. Within homes, windowsill had more than an order of magnitude higher Pb level (691.8 µg/ft^2) compared to other areas (common entry, bedroom, kitchen, and dust) sampled in North Carolina, suggesting windowsill as a prominent source of children Pb exposure in homes. In Pitt County, Greenville had the highest number of homes with elevated Pb compared to other major cities. Overall, children between the age of 1 year 3 month and 3 year 6 month showed a pattern of elevated BLL, while around the 2 yr. age group, the W population had a BLL over the current CDC threshold (3.5 µg/dL) and almost reaching the previous CDC threshold (5 µg /dL), underscoring the need to protect White children that may be disproportionately exposed to Pb in homes. The lack of specific federal and state laws and/or policies around the need to testing all children for BLL calls for an immediate action to implement mandatory testing for children BLL regardless of race or housing conditions. Only then more children could be protected from Pb exposure and health risks.

Human Health Effects of Lead in the Environment: A Multi-Source Approach of Elevated Lead Exposures Among At-Risk Populations in Pitt County, North Carolina, USA

A Dissertation

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CHAPTER 1: INTRODUCTION

Lead (Pb) is a toxic heavy metal found naturally in the Earth's crust and the environment (Rosen et al., 2017). The use of Pb has declined over the past half-century, but Pb exposure continues to be a major public health concern (Rosen et al., 2017). This heavy metal is a persistent environmental contaminant and is a known neurotoxicant for humans (Lu et al., 2022). Lead is harmful to humans in ways that will affect overall bodily function for anyone that ingests or inhales at various levels. This can include impaired brain function, anemia, and hypertension, additional illness and disease may develop among children at an older age, depending on the extent of Pb exposure (WHO, 2021; Mayans, 2019). More specifically, impaired brain function, behavioral disorders, including reduced attention span, memory loss, lower IQ, antisocial behavior and mood disorders are known health effects of elevated Pb exposures in children (Mason et al., 2014).

Children are most vulnerable to Pb poisoning or plumbism because they are still developing, while lower-income and rural populations are exposed to Pb from homes equipped with Pb-based piping, Pb paint, and other sources (Hanna-Attisha et al., 2018; Trueman et al., 2016). The continued burden of Pb in at-risk populations, including minority populations, pregnant women, and children, can lead to increased healthcare costs. With no effective treatment against lead poisoning, the urgency to renovate and replace Pb piping and Pb-paint must be a high priority.

Lead in public drinking water is an ongoing public health concern in the United States and worldwide. However, acute, and chronic health effects of Pb in humans are yet to be thoroughly investigated (Pieper et al., 2019). The Centers for Disease Control and Prevention (CDC) and the World Health Organization (WHO) have asserted that no amount of Pb is safe for humans (CDC, 2022; WHO, 2021). Through previous years, the amount of Pb considered acceptable by the

CDC has been lowered multiple times based on new knowledge. Per the CDC, the current acceptable blood Pb level (BLL) is 3.5 micrograms per deciliter (μg/dL) (CDC, 2022).

The United States Environmental Protection Agency (US EPA) enacted the Lead and Copper Rule (LCR) in 1991 to regulate Pb and Cu in drinking water and for Pb concentrations not to exceed 15 parts per billion (ppb) (Lu et al., 2022; Fields, 2006). The act has been revised multiple times throughout the past three decades to provide up-to-date information for consumers and communities. Upon the act's passing, multiple Pb and Cu violations were discovered in communities and homes across the nation. Most of these violations occurred at homes with Pb-based piping and paint in communities with an overall lower infrastructure within the city; lower infrastructure includes homes built before 1978, before the ban of Pb based paint. In 1974, the Safe Drinking Water Act (SDWA) was passed that mandated safe drinking water for all consumers in the United States (Raucher, 1996). The SDWA was later amended in 1986 to include the abolishment of Pb-based piping for drinking water for homes, businesses, and schools. Both acts regulate drinking water. However, potential contamination of public drinking water supply with Pb, Cu, other heavy metals and contaminants still occurs today.

In the US, multiple regulations and policies are in place but at-risk populations are still vulnerable to Pb in public water, Pb paint, and other sources of Pb; the risk is high enough to where illness and disease can occur. Those at risk of high BLL are low-income and rural populations including children and pregnant women, two of the most vulnerable groups for heavy metal poisoning. These groups have been reported to have higher BLLs than the average Caucasian urban residents (Cassidy-Bushrow et al., 2017). Over the past several decades, minority and income populations have had an average Pb level above the acceptable threshold of 3.5 μg/dL, a few years ago the threshold was 5 μg/dL, and years before this, 10 μg/dL (CDC, 2022). Across all of these years, according to The National Health and Nutrition Examination Survey, minority populations had a BLL above the acceptable threshold from 1976 to 2016 (Egan et al., 2021)

Despite the SDWA and its amendment banning Pb-based piping, there are no rules or regulations within the act stating that Pb piping must be replaced within a specific time. Thus, Pb piping is still prevalent within the nation, specifically in rural and lower-income neighborhoods and communities with older homes. In addition, older homes built before 1986 contain Pb-based piping that can leach Pb into the water supply and are covered in Pb-painted walls (Jarvis et al., 2018). In the United States, there are an estimated 9.7 million homes with full Pb-based piping for drinking water and an estimated 81 million homes with Pb solder joints, another source of Pb in drinking water (Jarvis et al., 2018).

Lead service lines (LSL), or Pb-based piping (LBP), are pipes made of Pb that connect a water main to a user's premises (Trueman et al., 2016). Research has shown that most, if not all, of the Pb consumed by the population, emanates from the LSL and not from the distribution center (Guo & Herrera, 2021). Lead and other toxic metals, such as Cu, is known to flake off or corrode LBP (Guo & Herrera, 2021). Homes without LBP but with brass or Cu parts or piping within their systems can still be the source of Pb exposure because Pb is allowed in piping but only up to 8% (Pieper et al., 2019). The 8% of Pb associated with non-Pb-based piping (NLBP) can lead to Pb poisoning or plumbism.

Plumbism is a disease that can affect all populations within the country and around the world. Plumbism occurs when Pb enters the body, either through inhalation or ingestion, and is deposited into the skeletal system and then released into the bloodstream, impacting multiple systems. Symptoms include developmental and learning disorders in children, including headache, fatigue, memory loss, hypertension, seizures, and rashes (Miracle, 2017).

The best way to treat plumbism is to prevent the disease before it starts. Plumbism can and should be prevented in all situations in which children and adults may be suspected of exposure. Exposure can include Pb-based paint (banned in the United States in 1978, but older homes built before 1978 still contain Pb paint), Pb-contaminated drinking water, pollution, brass fixtures, and chemical plants/construction zones (Miracle, 2017).

Lead in Dust

Most Pb in dust articles are based in urban environments studied/conducted after the ban on Pb within the home in the early 1990s (Studies include Egan et al., 2021; Ettinger et al., 2019; Dignam et al., 2019; Cassidy-Bushrow et al., 2017; Wani et al., 2015; Kianoush et al., 2015; Harvey, 2002). There have been very few studies since the ban of Pb products for the home conducted on Pb in dust. The author was able to conduct assessments of Pb-in-dust articles from the late 1990s to the early 2000s and concluded that there is no extensive research regarding Pb in dust in the present day. The research conducted was based on prior guidelines outlined in the early stages of Pb banning and does not reflect current actions taken in the past.

These articles (Egan et al., 2021; Ettinger et al., 2019; Dignam et al., 2019; Cassidy-Bushrow et al., 2017; Wani et al., 2015; Kianoush et al., 2015; Harvey, 2002) are based on children in urban populations that included all populations regardless of race/ethnicity, income, gender, and other deciding factors that may limit inclusion within a study. Most of the studies concluded that Pb in dust comes from a variety of factors that include environmental, behavioral, socioeconomic, high Pb level environment, and housing evaluations. Neither of these factors was individually tested/studied for specific populations, leading to the conclusion that dust, for all populations, affects all children. There were no specific levels of Pb in dust that affected children on different levels because there is no safe level of Pb for children or adults. The studies conducted reflected prior standards of CDC guidelines of the acceptable level of Pb as 10 µg/dL; most of the studies conducted had at least half of this amount or over this BLL in the adolescent populations.

Many of these studies conducted included only toddlers or children aged less than 48 months/4 years old. Studies were not conducted on children older than 4 years old; based on the research conducted for this study. Within these studies, follow-ups were conducted between 3 and 12 months, but none beyond the 12-month mark, making it difficult to determine if elevated BLL can affect children at their toddler stage into their older years. BLL can contribute to higher rates of behavioral and physical ailments that are possibly not known until years after exposure. Inhaled and ingested Pb can be deposited in the bones and released over time at a rate that may be detrimental to someone's health.

Based on the studies/research conducted for this study, Pb in dust is one of the leading contributing factors to elevated BLL in children of all populations in urban areas; none of the studies researched were conducted in rural populations with at-risk populations. In all studies, among most of the population studied, there were confirmed cases of elevated BLL.

Lead in Paint

An estimated 38 million housing units in the United States have Pb paint with an estimated 24 million having significant Pb hazards that could affect an individual's health (Jacobs et al., 2002). About 20% of this population are low-income families living at or below the poverty level during this time, making $30,000 a year or less. Over 50% of the low-income housing units in this population had a declared hazard for Pb paint in the home. Households making above $30,000 had a 19% rate of a declared hazard (Jacobs et al., 2002).

As with dust, Pb paint has been extensively studied across all populations since the ban in 1978. The ban brought new research on the effects of Pb paint in children. There are limited studies on how Pb in paint effects in both short- and long-term. Again, research was done on all populations with no specification as to gender, race/ethnicity, and location. Although, most studies (including Egan et al., 2021, Cassidy-Bushrow et al., 2017, Sampson, 2016, and Harvey, 2002) were conducted on children aged 6 or less, and the results were similar to Pb in dust and Pb in water. There is no safe level of Pb paint, and ingested paint that has Pb can lead to an increased risk of health problems in acute or long-term settings (CDC, 2022).

Acute health problems were discussed in these studies (Egan et al., 2021, Cassidy-Bushrow et al., 2017, Sampson, 2016, Harvey, 2002, and many others) but the long-term effects were not discussed. All studies utilized for this study documented Pb levels in children and did not follow them for several years after; potentially leading to a gap in knowledge as to how Pb in paint can affect children who live in the home for extended periods. The studies concluded that children are only affected by Pb in paint if the paint is ingested as flakes or chips released from the wall. Flaking or chipping of paint can lead to increased levels of dust and Pb exposure through inhalation, further contributing to Pb toxicity.

Specific Aims of the Study

The main objective of this study was to determine if and how Pb within the home affects at-risk populations in terms of health in the United States, North Carolina (NC), and Pitt County, NC. This central objective was met with three Specific Aims below:

Specific Aim 1: Determine if at-risk populations are disproportionately affected by Pb within the home.

Specific Aim 2: Determine whether there are specific clusters of homes with excess Pb in Pitt County, North Carolina.

Specific Aim 3: Assess the effectiveness of the current Pb policies and regulations and provide recommendations to protect at-risk populations.

Hypothesis and Research Questions

Null Hypothesis (H_0): The varying degree of Pb within the home will not disproportionately affect at-risk population's health.

Alternate hypothesis (H_A): The varying degree of Pb within the home will disproportionately affect at-risk population's health.

The primary research questions for this study are:

1. How do household Pb levels compare among Pitt County, North Carolina (NC), NC, and the United States?
2. Does Pb disproportionately affect low-income and rural populations?
3. What laws, policies, and mitigation measures can help address Pb exposure among at-risk populations?

Rationale and Significance of the Study

Lead has been researched and deciphered more than any other element on the periodic table in terms of exposure via water, paint, and dust. Lead contamination within home and workplace has decreased significantly over the past several decades, which has led to a steady decrease in BLL across all populations across the country, including children. The BLL has decreased for all minority populations, including males, females, African Americans, Latinos/Hispanics, and other races/ethnicities. The rate of Pb poisoning for African Americans and other minority populations has decreased over the last several decades; along with the dominant population, Caucasian, who also had a decrease in Pb levels. Lead poisoning among minority populations is declining rather at a slower rate compared to the Caucasian populations (Egan et al., 2021). There was no significant difference in BLLs between genders. However, potential disparity in BLL between races/ethnicities has not been thoroughly studied because most studies concluded nearly all populations, regardless of race/ethnicity, gender, age, or other deciding factors, have the potential to be diagnosed with Pb poisoning. Nonetheless, some studies suggest that African Americans may have an increased risk of elevated BLL because of their overall lower economic status, educational status, and occupational status leading to an overall lower income (Cassidy-Bushrow et al., 2017). Their lower income leads to lower-income housing units, homes, or apartments. Most of these housing units were built before Pb-based paint and Pb-based piping were banned in 1986 and 1978, respectively. There are no rules or regulations stating that Pb-based paint and Pb-based piping will need to be replaced when the ban began. The African American population is housed in most of these older homes built before 1978 with Pb-based paint and/or Pb-based piping. Most of these units have not been renovated and others have historical restrictions to alter the housing structure. More so, with the lack of income and affordability, these housing units cannot be refurbished (U.S. National Park Services (USNPS), 2023).

A large body of research has concluded that Pb-based ailments, such as water, paint, soil, dust, and more can have detrimental effects on the human body, leading to a variety of diseases that may not be treatable. This has been researched extensively across the population but not within individual populations. Knowing which population has the worst health effects of plumbism can lead to advanced policy and regulation creation that will close the gap in healthcare between low-income/minority populations and higher income/majority populations. There is limited research on the extent to which plumbism occurs in minority populations. What was discovered is how much of a gap in literature there is between Pb in the home and the affected population that lives in the home. Pb in water has been researched and exhausted but the rate of Pb throughout the home has not been as thoroughly researched. Additionally, there are no other methods of detection for Pb-based ailments in the home across the United States. More specifically, there are no records or maps of homes with Pb-based piping, Pb paint, or heavy deposits of Pb in or around the home.

The central goal of this study was to assess the extent of Pb contamination in homes with at-risk populations across the United States, North Carolina, and Pitt County, NC. Through heat maps based on Pb levels, specific clusters of communities were identified in the United States, the state of North Carolina, and Pitt County, NC. Understanding how Pb levels affect at-risk populations on a state and county level can help address the healthcare needs of the minority populations and advocate for equal housing opportunity.

This is a public health issue because of the rate of elevated BLL and housing inequalities that plague the county, state, and country levels. With the assistance of government-based policies and laws being passed, such as the LCR and SDWA, creating guidelines specifically for at-risk populations will lead to an increase in overall health, safety, and equal housing opportunity. This study may serve as a guiding framework for health professionals and policy makers to understand how Pb can have detrimental effects on certain populations and not others. Further, this study may shed light on how older homes can be a major source of Pb exposure to children that can lead to elevated BLL and poor health outcomes.

Theoretical Framework:

This study follows Exposure Assessment framework. An exposure assessment process estimates the rates at which chemicals are absorbed by potential human receptors; generally used to determine the magnitude of actual and/or potential receptor exposure to chemical constituents (Asante-Duah, 2017). There are three fundamental steps to exposure assessment (Asante-Duah, 2017):

1. Characterization of the exposure setting: to include the physical environment and potentially exposed populations.
2. Identification of the significant exposure pathways: include sources or origins of release, exposure point, and exposure routes.
3. Quantification of exposure: to include efforts directed at determining exposure concentrations as an intake variable.

The exposure assessment is used as a public health intervention method that dictates the severity of chemicals against the human population. Pb is a highly toxic chemical that can have detrimental effects on the human body. Utilizing this assessment will create a detailed outline of how Pb affects at-risk populations. Utilizing the exposure assessment to conclude the overall risk of plumbism and elevated BLL in at-risk populations will potentially add to the research needed to create/promote health promotion programs through the public health sector for at-risk populations (Asante-Duah, 2017):

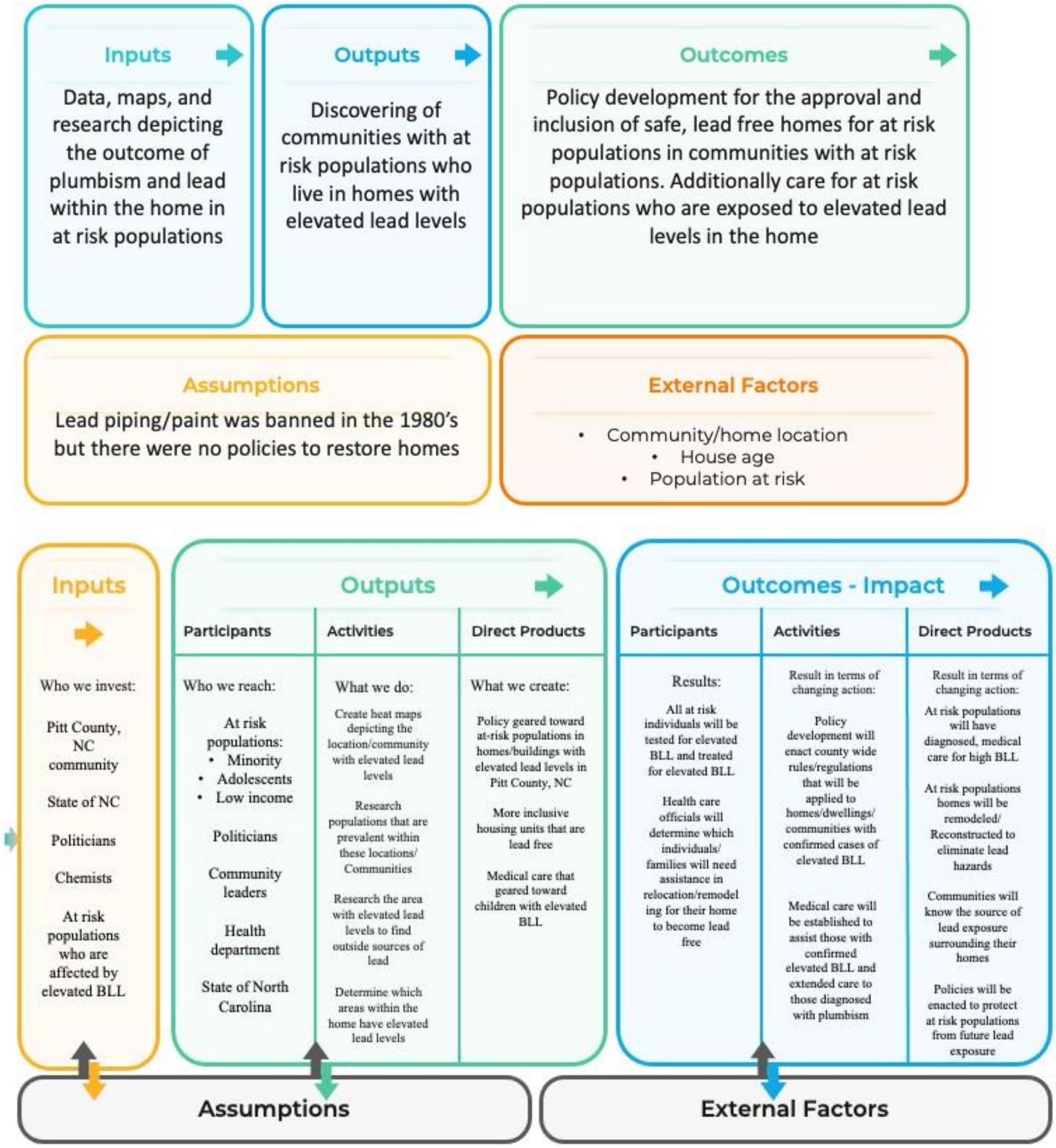

Figure 1: The logic model depicts the inputs, outputs, and outcomes for a population with elevated BLL.

