Environmental Equity in North Carolina

Economic and Geo-Spatial Analysis of Fine Particulate Matter (PM2.5) Point Sources and Socioeconomic Status in North Carolina

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Introduction

The spatial distribution of economic wastes within society is a heated debate amongst corporations, policy writers, urban planners, and social activists. Some believe that noxious wastes are deposited in greater concentrations amongst disadvantaged communities of lower socioeconomic and/minority status, while others believing there is no correlation between economic wastes and specific groups within society. Determining if specific groups within society are exposed to disproportionate levels of toxic wastes and various health hazards is critical in assessing health affects of exposure, determining high risk populations, and creating a more equitable society. If it can be determined that economically disadvantaged groups or minority populations are disproportionately exposed to noxious wastes, it raises many social equity questions as well as whether or not people have equal rights to a healthy environment. Because the relationship between the location of economic wastes and socio-economic status is not completely understood, many social scientists, health scientists, and social activists have conducted research in hopes of determining what relationships do exist. This research paper focuses on determining these possible relationships in a specific case study. More specifically this paper will examine the possible relationships between the location of fine particulate matter ($PM_{2.5}$) point sources and socioeconomic status in North Carolina. This type of research is vital in order to provide insights to guide policy action regarding a more diligent health surveillance of high-risk populations, a better understanding of the environmental problems North Carolina residents face, and a more equitable disposal of hazardous pollutants [1]

[1] Jarrett, Michael and Richard T. Burnett, "*A GIS- Environmental Justice Analysis of Particulate Air Pollution in Hamilton, Canada*." Environment and Planning A 2001, Volume 33, pg. 955-973

Literature Review

There are many social, economic, geographic, and political factors that can influence the location of hazardous pollutants throughout society. However, the complexity of understanding every factor is beyond the ability of scientific research today. As a result, many social scientists have chosen to look at the possible relationships between the spatial distribution of pollutants and socioeconomic indicators such as income and race, which has become known as environmental justice research. Environmental justice is essentially the principle that all communities regardless of race and income are entitled to equal protection and enforcement of environmental, health, employment, housing, transportation, and civil rights laws and regulations that have an impact on the quality of life.[2] Environmental justice research primarily focuses on identifying area of inequitable distribution of environmental hazards into disadvantaged communities.

The foundations of the environmental justice research are widespread. Some look to a series of protests in 1982 by African Americans against the siting of a toxic waste dump in poor and predominantly African American Warren County, North Carolina as the beginning of the environmental justice movement. Others see Dr. Martin Luther King Jr.'s trip to Memphis, Tennessee to support striking garbage workers when he was assassinated in 1968 as the beginning.[3] Some look even deeper into America's history, and consider the first environmental justice struggle to have taken place 500 years ago with the invasion of Europeans and subsequent displacement of Native American peoples. Highly publicized incidents like Love Canal, New York and Times Beach,

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[2] Bullard, Robert D., It's Not Just Pollution" http://www.ourplanet.com/imgversn/122/bullard.html

[3] Cole, Luke W and Sheila R. Foster, "*From the Ground Up: Environmental Racism and the Rise of the Environmental Justice Movement*" Pg 9-11

Missouri, where residents had to be removed from their communities because of their proximity to highly toxic waste dumps sites many Americans have influenced environmental justice research as well as raised concerns amongst many Americans with how pollution is affecting their homes, neighborhoods, workplace, and schools.[4]

Wherever the predecessors lie, environmental justice research is very much apart of the Civil Rights Movement of the 1950's, 1960's, and 1970's and echoes many of the same struggles. Being a facet of the Civil Rights Movement, environmental justice research also found its foundation in the southern United States and northern urban areas where socioeconomic and racial divisions are the strongest. As was also the case in the Civil Rights Movement, the early environmental justice movements found its leaders and organizers within the church. When the Environmental Justice Movement began building momentum in the 1980's, it was church based leaders like Rev. Benjamin Chavis and Charles Lee, seasoned in the Civil Rights Movement, who were at its fore.[5] The 1982 protests in Warren County, North Carolina and the 1987 United Church of Christ Commission for Racial Justice study, "*Toxic Waste and Race in the United States*" are recognized as two of the most influential benchmarks in the environmental justice movement, and were the products of grassroots organization by civil rights activists within the church. Further, environmental justice protests and action in communities in Chester, Pennsylvania; Houston and Dallas, Texas; Alsen, Louisiana; Kettleman City, California; Institute, West Virginia; and Emelle, Alabama were all carried out using the direct action and legal approach that was developed through the Civil Rights Movement.

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[4] Dunlap, Riley E. , and Rik Scarce. 1991. "Poll Trends: Environmental Problems and Protection." The Polls 55.4: 651-672.

The academic world is arguable the most prominent driving force of environmental justice research today, and has played a crucial role in shaping environmental justice issues into a broad-based social movement in the United States.[6] During the 1960's, a handful isolated social researches began finding empirical results indicating that low income and/or African American communities were bearing a disproportionate burden of environmental hazards.[7] However, the environmental justice literature and research was truly pioneered by Robert D. Bullard of the Environmental Justice Resource Center at Clark Atlanta University (previously at the University of California-Riverside), Bunyan Bryant of the University of Michigan, and Charles Lee of the United Church of Christ. More recently, research universities have responded to a general lack of information about environmental justice relationships through increased literature, and multiple empirical environmental equity studies throughout the United States. Universities like Clark Atlanta University in Atlanta, Georgia; Xavier University of Louisiana in Louisiana, New Orleans; Texas Southern University in Houston, Texas; and Florida A&M University in Tallahassee, Florida have created centers specifically for environmental justice research.

Research and attention surrounding environmental justice questions have grown considerably over the last 30 years; as a result, environmental equity questions have begun to influence both political and environmental policy in the United States. The most significant emergence of environmental justice and equity issues as an important

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[5], Cole, Luke W and Sheila R. Foster, "*From the Ground Up: Environmental Racism and the Rise of the Environmental Justice Movement*" Pg 20

[6] Cole, Luke W and Sheila R. Foster, "*From the Ground Up: Environmental Racism and the Rise of the Environmental Justice Movement*" Pg 24

[7] Paul Mohai and Bunyan Bryant, "*Environmental Racism, reviewing the Evidence*, in Race and the Incidence of Environmental Hazards: A Time for Discourse" pg. 163. 1992

dimension of political, environmental, and public health policy at the federal level grew out of the Clinton administration. Due in great part to Rev. Benjamin Chavis and Robert D. Bullard's work in the EPA, and in the Departments of Energy, Interior, and Agriculture, President Clinton signed Environmental Justice executive order 12898 on February 11, 1994. Executive order 12898 established the National Environmental Justice Advisory Council (NEJAC), which was created to advise the EPA and other federal agencies on the environmental justice consequences of their decisions. In other words, NEJAC was established to help assess the degree to that federal decisions may be exacerbating, or could help alleviate, the disproportionate environmental health risks low income and/or minority communities might face.[8]

Several empirical studies of the spatial distribution of negative externalities have been conducted (for a recent review, see McMaster et al, 1997).[9] The United Church of Christ Commission for Racial Justice (UCC) 1987 study, *Toxic Waste and Race in the United States,* is the most influential and widely recognized study of environmental equity.[10] The UCC research was a nation wide study that examined the relationship between social and economic characteristics of communities and the presence of hazardous waste treatment, storage, and disposal facilities; measured at the level of five-digit zip codes.[11] The author's of the UCC study concluded that race is the most

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[8] Jarrett, Michael and Richard T. Burnett, "*A GIS- Environmental Justice Analysis of Particulate Air Pollution in Hamilton, Canada*." Environment and Planning A 2001, Volume 33, pg. 955-973

[9] McMaster R, Leit H, Sheppard E, 1997. "*GIS-based Environmental Equity and Risk Assessment: Methodological Problems and Prospects"* Cartography and Geographic Information Systems 24, pg 172-189. And, Jarrett, Michael and Richard T. Burnett, "*A GIS- Environmental Justice Analysis of Particulate Air Pollution in Hamilton, Canada*." Environment and Planning A 2001, Volume 33, pg. 955-973

[10] Comancho, David E., "*Environmental Injustices, Political Struggles: Race, Class, and the Environment*" Pg. 1.

[11] Vittles, Elliot M. and Philip H. Pollock, III. "*Poverty, Pollution, and Solid and Hazardous Waste Siting: How Strong are the Links?"* Florida Center For Hazardous Waste Management

prominent factor in the location of commercial hazardous waste facilities than any other factor examined.[12] The UCC's conclusions are echoed in Mohai and Bryant's 1992 analysis sponsored by the University of Michigan, which uses random sampling, probability, and linear regression analysis in the Detroit area.[13] A more recent study funded by Chemical Waste Management conducted by Douglas Anderton and other colleagues in 1994, uses national census data and concludes that race and income do not hold strong correlations with the location of industrial waste treatment, storage, and disposal facilities (TSDF's).[14] [15]

Recently, more sophisticated modeling techniques have been developed through the use of Geographic Information Systems (GIS) and more comprehensive data supplied by the EPA and other monitoring agencies. GIS has allowed for a much greater level of resolution and accuracy, as community's socioeconomic characteristics can be analyzed at the Census block group level. Supplied with better data and tools, results from some recent empirical studies looking at the relationship between low-income or minority populations and the location of hazardous wastes and/or facilities are equivocal. Especially at the state and regional level, researchers have found no, or negative, correlations between income and/or race with the presence of hazardous facilities.[16]

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[12] United Church of Christ Comission for racial Justice (UCC). 1987. "*Toxic Waste and Race in the United States: A National Report on the Racial and Socio-Economic Characteristics of Communities with Hazardous Waste Sites"*. New York: Public Data Access, Inc.

[13] Race and the Incidence of Environmental Hazards: A Time for Discourse.

