AN ANALYSIS OF RACIAL, SOCIOECONOMIC, AND AGE DISPARITIES WITHIN SULFUR DIOXIDE NONATTAINMENT AREAS IN EPA REGION 5

by

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Table of Contents

List of Abbreviations	4
Abstract & Acknowledgments	5
Chapter 1: Introduction	6
Chapter 2: Environmental Justice	11
Chapter 3: Sulfur Dioxide and Environmental Health and Toxicology	22
Chapter 4: Policy and Regulations	30
Chapter 5: Methods	40
Chapter 6: Results	43
Chapter 7: Discussion	56
Literature Cited	62

List of Abbreviations

AERMOD	American Meteorological Society/Environmental Protection Agency Regulatory Model
CAA	Clean Air Act
FIP	Federal Implementation Plan
NAAQS	National Ambient Air Quality Standards
SES	Socioeconomic Status
SIP	State Implementation Plan
SO_2	Sulfur Dioxide
TRI	Toxics Release Inventory
UCC	United Church of Christ
USEPA	United State Environmental Protection Agency

Abstract

The rates of asthma in the United States are increasing annually. This rise can be attributed to air pollution exposure. Under the Clean Air Act's NAAQS, regions with sulfur dioxide levels in excess of 75 ppb averaged over 3 years are considered "nonattainment areas" and the state is required to draft and implement a plan to reduce the pollution levels. In EPA Region 5 there are 14 nonattainment areas. Vulnerable populations residing in these areas are at an increased risk of developing respiratory and cardiac diseases. Children and infants are at a high risk of low birth weights, asthma, and mortality. In this study, non-Hispanic black, Hispanic, non-Hispanic white, women of childbearing age, children under the age of 18, individuals 65 years of age and older, and households living below the poverty line are evaluated at the block group level and the likelihood of each population to live within a nonattainment area in eight states in the Midwestern United States. The results indicate that as the proportion of individuals living below the poverty line and proportion of racial minorities increases, the likelihood of living within a sulfur dioxide nonattainment area also increases, confirming the environmental justice hypothesis. Additionally, the most vulnerable members of society to sulfur dioxide exposure, i.e. women of childbearing age, children under the age of 18, and adults aged 65 and older, are found to be at the greatest risk of living within nonattainment areas when examining the percentage of individuals in nonattainment block groups based on poverty and race information. Policy recommendations are discussed along with recommendations for future research.

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CHAPTER 1: Introduction

The CDC reports that the rates of asthma are increasing each year. In 2009, approximately 1 in 12 Americans had asthma (Moorman et al. 2012). The National Heart, Lung, and Blood Institute attributes the high prevalence of asthma symptoms and disease to a combination of genetic and environmental factors (NHLB). One of the primary culprits is ambient sulfur dioxide (SO_2).

The inhalation of sulfur dioxide has been found to increase respiratory and cardiac diseases. Pregnant women exposed to the contaminant are at an increased risk of delivering a low-birth weight child. High levels of the irritant can result in elevated hospital admissions due to asthmatic symptoms in polluted regions.

In the United States, 94% of ambient sulfur dioxide is emitted by coal-fired power plants (Clean Air Task Force 2001). In the Midwest, 99% of sulfur dioxide is released via power plant facilities and equates to 28% of total U.S. SO_2 emissions, or 5.4 million tons annually. Under the amended 1990 Clean Air Act, the Environmental Protection Agency (EPA) is legally bound to regulate and monitor the level of emissions of six criteria pollutants within each state. Under the National Ambient Air Quality Standards (NAAQs), a safe 1-hour standard of sulfur dioxide is 75 ppb averaged over 3 years. Any geographic area exceeding this limit poses a threat to human health and safety. The United States has 30 areas that exceed the NAAQs for sulfur dioxide. Nearly half of these areas, 14, exist within 8 states in the Midwest. This thesis study seeks to examine those most impacted by the high levels of sulfur dioxide.

This study focuses on the Midwest region due to the prevalence of nonattainment areas, or geographic areas exceeding NAAQs for SO_2, found in the region. The states chosen are within the jurisdiction of EPA's Region 5 (Illinois, Indiana, Michigan, Minnesota, Ohio, and Wisconsin). Kentucky and West Virginia are also included in the analysis as two nonattainment areas cross state boundaries. I selected only states within Region 5 as they are directly accountable to one Regional Administrator. Additionally, the topographical, meteorological, and sociological composition of each state in the region is similar.

1.1 Research Questions

In conducting this study, the main research questions I sought to answer are:

1. What is a nonattainment site? What is the standard for SO_2?
2. What is the geographic distribution of nonattainment areas in the United States?
3. What is the geographic distribution of nonattainment areas within EPA Region 5?
4. Who are the most vulnerable populations to the adverse effects of high levels of sulfur dioxide and what studies have demonstrated a correlation between SO_2 emissions and health outcomes?
5. Is there a greater percentage of racial and socioeconomic minorities living within sulfur dioxide nonattainment areas than the geographic region of EPA Region 5?
6. Is there a greater percentage of racial and socioeconomic minorities living within SO_2 nonattainment areas than SO_2 attainment areas in each state?

1.2 Hypotheses

Chapters 2 and 3 illuminate the hazards of living within nonattainment areas and the environmental justice concerns. Since the 1983 GAO study found that environmental risks, specifically hazardous landfills, were purposefully located in regions of racial minorities, the environmental justice research has exposed numerous cases in which impoverished and racial minorities were being exploited by industrial pollution (GAO 1983; UCC 1987). In the United States, the Black and Hispanic populations were at the greatest threat of environmental risks in their neighborhoods (Mohai 1995). Further research exposed that industrial air toxics also put communities of color and the poor at risk of developing adverse outcomes due to exposure levels above the National Ambient Air Quality Standards (Hajat et al. 2013; Zwickl et al. 2014). Research into air pollution revealed that along with racial minority populations, lower-income white populations were at a higher risk of pollutant exposure than upper-income whites (Zwickl et al. 2014).

Based on the research findings in Chapters 2 and 3 of this study, the main hypotheses for this research are:

1. Block groups with higher proportions of racial minorities (non-Hispanic Black and Hispanic populations) are more likely located within SO_2 nonattainment regions than areas with lower proportions of racial minorities in the Midwest.
2. Lower socioeconomic (SES) populations (households living below the poverty line) will be more likely to live in block groups located within SO_2 nonattainment regions than upper SES populations (households living above the poverty line) in the study area.
3. Racial minorities and lower socioeconomic populations will be more likely to live in block groups located within SO_2 nonattainment regions in the study area.
4. Women of childbearing age who come from a racial and socioeconomic minority background will be more likely to live in a nonattainment area.

5. Children under the age of 18 who have a racial and socioeconomic minority background are more likely to live in nonattainment areas.
6. Individuals of 65 years of age or older who come from a racial and socioeconomic minority background are more likely to live in nonattainment areas.

1.3 Contributions to Greater Body of Literature

Despite a growing body of environmental justice literature and an extensive library of public health research on sulfur dioxide health outcomes including asthma, very few studies have examined the racial and socioeconomic composition of regions known to exceed sulfur dioxide health standards. A single study conducted by Zou et al. in 2014 examined the social inequities related to exposure to low concentrations of sulfur dioxide in Dallas-Fort Worth, Texas. Yet, despite their conclusive findings that non-whites are most likely to be exposed to unhealthy levels of SO_2, no further studies have sought to examine the relationship between a region out of attainment and its residents, especially relating to potential adverse health outcomes (Zou et al. 2014).

This study will provide the foundation for future research and public health policies on sulfur dioxide. It will give insight into the populations at the greatest risk of developing poor health outcomes. Additionally, it will call into question the effectiveness of current NAAQs enforcement standards in protecting the health of Americans. Finally, the ultimate goal of the study is to provide community members, advocates, and policy makers evidence in which to remedy or call for solutions to the problem.

1.4 Organization of the Study

To guide the reader, this study is organized by chapters.

In Chapter 2, a brief history of the environmental justice movement to the present day is outlined. It provides examples of previous environmental justice studies including the first studies on hazardous waste sites and the most recent environmental justice literature on industrial air toxics.

Chapter 3, entitled "Sulfur Dioxide and Environmental Health and Toxicology" gives an in-depth report on the toxicological effects of sulfur dioxide on the most vulnerable populations: children, women of childbearing age, and the elderly.

The events leading up to the Clean Air Act are described in Chapter 4 on Policy and Regulations. The Clean Air Act and subsequent regulations of sulfur dioxide under the National Ambient Air Quality Standards including State Implementation Plans and Federal Implementation Plans are summarized. The chapter also provides key definitions for the empirical analysis in Chapter 5.

Chapter 5 describes the methodology of the environmental justice study.

Chapter 6 relays the results of the empirical analysis.

Chapter 7 provides a discussion of the results, the limitations of the study, and recommendations for future research in this field.

CHAPTER 2: Environmental Justice

2.1 Environmental Justice: Introduction

Environmental justice has become a recognized terminology among academics and legal experts in the environmental field. However, the term, "environmental justice" has evolved only within the last fifty years (Bryant and Mohai 1992). During the mid-1900s, the intersection of public health, civil rights, and environmental protection was not viewed as interrelated. Even today, the definition of environmental justice remains vague. According to the Environmental Protection agency, environmental justice is defined as:

"the fair treatment and meaningful involvement of people regardless of race, color, national origin, or income with respect to development, implementation, and enforcement of environmental laws, regulations, and policies" (EPA 2016).

The evolution of environmental justice ranges from a small county in North Carolina to a presidential executive order.

2.2 History of EJ

2.2.1 Warren County, North Carolina

The state of North Carolina proposed the construction of a landfill site in Warren County to dispose of polychlorinated biphenyl (PCB)-contaminated soil (McGurty 2009). Warren County was composed of a predominantly African American population—an unusual demographic makeup in the state. In fact, many protestors of the hazardous waste site claimed that the state sited the facility in Warren County due to the racial and socioeconomic minorities in the community (McGurty 2009).