Chapter Summary

Plumbism is a disease that has no cure or formal method of treatment. The effects of plumbism can be acute, long-term, or lifelong, based on the severity of the diagnosis/level of poisoning. Pb in water and homes has been an ongoing public health issue for decades with policy implementation for the general population. At-risk populations, pregnant women, children, low-income, and minority populations have a higher risk of plumbism which can lead to increased illness, lower socio-economic status, and an increased risk of death among the population. Most of these at-risk populations live in older homes, built before 1986 when all bans were finally enacted after decades of research, live near areas with high traffic or chemical work, and live in apartment/low-income housing units. A majority of minority populations cannot either afford to remodel their home, cannot remodel their home because of age, or are not able to move outside of their current residence.

Most of these residents do not know that there is elevated Pb within the home unless the homes are tested or someone within the home has an elevated BLL. Pb in homes can be detected in dust, windowsills, water, paint, bedrooms, and other areas within the home. Yet the rate of Pb within the home varies based on the age of the home, location, traffic within the home (individuals and pets), and the material the home was built with (LBP and Pb paint). Although, homes can be remodeled or refurbished to eliminate most traces of Pb. Most at-risk individuals and families do not have the funds to rid their homes of Pb or apartments buildings do not have the funds to remodel entire complexes. Because there were no policies or guidelines after the Pb ban in 1986 to remodel homes and buildings of Pb paint and piping, most homes today are still affected by elevated Pb levels to this day.

With the assistance of government-based programs, policies, and regulations children who are born into families with government assistance can get tested for elevated BLL six months after they are born and receive treatment upon confirmed case of 3.5μg/dL or higher. Although, groups outside of the at-risk population are not tested unless signs and symptoms occur because there are no policies, rules, or regulations for testing BLL when children are born or any other time thereafter unless the need arises. Because of this, individuals in at-risk populations oftentimes get undiagnosed cases of elevated BLL and are treated as another illness.

This study aims to develop recommendations for establishing necessary policies to test individuals among at-risk populations, discover populations/communities in Pitt County, NC that have elevated BLL, and inform regulators and stakeholders on the need to mitigate Pb exposure that may disproportionately affect at-risk populations living in older homes. Prior research concluded that Pb in the home is a significant public health hazard not effectively addressed. More specifically, Pb in water, paint, and dust was discussed exhaustively decades ago but with newfound healthcare access and research, new policy implementation and testing should be done.

CHAPTER 2: LITERATURE REVIEW

History and Chemical Properties of Lead

In small quantities, certain heavy metals, such as Zinc (Zn), Arsenic (As), and Chromium (Cr) are beneficial to the human body, as a nutritional source for a healthy life. For some heavy metals, such as Pb, Hg, and Cd, this is not the case as they are harmful to humans (O.B. & M., 2010). Pb has been linked to being the most toxic metal for humans and causes the most damage to the human body because it cannot be broken down within the human body in its natural state. Without degradation, these chemicals will accumulate within the human body and be stored, mainly, within the skeletal system (O.B. & M., 2010).

Pb is a heavy metal that can be found around the world and is used widely for multiple products that consumers use every day (Rosen et al., 2017; Kianoush et al., 2015; Wani et al., 2015). Because of its malleable and soft texture, Pb has been used for thousands of years (ATSDR, 2021; Rahimzadeh et al., 2015). During ancient times, Pb was used for building, sweetener for wine, and for other uses that are not common practice in the present (Rahimzadeh et al., 2015). Today, Pb is used far less because of the high risk of exposure that can cause illness in the population. Previously, Pb was a common ingredient in household paint, water plumbing fixtures, gasoline, toys, craft supplies, and batteries but is mostly banned today in these items based on research regarding the harmful effects of this chemical in everyday products (CDC, 2020; Grant, 2020).

There can still be traces of Pb in these products and more, but the amount of Pb found in these products has decreased significantly. The decline of Pb within these products and more has occurred over the past several decades. There has been a steady decline of Pb because Pb is formally recognized as a general metabolic poison (Damstra, 1977). The elimination of Pb in products stems from the chemical causing illnesses in all populations, specifically at-risk populations. Individuals in at-risk populations include pregnant women, children, and minority groups (Cassidy-Bushrow et al., 2017). Research has concluded that Pb affects different populations because of varying factors. These factors include occupation, housing, and socioeconomic status.

At-risk populations are not limited to underserved, disabled, economically disabled individuals, communities, or populations that are made up of racial and ethnic minorities (Chin, 2005). The definition of at-risk populations can change varying on the population and the situation that the population is in. For this paper, at-risk populations are communities or individuals, including children and pregnant women, who have a high risk of developing plumbism.

At-Risk Populations

Populations at risk of increased Pb exposure include low-income, minority, residents in both rural and urban settings, living next to a high-volume roadway, or living in a home/building/apartment that was built before 1978 (Sansom et al., 2019). Research over the past several decades has concluded and shown that low-income and minority communities have a higher risk of Pb exposure through various routes, including ingestion and inhalation through Pb-based paint, water, dirt, or fumes compared to more affluent populations (Sansom et al., 2019). Affluent populations can include, but are not limited to, individuals in majority populations, newer homes built after the passing of the laws regarding Pb in the home, and individuals who have replaced their Pb-based piping within their residence. Research has concluded this evidence, but few studies have explored the injustices and inequities related to at-risk populations' drinking water, Pb paint, and other sources of Pb. This has been tedious to accomplish because there are no plans or maps stating which houses, apartments buildings, and other residents have Pb-based plumbing, Pb paint, or higher confirmed levels of Pb within the home. A study completed in 2020 concluded that there could be roughly 3-6% of the United States population could have Pb-based plumbing, but this is only an estimate based on surveys from across the country (Triantafyllidou & Edwards, 2012). There could be housing or residents, including businesses that have Pb-based plumbing and may not know it.

In 2020, the CDC estimated 2.6 million African American families were at risk for plumbism from various sources in their homes including the water supply, interior paint, and outside sources including chemical plants within the surrounding living area (Biggers and Lockett, 2022; CDC, 2020). This is just a fraction of the estimated number of 9.7 million houses that are supplied by Pb-based piping or Pb-based connection pipes (Jarvis et al., 2018). Even more, an estimated 81 million homes contain Pb-based connections or solder joints (Jarvis et al., 2018). The estimation of 2.6 million African American families at risk for plumbism is included in the 9.7 million houses that are supplied by Pb-based plumbing, but the 2.6 million do not include other minority populations.

These minority populations include not only the African American population, but also Hispanic/Latina, Pacific Islander, Asian, Native Americans, and more. Within these populations, children and pregnant women are more at risk because of their circumstances. Circumstances include, for children, their developing bodies, making it more suspectable for illness/disease and hand-to-mouth gestures that will lead to cross-contamination (Wani et al., 2015). For pregnant women, the risk of developing plumbism can be detrimental to their health because of their developing fetus and then the breastfeeding of the infant (Ettinger et al., 2020). Because Pb can readily cross the placenta, Pb exposure can begin for individuals within the womb and continue when the baby is born (Ettinger et al., 2020). Additionally, breastfeeding can transfer Pb from the nursing mother to the offspring.

Children and Lead

Children's exposure to plumbism is an ongoing public health issue that has been studied and researched for centuries. Historically, over the past half-century, children's BLL has decreased from an average of 12.8 µg/dL between 1960 and 1990 to 0.84 µg/dL by 2014 (Gibson et al., 2020). This decrease stems from the elimination of Pb in common products, such as paint, toys, and gasoline (CDC, 2020). Additionally, the advances in medicine and the understanding of how toxic metals, such as Pb, affect the human body, have made medical professionals, scientists, and policymakers change how we interact with chemicals. With the advancements and knowledge that we have now of Pb, the rate of plumbism across the nation for children, in general, has decreased (Gibson et al., 2020; Ettinger et al., 2019). As of 2016, roughly 4% of children aged 7 or below have a high, above 3.5 µg/dL, BLL (Gibson et al., 2020). The newest guideline from the CDC, as of 2022, of acceptable BLL in children is 3.5 µg/dL. This guideline has changed drastically over the past four decades because of the continued understanding of how Pb affects the human body; although, the CDC does state that there is no safe level of Pb in the human body.

Defining a typical case for childhood Pb exposure can be misleading because Pb exposure can occur across multiple stages of childhood and affect every child differently (Sansom et al., 2019). Children are most vulnerable because of absorption in the ingested Pb because of their underdeveloped bodily systems, including neurological and skeletal. More specifically, the absorption of Pb within the gastrointestinal tract in a children's body can be 50% greater than in adults (Sansom et al., 2019). With this absorption within the gastrointestinal tract, Pb can be spread or carried throughout the body.

When Pb spreads throughout the body, it can reach the brain and other vital organs/systems and cause significant, irreversible damage or illness to the child. Illness can include a decreased IQ and attention disorders from a neurological standpoint, or physical symptoms from nausea, vomiting, and organ damage (Gibson et al., 2020). While the burden of plumbism can happen at any age across childhood or adulthood, the effects of Pb are worse on children.

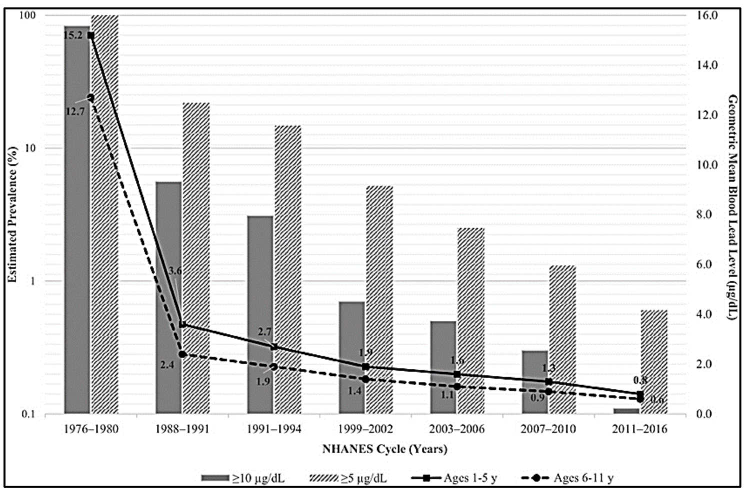

Figure 2: The estimated percentage of BLL in children aged 1-11 from 1976 to 2016 (Egan et al., 2021).

The National Health and Nutrition Examination Survey (NHANES) conducts annual surveys on a variety of health concerns for children and adults. Since its founding in the 1960s, the program seeks to gather and distribute information regarding public health concerns that are at the forefront of society (CDC, 2019; Markowitz, 2000).

The NHANES created this graph over the past forty years depicting the steady decrease of BLL of children aged 1-5 and 6-11 (The graph is divided by age group) for all children in the United States (Egan et al., 2021). Each period, roughly 4 years, depicts two age groups, ages 1-5 and 6-11 of children's exposure to Pb. In the graph, each period depicts two bars; the solid-shaped bar shows the rate of exposure for children above 10 µg/dL and the striped box depicts the rate of exposure above 5 µg/dL. The solid line represents ages 1-5 and the dotted lines represent ages 6-11. As the rate of plumbism declines, so do the bars on the graph. More specifically, the solid and lined bars are for estimated percentages. The estimated percentage on the left side of the graph represents the estimated percentage of children in the United States who have a BLL over 5 µg/dL or over 10 µg/dL. Starting with the first-time block, children between the ages of 1-5 had an estimated percentage of almost 100% for a BLL of over 10 µg/dL and a 100% rating for 5 µg/dL. This means that all children in the United States, between the ages of 1-5, had a least a BLL of 5 µg/dL, and the majority had over 10 µg/dL, or an overall average of 15.2 µg/dL per child in the United States for children aged 1-5 between 1976 and 1980. For children between the ages of 6-11, the average BLL was 12.7 µg/dL between 1976 and 1980. The highest rate of BLL among children in the United States, per the data from NHANES, was 15.2 µg/dL for ages 1-5. The second highest was from the same period, 1976-1980,

NHANES concluded that the cause of the decline of BLL among children is the advances in medical research, public health awareness, the decline or elimination of Pb in common products used daily, and the change of Pb-based piping (Egan et al., 2021). NHANES has the only period data providing the decline of BLL of children over an extended period, ultimately no organization, program, or policy has documented the BLL for all forty years post the passing of the LCR.

Health Effects of Lead

Drinking water has been established as a significant factor and contribution to an individual's overall Pb content ranging from 1%-20% of the total burden within the body (Jarvis et al., 2018). The overall Pb burden can be greater than 20% because of Pb in public water or from other sources. Pb is a divalent cation, and it binds tightly to certain groups of proteins; this binding affects many organs and systems within the human body, including, the most important, central nervous system (CNS) (Needleman, 2004). It is not completely understood or known the exact amount of Pb being consumed from Pb-based piping and the amount of Pb that flakes or erodes from the Pb-based piping (Jarvis et al., 2018). Factors such as temperature, plumbing material, corrosion, and water use patterns can vary from home to home and because of this the amount of Pb leached in the water supply varies (Clark et al., 2014). Because of the unknown amount of erosion from Pb-based piping, the fluctuation of Pb exposure can be high, specifically from season to season. Trueman et al. concluded that Pb released from Pb-based piping can be high during the summer months and low during the Winter months varying greatly because of the temperature and use of water during these seasons. It is suggested during the summer months, more water is consumed, and more Pb is eroded from the pipes because of the high temperature. During the Winter months, water consumption decreases along with the lower temperature which would cause lower erosion (Trueman et al., 2022).

The classical definition of a diagnosis of acute plumbism typically involves the clinical observation of signs and symptoms. Signs and symptoms can include impairments of red blood cell (RBC) formation and function; severe CNS and peripheral nervous systems (PNS) functional impairment; kidney and renal dysfunctions (Grant, 2020). If an individual were to suffer from any of these conditions, their illness may be life-threatening (Grant, 2020). To conclude that plumbism is the actual cause of the signs and symptoms that are listed previously, more than a clinical examination will be needed.

The toxicity of Pb can be contributed to the distortion of enzymes and structural proteins and can target specific systems of the body, not only the CNS and PNS (Needleman, 2004). The effects on the CNS, PNS, and other major organs and systems do not occur unless there is prolonged exposure to Pb and heavy intoxication of Pb within the body. In many cases, plumbism has minor symptoms that subside with treatment; these symptoms include abdominal pain, nausea, and high blood pressure (Hussain et al., 2019). Targeted systems and organs other than the CNS and PNS include the skeletal system and kidneys (Hussain et al., 2019). If the kidneys become infected with plumbism, the damage can result in severe failure of the organ (Hussain et al., 2019). These cases of illness not only affect adults but children as well. Although, children will be affected on a higher level.

Pb toxicity can be examined in three different stages or levels: biochemical, subclinical, and clinical (Markowitz, 2000). Biochemical: On the biochemical level, Pb is distributed to all cells in the body, not targeting any specific organs or systems. On this level, Pb is bound or replaces calcium in calcium-binding proteins; once bound to the molecule, roles within the cell or human body intently meant for calcium mediation may be activated or inhibited (Markowitz, 2000). When this occurs, normal intracellular calcium-relayed messages are disrupted causing miscommunication between cells, body systems, and organs. Subclinical: The second level involves behaviors and physical impairments. Behaviors can include, in children, unruly behavior, such as lashing out in a negative way or hyperactivity (Markowitz, 2000). Clinical: This is the worst and most symptomatic level of plumbism, affecting the CNS and gastrointestinal tract (Needleman, 2004; Markowitz, 2000). When BLL reaches above 20 µg/dL on average, physical symptoms, such as abdominal pain, nausea, and headaches occur (Markowitz, 2000). Although, the threshold for physical symptoms to occur varies among children and adults and the actual threshold is unknown (ATSDR, 2021; Markowitz, 2000).

Multiple levels of plumbism still need to be studied and researched but the treatment for plumbism has been studied extensively. No cure currently exists for Pb poisoning, except that the signs and symptoms are treated. There are four modes of treatment: identification and elimination of the source of exposure; behavioral changes to diminish non-food related hand-to-mouth activity; nutritional counseling to inhibit Pb absorption; chelation therapy to increase Pb excretion. Chelation therapy is the most medically induced treatment that targets the Pb within the body and assists with elimination.

The EDTA (Ethylenediaminetetraacetic acid) chelation therapy effectively lowers high BLL but may not reduce defects or the side effects of plumbism (Gracia and Snodgrass, 2007). This is the case because there are no medical treatments or health effects to eliminate all Pb within the human body (Gracia and Snodgrass, 2007). Because of this, chelation may or may not be an effective treatment for plumbism and the need for this treatment for BLL below 45 μg/dL is controversial (Gracia and Snodgrass, 2007). The risk of chelation therapy can interfere with drugs that the adult or child is already taking, which can worsen the health effects (Gracia and Snodgrass, 2007). This is the case because chelation therapy causes a drastic decrease in BLL causing a possible influx or release of Pb from storage sites, such as the skeletal system, within the body (Gracia and Snodgrass, 2007).

Racial Inequality and Plumbism

Hundreds of years ago, the nation was divided by a racial disparity between the majority population, Caucasian, and minority populations, including African Americans, Hispanics/Latinos, Asian and Pacific Islanders, and others. The segregation gap between these majority and minority populations has closed significantly across various platforms of social, environmental, and occupational standpoints. More unheard-of segregation comes from exposure. Exposure in terms of poverty, housing structure, chemical exposure, medical treatment, and outreach.

Few studies have investigated racial and ethnic exposure to toxic heavy metals and chemicals. Those that have looked at race and ethnicity and compared them to chemical exposure have concluded that minority populations, specifically African American/Black populations, have a high risk of chemical exposure, whether it be from exposure within the home, living next to a chemical plant, and/or occupation (Gibson et al., 2020; Sansom et al., 2019; Cassidy-Bushrow et al., 2017; Sampson and Winter, 2016; Markowitz, 2000). More specifically, African American populations suffer greatly from chemical exposure, especially with Pb in the water supply (Gibson et al., 2020). In a study done by Gibson et al., nationwide there are persistent socioeconomic and racial disparities in minority populations, especially in African American children's populations.

African American children populations experience a higher rate of exposure than other majority and minority child populations; this rate accounts for nearly 5 µg/dL on average per child across the U.S. (Gibson et al., 2020). This rate is strictly for African American children, but African American adults (Besides African American children) still experience a high rate of BLL among other minority and majority populations as well. African American adults experience a

BLL almost twice as high as other majority and minority populations (Gibson et al., 2020). The suggested root cause of these higher rates of BLL occurs because of low-income, poor housing/older homes, and living in high-poverty neighborhoods with poor infrastructure (Gibson et al., 2020; Sampson and Winter, 2016). Again, very few studies have investigated the effects of these causes on BLL.

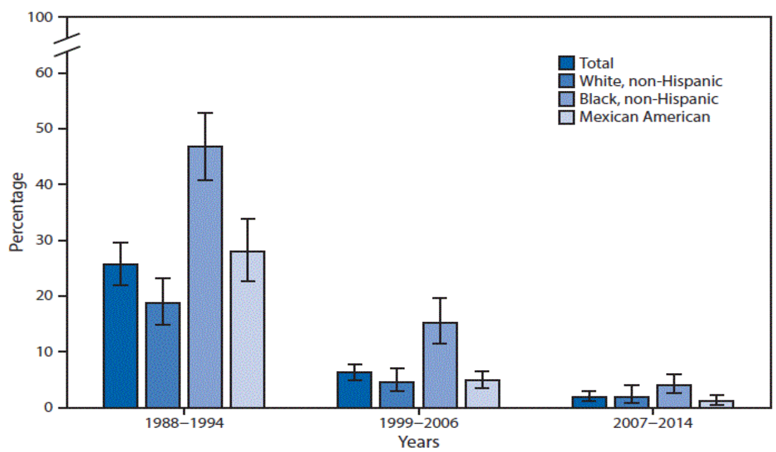

Figure 3: Changes in percentage of U.S. children aged 1-5 year with blood lead level (BLL) above 5 µg/dL compared across three races: White non-Hispanic, Black non-Hispanic, and Mexican American, over time (CDC, 2016).