[14] Anderton Douglas L., Andy B. Aderson, John Michael Oakes, and Michael Fraser. 1994. *"Environmental Equity: The Demographics of Dumping."*

[15] Anderton Douglas L., Andy B. Aderson, John Michael Oakes, and Michael Fraser, Elenour W. Weber, and Edward J. Calabrese, " Hazardous Waste Facilites: 'Environemtal Equity' Issues in Metropolitan Areas," Evaluation Review (vol. 18, no.2), pp. 123-40. 1994.

[14]See: -Jarrett, Michael and Richard T. Burnett. 2001. "*A GIS- Environmental Justice Analysis of Particulate Air Pollution in Hamilton, Canada*." Environment and Planning A, Volume 33, pg. 955-973

-Anderton Douglas L., Andy B. Aderson, John Michael Oakes, and Michael Fraser. 1994. *"Environmental Equity: The Demographics of Dumping."*

However, more localized studies at the countywide or citywide scale, continue to find statistically significant inequities in the distribution of negative environmental externalities.[17] The disproportionate amount of research indicating environmental inequities is conducted at a more localized city or countywide scale.[18] This is probably because accurate modeling becomes more complex with greater areas, and researchers tend to focus on more localized areas where inequity is evident so their environmental injustice hypotheses will be supported. As a result, the vast majority of empirical environmental justice research is focused on more localized regions, and methods used to estimate potential exposure in disadvantaged populations on a greater scale represents major challenge to current research.[19]

Environmental Justice Conceptual Model

Though results from empirical studies looking at the relationship between environmental hazards and socioeconomic status are mixed, the primary conceptual model that is tested in these studies is based on the belief that some individuals, groups, and communities receive less environmental protections because of unequal political and

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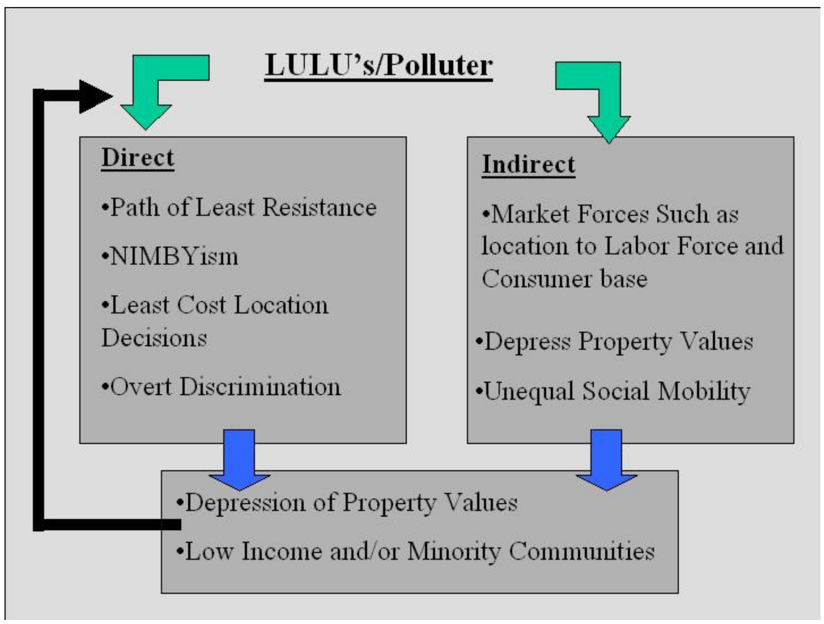
-Bowen W M, Salling M J, Haynes K E, Cyran E J. 1995. "*Toward Environmental Justice: Spatial Equity in Ohio and Clevland*" Annals of the Association of American Geographers 85, 641-663
-Jerrett M, Eyles J, Cole D, Reader S. 1997. "*Environmental Equity in Canada: an Empirical Investigation Into the Income Distribution of Pollution In Canada*." Environment and Planning A 29 1777-1800

[17] See: -Vittles, Elliot M. and Philip H. Pollock, III. "*Poverty, Pollution, and Solid and Hazardous Waste Siting: How Strong are the Links?"* Florida Center For Hazardous Waste Management
-Jarrett, Michael and Richard T. Burnett. 2001. "*A GIS- Environmental Justice Analysis of Particulate Air Pollution in Hamilton, Canada*." Environment and Planning A, Volume 33, pg. 955-973
-Buzzelli, Jerrett, Burnett, and Finklestein. *Spatiotemperal perspectives on Air Pollution and Environmental Justice in Hamilton, Canada, 1985-1996,.* Annals of the Association of American Geographers, 93 3 (3), 2003, pp. 557-573

[18] Jarrett, Michael and Richard T. Burnett, "*A GIS- Environmental Justice Analysis of Particulate Air Pollution in Hamilton, Canada*." Environment and Planning A 2001, Volume 33, pg. 955-973
[19] Sexton K, Adgate J L. 1999. "Looking at Environmental Justice From an Environmental Health Perpecitive" Journal of Exposure Analysis and Environmental Epidemiology 9, pg. 3-8

economic powers as well as environmental laws, regulations, and policies not being applied fairly across all segments of the population. .[20 21] Consequently, certain disadvantaged groups may bear a disproportionate burden of societies wastes depending on their geographic location, race, and economic status.[22] The economic reasoning behind this conceptual model is shown graphically in figure 1.

Figure 1:



There are essentially two paths of reasoning for why LULU's tend to be disproportionately located in communities of lower socioeconomic and/or minority status. On the one hand, it is often argued that polluters are directly sited in disadvantaged communities because these types of communities represent both the path

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20 Bullard, Robert D., *Dumping in Dixie: Race, Class and Environmental Quality*. Boulder, CO: Westview Press, 1994.
21 Pulido, Laura. 1996. "A Critical Review of the Methodology of Environmental Racism Research." Antipode 28(2), pp. 142-59
22 Bullard, Robert D. (ed.), *Unequal Protection: Environmental Justice and Communities of Color*. San Francisco: Sierra Club, 1994

of least resistance and the least cost location decisions. On the other hand, it is argued that polluters move into an area void of discriminatory agendas, but because of unequal social mobility as well as social mechanisms that are not completely understood between classes and races the generally more affluent Caucasian household are able to move away from the polluter; in turn, leaving primarily low income and/or minority households disproportionately located near polluters. The only way to determine which came first, the polluter or community, is to conduct a historical land use analysis of each site in reference to the surrounding communities demographic during the time of siting. Considering each PM2.5 polluter in North Carolina was presumably established at a different time, this type of historical analysis is beyond the scope of this paper.

The environmental justice conceptual model begins with the polluting facility, which are often referred to as locally unwanted land uses (LULUs) because no one wants them located in their communities. These include any noxious facility such as a landfill, waste treatment plant, manufacturing facilities; and in the case of this study, a fine particulate air emitter such as electric utilities, smelting factories, paper mill, and several other industrial processes. All communities resist LULUs because they are serious health hazards, are unsightly, degrade surrounding ecosystems, and they depress property values. Thus, when a community is faced with the prospect of having a LULU being located in their neighborhood, the response is usually “not in my backyard!” This response has become known as the NIMBY principle, and is major factor in the siting of these faculties. Though no community wants waste generating facilities in their midst, a polluting factory may be sited directly into a community of lower income or a greater minority population because it is primarily the more vocal, affluent, organized, educated, and Caucasian communities that have the power and political clout to expel these land uses from their communities. [23] In addition, environmental activism also tends to be more prominent amongst groups with an above-average education, greater access to economic resources, political influence, and a greater sense of personal efficacy.[24] As a result, environmental activism has historically been most pronounced within the middle- and upper-middle-class Caucasian communities, while poor and minority communities have remained relatively less active.

Polluting facilities may also move directly into communities of lower income and/or minority status because these types communities represent least cost location decisions. In order to keep costs down and maximize profit, companies tend to site their factories in areas where property values are relatively low. These areas tend to be land that is generally undesirable because of geologic conditions, antecedent pollution conditions, or undesirable proximity to cities/towns. Yet, areas with relatively low property values also tend to be occupied by families and individuals of relatively lower socioeconomic status due to the fact that they are reliant on the low rents. Further, because communities of lower socioeconomic and minority statuses represent the path of least resistance, the disproportionate siting of facilities in their communities is also a reflection least cost location decisions. Since poor and/or minority communities tend to be less vocal, less educated and involved in legal and political systems, and have less time and income than their Caucasian affluent counterparts, they tend to pose far fewer political and legal costs to industry. Communities with greater affluence and political

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[23] Bullard, Robert D., Dumping in Dixie: Race, Class and Environmental Quality. Boulder, CO: Westview Press, 1994. (pg.1

[24] Bullard, Robert D., Dumping in Dixie: Race, Class and Environmental Quality. Boulder, CO: Westview Press, 1994. (pg.1)

clout will naturally use their power to resist the siting of hazardous wastes in their communities through lobbying, lawsuits, and political persuasion. To escape the costs associated with these resistant barriers, it is most economical for facilities to simply relocate into the less powerful low-income and/or minority communities.