After four years of legal battles between the residents and the U.S. Environmental Protection Agency, the community took their case to Reverend Leon White, the director of the United Church of Christ's Commission for Racial Justice (Bryant and Mohai 1992). White was not an environmentalist, he was a civil rights activist. He recognized in the Warren County case a civil rights violation. The intersection between race and environment brought together white and black Southerners to protest the landfill (Bryant and Mohai 1992). While the protesters were able to disrupt the landfill operations for six weeks by laying on the streets leading to the site, they were unable to enjoin the landfill construction permanently. What was considered a failure at the time, became a victory for future environmental sites. The Warren County protests brought to a national stage the recognition of the spatial distribution of environmental hazards to minority communities. Robert Bullard in *Dumping Dixie* praised Warren County as "the first national protest by blacks on a hazardous waste issue that focused national attention on toxics in the black community" (Bullard 1990; Mohai, Pellow, and Roberts 2009).

While the phrase "environmental justice" was not yet in the legal vernacular, Bullard and others helped to coin the term, "environmental racism" to highlight the unjust practice of siting hazardous facilities in African American communities (Perez et al. 2015).

2.2.2 The GAO Study

In the wake of Warren County, the United States General Accounting Office (GAO) was commissioned by the House of Representatives in 1983 to "determine the correlation between the location of hazardous waste landfills and the racial and economic status of the surrounding communities" in the Southeast (GAO 1983: 2). The results of the study found that within EPA Region 4, three of the four landfills are located in communities where the predominant race is black. Warren County in particular had both a large population of blacks and American Indians living below the poverty line.

While it was considered a landmark study, the GAO's methodology limited its usage (Bryant and Mohai 1992). The study restricted itself to one region of the United States with only four hazardous waste landfills (GAO 1983). The conclusion, that a link between hazardous waste facility siting and race exists, could not be extrapolated to the rest of the United States (UCC 1987).

2.2.3 The United Church of Christ's Commission for Racial Justice

The United Church of Christ's Commission for Racial Justice sought to fill the "void" that the GAO study had created (UCC 1987). During the 1980s, the United Church of Christ was a national faith-based organization with nearly 1.7 Protestant members (Bryant and Mohai 1992). While the Commission for Racial Justice was created to defend civil rights issues in the 1960s, the organization became invested in environmental concerns after being approached by concerned Warren County residents. In a study that would be later entitled, "Toxic Wastes and Race in the United States", the Commission conducted two cross-sectional analyses to "determine the racial and socioeconomic characteristics of Americans living in residential areas surrounding commercial hazardous waste facilities and uncontrolled toxic waste sites throughout the United States" (UCC 1987: ix). The first analysis examined the demographic similarities of where the facilities were located while the second analysis was descriptive and separated out the individual races and ethnic backgrounds of each community. It was the first national study to analyze the "distribution of commercial hazardous waste facilities and abandoned waste sites by race and income" (Mohai 1995; 615).

The results of the UCC studies confirmed the findings of the GAO study on a larger scale. Zip code areas with larger proportions of racial and ethnic minorities were predictors of hazardous waste sites. The empirical analysis found that racial composition was a greater indicator than socioeconomic status (UCC 1987). The populations most impacted were blacks and Hispanics. The percentage of racial minorities within a zip code containing a facility was double the amount of a zip code without a hazardous waste facility (Mohai 1995).

In light of these findings, the Commission enumerated numerous recommendations to both the federal, state, and local governments (Bryant and Mohai 1992; UCC 1987). As a final recommendation, the UCC Commission's report calls upon the President of the United States to issue an executive order to "consider the impact of their current policies and regulations on racial and ethnic communities" in regards to future hazardous waste facilities. The study and recommendations were published on April 15, 1987. The UCC Study would become one of the key motivators to advance the environmental justice movement (Mohai 1995).

2.2.4 Environmental Racism and Executive Order

With the publication of "Toxic Wastes and Race", the term "environmental racism" arose due to the Executive Director of the UCC Commission for Racial Justice, Dr. Benjamin F. Chavis, Jr (Bryant and Mohai 1992, Mohai, Pellow and Roberts 2009).

Environmental racism is most closely aligned with environmental inequity: one social group, i.e. a race, is impacted by an environmental hazard more than another social group (Brulle and Pellow 2006, Mohai, Pellow, and Roberts 2009). According to Chavis, it is:

"racial discrimination in environmental policymaking, the enforcement of regulations and laws, the deliberate targeting of communities of color for toxic waste facilities, the official sanctioning of the life-threatening presence of poisons and pollutants in our communities, and the history of excluding people of color from leadership of the ecology movements" (Brulle and Pellow 2006: 3).

The definition also qualified that any disadvantage resulting from a "policy, practice or directive" can be intentional or unintentional and still classified as environmental racism (Brulle and Pellow 2006).

By 1990, University of Michigan researchers Bunyan Bryant and Paul Mohai organized a conference on the issue of environmental racism: Conference on Race and the Incidence of Environmental Hazards (Brulle and Pellow 2006). Scientists and researchers from across the nation gathered and further confirmed the results of the UCC. The summary of the conference was published in the volume, *Race and the Incidence of Environmental Hazards.* The conference generated interest at the national level. In 1992, the EPA published *Environmental Equity: Reducing Risks for All Communities*.

In his study, *Dumping in Dixie,* renowned sociologist Robert Bullard recognized that environmental racism ostracized many other individuals, most notably impoverished communities. In order to protect all individuals, Bullard was the first researcher to broaden environmental racism to environmental justice, or "the principle that all people and communities are entitled to equal protection of environmental and public health laws and regulations" (Mohai, Pellow, Roberts 2009: 407).

In the wake of major environmental justice milestones, such as Warren County, the GAO and UCC Reports, and the EPA's report informed by the conclusions from the Conference on Race and the Incidence of Environmental Hazards at the University of Michigan, the U.S. government was forced to recognize the legitimacy of the principle. Through an executive order, the Clinton administration brought environmental justice into the legal lexicon in 1994. Executive Order 12898 sought to protect all racial and socioeconomic minorities from threats to their health due to environmental effects (E.O. 1994). The order also created an Interagency Working Group on environmental justice to be led by the EPA Administrator and 11 federal departmental and agency heads.

2.3 Environmental Justice in the 21st Century

Despite a presidential order, minority communities continue to experience discrimination relative to their white, wealthy counterparts.

In 2007, the UCC study was updated. The report, *Toxic Wastes and Race at Twenty 1987-2007: Grassroots Struggles to Dismantle Environmental Racism in the United States*, utilized more advanced geocoding technology and found that "the poor and people of color are more heavily concentrated around such [hazardous waste] facilities than what previous studies found, including the 1987 UCC Report" (Mohai, Pellow, and Roberts 2009: 422). This means that as of 2007, 9,222,000 Americans live in neighborhoods within 3 kilometers of the 413 hazardous waste facilities in the U.S. (Bullard et al. 2007). The neighborhood demographics within 3 kilometers of a hazardous waste facility are 56% racial minorities whereas areas beyond the 3 kilometers are composed of only 30% racial minorities (Bullard et al. 2007). The UCC Report also found that poverty increases from 12% to 18% when examining neighborhoods without hazardous waste facilities versus those with them. At the regional level, EPA Regions 1, 4, 5, 6, and 9 saw the greatest racial disparities between neighborhoods with hazardous waste facilities and those without. Region 5, the Midwest, saw the greatest racial disparities 53% versus 19% (Bullard et al. 2007).

These results were further confirmed in a study conducted by Mohai et al (2009). In the study, the authors sought to evaluate which variable was the strongest predictor of the likelihood of living within 1 mile (1.6 kilometers) of a Toxics Release Industrial facility in the Midwest and West, and suburban South. The Toxics Release Inventory (TRI) is a resource that compiles industry submitted records of all air, water, and land chemical releases (See TRI Program) (EPA 2016 "TRI"). They used data from the Americans' Changing Lives study to look at the variables of race, income, and education (Mohai, Lantz, et al 2009). Their results illuminated that households residing in cities or the suburbs are at the greatest risk of exposure to emissions from Toxics Release Inventory (TRI) facilities. Their results also illuminated that the black population and less educated populations were more likely to live in households near TRI facilities. Households with less than a high school diploma were more likely to live near a TRI facility than households with high school diplomas or college degrees (OR=1.42; 95% CI=1.10, 1.84) (Mohai, Lantz, et al. 2009). However, while race was statistically significant when socioeconomic factors of income and education were considered (OR=1.38; 95% CI=1.10, 1.72), perhaps the most compelling finding was that "racial disparities in proximity were explained partially but not fully by socioeconomic differences" (Mohai, Lantz, et al. 2009: S649).

2.4 Environmental Justice: From Hazardous Waste Facilities to Air Pollution

The first studies to document racial and socioeconomic disparities and the proximity of environmental health risks focused on hazardous waste sites. With the passage of the major environmental acts, Clean Air, Water, Resource Conservation and Recovery Act, and the Comprehensive Environmental Response, Compensation and Liability Act of 1980 and Executive Order 12898, researchers began looking into other contaminating industries (Asch and Seneca 1978; Bell 2007; Hajat et al. 2013; Zwickl et al. 2014). A large body of literature was formed. For the purpose of this thesis, I will focus on the findings from air pollution environmental justice studies.

Numerous studies examined the effects of multiple air toxic exposures on human health. Respiratory and cardiovascular disease was on the rise and many researchers found that air pollution was partially to blame. However, other contributing factors exist, such as socioeconomic status. To explain causality, Hajat et. al sought to find if a relationship exists between socioeconomic status and air pollution (2013). Their research examined "how both individual and neighborhood SES are related to air pollution" (Hajat et. al 2013; 1325). In their research, they used data from the Multi-Ethnic Study of Atherosclerosis (MESA). Their examination of all air pollutants was limited. MESA only predicts ambient concentrations of particulate matter and nitrogen oxide. They found that neighborhood SES has a greater association with air pollution concentrations than individual SES. They also recognize that pollution concentrations are related to geographic location as pollution levels are context-specific. The relationship between pollution concentrations and socioeconomic status are also pollutant-specific. For example, nitrogen oxide has a stronger association than particulate matter 2.5 with lower income status (2013).