Over the past three decades, there has been a drastic decline in BLL for all races in total and individually. For the total, or percentage, of all the children between the ages of 1-5 declined drastically from 1988-1994 to 1999-2006. During this period of decline, the use of Pb in different products declined or was eliminated. According to the graph, the total rate of BLL for White non-Hispanic children was less than 20% for all three time periods; Mexican American is the second lowest coming in at less than 30%; Black non-Hispanic has the highest rate of BLL with almost a 50% infection rate for all children aged 1-5 in the United States between 1988 and 1994. Although, the latter group had the most drastic decrease in cases between the first and second periods. These rates are not just for plumbism related to water consumption but for other forms such as inhalation from dust or paint from older homes. Even though rates have declined, there are still an estimated 500,000 children aged 1-5 years of age above the CDC-recommended guideline of 3.5 µg/dL (Egan et al., 2022; Ettinger et al., 2019). This is just a rough estimation and may not include all children within this age range.

Social Determinants of Health

***Income*:** Poverty and income by race/ethnicity have been an ongoing trend since the 1960s. The African American population is the biggest minority population in the United States, yet it's the population that has the highest rate of correlation between poverty and income. The rates of poverty and income have increased over the past several decades because of the increased value in the economy. The United States Census (2022) depicts the real median household income by race and Hispanic origin from 1967 to 2021. The data shows the upward trend of the value of money with the growing population; there is no rate of races/ethnicities fluctuating. All races/ethnicities have an upward trend, but no races/ethnicities are being devalued into one another. The highest population, by income, is Asian, and the lowest population is African American/Black. The median household income for African Americans in the United States in 1967 was an average of $30,000 a year, by 2021, the average was $48, 297. The only income base below $50,000 for all populations. The dominant population, Caucasians, has a median household income of $77, 999 in 2021, an $18,000 increase from 1967, $60,000, and an almost $30,000 increase from the African American population in 2021. Hispanics have an estimated $57, 981 incomes in 2021, over $8,000 difference from the African American population.

***Housing*:** Low income can coincide with low-income housing, older homes with a lower mortgage rate, and Section 8 housing. Most of these housing units are occupied by African Americans because of their average income level. By 2021, the United States population had a poverty rate of 12%; of that 12%, 20% equated to the African American population, and only

8.1% equated to the Caucasian population (USAFacts, 2021). Reports from the National Low Income Housing Coalition (NLIHS) document that Black, Native American, and Hispanic households are more likely than the dominant population, Caucasian, to be extremely low-income renters and live in or below the 30% poverty level of their area median income. The racial disparity and housing disparity equates to income, real estate, lending practices, and federal housing policies have made it much harder for minorities to obtain adequate housing. Racial disparities in housing were outlawed by the Fair Housing Act, but there are still barriers between races (NLIHS, 2019).

***Health Care Access*:** Minority populations have an increased rate of lower healthcare treatment from multiple aspects of healthcare, including obtaining insurance, dental care, and childbirth. Lower access to healthcare leads to an increased risk of treatable illness that is amplified by poor housing units. Plumbism can be treated when detected in the early stages. Cases of plumbism can be misdiagnosed as other illnesses; this is common among younger children who display symptoms of other common diagnoses, including Attention-Deficit/Hyperactivity Disorder (ADHD) and other mental health disorders, nausea, bowel syndromes, and slowed or delayed growth. Most of these common illnesses can be treated with over-the-counter medication, although plumbism cannot be treated with over-the-counter medication. Subsiding symptoms will not decrease the risk or effects of plumbism in children or adults.

Many parents, especially minority parents, do not know the risks associated with plumbism and how they affect children. This is also the case for many other illnesses because most of the minority population does not know the serious side effects of illnesses that can affect children and adults' long term. This is because healthcare access to the minority population is not as efficient as other major populations. The lack of care and access for minority populations affects their health negatively; there has been an increase in the gap between healthcare and majority populations, including the risk of death and the average age of living.

Low-income housing, income, and health benefits all coincide with an increased risk of plumbism and an increased risk of negative signs and symptoms progressing into adulthood for children in these situations. Not all children who come into contact will develop high Pb levels or plumbism, their anatomy, and other factors determine how their bodies will react to Pb exposure. Including these social determinants of health amplifies the risk of plumbism for minority populations.

Identifying Sources of Lead Exposure

***Lead in Public Water Supply*:** Episodes of Pb exposure and plumbism linked to drinking water have been recorded for centuries (Hayes & Hydes, 2012). Based on medical advice and evidence from previous studies, plumbism has been an ongoing health problem (Hayes & Hydes, 2012).

These studies were not just from the United States, but from other countries as well, including Canada, the United Kingdom, and countries in Europe (Guo & Herrera, 2021; Hussain et al., 2019). Other countries, including developing and first-world countries, have the same issues as the United States. In a study done in the United Kingdom (UK) by Hayes and Hydes, the UK started noticing Pb-based illnesses, such as plumbism, when the United States began passing acts and amendments for Pb in public water and other products. This kickstarted a global need for inquiries into the Pb in public water sourced by the WHO (Hayes and Hydes, 2012). When WHO put Pb in public water as a global public health problem, studies among a variety of different countries were published to state how their country or population was affected by this public health issue. This is important to note because when the United States began looking at the Pb in public water, high BLL, the effects on children, and other various factors coming to light, it started a global push for change that is still ongoing to this day.

Drinking water usually contains little to no Pb when it leaves the distribution center or water treatment plant (Triantafyllidou & Edwards, 2012). The distribution center of water treatment plants includes water from different sources, including desalination, surface, and groundwater (Barnett-Itzhaki et al., 2019). When the water leaves the distribution center after it has been purified, the only other source of contamination would come from the piping leading to the consumer. Most of the Pb that infects water supplies comes from Pb service lines. Pb service lines (LSL) are the largest contributor of Pb in drinking water to residences; this contamination is responsible for 75-86% of Pb at the tap (Lytle et al., 2021). LSL can include other plumbing materials, such as brass and copper, along with Pb. These fixtures that include brass and copper can contain trace amounts of Pb as well.

After the passing of several acts and amendments in the 1970s and 1980s, Pb-based piping was banned, but there were no acts or amendments to replace Pb-based piping. The replacement of Pb-based piping is up to the control of the resident, city, or business. During this time, Pb-based piping was a massive public health issue with a BLL of over 10 μg/dL for the average adult American, so the need for replacement was of the greatest importance (Dignam et al., 2019). The replacement of Pb-based piping started almost immediately after reports started circulating about the deadly implications plumbism can have. The reconstruction of Pb-based piping to another form of piping or water distribution piping, such as unplasticized polyvinyl chloride (uPVC) piping, was beginning (Zhang and Lin, 2014). While using an alternative type of piping and alternative fixtures, Pb can still seep into the water supply because Pb is still allowed in water distribution supplies, such as brass and bronze fixtures. Only up to 8% of the weight of Pb in the piping can be used for brass and bronze plumbing components (Triantafyllidou & Edwards, 2012). The use of Pb within these components is to reduce the leakage of water from the piping (Triantafyllidou & Edwards, 2012).

The replacement of Pb-based piping with other forms of piping comes with a hefty price tag and ownership responsibilities. When Pb-based piping was first replaced in the 1970s and 1980s, most of the reconstruction occurred in high-income, urban populations predominantly with Caucasian populations that had the funds to replace the Pb-based piping. Pb-based piping can cost upwards of $45 billion for the entire country or roughly $10,000 per service line for every household, not including distribution systems (Campbell and Wessel, 2021). Most residents, families, businesses, and/or cities do not have the money and capacity to replace all the Pb-based piping within their vicinity. Besides the overall cost of replacing Pb-based piping, the timing and aesthetic construction or view of replacing the piping can be overwhelming. One way to combat the cost of replacing Pb-based piping was replacing parts of the piping.

LSL can either be fully replaced with new piping or partially replaced. Partial replacement of LSL or Pb service line replacement (LSLR) was an important strategy for diminishing the effects of Pb corroding in drinking water (Trueman et al., 2016). This was a popular option for LSLs that were partly owned, public to private, or private to public LSL. This part of the LSL is replaced with copper and joined to the private LSL left in place (Trueman et al., 2016). Although, partial LSLR can lead to increased Pb in public water because of the disturbance of the piping and fixtures, the authors concluded that partial LSLRs are not as effective as full-service LSL replacements.

The lasting effects of replacing Pb-based piping outweigh the negative aspects from a public health perspective. Although, this perspective alone does not qualify or require Pb-based piping to be replaced. The replacement is up to the sole discretion of the owner of the Pb-based piping system. Additionally, the unknown aspect of when and where Pb-based piping is located, and the mix of Pb-based piping and non-Pb-based piping can be underestimated. Therefore, sampling all tap water before any replacement is done is necessary to ascertain the amount of Pb in drinking water (Lytle et al., 2021).

The most used and most studied technique for sampling drinking water for chemicals, not just Pb, includes first draw sampling, a method agreed upon by EPA LCR, flush sampling, stagnation of profile sampling, and random daytime sampling (Lytle et al., 2021; EPA, 2015). The first draw sampling is taking a water sample directly from the tap without letting the tap run for an extended period. Flush sampling, or pro-sampling, is a method used to take samples after the tap has run for an extended period. Stagnation of profile sampling is when multiple samples are collected; the stagnated time can range from minutes to hours to days (Bédard et al., 2018). All these methods, and more, can conclude if a water piping system contains trace amounts of Pb. Even though there are techniques to test water samples, Pb can be missed in samples (Clark et al., 2014).

These methods are more suitable for individual residents or stand-alone homes, not apartment buildings or businesses (Triantafyllidou et al., 2021). The variability in methods to obtain water samples can cause variability in the amount of Pb that was collected in each sample. More specifically, the first draw samples will contain the most Pb because the water coming out of the tap first was being held in the piping without movement. Without constant movement of water through piping, sitting water can erode Pb-based piping and cause a buildup of chemicals and bacteria at the holding site.

***Lead in Paint*:** Federal law defines a Pb paint hazard as a "condition in which exposure to Pb from Pb-contaminated dust, Pb-contaminated soil, or deteriorated Pb paint will harm human health" (Harvey, 2002). Pb in paint and residential surfaces was banned in 1978, and up to 75% of housing built before 1980 consists of some amount of Pb paint within the home. Beyond this period, the amount of Pb-based paint in homes before 1950 is much greater. Homes built before 1940 contain 90% trace amounts of Pb, containing more than 1 mg/cm^2. The direct and indirect exposure of children to Pb paint that has deteriorated because of deferred maintenance is likely the major factor in the increased risk of EBLL associated with poverty and living in older homes (Harvey, 2002). Data from NHANES indicates that there is an increase in EBLL among children living in homes built before 1946 compared to homes built after 1973. This concludes that Pb-based paint does not erode or break down over time, creating a space that is prevalent with Pb until the paint is deconstructed. Children who live in homes built before 1946 have an average of 16% EBLL among the population compared to middle-income children who have an average of 4% EBLL. The main exposure pathway for children and Pb is ingestion and inhalation from paint chips that flake from the wall.

***Lead in Dust*:** Pb paint that flakes off the wall can contaminate dust and Pb to elevated contamination across the home. This occurs mainly in older homes because they have a higher level of dust because of erosion and higher trafficking areas compared to newer homes. The amount of Pb in house dust has a strong correlation with the BLL of young children and is more predictive of BLL in children than the amount of Pb in house paint (Harvey, 2002). Although, the spread and settlement of dust within the home depend greatly on the house's age, amount of Pb paint, human trafficking, outside wind sources from open windows, and cleaning measures.

***Lead in Soil*:** Pb contamination from outside sources, such as Pb smelters, previous use of Pb gasoline, weathering of exterior paint, and metal recycling plants, have elevated levels surrounding these areas. The rate of exposure from these sources can spread throughout the soil and contaminate unaffected areas, wildlife, and vegetation. Soil contamination from Pb paint can lead to EBLL around dwellings. A national survey concluded that exterior Pb-based paint on homes can Pb to elevated Pb levels in soil compared to homes without exterior Pb-based paint, leading to more elevated Pb levels inside the home.

Current Laws and Policies Governing Lead in Various Sources

***Pb in Water*:** The Clean Water Act (CWA) of 1972 is a common structure and guidelines for regulating the discharge of chemicals and pollutants into the public water supply across the United States and regulating quality standards for surface waters (EPA, 2022). The EPA utilizes this act to monitor water quality standards and control discharge from point sources. The act protects all public water access to all citizens of the United States although the status and protection and such waters are up to the local region, state, city, or county. Multiple amendments have been made to accommodate the growing population, newly built water structures, and changes to policies from the original act creation. These amendments have created and implemented pollution control for wastewater and surface water (EPA, 2022).

States, counties, cities, or regions have their method variation for applying the CWA and are regulated by their standards. Under these standards, states are able and required to classify bodies of water by specific activity and adopt a plan to ensure that the bodies of water meet the standards that are given for that activity. The EPA must review and approve these plans, bodies of water, and regulations. If the EPA does not approve the plan set forth by the state, then a plan will be created by the EPA and put into effect for the state (EPA, 2022).

Table 1: Current rules and regulations for Pb in various sources.

Pb Sources	USEPA	WHO
Pb-Based Piping	Pb-based piping was banned in 1986 through policies created by the EPA under the SDA and CWA. Amendments and changes are being made to both policies frequently.	WHO does not have any rules or regulations for Pb-based piping but guidelines to consider when using piping and fixtures of heavy metals for restoration to replace Pb-based piping.
Water	Pb is regulated under the SDWA and CWA, and the approved amount is 15ug/L The CWA prohibits anyone from discharging pollutants, including lead, through a point source into the water in the United States unless they have a permit. Pb is regulated under the LCR under EPA through treatment techniques	WHO does not control any aspect of drinking water; they provide research and guidance on the dangers of Pb ingestion through various means. WHO does work with other government-based agencies, but ultimately, they do not set rules, regulations, or policies for Pb in drinking water.
Paint	Pb-based paint is regulated by the EPA and other authorities. EPA passed rules and regulations about homes being built before 1978, renovating activities, and clearance levels. These policies should be conducted by trained personnel for specific practices to ensure accuracy and safety.	WHO is actively working with several countries to pass policies to control Pb in paint. They also work with multiple government agencies to develop guidelines on lead exposure for paint.
Soil	EPA has a soil screening level that contains 7 steps of screening soil, from creating site maps as step 1 to discussing/identifying Pb in soil. Most of the steps are done at the site and soil Pb levels can be calculated in a lab using site-specific soil screening levels.	WHO does not have specific guidelines for Pb in soil.
BLL	CDC has established a "reference level" of **3.5 µg/dL** to be used to identify children with elevated blood lead levels. Children who have a Pb level starting at this threshold with start Pb prevention treatment, but not medication. Medication (Chelation therapy) will be given if a BLL is at least 45 µg/dL.	WHO has information about Pb levels but no specific guidelines or rules about Pb levels.

- BLL: Blood Lead Level
- Pb: Lead
- WHO: World Health Organization
- CDC: Center for Disease Control and Prevention
- SDWA: Safe Drinking Water Act
- CWA: Clean Water Act
- EPA: Environmental Protection Agency
- LCR: Lead and Copper Rule
- µg/dL: Micrograms per deciliter

Safe Drinking Water Act: The Safe Drinking Water Act (SDWA) was passed by Congress in 1974 by regulating the nation's public water supply. There were multiple amendments to the act several years later to cover all bodies of drinking water and its sources. The sources can include any body of water used for clean drinking water and water systems. Water systems can include community, non-community, non-transient non-community, and transient non-community. These different water systems have different service needs by number/population and location. Unlike the CWA, the SDWA has all parties, EPA, states, and water systems work together to create standards for the population being served. This will apply to all public water systems within the United States and the responsibility to adhere to the policy for these systems is divided between the EPA, states, water systems, tribes, and the public (EPA, 2023).

CHAPTER 3: METHODS

Data Collection

Data were collected from the Department of North Carolina Health and Human Services North Carolina State Lab of Public Health database through the North Carolina State Laboratory Clinical and Environmental Lab Results (CELR) and the Pitt County Health Department in North Carolina (PCHD); the data collected were BLL and Pb reports from samples taken within the home. The dates of the Pb reports collected ranged from January 1, 2018, to December 31, 2020. Hundreds of reports were taken throughout this period, yet the inclusion criteria eliminated many of these reports. The data collected from PCHD came from the Environmental Health Department, Pb environmental specialist. The data from PCHD was cross-referenced from the data from CELR, and matching data sets were eliminated in the instances of dual results. The data was entered into SPSS and Microsoft Excel to assist in creating heat maps for North Carolina and Pitt County, NC. SPSS and Excel were also used to create graphs and charts to depict different rates of BLL, specific trends in populations, and the rate of exposure for minority and majority populations.

The data used from this study came from multiple, public sources that were collected and analyzed through SPSS, Microsoft Excel, ArcMap, and EPA EJScreen. SPSS was used to create various data sheets to build maps through ArcMap. The data used included Pb-level samples taken throughout the home and published to the NCDHHS database. The database did not have data that was already transcribed into Excel, SPSS, or other data analysis programs. All the data from NCDHHS was used either in Excel or SPSS to create means, graphs, and charts to depict the various Pb levels throughout North Carolina, counties in North Carolina, Pitt County, NC, and homes based in North Carolina.

Excel was used specifically to create correlations between the BLL of children in terms of race, ethnicity, gender, and the year that the diagnosis was given. The results from Excel for this data set were used to create graphs and charts that were used to visualize the different varying levels of BLL among populations with various characteristics. Additionally, Excel was used to create graphs showing the rate of elevated BLL among children comparable to the United States, North Carolina, and Pitt County. SPSS was specifically used to analyze data through the means of getting averages for Pb levels within homes, creating line graphs depicting the varying levels of Pb within the home, and averaging amounts of Pb throughout North Carolina counties to create maps in ArcMap. Both programs were used for different stages of the study and both programs had features that were beneficial to certain aspects of the study.

***CELR Data*:** The data collected from the Clinical and Environmental Lab Result (CELR) database were based on two parts: BLL data, and housing data.

Housing data were collected across 48 out of the 100 counties in North Carolina. 52 of the counties did not have the inclusion data or had no data within the CELR database. The housing data collected consisted of the following inclusion criteria:

- Must include chemical Pb reports between January 1, 2018, and December 31, 2020
- Must include specific room/area collection labels.
- At least three or more of the five-room/area collection should be within the:
    - Dust
    - Kitchen
    - Common Entry
    - Bedroom
    - Windowsill (Excluding window troughs)

- At least 4.99 µg/dL was reported within a room/area.
- At least 5 clinical reports, but no more than 20 clinical reports are used per county.

The housing data was used to create maps across North Carolina to determine the rate of Pb across multiple rooms/areas within the home. The maps were used as a visual viewpoint to compare the rate of Pb between counties. The method behind creating the maps stems from understanding which areas around North Carolina currently have the highest rates of Pb within the home. Understanding which counties have the highest rates of Pb can be compared to the rate of minority populations, low-income populations, social determinants of health within these populations, and the rate of older homes within the county. The correlation of elevated Pb levels within homes and within counties could yield results that show how at-risk populations have unhealthy living standards compared to higher-income, dominant populations.