The counter argument to the direct siting of a polluting facility into a disadvantaged community is that siting decisions are non-discriminatory and purely based on market forces such as proximity to labor and consumer base. In addition, the economic and political costs associated with locating a noxious facility in a disadvantaged community based on classist or racist biases have become very high in recent society. Though the initial siting decision of a given facility may not involve any discriminatory considerations, there are many social inequalities that may result in the facility eventually being located in a predominantly lower income and/or minority communities.[25] Hypothetically, imagine community A and B in figure 2 are two perfectly equal communities in terms of size, property values and proximity to natural and societal amenities. Also imagine that each community is also perfectly equitable within itself in that there are an equal number of low-income households and high-income households. If an emitter locates into community A, land will become less desirable in A because of the health risk associated with living near a toxic facility, and property values will lower. Property value in community B will rise because its land will become more desirable. Though no household wants to be located near the emitter, only the wealthiest families in community A will be able to relocate into community B because they have the means to pay the higher property values. In addition, if a low income family in community B does

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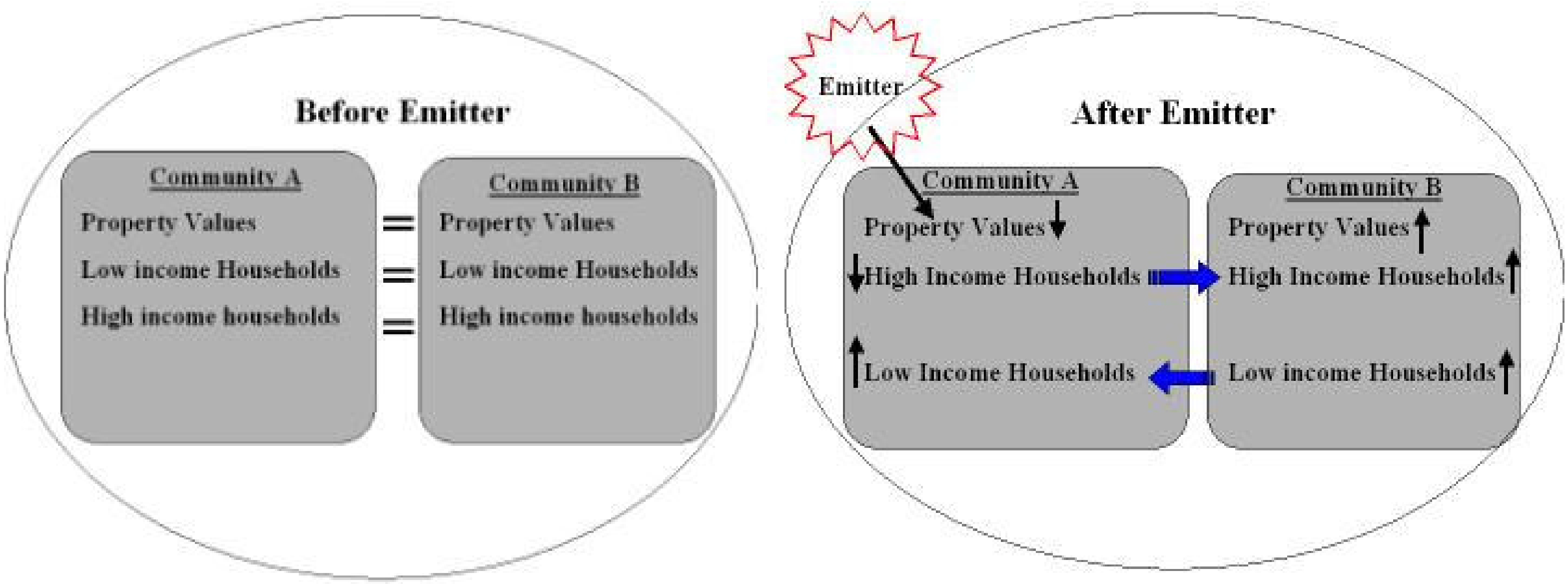
[25] Been, Vicki, "Locally Undesirable Land Uses in Minority Neighborhoods" T*he Yale Law Journal*, Vol.103, pages 1383-1422

not own its dwelling, which is often the case in lower income households, many of low income families living in community B will be forced to move to relocate to community A where they can afford the lower rents. Thus, the result of an emitter locating into community A will be that the two communities will no longer be equal, with community A predominantly comprised of low income households and community B the opposite.

Figure 2:



The fact that community A is now predominately a low income community may also make it more susceptible to addition emitters locating into it through following the path of least resistance and least cost location decisions. Thus, both figure 1 and figure 2 also represent negative feedback loops in that when a location for a noxious facility is chosen, for whatever political, economic, or social reason, the result is a depression of property values in that area. Low property values and rents in that area will attract people of lower socioeconomic status and deter households of relatively high socioeconomic status. Thus the socioeconomic demographics of an area surrounding this type of facility will be of relatively low affluence. These communities of lower socioeconomic status theoretically represent the path of least resistance, and will therefore tend to attract more noxious faculties than communities of greater socioeconomic status. As more facilities are sited in these areas, property values are further depressed and households of even lower socioeconomic status will locate to the area.

The hypothetical model in figure 2 can also be used to help understand the social dynamics that can result in polluting facilities being disproportionately located in African American communities though the initial siting decision may not be racist. In 1999, median household income for African American was $27,900 compared to $44,000 for Caucasians.[26] Since African Americans generally have lower wealth and incomes than Caucasians, due in part or wholly to overt and/or institutionalized discrimination, low-income households in figure 2 would best represent African Americans households while the higher income households would best represent Caucasians. If a major polluter sites in community A, which is initially equally Caucasian and African American, Property values will fall due to the local pollution as well as the sale of property values. However,

[26] U.S. Census Bureau, Current Population Survey, 2000

it will be the generally more affluent Caucasian households that will relocate out of community A and into community B. From the same market forces, the generally lower income African American households will migrate out of community B because property rents have increased due to greater demand and will relocate into community A where rents are relatively lower. Clearly the initial citing decision was not discriminatory. However, antecedent overt and institutional racist conditions such as job discrimination and stereotyping have led to African American households having significantly less annual income than Caucasians; and therefore, having less spatial mobility to live in environments free of pollution.

While the theories discussed above give reasoning for some of the various economic and social mechanisms that can result in polluting facilities being disproportionately located in societies disadvantaged communities, it can also be argued that there is no inequitable distribution of polluting facilities. As mentioned earlier, the results from empirical studies looking at the relationship between toxic emitters and socioeconomic status are mixed, with some studies reporting no correlation between the location of noxious emitters and socioeconomic status. The equivocal results of environmental justice studies are due in part to varying research methods and different study locations. Through the use of Geographic Information Systems (GIS) and multiple regression analysis, this paper will use North Carolina as a case study to analyze the spatial relationship of fine particulate matter point sources with the socioeconomic status of the communities that these types of emitters are located in.

Fine Particulate Matter Point Sources and North Carolina

This study will analyze the spatial distribution of fine particulate matter ($PM_{2.5}$) point sources, the mass of total pollution released from those point sources, and examine the placement of these sources with respect to the socioeconomic status of the surrounding communities. It is important to examine the location of $PM_{2.5}$ point sources in relation to socioeconomic status for several reasons; $PM_{2.5}$ emissions have been proven to cause significant health problems, many types of economic processes emit them, and they are frequently associated with other types of pollutants.

Air pollution has been recognized as an undesirable by-product of human societies for more than a century. The first significant air pollution problems were recorded in London in the late 1800's, when smog from industrial sources and coal fire places killed an estimated 4000 people between 1873 and 1892.[27] In the United States, the Environmental Protection Agency (U.S. EPA) monitors six air pollutants commonly found in ambient air that have been categorized as high priority because of health concerns and environmental impacts. These six criteria pollutants include ozone, carbon monoxide, nitrogen oxide, sulfur dioxide, lead, and particulate matter. Though all of these pollutants are harmful, and their relation to socioeconomic status should be explored, $PM_{2.5}$ was chosen for this study because its toxicity affects on humans is severe and well documented.

Broadly defined, particulate matter is a complex mixture of microscopic solid and liquid particles composed of chemicals, soot, and dust. The main source of $PM_{2.5}$ is the combustion of fossil fuels such as coal, gasoline, and oils. Along with sulfur dioxide (SO2) and nitrogen oxides (NOx), $PM_{2.5}$ is a major constituent of ground level ozone

[27] http://edugreen.teri.res.in/explore/air/smog.htm

pollution, which is especially harmful to human health because it directly affects the air we breathe. This is important because the greatest affects of PM2.5 emissions will be felt by communities in close proximity to point sources. For comparison, the negative affects of carbon dioxide (CO_2) are not greater closer to the point source because it is a pollutant that affects the upper atmosphere and stratosphere, and affects all humans through accelerated global warming and ozone depletion.

The health effects of particulate matter vary depending on the size of the molecule, with smaller particulates posing the greatest health risk.[28] Particles less than or equal to 10 microns (µm) in diameter are small enough to be inhaled into the human lungs and can cause serious health problems; however, those particles smaller than 2.5µm can be inhaled into the sensitive alveolar or deep lung region and pose the greatest health risk. Particulate matter emissions smaller than 2.5µm ($PM_{2.5}$) are the focus of this study because they pose the greatest health risk humans.

The noxious effects of $PM_{2.5}$ are severe and well documented. Based on multiple epidemiological and EPA health studies, inhalation if $PM_{2.5}$ is linked to illness and death from heart and lung diseases, asthma, chronic bronchitis, decreased lung function, cardiac arrhythmias (heartbeat irregularities), premature death, and heart attacks (EPA, Pope and Dockery, 1999)[29]. A study conducted by Dr. David Abbey of Loma Linda University found that people living in areas of Los Angeles that violated federal particulate standards at least 42 days per year had a 33 percent greater risk of bronchitis and 74 percent greater risk of asthma than a control group. The study also found that women

[28] http://www.epa.gov/air/airtrends/aqtrnd01/pmatter.html
[29] http://www.epa.gov/air/urbanair/pm/hlth1.html

living in high particulate areas had a 37 percent higher risk of developing cancer.[30] Further, sensitive populations such children, the elderly, and people with preexisting asthma and other lung and/or heart problems are at greatest risk to develop the health problems associated with exposure to $PM_{2.5}$ emissions.