Zwickl et al. (2014) examined disparities related to air pollution from industries. They hypothesized that exposure to industrial air toxics is associated with lower income status. They used data from the EPA's Risk Screen Environmental Indicators model which included chemicals from over 25,000 facilities nationwide. They found that in eight out of ten of the EPA regions, exposure to industrial air toxics in a completely non-Hispanic, black population would be 93% higher than that of a block group with only white individuals (Zwickl et al. 2014). The mid-Atlantic region is the only area of the United States where the estimated coefficient for "African-American share of block group population" was negative (Zwickl et al. 2014:12). For the Hispanic population, they found that six of the regions saw the percentage of Hispanic population increases with increasing pollution levels. Finally, they found five regions saw a decrease in pollution with rising income levels. All of these results held true for EPA Region 5. Overall, EPA Region 5 sees higher pollution levels with a greater percentage of explicitly black, Hispanic, and low-income populations. The study also demonstrated that regardless of income status in the region, minority communities were more likely to be exposed to air pollutants than the white population. Lower income whites, those with an income of less than $25,000, tended to have higher percentages of exposure than higher income whites (2014).

While many studies such as these examine the economic and racial disparities relating to exposure to industrial air toxics, there has been little research conducted on the intersection of vulnerable population health and pollutant exposure. The foundation of a study by Morello-Frosch and Shenassa is that “place-based stressors are biologically relevant components of the human environment and can function independently of individual-level stressors to determine health” (Morello-Frosch and Shenassa 2006: 1151).

One of the least studied pollutant exposures for disparities and environmental health outcomes is sulfur dioxide. A single study conducted by Zou et. al in 2014 merely scratches the surface of the desire Morello-Frosch and Shenassa sought in their 2006 study. Zou et al. recognize that, “identification of susceptible and disadvantaged socioeconomic status (SES) groups at the greatest risk of air pollution exposure is critical for accurately estimating the adverse outcomes of air pollution and may provide additional explanations for inconsistency in results between studies” (Zou et. al 2014: 491). The Zou et al. study conducts a traditional environmental justice analysis, but broadens it to evaluate sulfur dioxide exposure using GIS and air dispersion modeling for both mobile and stationary SO_2 sources. This study is also limited because it only examines race, age, and individuals with “low income or less education” in a single area: metropolitan Dallas-Fort Worth, Texas (2014). Age was the greatest factor in determining exposure to sulfur dioxide.

My study seeks to aid in filling the gap between environmental health and environmental justice research. I will examine the populations at the greatest risk of adverse health outcomes in regions highly contaminated with ambient sulfur dioxide from regional industries.

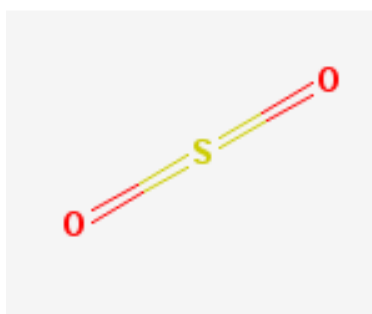
CHAPTER 3: Sulfur Dioxide and Environmental Health and Toxicology

Among environmental scientists and epidemiologists, sulfur dioxide is considered a "low-risk pollutant" and generally overlooked in air toxic exposure studies in both the public health and environmental justice field (Zou et al. 2014). Until recently, the low-levels of sulfur dioxide present in many areas were not considered harmful to human health. With the discovery by Bell (2007) of adverse health effects associated with low-level exposure, the research in the field is slowly developing. Few environmental justice researchers have examined the relationship between the presence of industrial sulfur dioxide and the proximity of racial and socioeconomic disparities (Zou et al. 2014).

3.1 Sulfur Dioxide Chemical Properties

Sulfur dioxide (SO_2) is a colorless, pungent smelling toxic gas (ATSDR 1998). It is an inorganic compound, readily dissolvable in water (PubChem 2016).

Figure 1. Image of 2D chemical structure of SO_2 (PubChem 2016)



Sulfur and compounds of sulfur from which SO_2 can be produced from combustion can be found in coal, aluminum, copper, zinc, iron, or lead ore, and crude oil (NCTOG 2014). It is released into the air during the combustion, or burning, of fossil fuels or volcanic eruptions (ATSDR 1998). In the air, SO_2 can become sulfuric acid (H_2SO_4), sulfate (SO_4^{2-}), and sulfur trioxide (SO_3). The primary industrial sources of sulfur dioxide are smelters, refineries, paper mills, coal power, and food processing plants (Winterton et. al 2000). Frequently, the compound binds to water molecules and returns to the ground as acid rain, damaging soil, bodies of water, agriculture, and infrastructure. However, it is the ambient air levels of SO_2 that are the greatest concern to public health.

3.3 Environmental Health and Sulfur Dioxide Toxicology

The public health risks from sulfur dioxide exposure have been confirmed by numerous studies in the literature. At both high and low-levels of exposure, SO_2 has adverse health effects, exacerbating respiratory and cardiac diseases, in particular asthma. In 2014, the CDC identified 24 million people in the United States as asthmatic (Kim et al. 2013). As of 2015, 1 in every 4 American deaths can be attributed to heart disease (CDC 2015). According to Kim et al., genetics alone can no longer explain such high rates of asthma and other negative health outcomes. Pollutant emitting facilities are directly responsible for the high prevalence of respiratory and cardiac diseases in the nation.

This study focuses on sulfur dioxide as a pollutant due to the widespread harmful health effects it has on numerous populations in the United States. A significant amount of environmental justice and health research has documented the impacts of exposure to high levels of air pollutants on communities. These studies typically focus on mobile-source pollutants such as $PM_{2.5}$, PM_{10}, and NO_x (Hajat et. al 2013). The environmental injustices relating to the emission of air pollutants like these are well researched. The literature identifies that pollution burdens tend to fall on disadvantaged communities based on ethnicity, race, and socioeconomic status (Asch and Seneca 1978; Mohai et. al 2011). Sulfur dioxide is one of the eight air pollutants strictly regulated by the United

States Environmental Protection Agency (USEPA). Yet, in many regions, the compound is present at levels unsafe to human health. With the exception of Zou et al. 2014, no study has examined the populations at risk in areas with sulfur dioxide levels exceeding public health and environmental standards from facility emissions. Their study was limited as it analyzed only the population in Dallas-Fort Worth, Texas, a fractional percentage of the total SO_2 impacted communities found in the U.S. It is for those populations who remain unaware of the effects of SO_2 on their lives that this study is conducted.

3.2.1 Exposure routes/physiology

Sulfur dioxide is a primary irritant. In high concentrations, it is known to "increase sensibility to respiratory infections in humans" (Leduc et al. 1995: 13). The primary route of exposure to SO_2 is through inhalation (PubChem 2016). A secondary route is through skin absorption and eye contact (ATSDR 1998).

After inhalation, SO_2 is absorbed through the upper portion of the lungs. If the concentration of sulfur dioxide in the air was low, the amount of sulfur dioxide absorbed will be low. If the concentration is over 100 ppm, the individual will absorb a greater dosage. The warm lung environment has the perfect conditions for SO_2 to react with the water suspended in the air to form sulfurous acid (H_2SO_3), bisulfate (HSO^{3-}), and sulfite (SO^{3-}). These new compounds are irritants and can cause damage to smooth muscles, neuronal processes, nerves, and lung functioning. The irritants signal the lung epithelium to activate inflammatory cells. The lungs become inflamed (Mathieu-Nolf 2002). From the lungs, the SO_2 passes directly into the bloodstream through mucous membranes. The remaining sulfur dioxide is metabolized by the liver and excreted through urine (NAS 2004).

Acute exposure to SO_2 results in a series of symptoms including nose and throat irritation, bronchoconstriction, wheezing, chest tightness, and dyspnea (NAS 2004; Kim et. al 2013; Winterton et. al 2000). Low dose symptoms can be treated and reversed. However, high doses can cause nausea, vomiting, airway obstruction and severe neurotoxic symptoms such as convulsions, fever, tremors, and peripheral neuritis (NAS 2004). The National Academy of Sciences and Kim et al. 2013 identify the exposure limits for humans to sulfur dioxide (See Table 1 below).

Table 1. Adverse Health Effects Associated with SO_2 Exposure

Concentration (ppm)	Health Effect
0.1	For asthmatics, a ten-minute exposure during exercise or strenuous activities can trigger asthma attacks.
1-5	Threshold. Healthy individuals will experience respiratory irritation during exercise or deep breaths.
3-5	Lung function starts to decrease due to slight airflow restriction.
5	Throat and nose dryness. Eye irritation. Bronchial airflow restriction in healthy individuals.
6-8	Total lung volume, tidal respiratory volume, decreases
10	Upper respiratory irritation. Symptoms arise in healthy individuals including coughing, sneezing, wheezing, and nosebleeds. Asthmatic individuals begin to experience asthma attacks or worsening of asthma-related symptoms.
10-15	Threshold for long-term exposure
20	Acute exposure yields bronchospasms. Long-term exposure results in death or paralysis.
50	Extreme discomfort with restriction of airways. Permanent effects possible with exposure lasting longer than 30 minutes.
>50	Glottis (opening between vocal cords) closes for short periods of time resulting in further breathing restrictions
150	Healthy individuals' maximum exposure limit without serious side effects. Exposure can only last several minutes without permanent damage.
400	Life-threatening level
>1000	Death within 10 minutes

3.2.2 Most Vulnerable Populations

Children, pregnant women, the elderly, and individuals with allergies are the most vulnerable populations to the adverse health effects associated with sulfur dioxide exposure (EPA 2016; Bell et al. 2007; Lin et al. 2004; Salvi 2007). In Dallas-Fort Worth, Texas, Zou et al. concluded that individuals under the age of 14 years or over 60 years have a greater risk of exposure to SO_2 than adult and middle-aged individuals. This section will elucidate the greatest causes of concern among these populations.