BLL data was collected between January 1, 2018, and December 31, 2020. Hundreds of reports were cross-referenced to the housing data, and a sample of 29 homes with documented BLL data was discovered. The BLL data was collected from the CELR database. The data had certain criteria that needed to be included:

- Address
- Race/ethnicity
- Data of BLL testing
- BLL measurement
- Gender

All BLL clinical reports (cases) were of younger infants, toddlers, or children less than 7 years of age. It was important to include non-at-risk races/ethnicities to compare how both groups have a higher rate of elevated BLL and which gender has a higher rate of elevated BLL. No specific age range was determined as all cases were of children aged younger than seven. This is common for BLL cases because most BLL testing occurs within the first two years an infant is born, and more, if necessary, if elevated BLL is detected; more testing is done in incremental time frames after the initial diagnosis and treatment. Immigrant children have their children tested upon arrival within the United States, and those whose parent/guardian is on child-care-based government benefits have their children tested within the first 6 months after birth.

Data Analyses

***EPA EJScreen*:** EPA's Environmental and Justice Screening and Mapping Tool, EPA EJScreen, is a mapping online software that creates country-wide maps depicting different levels of chemicals, environmental injustices, pollution, health disparities, climate change data, and various demographics. The mapping software can create maps on a country-wide level and from states to cities. Multiple maps were created to depict the rate of Pb within the home through paint, minority population prevalence, and low-income housing. The entire United States was mapped with these criteria for comparison between states to determine which states/areas around the country had elevated Pb within the home along with the distribution of minority populations and low-income housing. The United States was looked at as a whole, then states in clusters (East Coast and West Coast). The United States was looked at as an entire country; then the country was divided to look at both sides of the country, East and West coast, as a comparison. The country was divided based on varying demopgraphics on the East and West coast. These demographics include income, housing, socioeconomic status, weathering/regional differences, and population/race differences.

ArcGIS: ArcGIS and ArcMap are software used to create various degrees of maps. The main software used is ArcMap because of its versatility and access to online templates. A template of the state of North Carolina with all 100 counties bordered was used. The CELR data that was collected in the 48 counties were used to create a map depicting the overall Pb levels across North Carolina. Each county had at least 5 but no more than 20 data reports that were used per county. Each of the 48 counties had at least 4.99 µg/dL of Pb with no maximum. The 48 counties were color-coded to show the varying amount of Pb per county, and counties with no Pb data were left blank. The base map indicates all Pb levels across the home, within all 5 rooms/areas. Once the base map was created, additional maps were created to display each room/area of the home individually. A single map of North Carolina was made, with all 100 counties, with 48 counties of data, per room/area of the home, and then another was made for the top 15 counties of each room/area of the home. Each room/area consisted of the kitchen, common entry, dust, bedroom, and windowsill. A total of 5 maps were created for each room/area, another 5 maps were created to depict the top 15 counties with the highest level of Pb per room/area and a single map was created to depict the overall top 15 counties with the highest levels of Pb across all room/areas.

Maps have been created on the country level, United States, state level, North Carolina, and the county level, Pitt County, NC. Pitt County is a county based in North Carolina with the city seat of Greenville, with other surrounding towns, including Ayden, Farmville, Bethel, Grimesland, and Grifton. Pitt County is a rural county that houses multiple communities within an hour's drive outside the state's capital, Raleigh. Because of the proximity to the state's capital, there is a bigger population of commuters coming into the city to work only. Additionally, the county has one of the major universities in the state, East Carolina University.

With the state capital being less than 100 miles from the city and an influx of younger generations coming into the city for university purposes, there are varying demographics in the city during different times of the year. This was considered when data was collected for this study. The data collected on the county level does not include populations that are housed in Pitt County temporarily for educational or work purposes.

The data used on the county level was collected from the CELR database and PCHD. PCHD was able to provide addresses of homes, a total of 50, with confirmed elevated BLL cases. These addresses were cross-referenced with the data collected from CELR, and duplicates were deleted. A total of 29 addresses were used on the county level. Hundreds of addresses were cross-referenced to be used on the county level, and the inclusion criteria were:

- Confirmed cases of elevated Pb levels in the home
- Full address with city and zip code
- The year the home was built

Not all BLL cases could be matched to the home address because of inclusion criteria and lack of information on reports made on the county level. Of the 29 addresses that were found, those were mapped on a Pitt County, NC template with the main county seat, Greenville, and the surrounding towns. Clusters were made on the maps to depict which areas or communities have the most cases of elevated Pb levels within the home, with the most being in Greenville. The clusters of the homes can help determine specific locations and SDH of the at-risk populations that may be affected.

Statistical Analysis: Children blood lead levels (BLL) are presented as scatter or bar plots. General linear model (GLM) was used to test the association of BLL (dependent variable) with covariates: child age, gender, race, and sample year. Race was categorized into three groups: White, Black, and Other. Other consisted of Hispanic/Latino, Asian, Native American and Pacific Islander, and Unknown races. The grouping of these races into Other was necessary due to small sample size for each race. Both main effects and interactions terms were explored, and since none of the interaction terms were significant, they were removed from the final model. A *p*-value of less than or equal to 0.05 was considered statistically significant. Data were analyzed in IBM SPSS (version 26.0)

CHAPTER 4: RESULTS AND DISCUSSION

Country Level

Lead Levels in the United States: Across the United States, at-risk populations are prevalent in every state, city, and community (Figs. 4A and 4B). The rate of at-risk populations varies greatly by region and state and is subject to income status, living situation, education, and overall economic status. Across the United States, the West Coast has the highest rate of low-income populations in the country, mainly in clusters in specific areas in the Western states. Many states on the West Coast have high rates of low-income populations, reaching a value of 100% in certain areas that are considered low-income populations (Fig. 4A). Compared to the East Coast, the West Coast have clusters of low-income populations that coincide with high rates of African American and minority populations (Figs. 4A, 4B).

The East Coast is a coastline or ribbon of minority populations that are scattered throughout the coast, making the East Coast more susceptible to lower-income and minority populations. Having groups or clusters of specific status populations can make it easier to pinpoint and address the current issues within that population. The West Coast has more of a clustered, defined low-income/minority population, and the East Coast has a scattered yet uniform low-income/minority population. Both sides of the United States have different hierarchies of industry, education, and immigration from other countries. All these factors contribute to income related to race/ethnicity because these factors, along with SDH, can have a high impact on one's lifestyle. Comparable, the West Coast is more affluent in business and industry, while the East Coast is more prevalent in history and culture. It is creating two different, varying sides of the United States that can be deemed opposite from one another.

Figure 4: Maps showing the distribution of low income (A), minority populations (B) and the estimated number of homes with lead paint (C), across the United States created using the EPA EJScreen online program.

Figure 4A shows low-income population for all races/ethnicities, gender, and ages across the United States. There were no features to eliminate or select certain populations for this map. The West Coast has clusters of low-income populations, while the East Coast has a continuous line or stretch of low-income populations that are scattered throughout the coastline. Each side of the United States has varying factors to contribute to low income, and one factor should not be ruled out or equaled to both sides. With the value of housing, lifestyle, and economic status, the West Coast has a higher income status than the East Coast, a $15,000 greater difference for the average, full-time working adult (Semega & Kollar, 2022). With the higher cost of living coinciding with higher income status, most minority populations are not able to adhere to this standard. The African American population has one of the highest rates of school dropouts for high school and university students, making a significant portion of the population uneducated with a university degree or high school diploma. This rate of uneducated adults leads to low-income, government assistance populations that cannot afford their lifestyle or area of living, forcing them to seek shelter in older, low-income housing.

Figure 4C shows the estimated rate of lead paint in homes across the United States. This is only an estimate because there are no documented numbers of homes/buildings with Pb-based paint on the walls of the home. It would also be impossible to document every home in the country that has Pb paint because this would take years and funding that many communities would not have to take samples from the home and test them. Additionally, children living in homes with Pb-based paint would have to be tested and treated for plumbism, and then the paint would have to be replaced. This could cost upwards of billions of dollars to cover the entire country.

Figure 4B depicts minority populations in the United States. The western states have an increased rate of low income based on education, job opportunity, and living expenses. The two maps above show a layover of low-income and minority populations within the same region/area across the United States. All three maps show clusters of all aspects across the West Coast and more scattered yet uniform across the Southeast going into the Northeastern region. According to the map and data from the Census, Southern states, and Western states have the highest rate of minority populations. Leaving most of Central United States to higher rates of the majority/Caucasian population. The minority population map shows an increased rate of in the West and South; this is important to note because most of the Southern and Western states see the most immigration from other countries. The maps above do not depict just United States citizens, but those who are documented to live/work in the United States, whether it be a Visa or temporary housing in the United States, all minority populations are documented for the three maps above.

Although Figure 4A is a rough estimate of the rate of minority populations in the United States, the map does not consider undocumented immigrants who live in the United States. The data for these maps could be skewed for a higher population of minority and low-income populations because the data is based on documented income and race/ethnicity location through the US Census Bureau. Undocumented populations could add to the higher percentiles for these maps because they are minorities, and most undocumented minority populations do not make it above the poverty level.

If these three maps were proportioned and stacked over one another, all three would highlight the same areas. Clusters in the Western states with a ribbon of continuous spread throughout the Eastern states. This is crucial because all three elements align with an increased rate of plumbism in at-risk communities and at-risk populations. The clustering of communities in the West and scattered areas throughout the South is evidence to also suggest that studies and research have not been done to justify how these areas are profoundly affected by these three elements. More elements, besides Pb paint, income status, and race/ethnicity, could suggest that plumbism involves more information and factors that may not have been researched or conducted before.

It is also important to note that just because a community has these three elements individually or combined does not justify having plumbism. Not all at-risk populations are at risk for plumbism, not all at-risk populations are low-income, and not all at-risk populations live in low-income housing. This is an important note because at-risk populations have the highest rate of plumbism but not all families or individuals in at-risk populations are at risk for plumbism.

These maps created are not just for at-risk populations but for all populations. Knowingly, not all at-risk populations are subjected to plumbism. The majority population, Caucasian, is also subject to plumbism because individuals and families in the Caucasian populations can have a low income; they can live in a home with Pb-paint but cannot be a minority population because they are the majority population in the United States.

At the country level, there are answers as to where at-risk populations that may be affected by Pb-based paint in the homes are located. Additionally, understanding the connection between these variables (This includes race/population, economic status, and living situations) and how limited research has been conducted as to why these elements are not studied as a key source of exposure and risk should be considered in the future.

Lead Levels in North Carolina: The state of North Carolina is within the Southeastern region of the United States and middle of the scattered yet uniform area of the South where Pb-based paint, low-income, and minority populations are housed. North Carolina is home to a diverse population of minority and majority populations; with multiple universities across the state, North Carolina sees multiple races/ethnicities and nationalities that individuals and families call home. Although, this does not mean that they are permanent residents. There are multiple universities and businesses in North Carolina that house temporary students and residents for a certain portion of the year; for this study, the author has excluded those who are not North Carolina citizens and those who are in the state temporarily for education or work needs.

North Carolina is home to multiple cities, including Raleigh (The state capitol), Fayetteville, Durham, Greensboro, and Charlotte. These major cities are home to universities, corporate businesses, and some of the highest rates of low-income and minority populations in the state. Each city has its minority populations based on income, race/ethnicity, and housing situation.

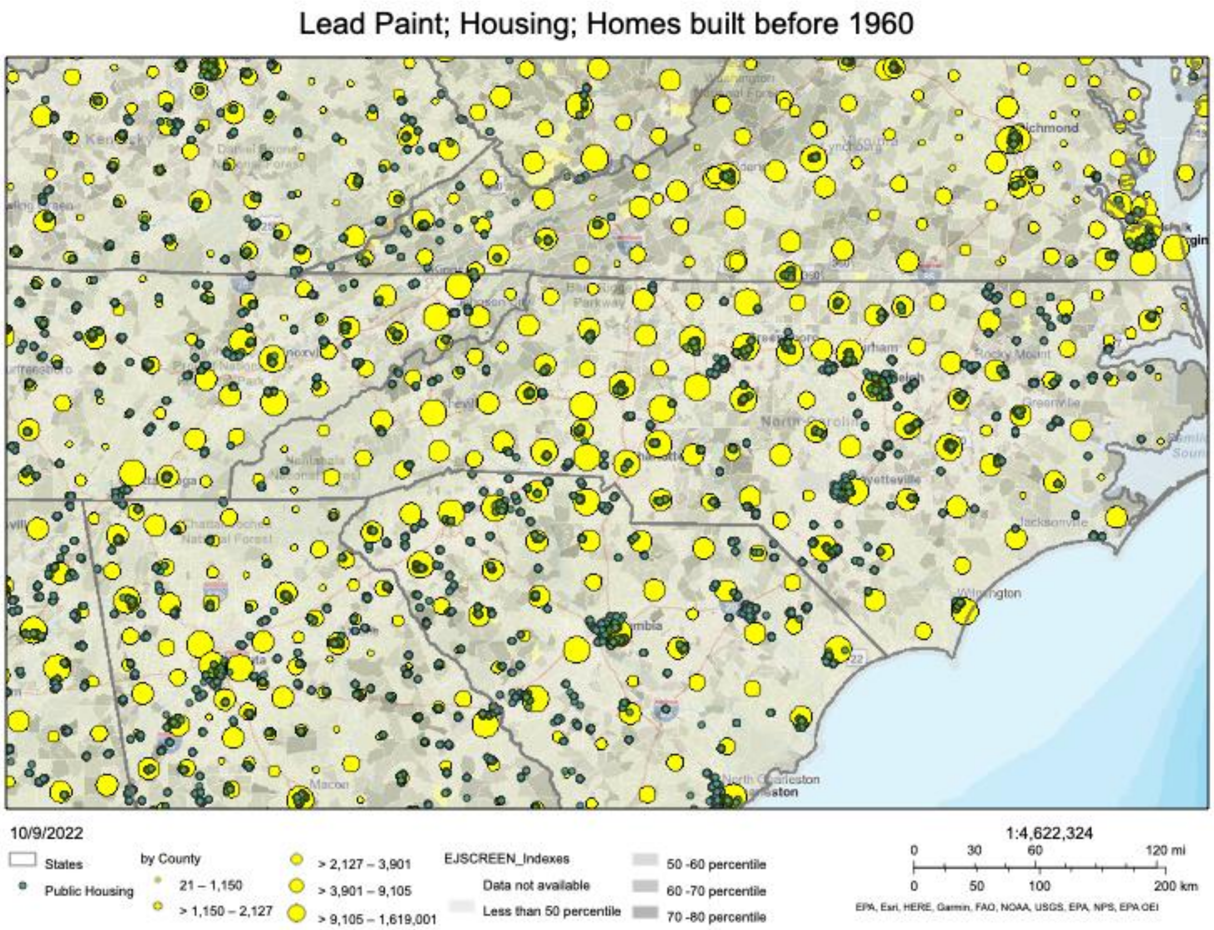

Figure 5: Distribution of Pb-based paint within homes by percentage, homes built before 1960, and public housing for North Carolina and the bordering states. The map was created using the EPA EJScreen program.

Figure 5 depicts the rate of estimated distribution of Pb-based paint in homes, the public housing (including Section 8 housing and other government-based housing units), and the homes built before 1960. The mapping software, EPA EJScreen, created this map from estimated Pb levels within homes based on housing age and percentile population that lives in public housing. The software did not allow for the home's values based between decades; only homes built before 1960 were assessed by the EPA and were included in this map for Pb-based paint.

Four major cities fall into the category of areas with high levels of public housing, homes built before 1960, and homes with Pb-based paint. Four areas circled within the map were the cities of Raleigh, Durham, Greensboro, and Fayetteville. It is important to note that each of these cities houses one or more major universities for the state, but students who did not move/register to the state of North Carolina as permanent residents were not included in this data.

Raleigh, Durham, Greensboro, and Fayetteville, plus Charlotte, but not pinpointed on the map, are the biggest cities in North Carolina. Each city has its diverse group of citizens, universities, and work fields. Raleigh, being the state capital, has some of the heaviest traffic and the highest rate of diversity within the state. Because of this, Raleigh has the highest rate of different races/ethnicities, incomes, and housing populations. According to the map, Raleigh has the highest correlation between Pb paint, housing built before 1960, and public housing. This city is also one of the biggest in North Carolina in terms of population.

On a county-level scale, the author was able to obtain data from data (reports) for 48 counties within the state. 52 of the counties did not meet the requirements for inclusion. The requirements for inclusion were that each county had at least 5 reports for homes with at least 3 rooms with at least 4.99 ug in each room. No more than 20 reports were used for data to create the maps below in this section.

Lead Levels in 48 Counties in North Carolina

Lead in Homes**:** Pb can accumulate in multiple places across the home, but certain areas of the home can accumulate Pb at an alarming rate due to traffic from individuals, families, and pets. These areas that can accumulate Pb the most are dust, kitchen, bedroom, windowsills, and the common entry. Each of these areas has a high rate of traffic and accumulation of bacteria, dust, dirt/grime, and chemicals that can be deposited from individuals or pets. The increased rate of traffic within these areas makes them a significant area to test for Pb. The author was able to create multiple maps and graphs showing the rate of Pb within multiple counties in North Carolina and.

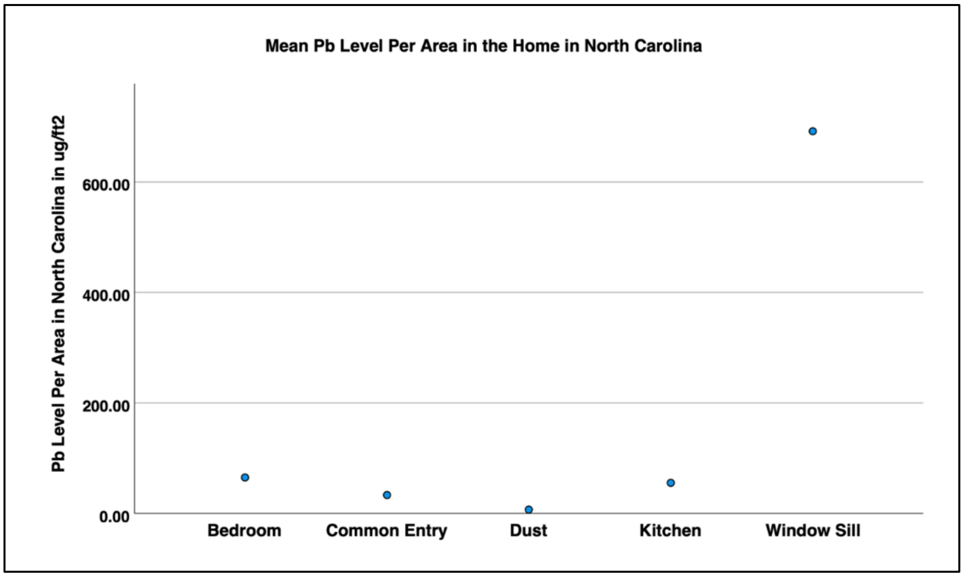

Figure 6: Average Pb level in dust, kitchen, bedrooms, windowsills, and common entry across 48 counties in North Carolina.

It is important to note that these five areas are not the only places where Pb can accumulate within the home. Other areas that accumulate Pb can include the living room/den, dining room, and even a vehicle that can harbor dust, dirt, and particles from different chemicals, including Pb. Additionally, the levels of Pb throughout the home can vary from home to home, and room to room, as seen in the data on the graph above. The variation comes from outside deposits from wind for the windowsills; foot traffic entering and exiting the home, common entry; constant entry/exit and activity for the kitchen and bedroom; buildup up particles, bacteria, and dirt/grime for dust. Because of the variations of Pb throughout the home, there is no set area where Pb levels could be high and could be low, even with testing, because Pb varies from home to home. According to the graphs above, the windowsill has the highest level of Pb within the home, but the reports did not indicate where the samples were taken from in specific rooms where the windowsills were located.