$PM_{2.5}$ is also the greatest contributor of outdoor haze of the six criteria air pollutants.[31] This is because $PM_{2.5}$ has the greatest ability to refract and scatter light. Outdoor haze is a major concern because it affects our everyday enjoyment of the natural environment; for example many national parks have been significantly impacted by haze issues, including the Grand Canyon, Big Bend, and the Great Smoky Mountains. In many parts of the U.S. the visual range has been reduced 70% from unpolluted conditions. The current visibility range in the eastern part of the U.S. is only 14-24 miles vs. an unimpaired visibility distance of 90 miles. In the western U.S., the current visibility range is 33-90 miles vs. a natural visibility of 140 miles.[32]

$PM_{2.5}$ emissions arise from a variety of sources. Non point sources such as motor vehicles are a major source of PM2.5 emissions; however, their effects are very hard to compare with socioeconomic status because they are mobile. Quantifying the impacts from non-point sources is a very challenging problem and is a vital research area, but is beyond the scope of the current research. Point sources include many different types of land uses and industries, including electric utilities, smelting factories, paper mills, textiles, bottling companies, lumber mills, pharmaceutics, packaging, construction, food productions, furniture, plastics/polymers, chemicals, and numerous other types of factories. Since point sources are not mobile their spatial relationship to socioeconomic

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[30] Jacobson, Mark *Atmospheric Pollution: History, Science, and Regulation.* Pg. 140. 2002
[31] http://www.epa.gov/ttn/oarpg/naaqsfin/pmhealth.html
[32] http://www.epa.gov/ttn/oarpg/naaqsfin/pmhealth.html

indicators is very plausible. In addition, major point sources are required to report their $PM_{2.5}$ emissions to the EPA; thus, quantifying their effects in relation to the communities where they are located is also feasible.

Many $PM_{2.5}$ point sources emit various other pollutants in addition to $PM_{2.5}$. For example, electric utilities emit carbon dioxide, nitrogen oxides, sulfur dioxide, and mercury; smelting factories emit trace metals into the air as well as into wastewater that can be transferred into drinking water systems if discharged into groundwater or surface waters. Since $PM_{2.5}$ is produced by so many types of industrial processes and land uses that also emit many other types of pollutants, it is a very good surrogate indicator for general pollutant exposure and releases. For comparison a more specific pollutant such as mercury is only emitted by limited number of industrial processes such as electric utilities and would not necessarily reflect the contributions from industries such as food processing.

Damages caused by $PM_{2.5}$ emissions to human health and natural environments are negative externalities, and a failure of the market. Negative externalities are defined as costs generated as a byproduct of an economic activity that do not accrue to the parties involved in the activity. Negative environmental externalities are costs that manifest themselves though changes in the physical-biological environment.[33] For example, the $PM_{2.5}$ pollution emitted by electric utilities, manufactures, and various other industries result in physical harm to people as well as social welfare. Though sources of $PM_{2.5}$ emissions presumably comply with regulations and do not intend to cause harm, the economic cost of the harm is not included in the cost of the product they are supplying. It

[33] Carlin, John: "Environmental Externalities in Electric Power Markets: Acid Rain, Urban Ozone, and Climate Change"

is important to study the spatial distribution of $PM_{2.5}$ point sources to determine whether particular societal groups are exposed to disproportionate levels of $PM_{2.5}$ emissions; if so, these affected groups would be paying a disproportionate amount of the negative externality costs through decreased health and quality of life, and through greater hospital bills.

North Carolina is chosen as the study area to explore the relationship between noxious facilities and socioeconomic status because it is both economically and racial diverse, has experienced a relatively large degree of economic growth in the past 15 years, and has relatively high levels of $PM_{2.5}$ pollution in its ambient air.[34] Figure 3 is the distribution of household income for the state in 1999, and indicates that there is a wide range of income in North Carolina households. However, the distribution is skewed to the low end with the majority of households in North Carolina having incomes below $50,000. Though skewness toward higher incomes is expected considering the wealth gap in the United States, the relatively large percent of households with very low annual incomes of less than $10,000 implies that a large percent of North Carolinians are quite poor. Further, 2000 census data reports that 10 percent of North Carolina's families are living at or below the federal poverty level.[35] The fact that North Carolina families do have a range in income levels is important in terms of being able to compare the number of emitters located in low income and high-income communities.

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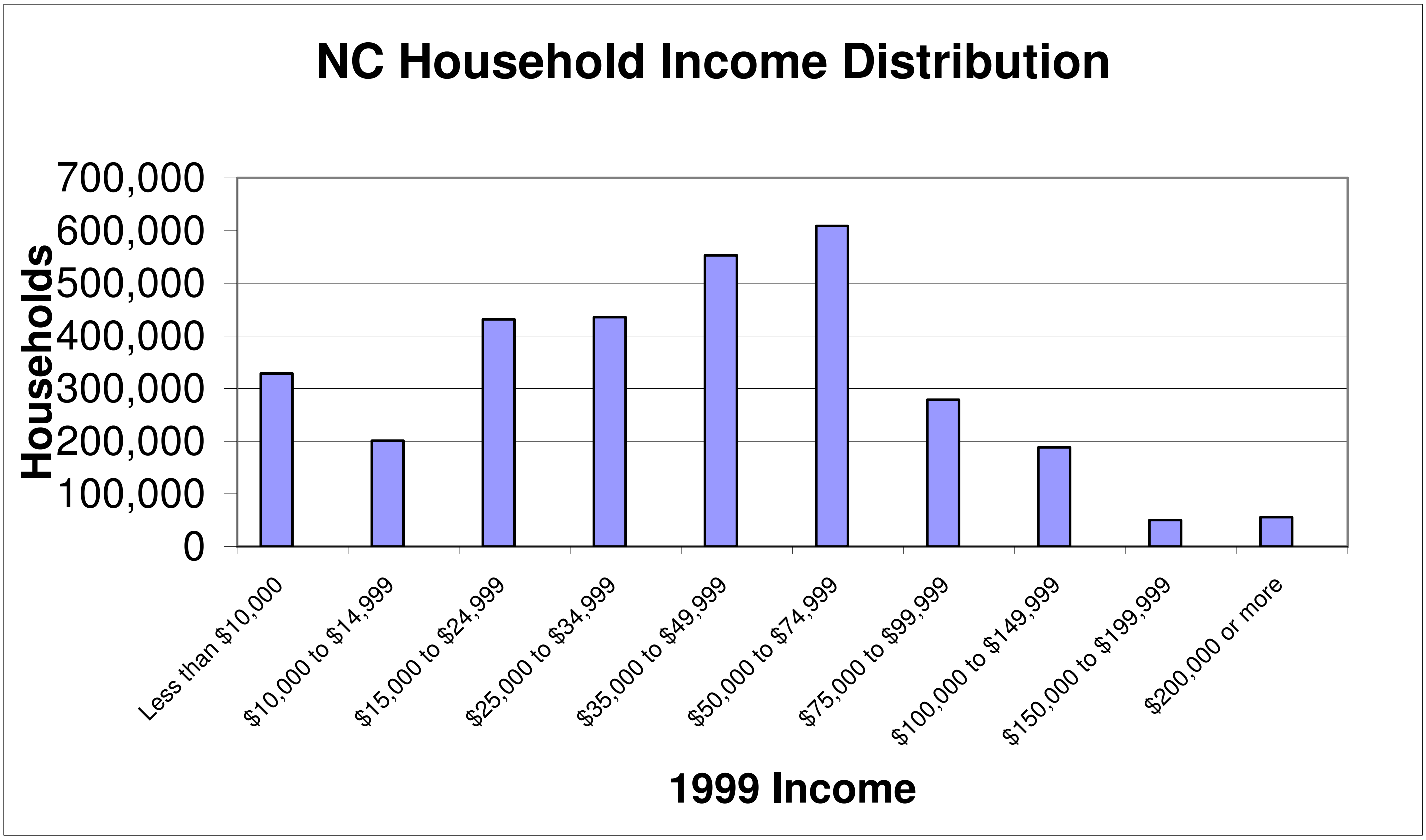
[34] North Carolina Economic Review 2002, North Carolina Department of Commerce, Policy Research, and Planning Division; http://cmedis.commerce.state.nc.us/econdata/review/NC_Economic_Review.pdf

[35] North Carolina Economic Review 2002, North Carolina Department of Commerce, Policy Research, and Planning Division; http://cmedis.commerce.state.nc.us/econdata/review/NC_Economic_Review.pdf

Figure 3:



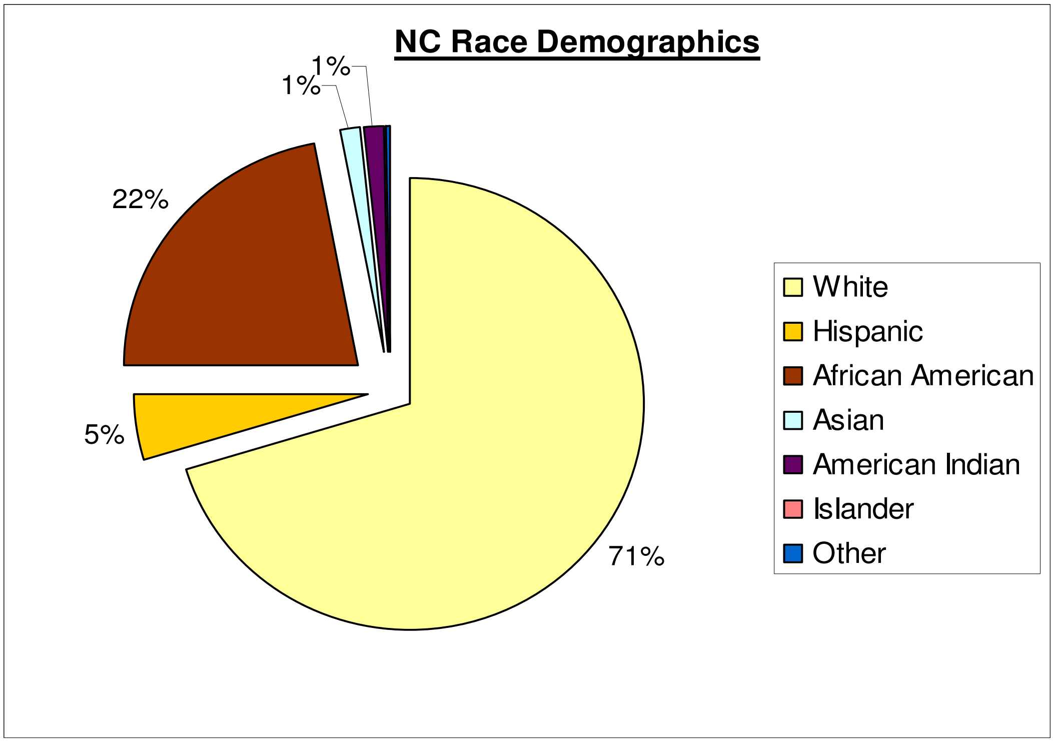
U.S Census Bureau, 2000

North Carolina is also a racially diverse state with a rather large African American population. Figure 4 shows the racial demographics of North Carolina, and reports that 22 percent of the states population is African American. This is a relatively large percent of the population that is African American considering African Americans only account for 12.3 percent of the national population.[36] It is important that the state is racially diverse in terms of being able to compare the spatial distribution of $PM_{2.5}$ emitters between racial groups. For comparison, the population of Vermont is 96.8% Caucasian and only 0.5% African American; a statewide analysis of the relationship