Pregnant women are a primary population at risk. The fetus is the most susceptible to exterior insults. When exposed to ambient air pollution, pollutants directly enter the blood stream. For pregnant women, the pollutants circulate through the blood into the placenta and umbilical cord (Salvi 2007). The placenta is not impermeable to air toxicants. A rapidly developing fetus will experience development disruptions due to the presence of the compounds. Birth defects, other developmental disorders during gestation, low birth weight and miscarriages become more frequent (Bell et al. 2007; Lin et al. 2004; Salvi 2007). Low birth weights are a particular threat for black mothers exposed to high levels of air pollution (Bell et al. 2007). In the U.S., China, Czech Republic, Canada, and Korea, prenatal exposure to sulfur dioxide results in an increased risk for preterm delivery and sudden infant death syndrome (Salvi 2007). The threat increases if a mother inhales a high dosage during her third trimester (Lin et al. 2004). A study by Lin et al., revealed that prenatal exposure to SO_2 caused a greater percentage of girls to be born with lower birth weights (2004). There exists the possibility that females are more negatively impacted by the compound during development.

Infants and toddlers continue to be susceptible to sulfur dioxide exposure. Exposure to SO_2 increases neonatal hospital admissions and young asthmatic patient admissions (Kim 2013; Salvi 2007).

According to the Census and health organizations, children are defined as individuals between the ages of infancy to 18 years. In 2000, 7% of U.S. children had asthma (Graham 2004). Children are more susceptible to SO_2 due to their larger surface area for their body mass. Children tend to be at a higher risk of exposure due to their nature to participate in more rigorous physical exercise and spend a greater time outside than adults. Their metabolisms are higher, allowing for a greater consumption of oxygen throughout their bodies. Additionally, their anatomy is constantly changing. The lungs grow and develop throughout childhood. As the lung capacity, size, and alveoli count exponential increase, the susceptibility of their lungs increases. The epithelium lining of a lung can easily be penetrated by pollutants and cause severe respiratory irritation, including acute respiratory infection and chronic obstructive pulmonary disease (Mathieu-Nolf 2002). A child's immune response is not fully matured and cannot efficiently combat the foreign compounds. In many countries, exposure to high levels of air pollutants is the main cause of death in children under five years old (Mathieu-Nolf 2002).

While many studies in the literature have examined acute effects of sulfur dioxide toxicity, few studies can confirm the effects air pollution has long-term on children. There is speculation that behavioral or cognitive development could be hindered or children undergoing puberty will experience endocrine disruption (Mathieu-Nolf 2002). Additionally, studies infrequently take into account the synergistic effects of multiple pollutants on a child's development. Since these effects are unknown, the precautionary principle should be adopted when creating regulations for pollutant emissions. The precautionary principle states: "when an activity raises threats of harm to the environment or human health, precautionary measures should be taken even if some cause and effect relationships are not fully established scientifically" (Wingspread 1998).

According to the EPA, the elderly are also particularly susceptible to SO_2 due to slower and weaker immune systems and a greater prevalence of pre-existing respiratory and heart diseases. However, little research has examined the health impacts of sulfur dioxide on populations over 65. Although, exposure to sulfur dioxide is known to increase hospitalization for cardiac diseases and mortality in individuals over 65 years of age (WHO 1979).

CHAPTER 4: Policy and Regulations

4.1 Sulfur Dioxide as a Pollutant: The Discovery

On October 26, 1948, a thick smog hung over western Pennsylvania and Ohio. In Donora, Pennsylvania residents were unable to see a few feet in front of them. Approximately 5,000 to 7,000 people, nearly half of the town's population became violently ill with upper respiratory and cardiac irritation. Over the course of five days, 20 residents died from the smog composed of industrial air pollutants. The U.S. government had no air emissions regulations and a temperature inversion prevented the pollution from dispersing (Helfand, Lazarus and Theerman 2001).

Donora, Pennsylvania's smog incident is one of the worst environmental disasters in the United States. The event led to the first health impact studies on air pollution. It inspired the passage of the Air Pollution Control Act in 1955 and later the Clean Air Acts of 1963, 1970, and 1990 (2001). The aftermath of the event led the U.S. Congress to restrict the emissions levels of several key pollutants, including sulfur dioxide, to protect the public's health and welfare.

4.2 National Standards

4.2.1 The Clean Air Act

The Clean Air Act (CAA), 42 U.S.C. §§7401 et seq (1970) enacted in 1970 is considered the "most successful piece of environmental legislation ever drafted" (Plater et al. 2010). As a federal law, its stipulations apply to every state. It is principally a "harm-based" law, where pollutants in the air were designated at levels that were adequate to protect the public's health, or "safe" levels. This does not mean that the public is completely safe from adverse health effects, but they are nearly safe. All pollutants had to meet the standards set by the policy under the National Ambient Air Quality Standards (NAAQS).

The Clean Air Act divided the different sources of air emissions into two categories: mobile and stationary. States are responsible for regulating stationary sources such as power plants and manufacturing facilities since they are unique in their construction and location. In order to keep states accountable but still give them freedom as to the methods by which pollution is reduced by each industry, Congress included a statute in the CAA called the State Implementation Plans.

"The Clean Air Act requires states to develop a general plan to attain or maintain the NAAQS in all areas of the country and a specific plan to attain the standards for each area designated nonattainment areas for a NAAQS" (EPA 2016). All SIPS are created by state and local air quality management agencies.

The original 1970 Clean Air Act had strict regulations for achieving compliance with the NAAQS. Within 3 years of an EPA approved SIP, a state had to have its noncompliant pollutants within the regulated standards. By 1977, few states had achieved this compliance. Many of the nonattainment areas, or geographical regions whose levels of a criteria pollutant were out of attainment, or compliance with NAAQS, were major industrial areas. They claimed they could not achieve compliance within the three years specified and recommended making compliance a goal rather than a requirement. Congress acquiesced. They allowed current stationary sources out of attainment to use Reasonably Available Control Technologies (RACT) while current sources were forced to negotiate with existing sources to balance their new emissions by cutting their emissions. Additionally, during operation, new facilities had to maintain the Lowest Achievable Emissions Rate (LAER). The revised 1977 Clean Air Act did little to improve the ambient air quality.

In 1990, Congress revised the CAA again, designating stricter standards for all sources of pollution. They enforced the deadlines for SIPs. If a state did not comply with the deadlines and the government was forced to issue a FIP, the 1990 amendments listed sanctions that reduced federal funding for state projects, such as highways. It also introduced an SO_2 trading system to reduce sulfur dioxide by 10 million tons. Acid rain had become a significant concern throughout the nation.

The NAAQS regulated six criteria pollutants: sulfur dioxide, carbon monoxide, ozone, lead, particulate matter, and nitrogen dioxide. They defined these six due to their prevalence in high quantities throughout the country and risk to human health and welfare. Each pollutant has a primary and secondary standard. The primary standard protects the health of sensitive populations including the elderly and children. The secondary standard protects the public welfare (South Carolina DHEC 2016). The process of defining the standards under the CAA has vague language. It is the responsibility of the EPA Administrator to establish standards that protect health. There is no mention of whether cost of achieving these standards should be factored into the definition, although a future 1997 revision to ozone and particulate matter standards would establish that cost should not be a consideration. Every five years, the EPA is required to reevaluate the NAAQSs.

Primary pollutant standards are set using three metrics: averaging period, level, and frequency. The averaging period indicates over what time the average concentration is measured. The level is the concentration of the pollutant that cannot be exceeded to be considered “in compliance” with NAAQS. The primary standard for sulfur dioxide was first set in 1971 at 0.14 ppm for 24 hours and 0.03 ppm annually. This meant that over a 24-hour period, the emissions of SO_2 could not exceed 0.14 ppm more than once a year. The average of the total 24-hour periods had to be less than or equal to 0.03 ppm. However, between 1980 and 1990, the scientific community became aware of the adverse effects of sulfur dioxide exposure on the vulnerable populations described in 3.1. Short-term, “high-level bursts” were of the greatest concern. The American Lung Association recommended making the NAAQS for sulfur dioxide more stringent. The EPA refused stating that the short-term effects, while harmful to the health of approximately 40,000 individuals, they were not a national phenomenon. It wasn’t until 2009 that the standards were revised to reflect current environmental health science. The EPA introduced a short-term standard to be measured over a one-hour period. The 1-hour SO_2 rule was enacted on June 2, 2010 making the standard 75 ppb averaged over the course of three years (South Carolina DHEC 2016). The 24-hour standard and annual standard was revoked (see Table 2 below).

Table 2. EPA's History of SO_2 Standards from 1971-2012 (EPA "Sulfur Dioxide" 2016)

Final Rule/Decision	Primary/ Secondary	Indicator (1)	Averaging Time	Level (2)	Form
1971 36 FR 8186 Apr 30, 1971	Primary	SO2	24-Hour	0.14 ppm	Not to be exceeded more than once per year
			Annual	0.03 ppm	Annual arithmetic average
	Secondary		3-Hour	0.5 ppm	Not to be exceeded more than once per year
			Annual (3)	0.02 ppm	Annual arithmetic average
1973 38 FR 25678 Sept 14, 1973	Secondary	Secondary 3-hour SO2 standard retained, without revision; secondary annual SO2 standard revoked.			
1996 61 FR 25566 May 22, 1996	Primary	Existing primary SO2 standards retained, without revision.			
2010 75 FR 35520 Jun 22, 2010 (4)	Primary	SO2	1-hour	75 ppb	99th percentile, averaged over 3 years (5)
		Primary annual and 24-hour SO2 standards revoked.			
2012 77 FR 20218April 3, 2012	Secondary	Existing secondary SO2 standard (3-hour average) retained, without revision.			