For example, in one report, the specialist could have sampled a windowsill in the bedroom; in another report, the sample could have come from the living room. With the unknown room where the windowsill was being sampled, this could be a deciding factor in why the kitchen and bedroom areas had such elevated Pb levels because, usually, open windows are set in the kitchen and bedroom. This does not exclude the living room as a potentially high area of Pb deposits and exposure; the living room area was not included in the reports taken for Pb samples throughout the home.

The samples taken did not specifically state where in the room they were taken. Potential areas where the samples could have taken place for dust could be mantles and coffee/end tables; the kitchen area could include the table, sink/faucets, and handles to appliances; the bedroom could be end tables, lamps, and door handles. The only known area where the samples were taken place was the common entry. Samples were taken place on the inside doorframe and floor of the common entry of the individual or family's home. The common entry could be the front, side, or back door; the most used entry/exit point was sampled. The report did not state which common entry was tested.

This is also the only area that is sampled once; if the home had multiple entries/exit points, the most used one was sampled. This is not the case for bedrooms. If multiple bedrooms were sampled, an average was taken for the entire home. It is unknown how many dust, kitchen, and windowsill samples were taken throughout the home. The reports included multiple rooms labeled for bedrooms, such as the master bedroom, bedroom 1, bedroom 2, etc. Other samples did not specify if there were multiple samples taken, such as windowsill 1, windowsill 2, dust sample 1, dust sample 2, etc. This could be a major contributing factor in the Pb levels throughout the home because sampling only specific windowsills or dusty areas can skew results and list the home as a potential site for elevated Pb levels throughout the home, even though it could be just one room or specific windowsill within the home.

***Elevated Pb Levels in Homes in North Carolina*:** Lead in dust can be highly toxic to at-risk populations and those with respiratory health issues. Although, Pb is not the only element or particle in dust. Dust can be an accumulation of parasites, bacteria, dirt, and other substances that can be harmful to humans. Lead in dust has not been researched extensively in at-risk populations in terms of health-related factors. This is a concerning subject to discuss because dust can invade anyone's home and become a hazard to those who encounter it.

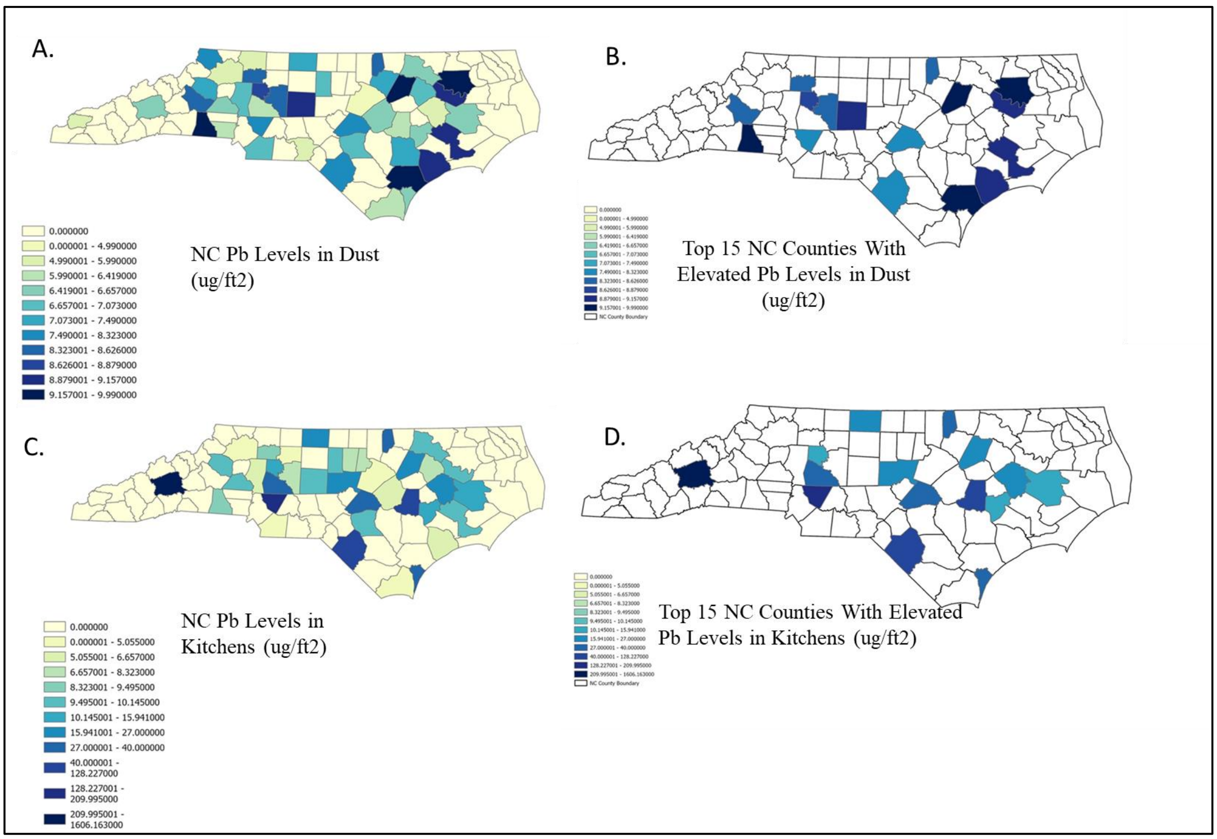

Figure 7: The four maps above show the value of Pb levels across the 48 counites in North Carolina. Map A and C show rates of Pb values in North Carolina. Map B and D show the value of Pb across the top 15/16 counties in North Carolina. Maps were made using ArcGIS.

Eastern North Carolina has the highest rate of Pb in dust, up to 9.99 µg/ft^2, Fig. 7A. Several decades ago, the EPA standard for BLL was 10 µg/dL. Under rules and regulations during the period, this level of Pb would be acceptable within the home. After several revisions, the acceptable Pb level, as of 2023, is 3.5 µg/dL. As of 2023, this level of Pb in dust within the home will not be acceptable. It is not known why the Eastern part of the state has higher Pb levels than the Western part of the state. This could be because of different soil levels, weather conditions/climates (oceanic conditions vs. mountain conditions), population levels within the different cities, or other factors. What is known is that different types of soil can have little or heavy trapping of elements, not only Pb. It is also known that coastal conditions bring/carry particles/elements onto land to be deposited. The breakdown of these factors and more cannot lead to a definite conclusion as to where/why elevated Pb levels are within certain areas in the state.

Fig. 7B shows Pb concentrations in dust in several counties in North Carolina. These are the top 15 counties (2 counties had the same level of Pb in dust); the counties are scattered, but most of the counties depicted on the map in the Eastern region have the highest levels of Pb in dust. Again, there is no definitive reason as to why there are more elevated Pb levels on the Eastern coast compared to the Western coast. It is important to note that the Eastern part of the state receives heavy weather conditions during hurricane season and more traffic through tourism across the beaches during the Summer. This could be a major contribution to not just Pb in dust but Pb throughout the home.

Research has concluded that Pb in dust is a contributing factor to elevated BLL in all populations, specifically in children. Children have the highest risk of contracting plumbism through dust because of their hand-to-mouth gestures. Although, this is dependent on the cleanliness of the home, the age of the home, Pb levels throughout the home, Pb-based paint, and traffic in and out of the home from individuals and pets. Additionally, an individual is more likely to contract plumbism through dust than drinking water because a significant amount of Pb in water must be ingested to have a high or elevated BLL. The dust has a barrier of dirt, bacteria, and chemicals that are on hard and soft surfaces that are invisible to the naked eye and can accumulate in layers. Causing an increased risk of harm, specifically for children with constant hand-to-mouth gestures and individuals with chronic respiratory conditions who inhale the dust regularly.

The kitchen is one of the heaviest trafficked rooms in the house. For larger families (More than 4 individuals in the family), constant exposure to the kitchen is throughout the day and, in some cases, throughout the night as well. The constant exposure can lead to the trafficking of dust, dirt/grime, and other particles that can be transferred from person to person or from person to surface or vice versa, leading to a cycle of cross-contamination. This cross-contamination could lead to substances being transferred to different areas of the home, causing an uptick in Pb levels being deposited from the kitchen to other areas and vice versa. According to the graph above, the kitchen is the third highest area/room with elevated Pb levels.

Figure 7C shows the variation of Pb levels across North Carolina within the kitchen. . There are variations across the state, with a majority of elevated Pb in the Eastern part of the state. Buncombe county is an outlier for elevated Pb in kitchen (Fig. 7D). Buncombe County is in the heart of the mountain region in North Carolina. The mountain region in North Carolina is home to harsh weather conditions, tourism, and factories that produce a variety of products, and this area is known for mining minerals. These could be deciding factors that contributed to this county having the highest Pb level contamination in kitchens for the state. However, the surrounding counties did not have data/inclusion criteria for this study, so a comparison of the Mountain region of the state to Piedmont to the Coastal region of the state could not be made.

Because of the variation in elevated Pb levels across the state with distinct pattern, it is unclear as to why some counties have the highest levels of Pb within their kitchen. More research must be done within these counties to better understand the reasons underpinning elevated Pb levels (above 15 $\mu g/ft^2$) in the dust and kitchen, (Fig. 7D). According to the EPA, there are no rules or regulations for how much Pb is acceptable within the home. Only water, paint, and soil (in certain residential and industrial areas) are regulated throughout the home by the EPA (EPA, 2015). This needs to change because elevated Pb levels within the home should warrant a need for policy implementation.

The common entry is referred to as the entry/exit point within the home that obtains the most traffic; this could be either the front, back, or side doors within the home. Only one entry/exit point was tested in the home according to the clinical reports that were used for Figures 8A and 8B. The reports did not state where the common entry/exit point was in the home; the author suggests that the front door entry/exit point is the commonly used door. This could be different based on entry/exit points on the patio, garage, or side door that could be commonly used amongst individuals and families, but this would vary between homes and the use of the entry/exit points.

Figures 8C and 8D shows that elevated Pb levels within the home are continuously located in the Eastern region and Piedmont region. This is a recurring theme among elevated Pb levels within the state, most are in counties located in the Piedmont and Coastal regions of the state. With a high correlation of elevated Pb levels in these areas, there must be a common source of Pb exposure that affects these areas over the Mountain region. Although, most of the

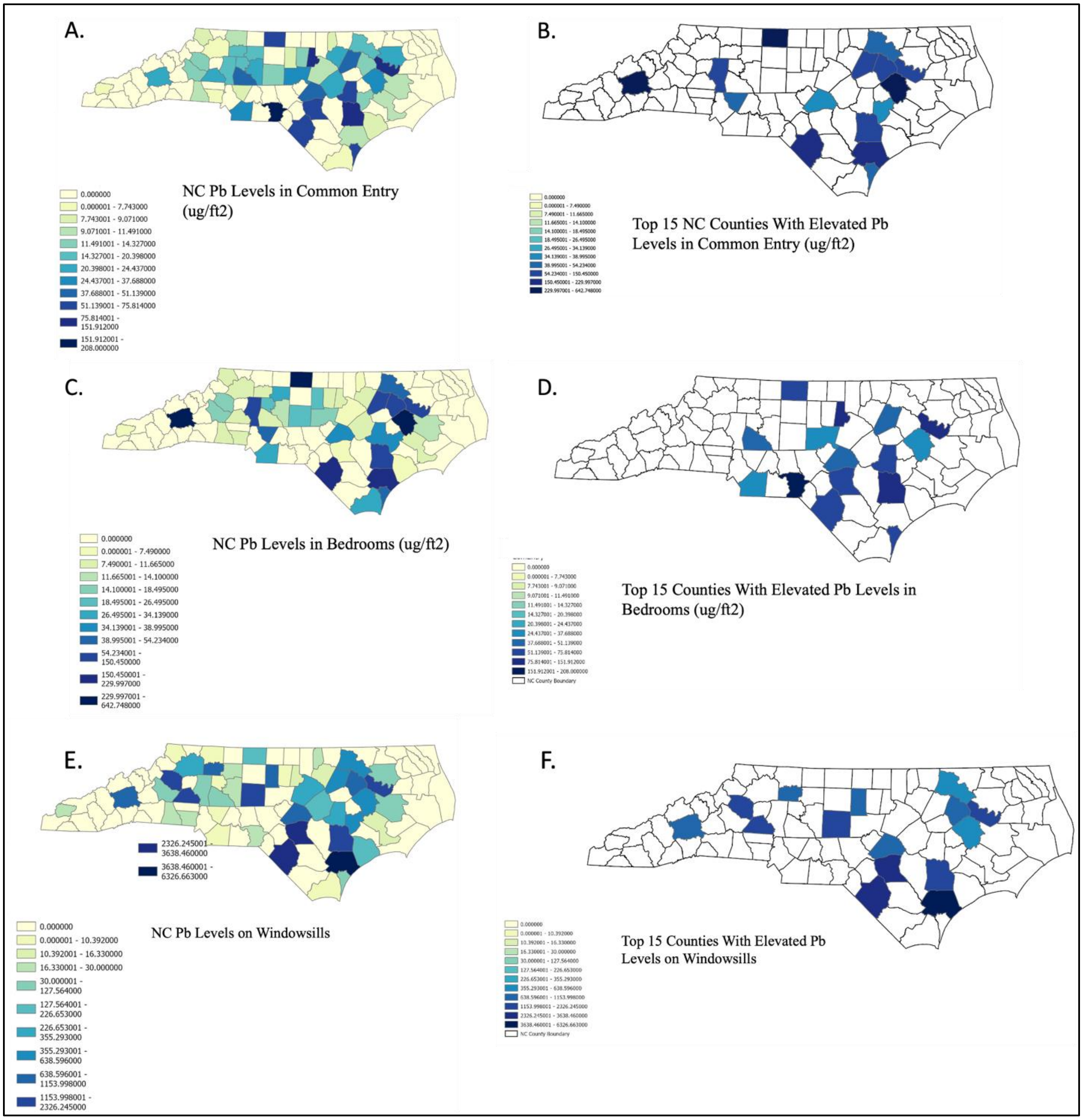

Figure 8: Maps A and B depict the values of Pb in homes across North Carolina. Map B shows the value of 15 counties with the highest rate of elevated Pb levels in the state. Maps C and D show different values of Pb across the state in bedrooms. Map D specifically shows elevated Pb levels across the top 15 counties in the state. Maps E and F show the value of Pb in windowsills. Map E shows a clustering of elevated counties in the Eastern region with Map F showing similar results with the Buncombe County as an outlier in the West. Maps were made using ArcGIS.

counites in the Mountain region did not have inclusive data for this study, the results of these maps demonstrate that the state has elevated Pb levels within the Piedmont and Coastal areas. Future studies should focus on sampling soils, identifying weather patterns, traffic, fossil fuel use, and land use patterns (agriculture, mining, industrial, etc.) that might contribute to elevated Pb levels in homes.

The author was able to conclude after the common entry map was conducted, that elevated Pb levels are prevalent among certain counties in North Carolina. Among the maps, Fig 8A, pictures a cluster of counties that are in the top 15 with the highest Pb levels in the common entry. It is not known how, where, and why these counites have such a high average of Pb levels within the home but looking at the common entry will show foot and body traffic, from individuals and pets, which will track elements from the outside.

Body traffic can include elements that are on your person, such as dirt, grime, flakes, or even dust that have caught onto an individual's clothing, hair, bags, or items that they carry into the home. It is also important to note that a significant number of individuals leave their shoes, jackets, umbrellas, etc., at the common entry when they enter/exit the home. Leaving items at the common entry/exit door frame can accumulate dirt and other elements within the home that can spread when the items are picked up, moved, or carried from room to room. This could be a reason why the common entry has the third highest rate of elevated Pb levels within the home.

In addition to the foot and body traffic entering and leaving the home, several households leave their door open to come in and out for a variety of reasons. Leaving your house door open can lead to more than just foot and body traffic from individuals and pets. Bugs, debris (Leaves and soil carried in from the wind), and other ailments can enter the home and bypass the common entry, entering the main rooms within the home. This could be a reason why Pb is in dust in the home or why there are elevated Pb levels within the kitchen because some common entries lead into the kitchen area. Again, more research and studies need to be done to conclude these theories and suggestions. More reasons not mentioned or listed within this study could contribute to elevated Pb levels within the home, not just for the common entry, kitchen, or dust.

Fig. 8C shows the values of Pb within bedrooms across North Carolina. Bedrooms in North Carolina have the second highest level of Pb throughout the home, 65 ug/ft^2. This level can cause severe illness to at-risk and majority populations to the point of chelation therapy (>45µg/dL). It is important to note that just because a room has an elevated Pb level at 65 ug/ft^2 does not mean that the individual will have that equal Pb level. 65 µg/dL is equal to 0.65mg/L, this equivalates to less than 1oz. of liquid or blood. 65 µg/dL equates to 0.45 $ug/inch^2$. These differences between the prevalence of Pb and the size of the area of a room, such as a kitchen, can have varying levels of Pb that can contribute to different BLLs.

Buncombe, as an outlier county in the Mountain region, had the highest rate of elevated Pb levels in household bedrooms. It is also important to note that Buncombe has the highest elevated Pb levels for the kitchen as well, two high trafficking areas that see the most activity. The bedroom is the most common place in someone's residence for lounging and sleeping; this area is also an open source to common open airways through windows.

According to Fig. 8D, three counties, including Buncombe, tie for the top three counties with the highest Pb levels in bedrooms. Although, the Eastern region continuously reigns over the Piedmont and Mountain regions, it is important to note, just as the Mountain region had little to no inclusion data, the far Eastern Coastal counties had little to no inclusion data. The Eastern region had the most inclusion data, but the bordering counties on the coast had limited data available. Because both sides of the opposing state had no inclusion data, the Piedmont and

Eastern Coastal regions of the state house the most data and possibly a similar visual representation of how both sides of the state may have looked with inclusive data. More data for all 100 counties would have to be collected and analyzed to get an accurate representation of the Pb contamination and exposure for the entire state.

Because the bedroom is where a majority of individuals and families sleep, this is the room/area that has the highest risk of exposure because of the prolonged use/stay within the room. There are definitive reasons why bedrooms have the highest rate of Pb within a room in the home. The main source of exposure that the author suggests would be open window access. Specifically in warmer months, open windows can bring in debris from the outside, leading to exposure to outside sources that can commonly cause allergies and respiratory reactions. This debris can deposit or settle anywhere within the bedroom or surround the area that an individual can breathe. In addition, an individual may sleep or occupy their bedroom with their door closed trapping the debris from the open window in the bedroom causing a cycle of inhaling and exhaling elements from the outside.

Windowsills have the highest value of Pb in a single location within the home across all counties in North Carolina (Fig 8E). The actual location of which windowsills were tested was not mentioned in the reports. Although, these windowsills with elevated Pb levels would have to be within a room with high traffic from deposits from the inside and outside of the home. It is also not known if the testing done on the windowsill was done on the actual windowsill, blinds, floor below the window, or the window itself. Window troughs were not included in the results because they had severely elevated Pb levels that could have skewed the results. Additionally, the troughs are located outside the home, Pb results were needed inside the home, only, for this study. It is unknown as to how much Pb on the windowsills comes from outside sources, but window troughs could have contributed to the elevated levels.

Window troughs can house flowers, bugs/insects, and small animals, such as birds, squirrels, and even birds nesting and laying eggs. These animals and bugs/insects can aid in bringing in elements, such as Pb, into the window through. The soil that houses the flowers in these troughs already has an unknown presence of Pb and outside forces, such as bugs/insects and animals, contribute to the Pb levels, and brings in more elements that could contribute to elevated Pb levels within the home.