[36] U.S. Census Bureau, *Statistical Abstract of the United States 2004-2005*

between pollutant emitting facilities and racial communities would not be a meaningful study under these conditions

Figure 4:



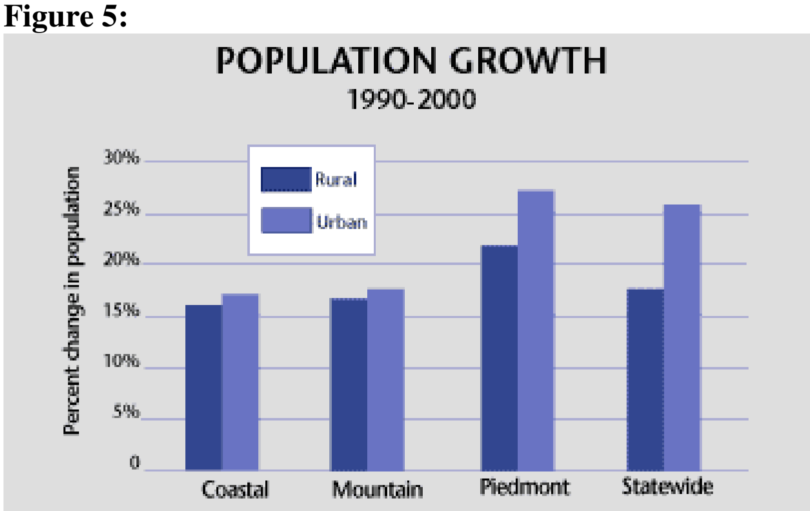
U.S Census Bureau, 2000[37]

North Carolina has experienced dramatic economic development, especially relative to other regions in the southeastern U.S. Between 1997 and 2001, North Carolina attracted $3.8 Billion in venture capital and $122,958 million in foreign direct investment, making North Carolina the second fastest growing economy in the southeast after Georgia.[38] The state also transitioned from being a net exporter of people in the 1980's to a net importer through out the 1990's. Between 1990 and 2000, rural counties grew 18 percent and added over 600,000 new residents, while urban areas grew roughly

[37] North Carolina 2000 Census Data: http://data.osbm.state.nc.us/profiles/mini/04037.pdf
[38] North Carolina Economic Review 2002, North Carolina Department of Commerce, Policy Research, and Planning Division; http://cmedis.commerce.state.nc.us/econdata/review/NC_Economic_Review.pdf

25 percent and added over 800,000 new people (see figure 5). [39] Assuming that economic growth correlates with an addition of PM2.5 emitters, the fact that North Carolina is growing economically indicates that many of the siting decision of $PM_{2.5}$ point sources are recent. However, to validate this assumption addition historical research would need to be conducted. If many point sources of PM2.5 are recent additions to the North Carolina economy, their location will give a good indication into the current social mechanisms that might create greater concentrations of polluters amongst some groups rather than others. For comparison, the location of facilities in a state like New York or New Jersey, which has been economically developed for a long time, are representational of past siting decisions. Though both New York and New Jersey are still growing considerably, new facilities are generally created where old ones existed or old facilities are simply modified to adapt to new technological and economic changes.

Figure 5:



Source: US Census Bureau

[39] US Census Bureau (2000) http://www.ncruralcenter.org/databank/trendpage_Population.asp

Looking at the location of $PM_{2.5}$ emitters in North Carolina is also relevant because ambient levels of PM2.5 air pollution are extremely high in many areas of North Carolina. Guilford, Catawba, and Davidson counties are all in non-attainment with EPA regulations for ambient $PM_{2.5}$ levels, and several other North Carolina counties including Forsyth and Durham have historically high levels of suspended $PM_{2.5.}$ According to the Clean Air Act, the EPA is required to set primary and secondary National Ambient Air Quality Standards (NAAQS) for pollutants that cause adverse effects to public health and the environment. Primary health standards include the monitoring of air pollutants that directly affect the public health, especially sensitive populations such as asthmatics, children, and the elderly. Secondary standards are established to monitor pollutants that affect public goods and welfare, including protection against decreased visibility, damage to animals, crops, vegetation, and buildings. $PM_{2.5}$ is classified as both a primary and secondary air pollutant, and various North Carolina counties have ambient $PM_{2.5}$ levels above established thresholds considered safe by the EPA.[40] Emissions of PM2.5 pollution can therefore be assumed to be contributing costs to North Carolina citizens, and it should be determined if there are specific socioeconomic groups within the state that are exposed to a disproportionate level of the $PM_{2.5}$.

Modeling:

In order to look a the spatial relationship between the location of North Carolina $PM_{2.5}$ point sources and the socioeconomic status of the surrounding community, ArcGIS 9.0 (produced by ESRI) and multiple regression analysis through Microsoft Excel (2003 version) will be used to compare economic data from the 2000 Census and $PM_{2.5}$ emitter

[40] EPA www.epa.gov/otaq/transp/conform/conf-regs.htm

point source data from the Environmental Protection Agency (EPA). ArcGIS is used as a tool to compile the data and visually perceive the spatial relationship between the location of $PM_{2.5}$ emitters and the various socio-economic indicators for North Carolina communities. The Census Bureau provides data for many geographic areas, including counties, cities, census tracts, block groups, and blocks. Blocks are the smallest unit of the census analysis, but the economic data for this group is not released to the public for confidentiality purposes. Census block groups are the next smallest unit of analysis and are used for this study. Block groups are areas bounded on all sides by visible features, such as streets, roads, streams, and railroad tracks, and by invisible boundaries, such as city, town, township, and county limits, property lines, and short, imaginary extensions of streets and roads.[41] Block groups are generally small in area; for example, a block bounded by city streets. However, block groups in sparsely settled areas may contain many square miles of territory.[42] Block group populations generally range between 600 and 3,000 people, with an optimal population of 1,500.[43]

North Carolina is broken up into 5263 block groups, as shown in Appendix 1. Block group data was obtained from ESRI (Redlands, CA), and includes 2000 census data for all 5263 block groups in North Carolina. However, 2 block groups were omitted from the regression because they did not report specific data. The sample size for this study is 5261 North Carolina block groups. From the census data, one economic indicator was extracted and 2 others were calculated for use as independent variables in GIS visualizations and the multiple regression model. The three independent variables that

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[41] Selected Appendixes: 2000. Summary Social, Economic, and Housing Characteristics. 2000 Census of Population and Housing

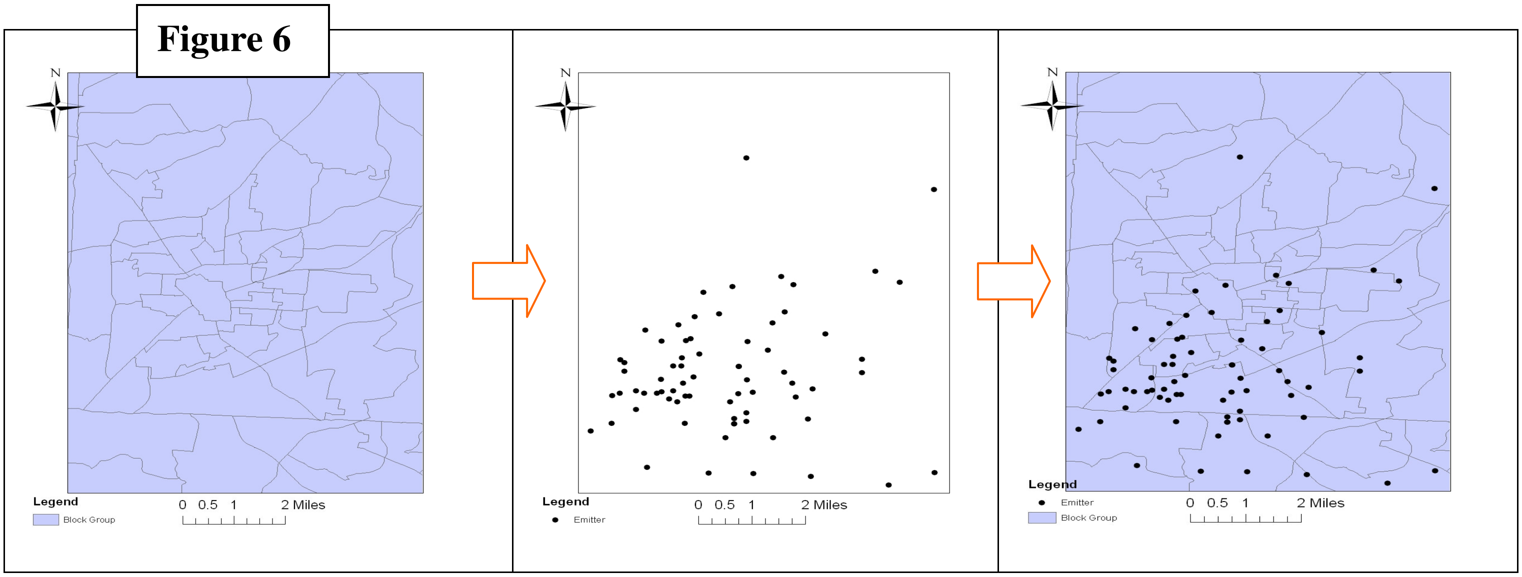
[42] Leise Gergely, "A GIS Investigation of Environmental Racism Using Toxic Emission and US Census Data" Fall 04'

[43] http://www.census.gov/geo/www/tiger/block.html

will act as the socio-economic indicators for this study are median household income, the percent of a block group's population that is African American, and the block group population density. These variables will be discussed in greater detail in following sections of this paper.