The designation of a sulfur dioxide nonattainment area involves identifying regions with sulfur dioxide levels exceeding the 75 ppb 1-hour standard using a highly sophisticated modeling system, the American Meteorological Society/Environmental Protection Agency Regulatory Model, or AERMOD. AERMOD takes into account (1) emission rate factors such as time of year, day and hour, (2) the source characterization such as a polluting facility's stack height, (3) the regional differences between urban and rural, the deposition and depletion of a plume of sulfur dioxide, and (4) the meteorological data (USEPA 2016). Once the model identifies an area exceeding the sulfur dioxide NAAQS standard, the EPA outlines the area based on county boundary lines, creates shapefiles, and distributes the SO_2 shapefiles data on their nonattainment area dataset website, Green Book Nonattainment Areas (See EPA Green Book). For policy purposes, the EPA identifies a nonattainment area based on the county containing the AERMOD region exceeding SO_2 standards (i.e. Wayne County, Michigan) (EPA 2016 "Green Book"). Only a few counties are identified as "complete nonattainment" areas. Most counties are only partially contaminated (USEPA 2016).

4.2.2 Clean Air Act Limitations

While the Clean Air Act was considered one of the most successful pieces of legislation, the 1970 Congress failed to realize the loopholes it created for industrial facilities to continue polluting at business-as-usual high levels. The writers of the CAA wrote standards and emissions regulations for "new sources," or facilities. To prevent modern 1970 industries from expensive retrofitting of their facilities before a upgrade was needed, Congress unintentionally allowed all existing plants to be grandfathered into the act. They assumed that all existing sources of emissions would need to undergo modifications or be shut down before the turn of the century (Flatt and Connolly 2005). If the facility was modified, the new modification would require a “new source review” with stringent laws on emissions levels and technology. Nearly five decades later, many of those plants are still operating and have not installed new technologies for reducing air pollution. Under the Clean Air Act, the industries’ polluting practices are completely legal, despite the fact that the level of pollutants they are releasing are known to cause health problems. While SIPs are intended to force the industries limit total exposure levels, they do not put restrictions on individual facilities.

4.3 EPA Region 5 Nonattainment Areas

The study area for this thesis as restricted to the Midwest region. Specifically, it will focus on EPA Region 5. The reasoning behind conducting a region-based instead of nationwide study is due to an explanation given by Zwickl et al.: “Although bound by US EPA’s common regulations, policies, and guidance to help ensure a consistent approach nationwide in the implementation of environmental requirements, the EPA regions are distinct administrative units with different bureaucratic cultures, state regulations, and data sources” (Zwickl, Ash and Boyce 2014). The unique EPA regions are somewhat divided by geographic areas sharing “distinct environmental and economic history” (Zwickl et al. 2014). For example, EPA Region 5 is the Old Northwest Territory and the states within the region have similar Southern African American and poor white migration narratives (Zwickl et al. 2014).

In addition, the results of the study can be used to inform local policies. Therefore, the study also restricts the area because, Zwickl et al. (2014) also found that in many cases, industrial facility inspections tend to be influenced by local politics. A study focusing on local pollution levels would be the most informative. In terms of air pollution studies, Perlin et al. (1995) found that demographic and emissions exposure data differ dramatically across the U.S. and national-level studies are not as telling as regionally-based analyses.

The map of the nonattainment areas nationally and by region are included in Figures 2 and 3 below. The designation of the nonattainment areas for 2010 were made using AERMOD. Note that Kentucky and West Virginia are included in the study due to the fact that two nonattainment areas in Ohio cross state boundaries. While the nonattainment areas are in a total of four different counties, the EPA identifies the areas as two nonattainment areas and not four.

Figure 2. EPA National Sulfur Dioxide Nonattainment Areas (2010 Standard) (EPA "Sulfur Dioxide" 2006).

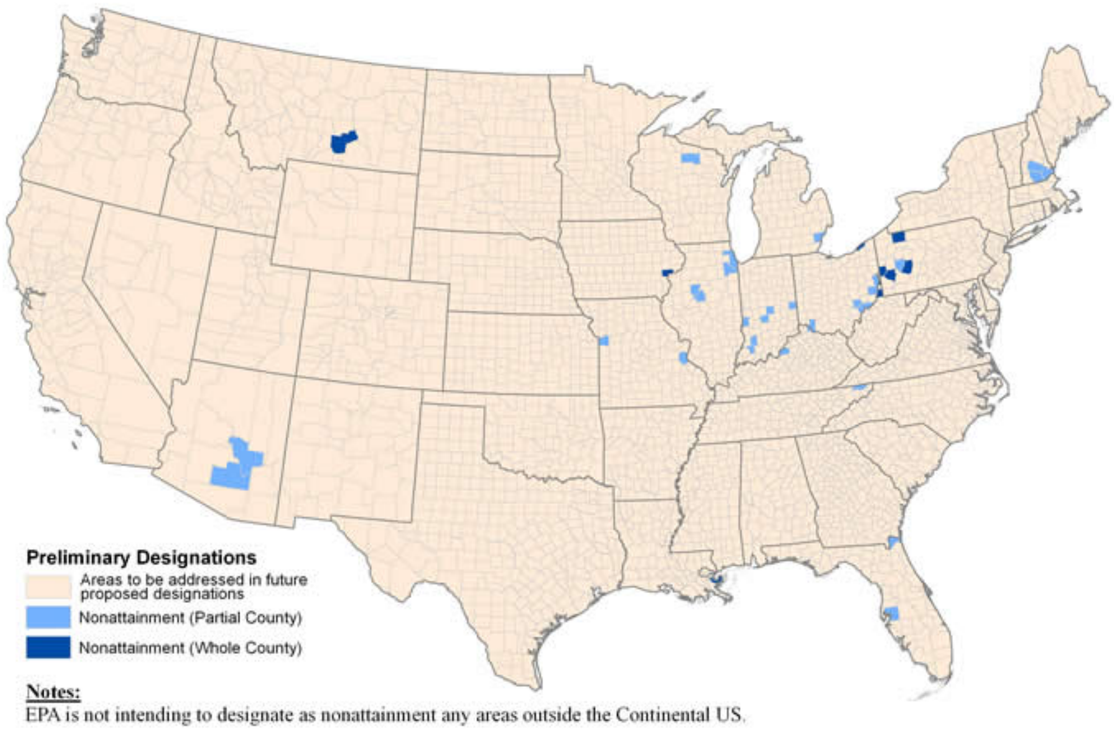
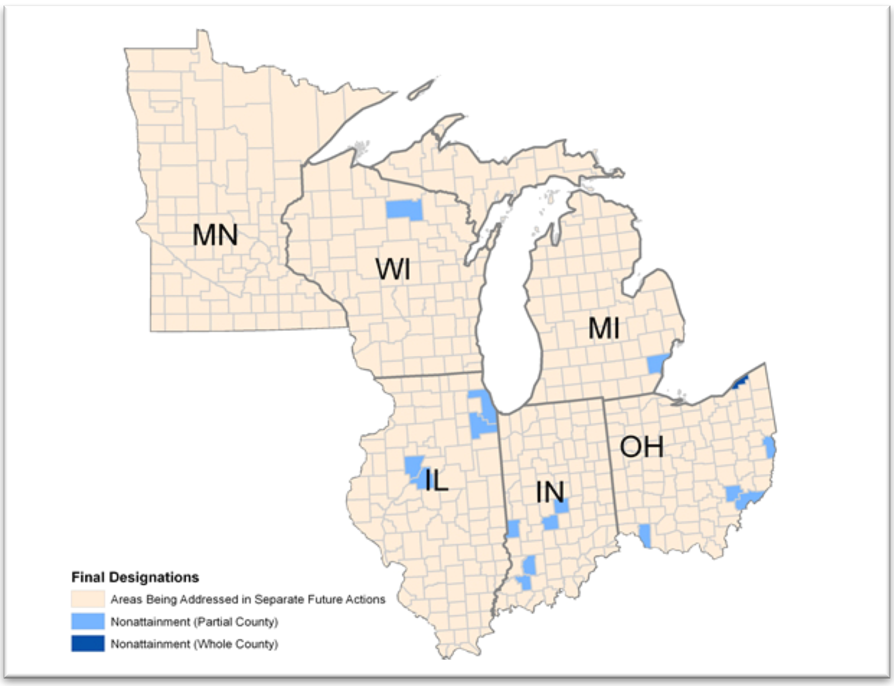


Figure 3. EPA Region 5 Sulfur Dioxide Nonattainment Areas (2010 Standard) (EPA "Sulfur Dioxide" 2006)



CHAPTER 5: Methods

5.1 Study Area

The study area was comprised of 2010 U.S. Census block groups from eight states: Illinois, Indiana, Kentucky, Michigan, Minnesota, Ohio, West Virginia, and Wisconsin. The region of interest was EPA's Region V (Illinois, Indiana, Michigan, Minnesota, Ohio, and Minnesota). However, two of the nonattainment areas in Ohio include counties in the states of Kentucky and West Virginia. Therefore, the areas in Kentucky and West Virginia were evaluated in this analysis. Minnesota contained no nonattainment areas, but was included in the analysis. The total number of areas in the study included 14, nearly half of the total SO_2 nonattainment areas throughout the United States. The defined study area comprised explicitly 45,425 block groups. One hundred and ninety-five of those block groups contained no individuals or households. Therefore, the analysis dataset was restricted to include only block groups with available data for race, SES, and age (N=45,230).

5.2 Sulfur Dioxide (2010) Nonattainment Area Data

The locations of sulfur dioxide nonattainment area data were obtained from the EPA Green Book website for the 2010 1-hour standard. The website offers the data in the form of a shapefile. ArcGIS 10.3 software was used to geocode the locations of all SO_2 nonattainment areas against a 2010 Census block group map of the map of the United States. Using the select query in ArcGIS, the block groups of interest were identified by their location within and/or containing the sulfur dioxide nonattainment shapefile boundary. Nonattainment area status was defined as a binary variable that equaled 1 if given a given block group was in a nonattainment area and 0 otherwise.