Windowsills have the highest level of Pb within the home, according to the values in Fig 8F; it is known how many windowsills were tested per home, but the location was not disclosed. Many homes tested included at least two windowsills per home, in some cases, only one was tested. It is known that the samples taken were inside the home and not the outside windowsill.

It is important to note that these elevated Pb levels on the windowsills were as high as 2,326 ug/ft^2; this is enough Pb to cause death in a human being. Although, it is not known with this area, or with any other area, of the location was cleaned or left as is for samples to be collected. If areas/locations were not cleaned before samples were taken, then this would mean either heavy interference within the home on windowsills, and other locations, or the cleanliness of the home is in question.

Between all five areas/locations within the home, the Eastern and Piedmont regions of the state had the most elevated Pb levels (Fig. 7B, 7D, 8B, 8D, 8F). Again, there are multiple reasons as to why this could be the case and this study did not conduct or know what those reasons are. This would need to be conducted in another study more focused on each county within the state because this study was only able to find data for 48 counties. The data used for this study is enough to warrant a new study dedicated to elevated Pb levels within the home specifically for low-income housing units.

Overall, five areas within the home, kitchen, dust, windowsill, common entry, and windowsills are common places that can collect Pb deposits. The deposits can vary from room to room depending on traffic and cleaning of the areas to eliminate Pb deposits and other elements. It is not certain how much Pb in the home can affect someone's health to the point of illness, but this study should be a starting point to research how Pb in the home affects children and at-risk populations on their health, whether it be from neurological illnesses to diagnosed, physical ailments that will impair everyday tasks. This study is meant to bridge a connection between at-risk populations and Pb within the home. These five areas prove that there is a possibility that individuals and families who live in these homes can become suspectable to dangerous Pb levels according to the data collected and shown within the study so far.

It is not known what other areas of the home can accumulate Pb to this magnitude in comparison to the five areas discussed. Although, other areas of the house should be considered, such as the bathroom, children's play areas, yards with childcare equipment, such as swings, and common sitting areas. These additional areas play a significant role in the daily lives of individuals and families. Adding these rooms/areas with lead to testing the entire home to get an accurate representation of Pb affects at-risk populations within their own home.

Clustering of Counties: Figure 9 depicts a section of the state sectioned within the Piedmont and Coastal regions of the state. According to the previous maps (Maps with the top 15 counties) and data (Elevated Pb levels within the Eastern part of the state), the circled area has a reoccurring theme. These areas/counties house the most elevated Pb levels in homes within the state. This is based on data from 48 counties and not all 100 counties. A more thorough investigation into all100 counties may or may not yield the same results as the maps above. It is not known why this area has the highest rate of Pb within the state, but similarities

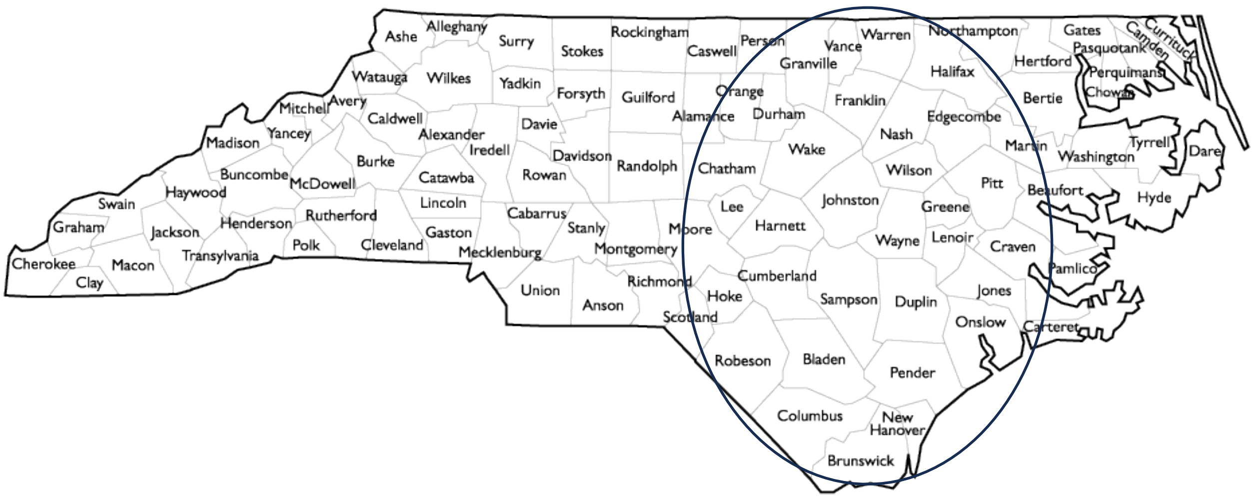

Figure 9: The map above shows all 100 counties in the state of North Carolina with a circle depicting the areas with the highest rates of Pb within the home from all five rooms/areas.

are considered among these counties. All major cities mentioned earlier in this chapter, Raleigh, Durham, Greensboro, and Fayetteville are all located within the selected area. Additionally, this area houses the major universities and workforce areas, such as hospitals and the state capital, and the highest rate of at-risk populations in the state. Previous maps depicted the rate of low-income, Pb paint, and public housing clusters that are mainly in four major cities in the state. These clusters along with an influx of heavy traffic at certain times throughout the year, can contribute to elevated Pb levels within this area.

Lead Levels in Pitt County Homes: Pitt County, NC is home to East Carolina University, multiple towns, and the city of Greenville. The towns/city that make up Pitt County includes Ayden, Grimesland, Greenville, Grifton, Bethel, and Farmville. Greenville is the largest and houses the biggest population and university for the county. The county itself houses a diverse population that consists of high-, middle-, and low-income populations with multiple races/ethnicities that make up these different economic classes. This diversity is in Greenville, with lower-income populations on the outskirts of the city and county lines.

Pitt County and the inclusive towns/city are dated and home to buildings built over a hundred years ago. East Carolina University was founded in 1907, over a hundred years ago, creating a historical landmark in the middle of the county. With the university being at the forefront of the county, along with the main hospital ECUHealth, the county sees a lot of traffic year-round from all over the state of North Carolina and beyond. ECUHealth has had many former names; built-in 1923, this is the main hospital for the branch of ECUHealth that services 29 counties in the Eastern part of North Carolina. With two major aspects of the state in one county, multiple interactions from major cities and universities come through Pitt County, making it a high-traffic area for business and education. Knowing this, the author was able to focus on private residences in Pitt County and eliminate traffic from non-residents who were in the county for business, healthcare, or educational purposes.

Pitt County is home to a diverse population estimated at 173,542 (Excluding those who travel into the city, students, and those seeking healthcare) as of July 2022 (Census, 2022). Of this population over 40% is of minority populations, with the African American population being the largest, and the majority, Caucasian, at almost 60% (Census, 2022).

With a decent size population, the housing market is made up of older homes, and numerous apartment complexes that are dated and need to be remodeled. Although, multiple new developments are in the works now to accommodate the growing population of students that are housed in Pitt County temporarily to attend the local university.

Figure 10 shows the average year of age for homes in Pitt County. The lowest average age for homes, located in Bethel, was built in 1915. Decades before the LCR and EPA rules and regulations were established to protect individuals and families from Pb-based products within the home. The highest average year, located in Grifton, is 1975. A time period that still had Pb-based products within the home. The only city, Greenville, has an average home built in 1957. Greenville, and the surrounding towns, have an average home built before the LCR and EPA rules and regulations were established. Most of these homes are still occupied today with little to no restoration.

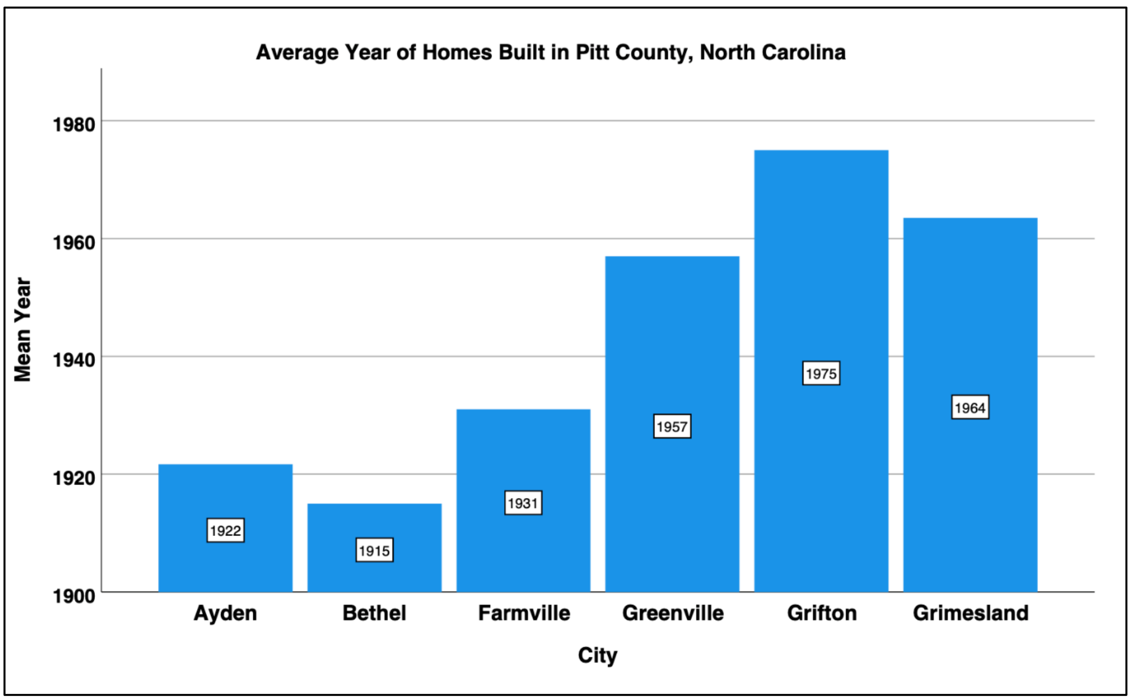

Figure 10: The chart above depicts the average age of homes across multiple towns in Pitt County.

Each room/area of the home within Pitt County had a significant amount of Pb within the room in the home. The data used for the maps below are from a sample of homes in Pitt County with confirmed cases of elevated Pb levels within the home and a confirmed elevated BLL case.

Figure 11 depicts a sample of 29 confirmed elevated Pb level cases based on an adolescent (< 6 years old) BLL and confirmed cases of elevated Pb levels within the same home. The sample cases were taken from January 1, 2018, to December 31, 2020. Greenville, the biggest and only city in Pitt County, had the most confirmed cases. It is known the location of where these samples were taken. Many of these homes were near or in at-risk communities or apartment complexes that have an increased rate of low income and minority populations who live in older homes/buildings. It is not known, however, how long these individuals have been living in their home to have an elevated BLL.

This opportunity to measure how long one lives in a home/building with confirmed elevated Pb levels to obtain an elevated BLL is unknown. This depends on the individual's anatomy, how much time they spend within the home, and how often they clean the home. These factors, and

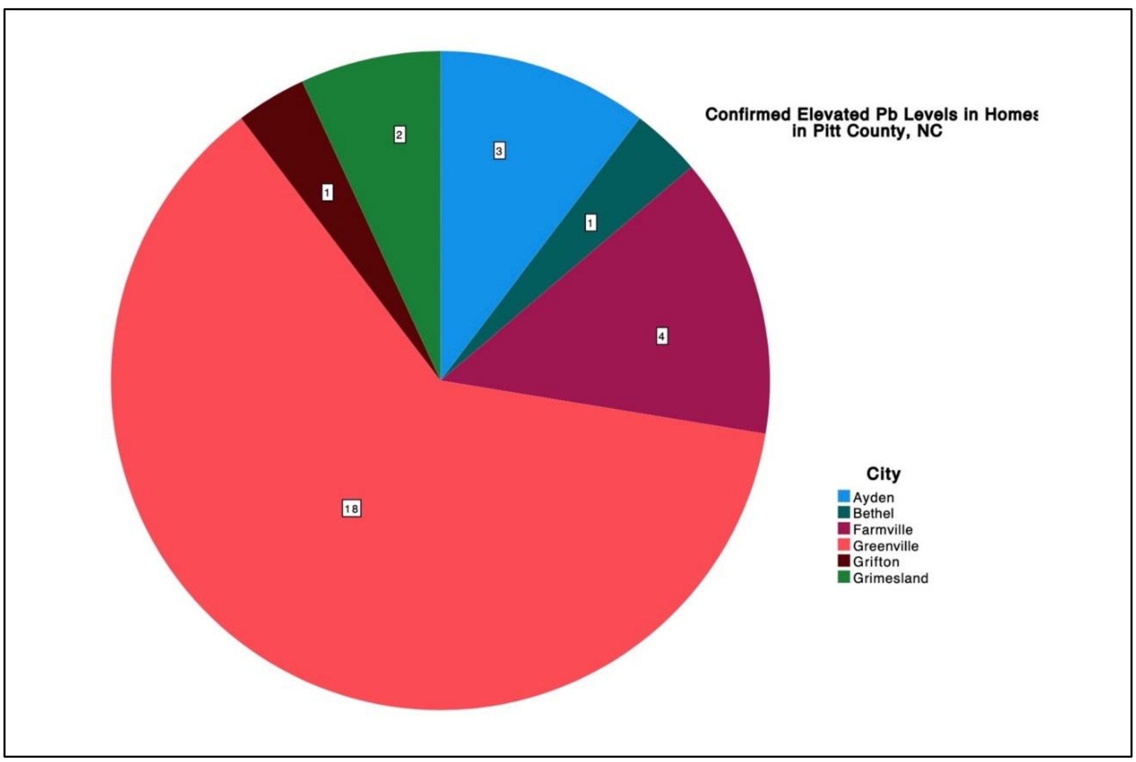

Figure 11: The pie chart showing confirmed elevated Pb levels in homes among major towns in Pitt County, NC.

more, should be considered when understanding how long it takes to have an elevated BLL. The known fact is that these homes house at least one adult individual and at least one child under the age of 6 years old. It is unknown if the adult individual had an elevated Pb level or not.

Child Pb Levels in Pitt County, North Carolina Homes

The results presented in Figure 12 are based on the 29 sampled homes for Pitt County. Common entry, dust, and windowsills were found to have elevated Pb levels, with Ayden with the highest Pb levels in the common entry (Fig. 12A). This could be because the average home age in Ayden was from 1922, over 100 years old, but other factors could contribute to this elevated Pb level. Population, the number of homes, and traffic throughout the town from businesses can be contributing factors to elevated Pb levels, but the actual reason(s) for elevated Pb levels is unknown. Similar to specific counties having elevated Pb levels over others, the same will be with the different towns that span Pitt County. Although, on the Pitt County level, the rate of elevated Pb levels is not as cohesive as they were on the state/multi-county level.

As with the state/multi-county level, not all towns within the county will have verified Pb levels within the home from each of the samples taken. Each home had at least 3 verified samples from 3 different locations throughout the home. For example, Grifton and Bethel only had one home within the sample; if either of these homes did not have a sample for a specific room/area within the home, then the town was not used.

Multiple samples were used for several of the towns within the county, as stated in the pie chart. The number of cases was not uniform across all towns because of inclusion data. More specifically, bedrooms did not have enough inclusion data for the various towns across Pitt County, North Carolina. Although, this should not be a factor within this sample because this sample is meant to justify how much Pb, on average, is in an occupied home in Pitt County. Again, this is only a sample of 29 counties and this data could be skewed if a larger sample/study were to take place within the county. The justification to only using 29 samples is to pinpoint exactly where these cases were within the county, such as the street, community, or neighborhood, but understanding how Pb affects Pitt County residences in the home first can lead to overall health and economic defects. The rate of dust within the county was uniform across all towns. This is similar to the state/multi-county level with an overall average of 7 ug/ft^2, with a standard deviation (STD) of +/- of 2 for all counties within the state. Dust, Fig 12B, has been the most uniform sample across the state/multi-county level and the Pitt County level. It is not known why Pb in dust has such a low average compared to the other samples taken throughout the home, but one of the main reasons could be cleanliness of the home. Homes

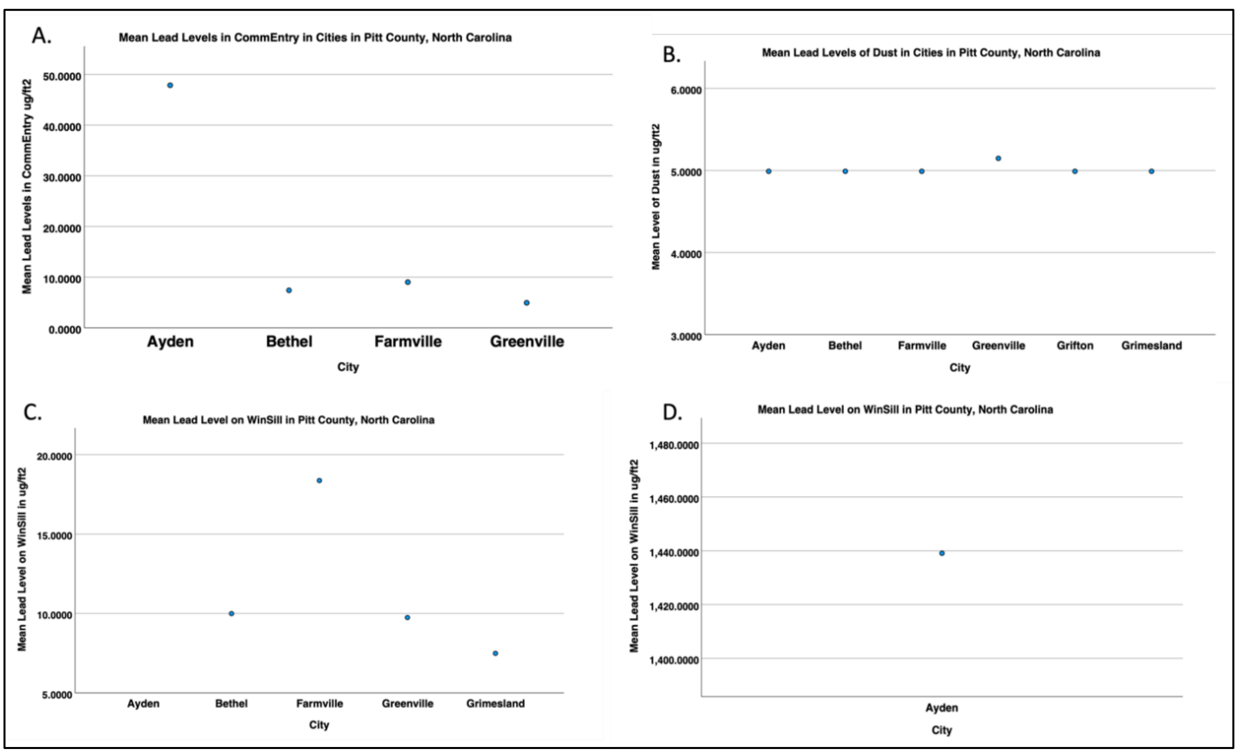

Figure 12: The chart above depicts Pb levels in the common entry, dust, and windowsills across verified samples/cases in Pitt County, NC.

with high levels of dust can cause severe illness for those with upper respiratory problems and a buildup of dirt and grime within the home. If, on average, an individual cleans their home once a week, the average amount of Pb within dust will be wiped every week and a new layer will accumulate with Pb within the layer of dust. Another main reason could be the area where the sample was taken from, again, the reports did not state where the dust sample was taken from in the home. If the sample was taken from an area with high traffic, with constant cleaning, then there would be less Pb within the sample. If the sample was taken from an area that had little to no traffic and a much less risk of upper respiratory issues if inhaled, then the risk of contracting plumbism from dust will be diminished.