Latitude and longitude coordinates for all regulated point sources of $PM_{2.5}$ emissions in the state of North Carolina were obtained from the Environmental Protection Agency's Air Quality System Database.[44] In addition to the location, the database also provided the amount of PM2.5 the individual facility is permitted to discharge to the atmospheres, in tons per year. These sources of air pollution are classified and monitored under the Clean Air Act, which requires facilities to report their emissions for inclusion in the database. The location and emission data were processed and imported into ArcGIS to generate a file that would identify each location on a map. This spatial information was then joined with the data from ESRI, in order to associate the given point source with the relevant geographic census block group. An example of joining emitter locations with block groups can be seen in the Figure 6 below.

Figure 6



[44] EPA's Air Quality System Database can be accessed at http://www.epa.gov/air/data/geosel.html

The area of each individual census block group (km^2) was calculated in ArcGIS using a script provided from the field calculator. The $PM_{2.5}$ emitter density for each block group (# of point sources/km2) was then calculated for all 5261 North Carolina block groups. In addition to the point source density, the total combined annual $PM_{2.5}$ emissions (in tons for 1999) for all point sources within a given block group was calculated. This value was then divided by the surface area of that block group to determine the annual $PM_{2.5}$ emission density (tons $PM_{2.5}$ emission in tons/km^2) for all 5261 North Carolina block groups in 1999. Both $PM_{2.5}$ point source density and emission density will be used as the dependent variables in the GIS visualizations and multiple regression analysis.

Variables:

*Dependent Variables***:**

$PM_{2.5}$ Point Source Density is the number of regulated $PM_{2.5}$ point sources in a given block group divided by the surface area of that block group. This density calculation is a better basis for comparing various block groups than simply comparing the number of point sources in each block group because the area of the individual block groups can vary widely. For example, two block groups a large block group with 3 point sources would have a much different point source density than a small block group with the same number of sources, and the impact on the surrounding community could be significantly different. This density calculation assumes that every location within the entire block group is ‘exposed’ to the particulate emissions equally. This is clearly an oversimplification and does not take into account the dynamic factors of air pollution transport or of the spacing between the point sources, but is acceptable for this initial study into the possible relationships among particulate pollution and socioeconomic indicators.

Block groups that had no emitters were given a value of 0. It is assumed that block groups with more $PM_{2.5}$ emitters located in them are going to be exposed to greater PM2.5 emissions, and as a result will be at greater risk for developing the numerous health problems associated with inhalation of $PM_{2.5}$ discussed earlier. However, this is not a completely accurate assumption because it gives all point sources the same value. For example, if there are two block groups of equal size but one block group has multiple small emitters located in while the other has one very large emitter located in it, the block group with multiple emitters will be given a greater $PM_{2.5}$ emitter point source density value regardless if the one large polluter in the other block group has greater total annual emissions of $PM_{2.5}$ than all of the smaller emitters combined.

$PM_{2.5}$ Emission Density is the total $PM_{2.5}$ emission from all point sources of $PM_{2.5}$ in a given block group divided by the surface area of that block group. $PM_{2.5}$ emission density is used to give a sense of pollution exposure and gives an indication to the toxicity of $PM_{2.5}$ point sources within a given block group. Though it does give some indication to $PM_{2.5}$ concentration within a given block group, because of the nature of air it cannot be assumed that the reported emissions for a given block group will stay within that block group. For example, as $PM_{2.5}$ emission are released from a given point source they can be suspended in ambient air for days to weeks at a time, and depending on wind patters can also be carried hundreds of miles before deposition. In addition, $PM_{2.5}$ emission density is reporting total annual emissions not daily emission. Thus, emission concentrations will vary from day to day. Further, depending on the geographic location of a given block group the potential effects of emissions can also be very different. Oceans, strong winds, rain, forests, and large bodies of water have strong assimilative capacity and act as natural sinks for air pollution as well as other pollutants. As a result, a block groups located in close proximity to one or more natural sinks will feel fewer deleterious effects from the $PM_{2.5}$ emitters located in their midst than would otherwise be true if the block group was located elsewhere. Hence, North Carolina block groups located by the Atlantic Ocean will be less exposed to the $PM_{2.5}$ emissions that surround their communities than block groups located in the piedmont.

Though concentrations of $PM_{2.5}$ emissions within a given block group are dynamic and change over time due to wind patterns, the amount of activity $PM_{2.5}$ sources are generating from day to day, and the assimilative capacity of the natural environment that they are located in, the greatest amount $PM_{2.5}$ deposition from a given point source will be in close proximity to that source. This is because the greatest concentrations of most pollutants will be directly around the point source. As natural processes carry the pollutant away from the source levels concentrations of the pollutant will dilute. Though, PM2.5 emissions can travel thousands of miles, concentrations will be highly diluted and the negative effects will be relatively minimal. The $PM_{2.5}$ emission density value also give insight into the types of emitters that are located in a given block group in terms of toxicity as well as the potential $PM_{2.5}$ exposure. Again, $PM_{2.5}$ emission density is a very simplified indicator, but accurate air pollution monitoring data is not available at the block group level and air pollution transport modeling is highly complex and beyond the scope of this study.

Independent Variables:

Air pollution modeling is extremely complex. Many environmental confounding variables such as wind patterns, geographic location, proximity to natural sinks, traffic patterns, education, proximity to major highways, and level of construction can all greatly affect levels of $PM_{2.5}$ in a given block group. Unfortunately information on these variables are either unavailable or would require modeling beyond the scope of this study. The confounding variables that were included into the regression include:

Median Household Income is used in this research as the socioeconomic status indicator and gives an indication of the affluence and socio-economic status of a given block group. A block group's median household income reports the value where half of the households within a block group have an annual income above the reported value and half of the households have an annual income below. Thus, block groups with a lower reported household income are considered of lower socioeconomic status than block groups with a higher median household income.

Percent of Block Groups Population that is African American is used as the indicator to quantify racial demographics within the block groups. The percent of African American population for a given block group was calculated based upon census data, and was obtained by dividing the number of African American citizens by the total population residing in that block group.

Confounding Variable:

Population Density is used as a development indicator and gives an indication of urbanization within a given block group. Though population density is not being specifically tested in reference to environmental justice issues, it is an important confounding variable that will presumably effect the spatial distribution of $PM_{2.5}$ point sources. Population density is calculated by dividing the total population of a given block group by the surface area (in kilometers) of that block group. Population density in many cases indicates whether the block group is located in an urban or rural area, although there could be some situations where a highly industrialized region has limited housing opportunities and therefore a relatively low population density. For this study, block groups with a higher population density are in more urban areas, while a smaller population is assumed to represent a rural location.

Hypotheses:

According to the environmental justice conceptual model there will be a relationship between the location of PM2.5 point sources as well as PM2.5 emission density. More specifically environmental justice reasoning would hypothesize that areas of lower socioeconomic status and greater minority populations will have higher concentrations of fine particulate emitters and greater PM2.5 emission densities than areas of greater affluence and less minority populations. Thus, the working hypotheses to be tested are as follows:

Hypothesis A: $PM_{2.5}$ Point Source Density as Dependent Variable

> HA_1: North Carolina block groups with lower median household incomes will have greater PM2.5 emitter point source density than block groups with higher median household incomes.
>
> HA_2: North Carolina block groups with a greater percent of their population that is African American will have greater PM2.5 emitter point source density than block groups with less percent of their population that is African American.

Hypothesis B: $PM_{2.5}$ Emission Density as Dependent Variable

HB_1: Block groups with lower median household income will have a greater PM2.5 emission density than block groups with a higher median household income.

HB_2: Block groups with a greater percent of their population that is African American will have a greater PM2.5 emission density than block groups with less percent of their population that is African American.

Though population density is being tested in the environmental justice model, it is an important confounding variable and is expected to have a positive correlation with both PM2.5 point source density as well and PM2.5 emission density. This is because polluting industries are manufacturing and/or supplying a good, and it is most economical to be located near people (consumers) and other industries in order to advertise and make their good accessible. Polluters also require a labor force, and the greatest access to labor is in urban areas of greater population density. Thus, the working hypothesis for this pollution development model is as follows:

HA_3: North Carolina block groups with greater population density will have greater PM2.5 emitter point source density than block groups with lower population density.