5.3 Demographic Data

Using U.S. Census data, I calculated at the census block group level the proportion of the population who were non-Hispanic black (proportion NHB), proportion Hispanic, and proportion non-Hispanic white (proportion NHW) along with the proportion of households whose income in the past 12 months was below the poverty level (proportion in poverty). To allow for a nonlinear relationship between a nonattainment area and each variable, tertiles of proportion NHB, proportion Hispanic, proportion NHW, and proportion in poverty were constructed to correspond to low (tertile 1), medium (tertile 2), and high (tertile 3) levels of each variable.

Age was also considered in the analysis. The proportion of a block group with a population under the age of 18 years, i.e. children, and the proportion of the population who are 65 years of age and older, i.e. elderly, were computed exclusively. Additionally, women between the ages of 16 and 49, i.e. of childbearing age, were considered. Women of childbearing age is the best variable available for pregnant women. All ages were chosen based on CDC's definitions of "youth", "elderly", and "women of childbearing age".

5.4 Statistical Analysis

The analysis dataset was restricted to include only block groups with available data for full race and poverty information across years (N=45,230). Multilevel and multivariate logistic regressions were conducted to model the association between nonattainment area status and variables of interest. A total of six logistic regressions were conducted. The nonattainment status was indicated by "1" if a given block group was in a sulfur dioxide nonattainment area and "0" if located outside of a sulfur dioxide nonattainment area. A state-level random intercept was included in all models to adjust standard errors for correlation among block groups within a given state. The variables of interest were the proportion non-Hispanic black, proportion Hispanic, proportion in poverty, proportion under the age of 18 years, proportion 65 years of age and older, and proportion of women of childbearing age within the study area. The first analysis examined the relationship between sulfur dioxide nonattainment status and tertiles of proportion non-Hispanic black and proportion in poverty.

The second analysis examined the relationship between sulfur dioxide nonattainment status and tertiles of proportion Hispanic and proportion in poverty. The third model examined the relationship between sulfur dioxide nonattainment status and tertiles of proportion non-Hispanic white and proportion in poverty. The fourth through sixth analyses explored the relationship between SO_2 nonatttainment status and the proportion of the study population that are women of childbearing age (ages 16-49), population under 18 years of age, and population of the age 65 and older within each race and poverty tertile. Statistical significance of interactions terms was evaluated using nested likelihood ratio tests. Odds ratios (ORs) and associated 95% confidence intervals based on the best-fitting model were estimated. All analyses were conducted in SAS 9.4 (SAS Institute, Cary, NC) and R 3.1.1 (R Foundation for Statistical Computing, Vienna, Austria). Statistical significance was set at α=0.05.

CHAPTER 6: Results

6.1 Race and poverty summary information

Race and poverty information were available for 45,230 block groups. 1,062 of those block groups were in a sulfur dioxide nonattainment area. In Table 3 block groups within a nonattainment area contained a higher proportion of non-Hispanic black (14.3% versus 12.5% respectively), Hispanic (10.3% versus 6.4% respectively), households in poverty (18.5% versus 15.5% respectively), under 18 years of age (23.7% versus 23.6% respectively), and women of childbearing age (46.2% versus 45.6% respectively) than those not in a nonattainment area. To evaluate the slight differences between the age variables (women of childbearing age, population under 18, and population 65 years of age and older), Tables 9-11 examine the location of the populations within a nonattainment area based on race and poverty status (see Tables 9-11).

The disparities among all variables except for the population under 18 years of age were found to be statistically significant for the difference between attainment and nonattainment groups (see Table 5).

Table 3. Number of block groups in attainment and nonattainment levels of SO_2 and the corresponding average proportion non-Hispanic Black, Hispanic, Non-Hispanic White, in poverty, under 18 years of age, 65 years of age and older, and women of childbearing age, EPA Region 5 (N=45,230).

	All	Nonattainment	Attainment
N	45,230	1,062	44,168
% Total	100.00%	2.3%	97.7%
% Non-Hispanic Black	12.6%	14.3%	12.5%
% Hispanic	6.5%	10.3%	6.4%
% Non-Hispanic White	79.9%	76.5%	79.9%
% in poverty	15.6%%	18.5%	15.5%
% Under 18 years	23.6%	23.7%	23.6%
% 65 years and older	14.0%	13.6%	14.0%
% Women of childbearing age	45.6%	46.2%	45.6%

Table 4. Summary statistics for nonattainment areas by proportion Non-Hispanic, Black, proportion Non-Hispanic White, proportion Hispanic, proportion under the age of 18, proportion 65 years of age and older, and proportion in poverty.

	Minimum	1st Quartile	Median	Mean	3rd Quartile	Maximum
% Non-Hispanic Black	0.00	0.008	0.038	0.143	0.167	0.987
% Hispanic	0.00	0.056	0.039	0.103	0.131	0.864
% Non-Hispanic White	0.006	0.628	0.884	0.765	0.959	0.999
% in poverty	0.00	0.059	0.140	0.185	0.286	0.802
% Under 18 years	0.002	0.204	0.235	0.237	0.273	0.423
% 65 years and older	0.004	0.085	0.124	0.136	0.171	0.856
% Women of childbearing age	0.027	0.414	0.463	0.462	0.506	0.978

Table 5. Two Sample T-Test results for differences between attainment and nonattainment block groups.

Outcome	Group Attainment Mean	Nonattainment Mean	95% CI for difference in % between attainment and nonattainment groups	t	df	p-value
% Non-Hispanic Black	0.125	0.143	-0.033, -0.003	-2.37	45228	0.017
% Hispanic	0.064	0.103	-0.047, -0.031	-10.0	45228	<2.2e-16
% Non-Hispanic White	0.800	0.765	0.018, 0.050	4.24	45228	2.24e-05
% in poverty	0.155	0.185	-0.038, -0.021	-6.74	45228	1.596e-11
% Under 18 years	0.236	0.237	-0.005, 0.002	-0.702	45228	0.482
% 65 years and older	0.140	0.136	9.743-05, 8.28e-03	2.01	45228	0.045
% Women of childbearing age	0.456	0.462	-0.011,-0.00	-2.08	45228	0.037

Abbreviations: CI, confidence interval. Statistical significance was set at α=0.05.

6.1.1 Non-Hispanic Blacks and Poverty

In Table 6, across the poverty stratum, the odds of living in a nonattainment block group characterized by high versus low proportion non-Hispanic black appeared to increase with increasing poverty. Of particular note is that within the medium non-Hispanic black stratum, the estimated odds of living in a nonattainment block group characterized by a medium versus low proportion in poverty is (2.29; 95% CI, 1.57-3.34) and the odds associated with a high versus lower proportion in poverty is (1.57; 95% CI, 1.02-2.4). When poverty is high, the odds of a block group being in a nonattainment area increases with increasing proportion of non-Hispanic black from medium to high when compared to low proportion non-Hispanic black (OR, 2.14; 95% CI, 1.36-3.37 and OR, 2.3; CI, 1.47-3.59 versus OR, 1.57; 95% CI, 1.02-2.4). The significance of the interaction between poverty and low proportion non-Hispanic black could be explained by urban/rural status. Nonattainment areas may be located in rural regions where the population has a low concentration of racial minorities and a high concentration of individuals living below the poverty line. According to a study conducted by the Housing Assistance Council, in 2010, African Americans made up only 8.2% of rural and small town populations and 17.3% of urban populations (HAC 2012). Non-Hispanic black individuals are more often found residing in cities than rural locations. Research into the effect the urban/rural status of a nonattainment area has on racial and socioeconomic disparities should be further investigated in future studies.

Table 6. Stratum-specific odds ratios and 95% confidence intervals for nonattainment areas by tertiles of proportion non-Hispanic black and proportion in poverty.

	% in poverty low	% in poverty medium	% in poverty high
% Black			
Low	1 [Reference]	1 [Reference]	1 [Reference]
Medium	0.84 (0.65, 1.08)	2.29*** (1.57, 3.34)	2.14** (1.36, 3.37)
High	1.12 (0.83, 1.52)	1.57* (1.02, 2.4)	2.3*** (1.47, 3.59)

Low, medium, and high represent the following tertile categories: proportion Non-Hispanic, Black 0.0-0.8%, 0.8-5.3%, and 5.3-100%, and proportion in poverty 0.00-7.2%, 7.2-17.4%, and 17.4-100.0%

6.1.2 Hispanics and Poverty

In Table 7, across the poverty strata, the odds of living in a nonattainment block group characterized by high versus low proportion Hispanic appear to increase with increasing poverty. Of particular note is that within the high poverty stratum, the estimated odds of living in a nonattainment block group characterized by a medium versus low proportion of Hispanic is 2.67 (95% CI, 1.73-4.12) and the odds associated with a high versus lower proportion Hispanic is 2.26 (95% CI, 1.53-3.33). Within Table 7, when poverty is low, the odds of a block group being in a nonattainment area decreases with increasing proportion of Hispanic from medium to high when compared to low proportion Hispanic (OR, 0.01; 95% CI, 0.00-0.03 versus OR, 0.63; CI, 0.47-0.84).

Table 7. Stratum-specific odds ratios and 95% confidence intervals for nonattainment areas by tertiles of proportion Hispanic and proportion in poverty.

	% in poverty low	% in poverty medium	% in poverty high
% Hispanic			
Low	1 [Reference]	1 [Reference]	1 [Reference]
Medium	0.01*** (0.00, 0.03)	1.50 (0.99, 2.26)	2.67*** (1.73, 4.12)
High	0.63** (0.47, 0.84)	1.08 (0.74, 1.58)	2.26*** (1.53, 3.33)

Low, medium, and high represent the following tertile categories: proportion Hispanic 0.00-1.58%, 1.58-4.01%, 4.01-99.1%, and proportion in poverty 0.00-7.2%, 7.2-17.4%, and 17.4-100.0%.