It is important to note that if the area of the home was noted as to where the sample was taken from, more information and studies could be generated to know specific rooms, other than common rooms, such as the bedroom and kitchen, that could be potential risk factors for plumbism. The lack of where the sample was taken from in the specific room/area leaves room for improvement in taking samples throughout the home, not just for Pb samples.

Fig. 12C above shows a much lower rate of the average amount of Pb on windowsills in Pitt County compared to the state/multi-county level, where Pb levels for some counties were above 2,000 ug/ft^2. These samples did not include window troughs, only samples taken within the home were assessed. All but one town is represented, Grifton, because no data was found for this sample area.

The only outlier, Fig 12D, Ayden, had an average of 1,439 ug/ft^2 of Pb on windowsills. This sample should be studied further because this was the average across three homes. If the sample was bigger, the amount of Pb could be lower, such as with Greenville. Greenville had 18 homes within the sample with an average of 9.7 ug/ft^2 per home. Does the lack of sample homes for

Ayden skew the results for Pb on windowsills? This is a question that should be studied further. Or it could just be an outlier town that has elevated Pb levels within multiple homes because of the age of the homes within the county. The average age of homes in Ayden is from 1922, this could be a definitive reason as to why Pb levels are so high on windowsills, because of possible Pb paint being chipped off the walls and settling onto the windowsills. In addition to the elevated Pb levels found in the common entry. But this would not explain the average Pb level across all towns with dust. The different variances of Pb within the home due to specific area is alarming because of the usage of the area. Common entry is used daily, sometimes multiple times a day; dust is across the home, in every room, and multiple fixtures; windowsills occupy almost every common sitting space, including the living room and bedroom, within homes. Yet the levels of Pb across these areas varies greatly.

The main outlier town, Ayden, Fig 12D, is now within a lower Pb level range compared to Grifton and Farmville, Fig 12A. It is important to note that Grifton only had one home within kitchen sample. This home equated to a 160 ug/ft^2 Pb level within the kitchen. The area of the sample taken within the kitchen is unknown. The sample could have been taken

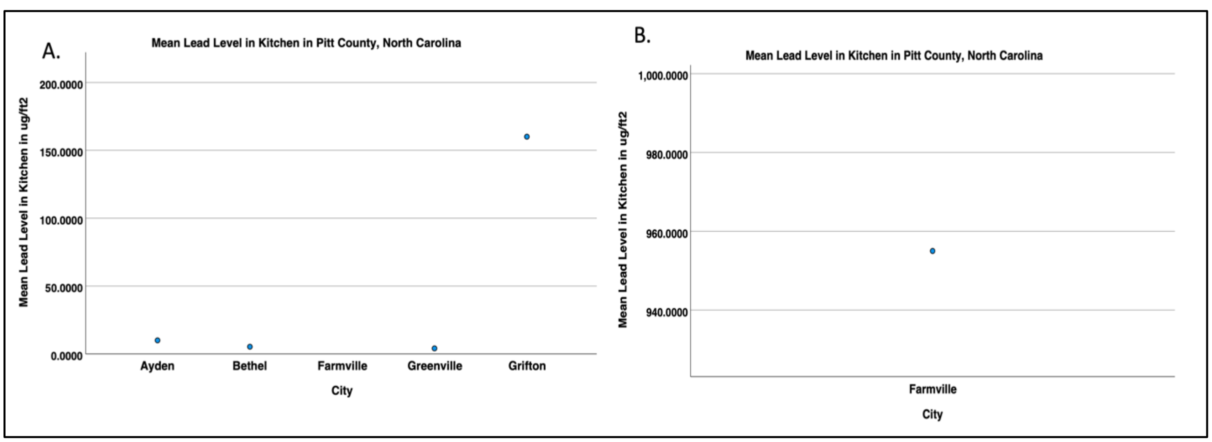

Figure 13: Elevated Pb levels in kitchen across major cities in Pitt County, NC.

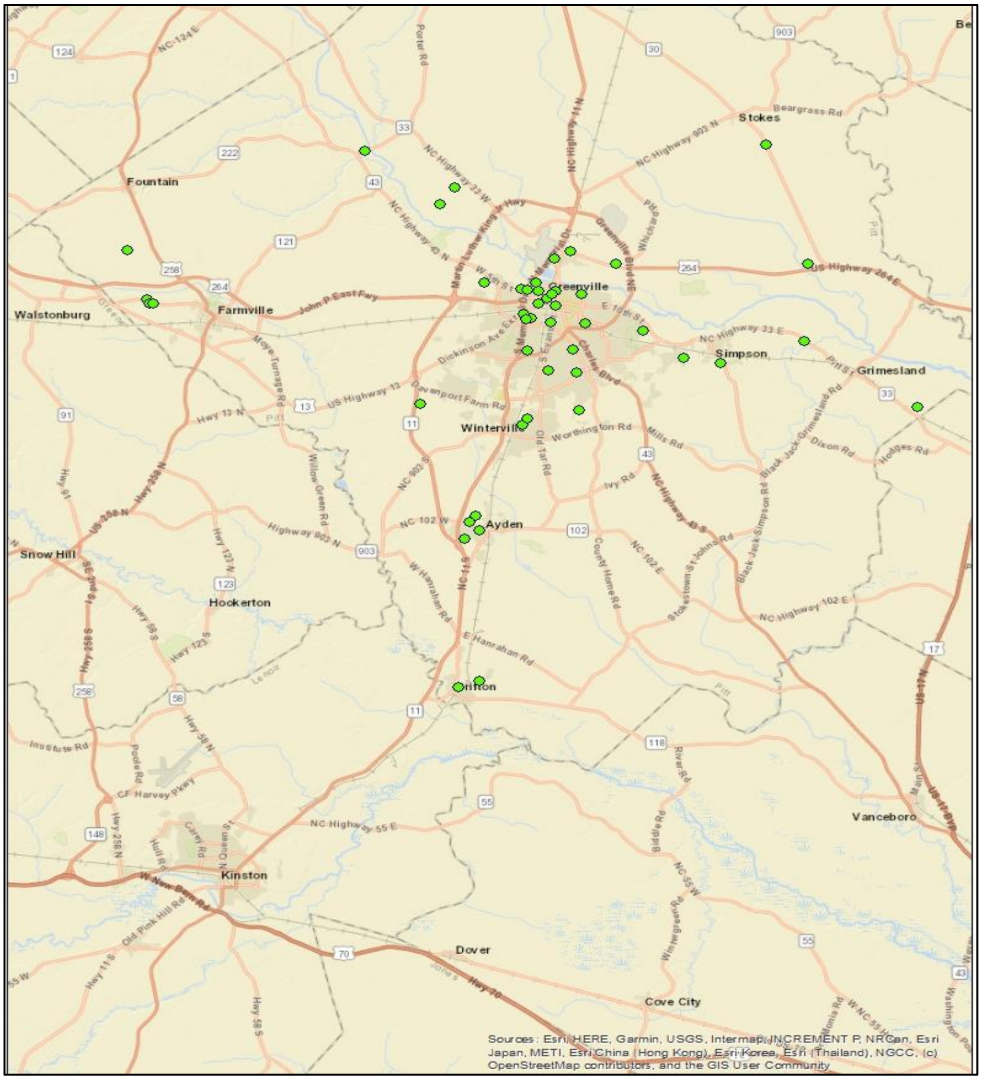

Figure 14: The map pinpoints the location of homes located in Pitt County, NC with a confirmed elevated BLL along with confirmed elevated Pb levels within the home. Map made using ArcGIS.

from an area that has a high rate of human contact, such as cabinets, appliance handles, or the kitchen sink. Farmville is the farthest outlier town for Pb levels in kitchens within the home. This town was uniform with the other towns within the county compared to Ayden, where it had multiple outliers across different rooms/areas. Farmville had 4 homes sampled, and this is a high Pb level that would need to be further researched. It is unknown as to why Farmville had such elevated Pb levels in the kitchen compared to the rest of the rooms/areas within the home.

The graphs above conclude that there is a significant level of Pb across various homes around Pitt County, North Carolina. The average age of the homes used for this sample were built before the Pb-based paint ban of 1978 and the Pb-based pipe ban of 1986. This is not to say that all homes within this age range and below have elevated Pb levels, there is a higher risk of contracting Pb from the home based on the age.

Figure 14 shows a sampled case of confirmed elevated BLL and confirmed elevated Pb levels within the same home. All of these pinpoints were used to create graphs across all towns in Pitt County, North Carolina. Homes were only sampled if a child had an elevated Pb level.

Documented BLL in Children in Pitt County, NC

As presented in Table 2, our general linear model showed that there was a significant positive association between BLL and age of the child (p=0.022). However, there were no significant racial or gender differences in BLL (p>0.05), and that sampled years (2018, 2019, 2020) did not differ significantly in BLL (p>0.05) (Table 2).

Figure 15 depicts the BLL for various races across all child populations from Pitt County, North Carolina between January 2018 and December 2020. The threshold lines on Fig 15A-D indicate the previous CDC acceptable BLL of 5.0 µg/dL, and the current CDC acceptable BLL of 3.5 µg/dL (as of 2022). The Caucasian or white (W) population (n = 104) had the highest elevated BLLs (Fig 15C). There was a total of 568 children with elevated BLL between January 1, 2018 and December 31, 2020. The sample size for W was 104, which is considerably lower than African American or black (B) children sampled (n = 339). The black children had average BLL of 1.21 µg/dL. The other (O) population was 125 children out of the sample.

Table 2. General linear model (GLM) showing main effects of sample year, gender, race and age in children aged 1 month to 6 year and 9 months with blood lead level (BLL) (top table), and parameter estimates of the model (bottom table).

Tests of Between-Subjects Effects					
Dependent Variable: BLLs					
Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Corrected Model	5.250[a]	6	.875	1.492	.179
Intercept	127.921	1	127.921	218.098	.000
Yr	.928	2	.464	.791	.454
Gdr	.436	1	.436	.744	.389
Race	.979	2	.490	.835	.434
Age	3.094	1	3.094	5.275	.022
Error	328.458	560	.587		
Total	1185.604	567			
Corrected Total	333.708	566			
a. R Squared = .016 (Adjusted R Squared = .005)					

Parameter Estimates						
Dependent Variable: BLLs						
					95% Confidence Interval	
Parameter	**B**	**Std. Error**	**t**	**Sig.**	**Lower Bound**	**Upper Bound**
Intercept	1.243	.122	10.160	.000	1.003	1.483
[Yr=2018]	-.101	.094	-1.076	.282	-.287	.084
[Yr=2019]	-.143	.119	-1.201	.230	-.376	.090
[Yr=2020]	0[a]	.	.	.	.	.
[Gdr=f]	.056	.065	.863	.389	-.071	.183
[Gdr=m]	0[a]	.	.	.	.	.
[Race=b]	-.105	.086	-1.217	.224	-.275	.065
[Race=or]	-.115	.103	-1.121	.263	-.317	.087
[Race=w]	0[a]	.	.	.	.	.
Age	.073	.032	2.297	.022	.011	.135
a. This parameter is set to zero because it is redundant.						

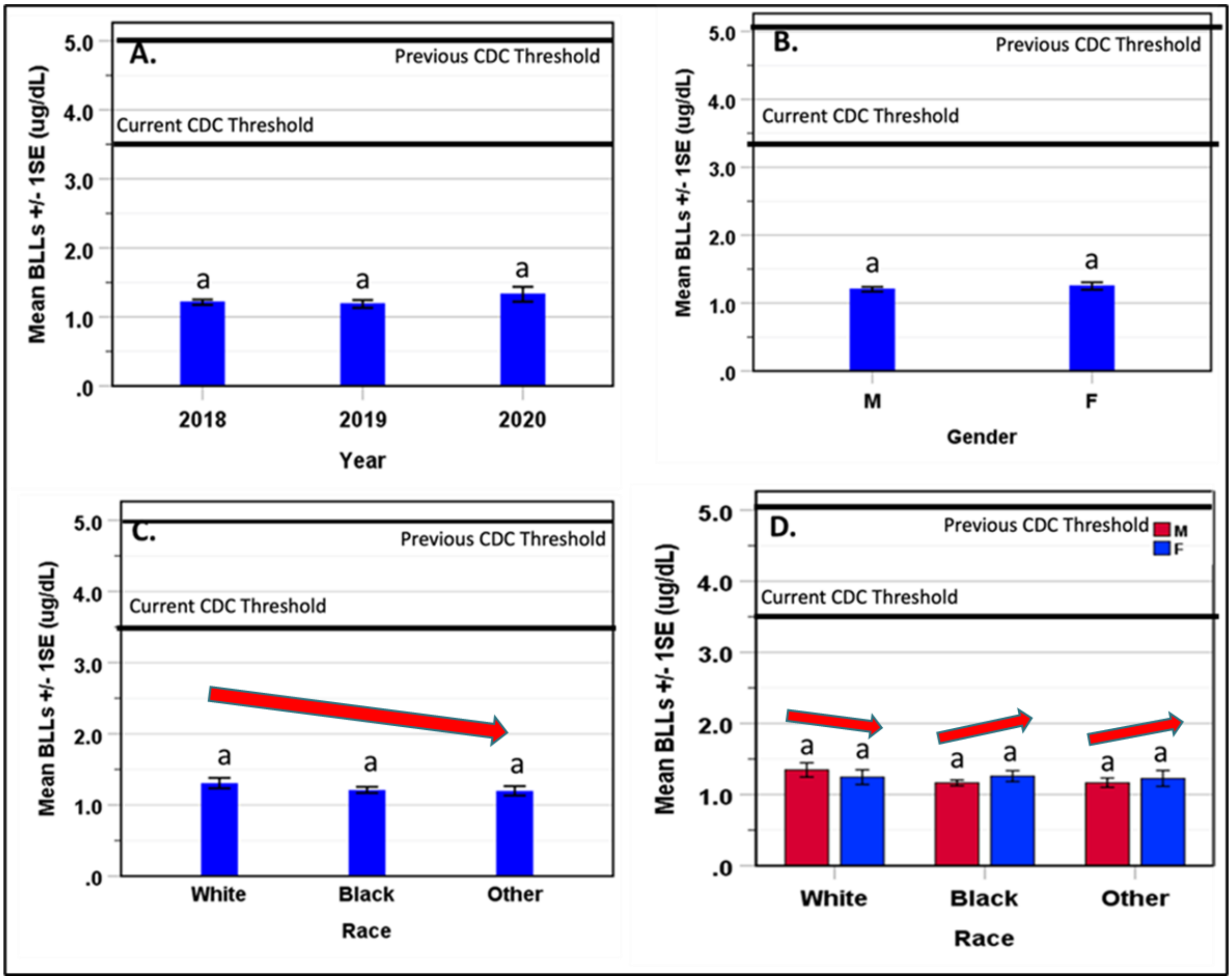

Figure 15: Differences in blood lead level (BLL) among gender, ethnicity, race, and sampling years.

It is unknown as to why the W population had the highest average BLL (1.30 µg/dL), yet the B population had the highest number of cases, 339 confirmed cases with an average BLL of 1.21 µg/dL. Other races (O) had lowest number of confirmed cases than the W and B population, including lower BLLs at 1.19 µg/dL (Fig. 15C). Overall, the average BLL by race was not above the current CDC threshold of 3.5 µg/dL with all three years combined (Fig 15C). Based on the data shown for all three races, there was no significant difference in BLL among races.

As shown in Figure 16, children between the age of 1 year 3 month and 3 year 6 month showed a pattern of elevated BLL, and in some cases BLLs were closer to or above the CDC threshold of 3.5 µg/dL. Around the 2 yr age group, the W population had a BLL over the current CDC threshold (3.5 µg/dL), and almost reaching the previous CDC threshold (5 µg /Dl) (Fig. 16)—a level that would cause concern to medical and public health professionals to take action.

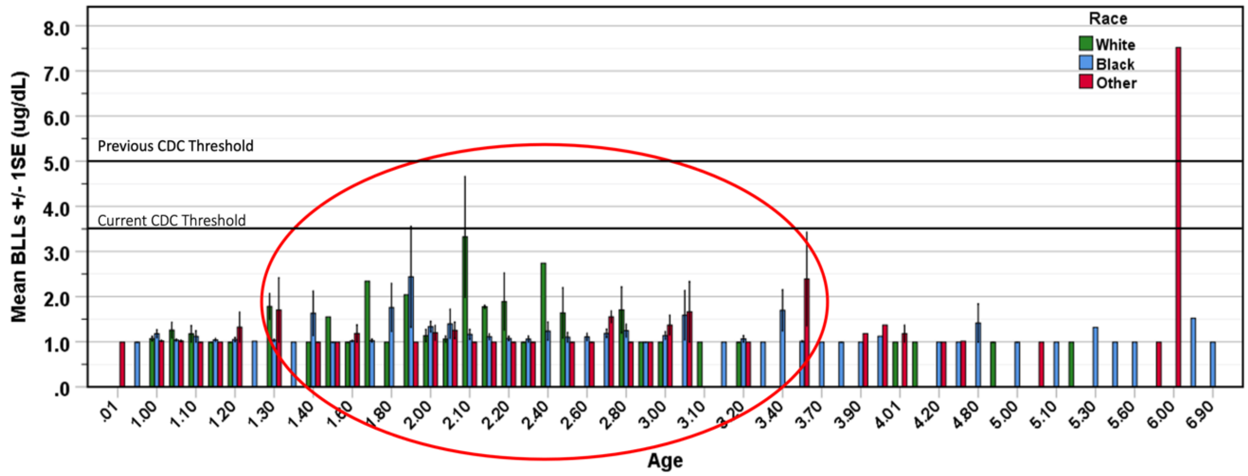

Figure 16: Mean blood lead levels (BLL) in children aged 1 month to 6 years and 9 months for a population of 568 children in Pitt County, NC.

Per the clinical reports, not all information was available across all clinical reports. Data, such as race/ethnicity, were omitted from several reports that could have been useful to this research. Additionally, a child's BLL was tested for multiple reasons: if they are an immigrant, on Women Infants and Children (WIC) government benefits, or other public assistance programs. Homes are only tested if a child within the home has tested for Pb, even if the test does not yield a threshold value of 3.5 µg/dL or higher. This sample population includes children who are at risk and those who may not be at risk for elevated BLL.

Gender was not statistically significant for BLL (Table 2, top panel). However, on average, females had a slightly elevated BLL compared to males (Fig. 15B); while considering the race, Black males and Other males had, on average, higher BLL whereas White females had higher

BLL, on average, compared to White males (Fig. 15D). Nonetheless, on average, both genders had BLL below the CDC threshold of 3.5 µg/Dl (Fig. 15B).

Current Policy and Recommendations for Policy Change

Lead is a toxic heavy metal that has detrimental effects on human body. The results of this study showed that White populations, especially children, are exposed to elevated Pb in homes similar to at-risk or minority populations, thus underscoring the need to target all children from Pb exposure regardless of their races.

Pb is a heavy metal that can cause irreversible damage leading to other illnesses. Plumbism can be detrimental with lifelong side effects; plumbism is often diagnosed in children as another illness, such as nausea, ADHD, ADD, among others. All children, within the infant and adolescent stage, are susceptible to Pb poisoning that can often go undiagnosed based on the type of medical tests conducted (Kalra et al., 2000).