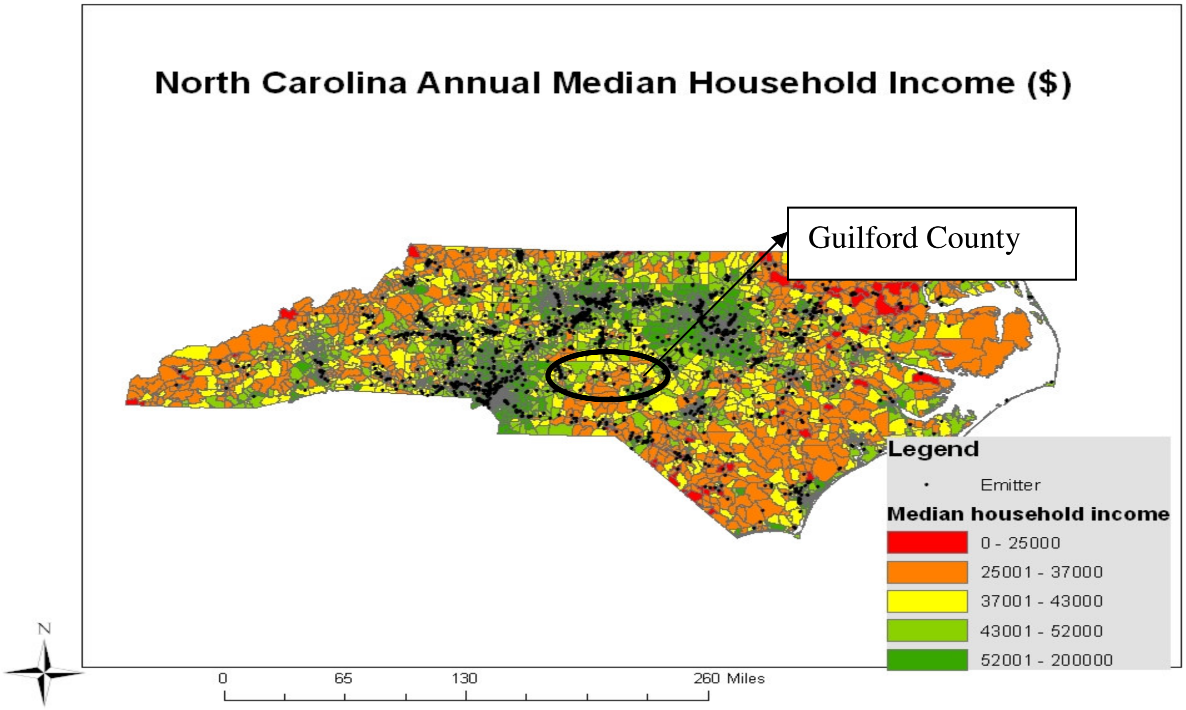
HB_3: Block groups with a greater population density will have a greater PM2.5 emission density than block groups with lower population density.

Results:

GIS Results

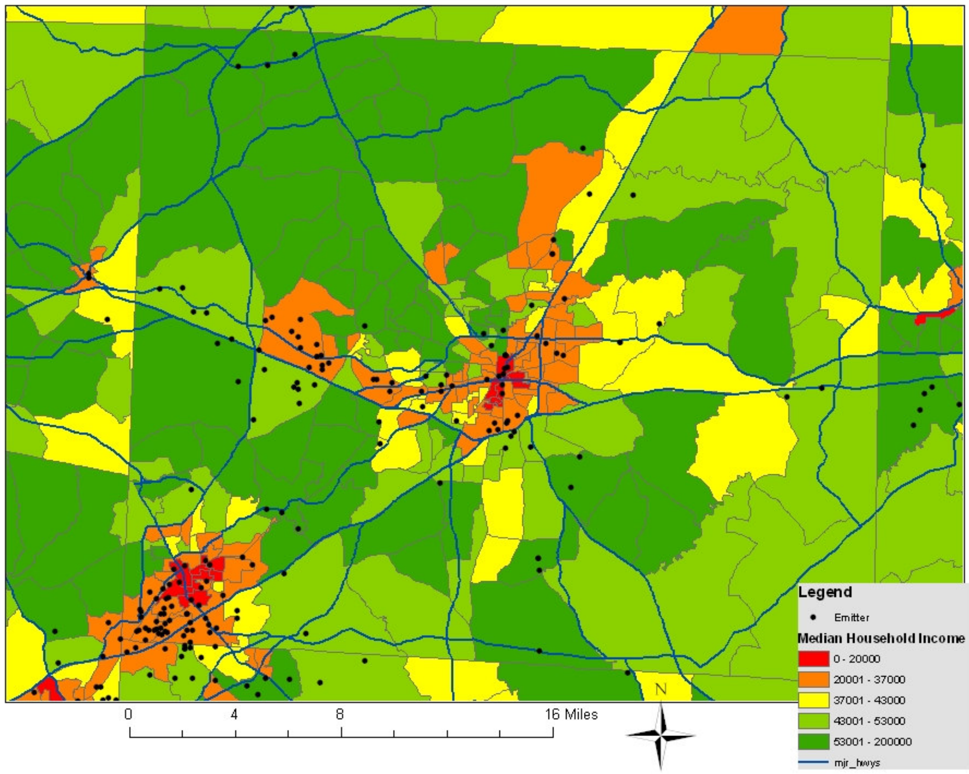
The locations of North Carolina PM2.5 emitters regulated by the EPA were geocoded to a block group base map using their latitude and longitude coordinates. As a result the location of these facilities in relation to median household income, race, and population density can be graphically depicted and are shown in Map 1. Map 1 shows median household income across all 5261 North Carolina block groups and the location of PM2.5 emitters regulated by the EPA. At first glance this map would be interpreted as having the vast majority of emitters sited in the $52,000 to $200,000 median household income range, located in the piedmont area (Charlotte, Greensboro, Raleigh, and Durham). However, this misleading due to the small resolution that block groups provide, especially in heavily populated urban centers. To show a better resolution of where these facilities are located, Guilford County was isolated and magnified in Map 2. Guilford County was chosen because the state map portrays it as being mostly in the green ($52,000 to $200,000) median household income range, and it also has diverse racial demographics. Maps of other various other counties can be seen in appendix 3.

Map 1:


North Carolina Annual Median Household Income ($)
Guilford County
Legend
Emitter
Median household income
0 - 25000
25001 - 37000
37001 - 43000
43001 - 52000
52001 - 200000
N
0
65
130
260 Miles

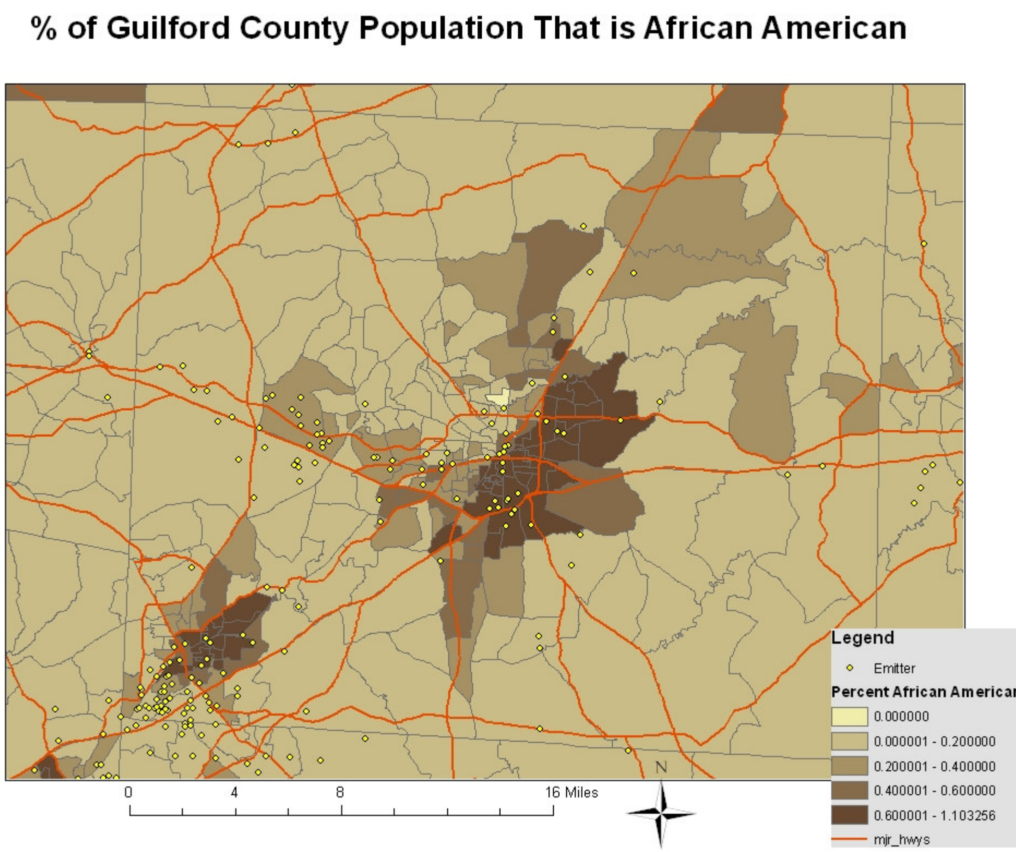
Map 2: :

Median Household Income For Guilford County



For reference, in Map 2 above the cluster of relatively smaller orange block groups in the middle of the map is Greensboro, and the cluster in the southwestern corner is High Point. Upon simple visual inspection, Figure 2 shows that the majority of the $PM_{2.5}$ point sources are not located in the higher median income areas (green), but are rather concentrated in the red and orange range block groups that have median household incomes between \$0 and \$37,000. It is also interesting that most of the PM2.5 point sources are heavily concentrated together and are located near major transportation networks, which are represented by the blue lines. Though PM2.5 emissions from cars could not be included in the current regression model, the spatial location of these roads gives an indication into what types of communities are most affected by PM2.5 emission from cars. Major roads are also probably located in areas of lower socioeconomic status for the same reasons as discussed for $PM_{2.5}$ point sources, being that of path of least resistance and market forces. PM2.5 sources are also probably located close to major transportation networks because roads are supply lines of economic activity, and these types of facilities need to be well connected in order to sell and distribute their product in the most efficient manner.