6.1.3. Non-Hispanic White and Poverty

Table 8 presents the stratum-specific odds ratios. In the medium non-Hispanic white stratum, patterns in associations were less clear. Within the high proportion of poverty and high non-Hispanic white stratum, the estimated odds of living in a nonattainment area block group characterized by a high versus low proportion in poverty were 0.41 (95% CI, 0.26-0.65). This odds ratio was highly significant. When the proportion of individuals residing in a block group are mostly white and living below the poverty line, the block group is less likely to exist in a nonattainment area. As surmised in the non-Hispanic black results, this finding could be due to an urban/rural effect. The Midwest is mostly rural. The wealthy white population may be more prevalent in rural areas. However, further research into nonattainment areas' rural/urban statuses is required to draw a conclusion.

Table 8. Stratum-specific odds ratios and 95% confidence intervals for nonattainment areas by tertiles of proportion non-Hispanic white and proportion in poverty.

% White	% in poverty low	% in poverty medium	% in poverty high
Low	1 [Reference]	1 [Reference]	1 [Reference]
Medium	0.73 (0.52, 1.0)	1.31 (0.85, 2.03)	0.83 (0.55, 1.24)
High	0.94 (0.69, 1.29)	0.70 (0.46, 1.08)	0.41*** (0.26, 0.65)

Low, medium, and high represent the following tertile categories: proportion Non-Hispanic, White 0.00-83.5%, 83.5-95.5%, 95.5-100.0%, and proportion in poverty 0.00-7.2%, 7.2-17.4%, and 17.4-100.0%.

6.1.4 Analyses of vulnerable populations

Unlike the previous analyses examining the interaction between socioeconomic status and racial background, the following results seek to determine what the average percentages of vulnerable populations are within block groups residing in sulfur dioxide nonattainment areas. Tables 9-11 further break down the results from Table 3. While the proportion differences between sulfur dioxide nonattainment and attainment areas appear very small, examining the ages by socioeconomic and racial status, a case of environmental justice in sulfur dioxide nonattainment areas becomes evident.

6.1.5 Women of child-bearing age

Table 3 saw only a 0.6% difference between the proportion of women of child bearing age living within a sulfur dioxide nonattainment area and nonattainment area (46.2% in nonattainment versus 45.6% in attainment). Within Table 9, the data illuminates that of the block groups located within a nonattainment area, the average percentage of women of childbearing age is approximately 50% of the block group population when the block group is high proportion non-Hispanic black and medium and high proportion in poverty. Women of childbearing age make up greater than 50% of the block group's population in a sulfur dioxide nonattainment area across all poverty tertiles when the proportion of non-Hispanic White population is low. This presents an important finding: poverty and race appear to be the greatest determinants of which women of childbearing age live within nonattainment areas.

Model 9. Average percentage of women of childbearing age in block groups within SO_2 nonattainment areas in EPA Region 5.

Table 9a. Non-Hispanic Black and Poverty in Women of Childbearing Age in SO_2 nonattainment area block groups

	% in poverty low	% in poverty medium	% in poverty high
% Non-Hispanic, Black Low	40.98%	40.70%	43.30%
% Non-Hispanic Black Medium	43.68%	43.16%	46.80%
% Non-Hispanic Black High	48.72%	50.00%	50.70%

Table 9b. Hispanic and Poverty in Women of Childbearing Age in SO_2 nonattainment area block groups

	% in poverty low	% in poverty medium	% in poverty high
% Hispanic Low	40.67%	39.93%	43.83%
% Hispanic Medium	42.11%	41.84%	48.96%
% Hispanic High	47.79%	49.65%	50.48%

Table 9c. Non-Hispanic White and Poverty in Women of Childbearing Age in SO_2 nonattainment area block groups

	% in poverty low	% in poverty medium	% in poverty high
% Non-Hispanic, White Low	50.06%	51.11%	50.83%
% Non-Hispanic White Medium	44.11%	43.72%	46.91%
% Non-Hispanic White High	40.74%	40.09%	42.29%

Low, medium, and high represent the following tertile categories: proportion Non-Hispanic, Black 0.0-0.8%, 0.8-5.3%, and 5.3-100%, proportion Non-Hispanic, proportion Hispanic 0.00-1.58%, 1.58-4.01%, 4.01-99.1%, White 0.00-83.5%, 83.5-95.5%, 95.5-100.0%, and proportion in poverty 0.00-7.2%, 7.2-17.4%, and 17.4-100.0%

6.1.6 Children (under 18 years of age)

Table 10 is particularly interesting. Table 3 indicated that the composition of children living within sulfur dioxide nonattainment areas and attainment areas were nearly identical (23.7% in nonattainment versus 23.6% in attainment). The block groups within sulfur dioxide nonattainment areas with the greatest percentage of children all reside within high minority tertiles (i.e. high proportion non-Hispanic black, high proportion Hispanic, and low proportion non-Hispanic White). The SO_2 nonattainment block groups with a high proportion of minorities are made up of at least 24% children regardless of the proportion in poverty.

Table 10 Average percentage of children under 18 years of age in block groups within SO_2 nonattainment areas in EPA Region 5.

Table 10a. Non-Hispanic Black and Poverty in Children Under 18 years of age in SO_2 nonattainment area block groups

	% in poverty low	% in poverty medium	% in poverty high
% Non-Hispanic, Black Low	22.39%	21.13%	23.00%
% Non-Hispanic Black Medium	22.58%	21.23%	24.72%
% Non-Hispanic Black High	25.50%	24.13%	25.82%

Table 10b. Hispanic Black and Poverty in Children Under 18 years of age in SO_2 nonattainment area block groups

	% in poverty low	% in poverty medium	% in poverty high
% Hispanic Low	21.44%	20.20%	22.71%
% Hispanic Medium	22.55%	20.75%	21.45%
% Hispanic High	25.26%	24.36%	27.21%

Table 10c. Non-Hispanic White and Poverty in Children Under 18 years of age in SO_2 nonattainment area block groups

	% in poverty low	% in poverty medium	% in poverty high
% Non-Hispanic, White Low	27.30%	25.13%	26.44%
% Non-Hispanic White Medium	22.67%	21.11%	23.08%
% Non-Hispanic White High	21.81%	20.70%	21.83%

Low, medium, and high represent the following tertile categories: proportion Non-Hispanic, Black 0.0-0.8%, 0.8-5.3%, and 5.3-100%, proportion Non-Hispanic, proportion Hispanic 0.00-1.58%, 1.58-4.01%, 4.01-99.1%, White 0.00-83.5%, 83.5-95.5%, 95.5-100.0%, and proportion in poverty 0.00-7.2%, 7.2-17.4%, and 17.4-100.0%.

6.1.7 65 years of age or older

Based on Table 3, it is assumed that the elderly population block groups are found only slightly more in nonattainment areas versus attainment (13.6% in nonattainment versus 14.0% in attainment). Table 11 demonstrates a near equal distribution of elderly among the various block group strata. The largest proportion of elderly residing in non-attainment areas appear to make up block groups with high non-Hispanic white populations. This result could be due to an urban/rural effect.

Table 11 Average percentage of adults 65 years of age or older in block groups within SO_2 nonattainment areas in EPA Region 5.

Table 11a. Non-Hispanic Black and Poverty in individuals 65 years of age or older in SO_2 nonattainment area block groups

	% in poverty low	% in poverty medium	% in poverty high
% Non-Hispanic, Black Low	16.46%	18.03%	16.45%
% Non-Hispanic Black Medium	15.24%	16.75%	13.43%
% Non-Hispanic Black High	10.93%	11.53%	10.00%

Table 11b. Hispanic Black and Poverty in individuals 65 years of age or older in SO_2 nonattainment area block groups

	% in poverty low	% in poverty medium	% in poverty high
% Hispanic Low	17.21%	19.10%	17.19%
% Hispanic Medium	16.43%	18.40%	13.46%
% Hispanic High	11.21%	11.01%	9.29%

Table 11c. Non-Hispanic White and Poverty in individuals 65 years of age or older in SO_2 nonattainment area block groups

	% in poverty low	% in poverty medium	% in poverty high
% Non-Hispanic, White Low	9.05%	10.22%	9.55%
% Non-Hispanic White Medium	14.84%	16.37%	13.88%
% Non-Hispanic White High	17.10%	18.90%	18.67%

Low, medium, and high represent the following tertile categories: proportion Non-Hispanic, Black 0.0-0.8%, 0.8-5.3%, and 5.3-100%, proportion Non-Hispanic, proportion Hispanic 0.00-1.58%, 1.58-4.01%, 4.01-99.1%, White 0.00-83.5%, 83.5-95.5%, 95.5-100.0%, and proportion in poverty 0.00-7.2%, 7.2-17.4%, and 17.4-100.

CHAPTER 7: Discussion

7.1 Discussion

Within nonattainment areas in EPA Region 5, certain impoverished and minority communities are at an increased risk of exposure to high levels of sulfur dioxide. Most of these populations are the most vulnerable for experiencing the adverse public health effects from sulfur dioxide exposure. For the non-Hispanic black population, the risk of living in a non-attainment area increases as poverty levels increase. This means that populations found within nonattainment areas are more likely to have high proportions of non-Hispanic black and individuals living below the poverty line, than those block groups with higher income individuals and lower proportion of black residents. These results are consistent with the only literature on environmental justice and sulfur dioxide exposure (Zou et al. 2014). Zou et al. found that non-Hispanic blacks and individuals living below the poverty line were distinctly related to exposure to industrial sulfur dioxide at the block group level (2014). My sulfur dioxide study is the first of its kind to look at how race and income interact in relation to where a block group is located. It is also the first study that examines nonattainment areas as a study area of interest. Socioeconomic status, regardless of racial status as a non-Hispanic black, is an important determinant of the risk of living in a nonattainment area.