Under North Carolina law, and throughout several states in the United States, children are only tested for BLL within a year from birth if they are under government assistance, are migrants, or live in a household where there are confirmed elevated Pb levels. This is public health law, not federal law. Federal law does not require all children born or within a certain age bracket to be tested for Pb. Public health law is a different set of guidelines set forth by states, cities, and counties. There is no nationwide policy against Pb levels and children, but guidelines recommended by the CDC with Pb level thresholds and CDC threshold guidelines for treatment for various elevated Pb levels (CDC, 2022).

The policy should be changed to include all children, regardless of their citizenship status or if they received government assistance. The results of this study confirmed that children that are not considered at-risk or minority as defined by the inclusion criteria of this study had confirmed elevated BLL. Potential action that could be taken would be testing the homes, medication intervention, and increasing sampling frequency for BLL testing. When a child has an elevated BLL, Pb can stay in their body, usually the skeletal system, for up to three decades (Mason et al., 2014). Treatment involves the use of EDTA chelation therapy that is aimed at reducing the circulating Pb concentration (Mason et al., 2014). With treatment being limited and the true known value of the average BLL per child in the United States is unknown, what was accomplished in this study is limited to the research and statistics that were readily available. Because all children are not required to test for BLL, the extent of Pb exposure and true BLL across children population are unknown, and thus more research is warranted. The CDC recommends that every child be tested for their BLL, but no law, policy, rule, or guidelines mandates this recommendation.

The state of North Carolina does not have a policy, rule, or regulation stating that all children born within the state must be tested for BLL. Additionally, the state does not provide enough medical providers to achieve this feature because there are various counties around the state that have a scarcity in pediatricians and medical providers. Pitt County, NC has the main hospital within a network or medical providers and facilities across Eastern North Carolina. If a Pb level is to be tested, it would be sent to a main lab within Raleigh, the state capitol, or a main hospital that has the supplies and professionals to handle the tests. As a reference, Pitt County's main medical center, ECUHealth, is the only main hospital between Greenville, and Raleigh. For most at risk and low-income populations who live between these two hospitals, the transportation to and from the closest hospital can be up to 40 miles one way. This, in addition to a confirmed elevated BLL test, the county in which the child and family resides would be notified, samples of the homes will be taken, and possible relocation of the family would be needed if the home needs repairs/removal of Pb contaminated objects, paint, or fixtures.

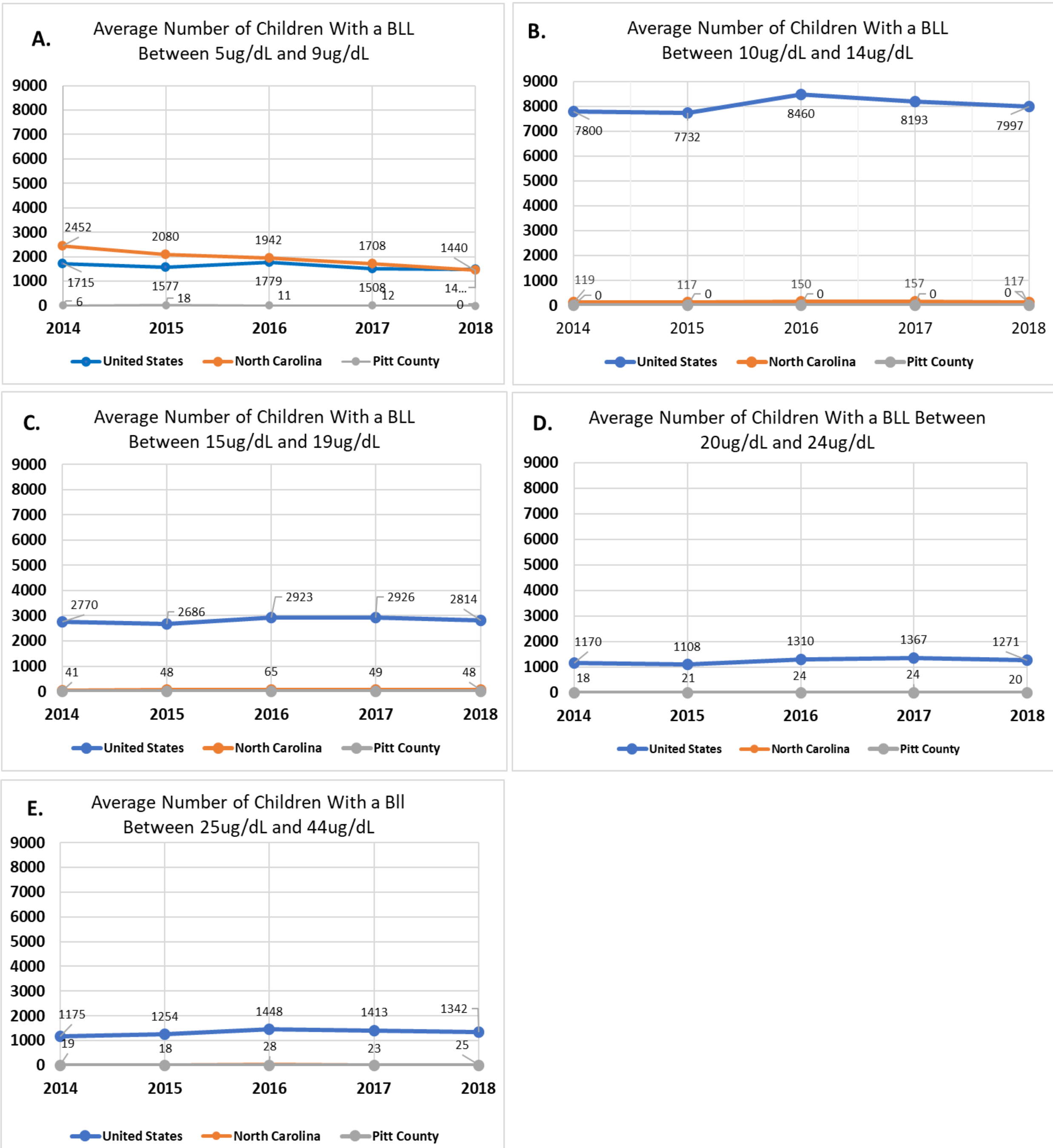

Figure 17: Comparison of elevated BLLs ranging from 5 - 9 µg/dL, 10 - 14 µg/dL, 15 - 19 µg/dL, 20 - 24 µg/dL, and 25 - 44 µg/dL among children (Y axis) in the United States, North Carolina, and Pitt County, NC across multiple years (X axis; 2014 - 2018) (CDC, 2022).

Counties, cities, and the state does not fund the removal of families in homes with elevated Pb levels or assist in the removal of Pb within the home. A majority of at-risk, minority, and low-income populations, and even middle-income populations, do not have the means to abide by recommendations by the county if the child has elevated Pb levels. It may take years for an elevated BLL to become low enough where the risk of harm has diminished significantly, although, not without a proper medical regime and overall healthy lifestyle.

Figure 17 compares elevated BLLs across the United States, the state of North Carolina, and Pitt County, NC. Although, the BLL has declined steadily throughout the past decade, North Carolina had higher number of children with an elevated BLL, 5-9 µg/dL, compared to the national average, Fig. 17A, but an overall lower average number of children with elevated BLL between 10-14 µg/dL to 25-44 µg/dL. Pitt County, NC did not have any cases resulting in a BLL above 9 µg/dL between 2014 and 2018, as reported by the CDC. As a state, these numbers should be less than the overall national average because of the growing healthcare advances that have happened over the last several years in NC. If a policy was put in place to test every child born in NC for their BLL, children tested with higher BLL would receive proper medical care and other support related to Pb mitigation at homes, and this would lead to health promotion.

Over the past several years, the average number of children with elevated Pb levels as declined rapidly, specifically if the elevated Pb level becomes higher than 9 µg/dL. Additionally, the United States average varies across the BLL averages with no consistency with a decline or increase in average.

CHAPTER 5: CONCLUSIONS

BLL Across All Children Populations: The findings of this study showed that children across all races and gender are susceptible to elevated Pb exposures in homes that can lead to elevated BLL, consequently Pb poisoning. While the Black children had the most cases of elevated Pb levels within the sampled population (n = 568) for Pitt County, North Carolina, their average BLL was 1.21 µg/dL, which was lower than that of White children (1.30 µg/dL; n = 104). Other race children had the lowest BLL (1.19 µg/dL; n = 125 cases). It is unknown why White children had the highest BLL, on average. One possible explanation would be that more White children might be living in older homes with higher Pb levels in windowsill and/or other areas of the homes or may reflect cultural differences in indoor versus outdoor activities, potentially leading to differential Pb exposure (Gochfeld et al., 2011).

Studies suggest that White population has better access to healthcare in the US compared to Black and other minority populations as the latter have higher rates of unemployment and under-representation in good-paying jobs that include health insurance as part of the benefit package (Williams and Rucker, 2000). The observed fewer cases of elevated BLL among the White population may suggest that they received timely treatment before their initial diagnosis compared to the Black and other minority populations. Despite increased pb exposure, plumbism can often be misdiagnosed or the underlying condition may improve due to changes in living environment and/or diet. Although Pb in body cannot be rid of in its entirety, EDTA chelation therapy and supportive medical care can help mitigate excess Pb in children and manage symptoms. Because the half-life of Pb within the human body can be decades long, combating the intake of Pb through various sources can improve one's overall health (Talayero et al., 2023).

What Can We Do Better? The population, either it be Pitt County, NC, the state of North Carolina, or the United States, can have more inclusion criteria for testing children and adults for elevated BLL. This study focused on children among at-risk populations, but our findings were surprising in that While children may be equally at-risk of elevated Pb exposure at homes akin to Black and other minority populations. Based on this finding, we recommend that medical professionals should test all children for BLL, regardless of race, gender, and household income status. As a population, health professionals and politicians need to set more inclusive guidelines, communicate more widely regarding elevated BLL and plumbism, and routine testing of homes with adolescent children. This will take several years and multiple drafts of policy and recommendations.

Housing, Children, and the Environment: A child's environment, specifically their living conditions, can affect their overall health. Housing assignments for at-risk populations consist of older homes that may need costly repairs, and that landlords or tenants may not be able to afford. Affordable housing is needed for Americans, yet the rate of housing stability is declining rapidly (Argonne, 2022). With older buildings and homes being used for individuals and families who need affordable housing, Pb paint can flake off resulting in increased exposure to anyone living within the home. Individuals can accumulate Pb in the body that can last several years, but a vast majority may not need treatment. This is not always the case, so frequent testing and policy implementation for heavy metal testing at least once a year can save children from Pb poisoning. Since safe housing is critical for normal child development, houses with high Pb contamination must be renovated to mitigate potential Pb exposure and health risks. This will take time, funding assistance, and resources that many cities, towns, and states may not have. Regardless, the federal and state governments ought to pass more policies and guidelines restricting unsafe housing and create a more inclusive environment for all populations, regardless of race/ethnicity and income status.

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Appendices

Appendix A: IRB Approval

EAST CAROLINA UNIVERSITY
University & Medical Center Institutional Review Board
4N-64 Brody Medical Sciences Building· Mail Stop 682
600 Moye Boulevard · Greenville, NC 27834
Office **252-744-2914** · Fax **252-744-2284** ·
rede.ecu.edu/umcirb/

Notification of Initial Approval: Expedited

From:	Biomedical IRB
To:	Elizabeth Abioro
CC:	Lok Pokhrel Gregory Kearney
Date:	6/5/2023
Re:	UMCIRB 23-001107 Human Health Effects of Lead in the Environment

I am pleased to inform you that your Expedited Application was approved. Approval of the study and any consent form(s) is for the period of 6/5/2023 to . The research study is eligible for review under expedited category # 5. The Chairperson (or designee) deemed this study no more than minimal risk.

As the Principal Investigator you are explicitly responsible for the conduct of all aspects of this study and must adhere to all reporting requirements for the study. Your responsibilities include but are not limited to:

1. Ensuring changes to the approved research (including the UMCIRB approved consent document) are only initiated with UMCIRB review and approval except when necessary to eliminate an apparent immediate hazard to the participant. All changes (e.g. a change in procedure, number of participants, personnel, study locations, new recruitment materials, study instruments, etc.) must be prospectively reviewed and approved by the UMCIRB before they are implemented;

2. Where informed consent has not been waived by the UMCIRB, ensuring that only valid versions of the UMCIRB approved, date-stamped informed consent document(s) are used for obtaining informed consent (consent documents with the IRB approval date stamp are found under the Documents tab in the ePIRATE study workspace);

3. Promptly reporting to the UMCIRB all unanticipated problems involving risks to participants and others;

4. Applying for continuing review and receive approval of continuation of the study prior to the study's current expiration date. Application for continuing review should be submitted no less than 30 days prior to the expiration date. Lapses in approval (i.e. study expiration) should be avoided to protect the safety and welfare of enrolled participants and liability to the University; and

5. Submission of a final report when the study meets the UMCIRB criteria for closure. Study approval should not be allowed to expire simply because the study is completed, rather the UMCIRB should be formally notified of study completion via the final report process.

The approval includes the following items:

Name	Description
Research Protocol Updated	Study Protocol or Grant Application

For research studies where a waiver or alteration of HIPAA Authorization has been approved, the IRB states that each of the waiver criteria in 45 CFR 164.512(i)(1)(i)(A) and (2)(i) through (v) have been met. Additionally, the elements of PHI to be collected as described in items 1 and 2 of the Application for Waiver of Authorization have been determined to be the minimal necessary for the specified research.

The Chairperson (or designee) does not have a potential for conflict of interest on this study.

Appendix B: CEPH Competencies Addressed

DrPH Foundational Competencies

***DrPH-1. Explain qualitative, quantitative, mixed methods and policy analysis research and evaluation methods to address health issues at multiple (individual, group, organization, community, and population) levels*: ** This study was able to create a mixed method, policy analysis, and evaluation project over Pb in the home in the United States, North Carolina, and Pitt County, NC. Data was used to create distribution maps that depicted the value of Pb in homes and clinical reports were collected to understand the variation of Pb across multiple child populations within Pitt County, NC. Policy analysis was made by conducting interviews with the Pitt County Health Department Environmental Health Lead Specialist Tashaunda Hill and Angela Manning. They were both able to provide information regarding Pitt County policies and guidelines and North Carolina policies and guidelines about Pb and children.

DrPH-4: Propose strategies for health improvement and elimination of health inequities by organizing stakeholders, including researchers, practitioners, community leaders and other partners: Addressed by proposing policy changes and collaborating with the health director for the PCHD Environmental Health and lead environmental health specialists Tashaunda Hill. There are no corroborations within the county level for the health department, potential researchers, health professionals (pediatricians), and community leaders, to combat the plumbism and elevated Pb levels in the community. This study highlights the importance of and addressed the lack of coordination between these entities and how a structured unit may be able to form to combat BLL in children.

DrPH-5. *Communicate public health science to diverse stakeholders, including individuals at levels of health literacy, for purposes* *of influencing behavior and policies:* Addressed by working directly with the Pitt County Health Department and directly with health professionals in the North Carolina Healthy Homes Agency. I was able to collaborate within these organizations to understand what gaps in healthcare access and in the literature that I would need to fill through my research.

DrPH EOH Concentration-Specific Competencies

DrPH-EOH-5. *Apply an intervention to an environmental or occupational health hazard and design method to reduce potential harm associated with identified hazard:* Addressed by collecting and analyzing Pb data within homes across North Carolina and Pitt County and pinpointing clusters/areas of extensive Pb exposure and proposing intervention/mitigation measures.

DrPH-EOH-7. *Interpret results of data analysis for public health research and policy:* Addressed by interpreting results of data analysis from multiple data sets using Arc GIS, EJScreen and SPSS.

Appendix C: Survey from Pb Specialist of Pitt County Health Department Environmental Health

1. **How often do you report elevated lead level cases in children? On average per year in Pitt County?**

Going back to 2019, I was able to put together the following information together. These include cases that made it to our Environmental Workflows which met the definition of an EBL or CBL child and required at minimum to offer an investigation for the family at the primary address for EBL's. Not all offers were accepted for EBL cases.

Year	EBL	CBL	Total
2019	3	1	4
2020	3	-	3
2021	3	3	6
2022	6	2	8
2023	6	1	7

2. What policies, laws, rules, or restrictions are put into place for elevated lead levels in children?

We follow guidelines and requirements per the Childhood Lead Poisoning Prevention Statutes and the 15A NCAC 18A .3100 Rules Governing Lead Poisoning Prevention in Children Program. DPH: Environmental Health Section: Rules (ncdhhs.gov) Amended in 2017 with an effective date of January 1, 2018, the blood lead action levels for lowered to recognize an EBL as 5 - 9 µg/dL and CBL as 10 µg/dL or greater to align with the federal guidelines published by the Centers for Disease Control and Prevention in 2012. This allows us to offer an environmental investigation for families of EBL children and pregnant women. In the case of an EBL, this offer for an investigation may be accepted or declined. While it is not required or an official policy, Pitt County has tried to provide additional follow-up with a family after an environmental investigation offer has been declined. We would continue to supply education to families to prevent lead exposures.

3. Do you have specific guidelines for certain communities in Pitt County? More specifically, do certain populations of children, low income, those on government aid, etc., have specific requirements when it comes to blood lead level testing or reporting?

All children should be screened at ages 1 and 2 to check their blood lead levels. Those children receiving Medicaid especially must have these results. In working with the Head Start Programs, this is part of the information they must verify when completing their health records for the children enrolled. (Additional follow-up for this question.)

4. Do you meet cases more in apartment complexes or single-family homes? If yes, how would you address the issue (technical help, training, oversight, etc.?)?

Honestly, it’s probably split. Looking back to 2019, about half of the cases investigated were in single family homes including mobile homes, and the other half were associated with apartment complexes. Often, for those associated with apartment complexes, hazards identified were not associated with the residence, instead hazards may have been associated with sources including spices, occupational exposures, hobbies, or other sources.

5. **Those who have confirmed elevated blood lead level cases are tested how many times after the first diagnoses? More specifically, are** the children treated first then tested in incremental time periods after possible treatment?

See the attached memo with clinical follow-up schedule. Recently, this was updated for March 2022. This provides guidance for repeat follow-up sampling for children with elevated blood lead levels. Previously, clinical follow-up did not occur at these lower levels. Since this change, the nursing staff now follow-up with families before they are identified as an EBL or CBL in our Environmental workflows. I will say that this has been helpful to reach families when I as an Environmental user must reach out to them. At that point they may have received some education and were expecting our call. They have been more willing to accept the offer for an investigation, and this has helped speed up the process so that we can complete an investigation where scheduling will allow.

6. Are there any laws, policies, rules, or regulations you can send me (via email) that may be beneficial?

See the link here: DPH: Environmental Health Section: Rules (ncdhhs.gov)

7. What gender, race and/or ethnicity has the most cases of elevated blood lead levels?

Follow-up with you

8. Does Pitt County partner with any other counties with lead prevention programs?

Pitt County has participated with the Lead and Healthy Homes Outreach Task Force, a collaboration of local & state agencies working to promote healthy homes include those which are free of lead hazards. Join the Task Force - NC Healthy Homes

We also participate in the Health Services Advisory Committees for our local Head Start Programs Economic Improvement Council which has 4 childcare locations in Pitt County and East Coast Migrant Head Start with 1 childcare program also in Pitt County. We provide support and education including for matters regarding lead poisoning prevention for the childcare program and families they serve. As we speak, I have been attendance for EIC's Head Start Health Fair, providing education to families on Lead Exposure and Prevention of Child Lead Poisonings. We collaborate with counties as when cases sometimes cross county lines and work to connect people with resources as needed. We will continue to participate in outreach to include Pitt County – Maternity Fair, Martin-Pitt Partnerships' Kids Spooktacular Fest, and other events and Health Fairs as invited.

9. What specific programs and policies that have been implemented in Pitt County are successful (or not)?

Follow-up with you.