Unfortunately, the population of Hispanics in the study area was small, 6.5%. However, the results revealed that, once again, minority status and income levels are significant determinants of whether or not an individual will live in a highly polluted region. Impoverished Hispanics are at an increased threat of living in sulfur dioxide nonattainment areas in the Midwest. Future public health studies should consider determining the particular vulnerabilities of Hispanics exposed to high levels of sulfur dioxide since they are a population threatened by violations of the NAAQS.

The non-Hispanic white population exhibited an unusual finding. The odds of living in a nonattainment area was low for block groups with a high proportion of white, impoverished individuals. A possible explanation for this result is due to rural/urban status of the nonattainment regions. According to the 2010 Census, the Midwest region is predominately white; 74% of all Census respondents identified themselves as non-Hispanic white (Census 2010). This finding warrants future research into whether the impacted individuals are from rural, suburban, or urban regions and if the location of these block groups differ from the block groups with high proportions of poverty levels and majority or minority races.

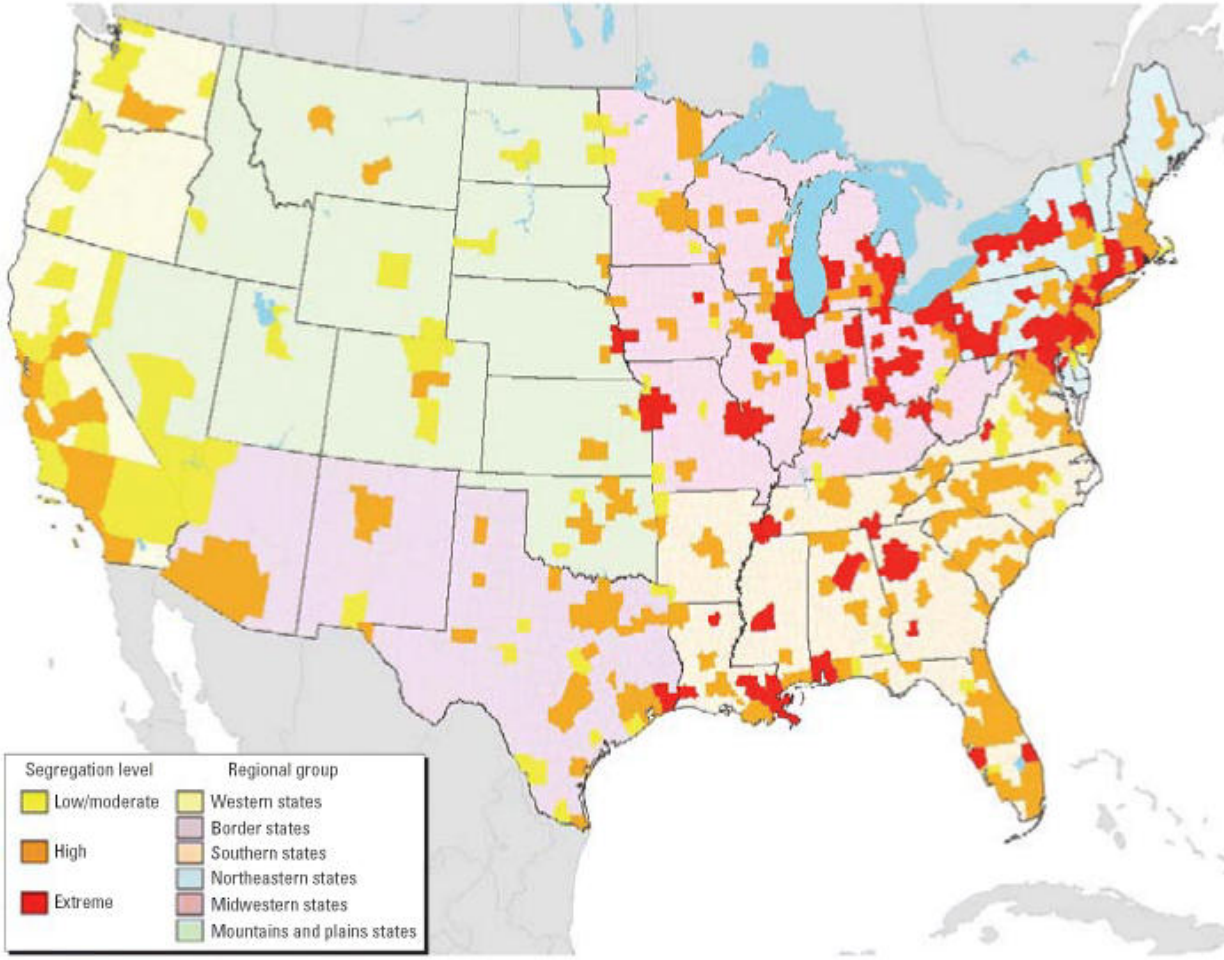
Among nonattainment area block groups containing women of childbearing age, the results indicate that women who are in the highest tertiles for poverty and non-Hispanic black or Hispanic are at the greatest risk of living in an area and that, should they become pregnant, their developing children would be at great risks for sudden infant death syndrome (SIDS), low birth weight, and preterm delivery as described in Chapter 3. It can be conjectured that due to the significance of block groups with high proportions of non-Hispanic black women of childbearing age likely found in the sulfur dioxide nonattainment areas, the birth weights of many infants will be low in the populations as evaluated by Bell et al. 2007.

As recognized by public health literature, children are the most susceptible to the effects of SO_2. In nonattainment block groups, the percentages living there are high for individuals under the age of 18 who are of a minority racial status. This was especially true for block groups with high non-Hispanic black populations and a high proportion of Hispanics. These findings are of great concern. Sulfur dioxide can affect a child’s lung and cardiac functioning. Many impoverished children are denied access to proper healthcare services and will suffer physically, emotionally, as well as educationally due to the inability to achieve a high quality of life from the adverse effects of sulfur dioxide.

Finally, the conclusions I can draw regarding the elderly are less clear. The populations living in the nonattainment area are block groups with high non-Hispanic black and Hispanic populations. Since the literature is still lacking in evidence demonstrating that sulfur dioxide alone has a strong impact on the elderly's health, the results do not provide any evidence to draw a conclusion on which populations of the elderly are at the greatest health risk. The findings do confirm, however, that there is a proportion of elderly within sulfur dioxide nonattainment areas in EPA Region 5 and that all individuals are being exposed to levels of concern.

While the results of this study are illuminating, they are not unexpected. Each of my original hypotheses were confirmed. The pattern of disparities in environmental justice literature is once again reinforced in this study: racial and socioeconomic minorities are at the greatest risk of living near and being exposed to environmental contaminants. It comes as no surprise that minority communities in the United States are victims of hazardous air pollution emissions due to past environmental movements such as the Not-In-My-Backyard, or NIMBYism, when wealthy, white communities tried to prevent environmental risks in their neighborhoods (Saha and Mohai 2005; Mohai, Pellow & Roberts 2009). History also has played a role, segregating races into certain sectors of states (see Figure 6 below and compare to nonattainment areas in EPA Region 5) (Morello-Frosch and Shenassa 2006).

Figure 4. 1990 Census Map of Racial Segregation in the United States (Morello-Frosch and Shenassa 2006)



Sulfur dioxide has been categorized as a "low risk pollutant" which tends to make nonattainment areas somewhat invisible. As reflected by the research, in order to protect the majority communities, block groups with high proportions of minorities have been sacrificed.

7.2 Limitations and Future Studies

My study was not without limitations. First, I used 2013 poverty data with 2010 racial composition data, as the American Community Survey replaced the census long form and the census no longer collects poverty or income information. There may have been confounding caused by urban/rural status, as large cities not in nonattainment areas contain areas of concentrated poverty and minority status. Future studies should examine this relationship by urban rural status. Due to certain block groups being located in large cities that contain concentrated areas of high disadvantage and high proportion minority, a next step would be to perform an analysis stratified by rural and urban areas. Additionally, an analysis of each region or state-by-state analysis would also be recommended for future research. However, the most pressing issue is how these findings relate to the public health of the nonattainment areas. Is there an association between the levels of sulfur dioxide, race, socioeconomic status, and health outcomes of the area?

Another problem remains that sulfur dioxide is not the only industrial air toxic that residents in nonattainment areas are exposed to. Currently, the National Environmental Justice Advisory Council (NEJAC) has acknowledged that there is limited scientific work on the "cumulative impact of multiple exposures to environmental hazards and the potential vulnerability of poor communities to their toxic effects" (Morello-Frosch and Shenassa 2006). In the future, research needs to determine how to study multi-contaminant cumulative impacts and their synergistic effects on all members of a population.

7.4 Conclusion

The fact remains that in order to change policy and protect people, more research must be conducted on sulfur dioxide nonattainment areas. The emissions levels at all 30 areas nationally need to be determined, evaluated, and regulations set based on the most vulnerable individual's exposure. This is a time-sensitive issue. As of 2016, all 30 sulfur dioxide nonattainment areas failed to submit a State Implementation Plan to the federal EPA. The EPA now has two years in which to write up their own stricter plans for the regional and state authorities to uphold. I recommend that in creating a Federal Implementation Plan (FIP) for each state in violation of sulfur dioxide NAAQS, the disproportionate impacts of sulfur dioxide on racial and socioeconomic minorities and vulnerable populations be taken into account. As evidenced by the results, it is the minority communities most impacted by the noncompliance of industries when they emit toxic levels of sulfur dioxide into the ambient environment. The noncompliance has gone unchecked by both the bureaucracy and industry because, as authors Konisky and Reenock state, the "costs associated with noncompliance and failure to detect noncompliance are lower in poor and minority communities because these communities have fewer resources with which to document and protest noncompliance" (Konisky and Reenock 2012: 3-4). This study cannot just become another work in the literature of environmental justice. It needs to become the foundation for resources to aid residents, researchers, and policymakers. The EPA must recognize in it's FIP that industries and regulatory agencies are discriminating against racial and socioeconomic minorities as well as women, children, and the elderly when they fail to uphold the legal requirements under the federal Clean Air Act. The cost of noncompliance for CAA violators in 2018 needs to be high to protect all members of society regardless of race, age, sex, or socioeconomic status.

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