Map 3:

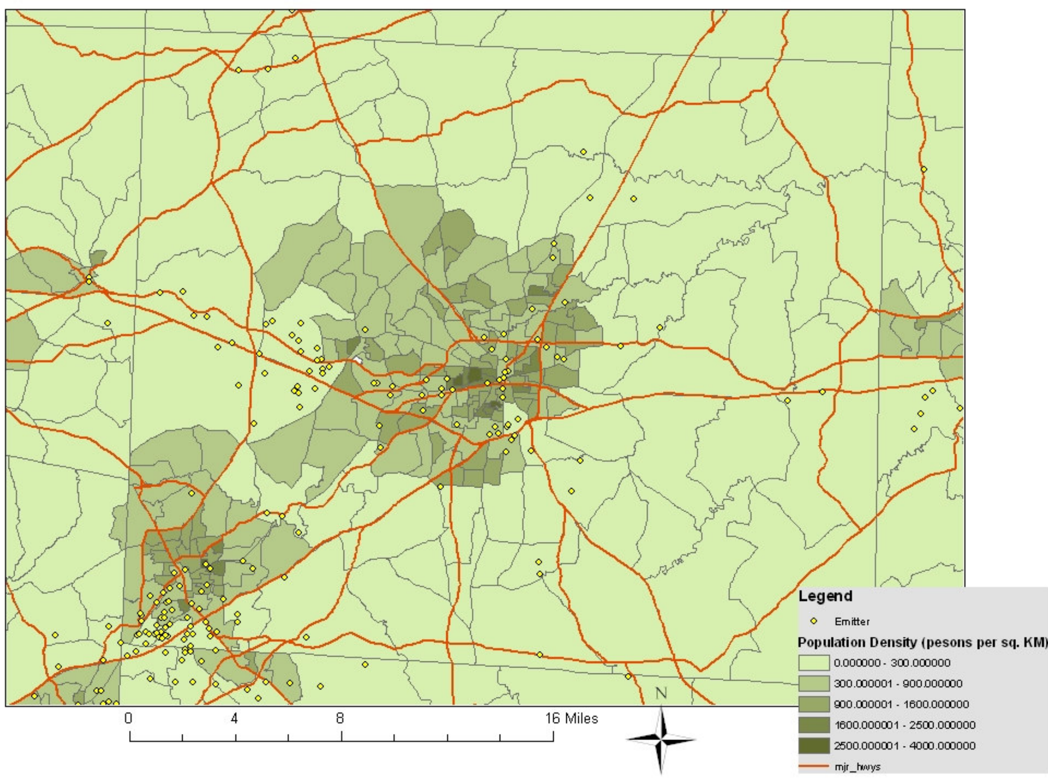


Map 3 shows the location of PM2.5 point sources in relation to percent of a block group's population that is African American, with darker colors indicating a greater proportion of African American residents. Upon visual inspection, there appears to be a trend showing that block groups with a higher percentage of their population being

African American tend to have a greater number of PM2.5 facilities located in or around them; however, this relationship seems to be weaker than was shown between median household income and pollutant point sources in Map 2.

Map 4:

Population Density of Guilford County (Person per square KM)



Map 4 shows the relationship between population density (people/km^2) and the location of $PM_{2.5}$ emitters in Guilford County block groups. Upon visual inspection, there appears to be a positive correlation between population density and the location of these facilities. In other words, there seems to be a greater number of $PM_{2.5}$ emitters located in block groups with greater population density than block groups with less population density.

Multiple Regression Analysis:

Regression A

Regression A uses $PM_{2.5}$ point source density for its dependent variable, median household income and percent of the population that is African American as independent variables, and population density as a confounding variable. According to the environmental justice conceptual model and pollution development model, the relationships expected are as follows:

> HA_1: North Carolina block groups with lower median household income will have a greater $PM_{2.5}$ point source density than block groups with a higher median household income.
>
> HA_2: North Carolina block groups with a greater percent of their population that is African American will have greater PM2.5 point source density than block groups with less percent of their population that is African American.
>
> HA_3: North Carolina block groups with greater population density will have greater PM2.5 point source density than block groups with lower population density.

Variables	**Coefficient**	**T-stat**	**P-value**
Y Intercept	**.1027**	**6.81**	**1.09E-11**
Median Household Income	**-1.6E-06**	**-5.65**	**1.71E-08**
Percent African American	**.059**	**2.77**	**.0055**
Population Density	**4.44E-05**	**4.79**	**1.69E-06**

The multiple regression analysis yielded the above results that give insight into how the independent variables are related to a North Carolina block group's $PM_{2.5}$ emitter point source density. Each independent variable's coefficient reports the relationship between that variable and $PM_{2.5}$ point source density, while holding all other independent variables constant. The coefficient also indicates whether an independent variable has a positive (direct) or negative (inverse) relationship with the dependent variable.

For regression A, a negative coefficient is reported for median household income, while a positive coefficient is reported for both percent of the population that is African American and population density. Hence, an increase in median household income is expected to decrease the $PM_{2.5}$ point source density within a block group, and an increase in the percent of a block group's population that is African American as well as population density is expected to result in an increase in $PM_{2.5}$ emitter point source density. The direction of relationship reported for each independent variable and $PM_{2.5}$ point source density supports the environmental justice conceptual model. The positive coefficient for population density is also expected as described earlier

In addition to reporting the direction of relationship between an independent variable and $PM_{2.5}$ emitter point source density, the coefficients in regression A also report how much each independent variable will affect $PM_{2.5}$ point source density while holding all other confounding variables constant. For example the independent variable median household income reported a coefficient of -.0000016, which implies that with all other variables held constant if a block group's median household income decreases by $10,000 $PM_{2.5}$ emitter point source density is expected to increase by 1.6 .emitter per km^2. Though an increase of 1.6 emitters, rather than a whole number such as 1 or 2, seems uninformed, the amount that median household income must decrease in order to see a significant change in $PM_{2.5}$ point source density seems plausible. Percent of a block group's population that is African American reported a coefficient of .059. This coefficient implies that 10% increase in the percent of block group's population that is

African American would reflect an increase of 5.9 PM2.5 point sources per km^2.Again 5.9 emitters is not regular, but the ratio seems relatively accurate. The coefficient reported for population density is .000044, which suggests an increase in 4.4 PM2.5 emitters per km^2 if population density increases by 1,000 people per km^2. This ratio is also rational despite the fact that 4.4 PM2.5 point sources is not possible.

Though the coefficient gives an insight into how the independent variables are related to $PM_{2.5}$ emitter point source density, the T-statistic and P-value indicates whether or not the coefficient is actually statistically significant. The coefficient ratio is only statistically significant is the T-statistic reported is above 2 (or below –2), and has a P-value below .05. The regression results reported that the key independent variable, median household income, has a t-stat of –5.65 and a p-value of 1.71E-08. These are statistically significant results; therefore, the hypothesis that North Carolina block groups with lower median household income will have a greater $PM_{2.5}$ emitter point source density than North Carolina block groups with higher median household income is supported. In addition, both the percent of a block group's population that is African American and population density yielded a statistically significant t-stat and p-value. The percent of a block group's population that is African American yielded a t-stat of 2.77 and a p-value of .0055, while population density yielded a t-stat of 4.79 and a p-value of 1.69E-06. As a result, it can be inferred that North Carolina block groups with a greater percent of their population being of African American decent and a greater population density will also have a greater $PM_{2.5}$ point source density than North Carolina block groups with a relatively smaller percent of its population being African American and smaller population density.

Regression B:

Regression B uses $PM_{2.5}$ emission density for its dependent variable, median household income and percent of the population that is African American as independent variables, and population density as a confounding variable. According to the environmental justice conceptual model and pollution development model, the relationships expected are as follows:

HB_1: Block groups with lower median household income will have a greater PM2.5 emission density than block groups with a higher median household income.

HB_2: Block groups with a greater percent of their population that is African American will have a greater PM2.5 emission density than block groups with less percent of their population that is African American.

HB_3: Block groups with a greater population density will have a greater PM2.5 emission density than block groups with lower population density.

Variables	Coefficient	T-stat	P-value
Y Intercept	**0.656**	**5.30**	**1.19E-07**
Median Household Income	**-8.7E-06**	**-3.85**	**.00012**
Percent African American	**-0.07**	**-0.40**	**.68589**
Population Density	**8.5E-05**	**1.12**	**.26377**

The multiple regression analysis yielded the above results that give insight into how the independent variables are related to North Carolina block group's $PM_{2.5}$ emission density. For regression B, each independent variable's coefficient reports the relationship between that variable and $PM_{2.5}$ emission density, while holding all other independent variables constant. The coefficients for regression B are expected to be in the same direction as regression A, with median household income reporting an inverse relationship and both percent of the population that is African American and population density reporting positive relationships with $PM_{2.5}$ emission density. This is because it is assumed that a greater $PM_{2.5}$ emitter point source density would have a strong positive correlation with $PM_{2.5}$ emission density; following the reasoning that a block group with more emitters located in it will have greater total emissions as well.

A negative coefficient is reported for both median household income and percent of the population that is African American, and a positive coefficient is reported for population density. Hence, an increase in median household income as well as an increase in the percent of the population that is African American is expected to reflect a decrease the $PM_{2.5}$ emission density within a block group, and an increase in population density would correlate with an increase in $PM_{2.5}$ emission density. The negative coefficient for median household income as well as the positive coefficient for population density is in line with the environmental justice conceptual model; however, the negative coefficient reported for percent of a block group's population that is African American is not. An increase in median household income was expected to decrease $PM_{2.5}$ emission density within a block group for the same reasons that an increase in median household income was expected to decrease $PM_{2.5}$ emitter point source density as outlined by the environmental justice reasoning. The reasoning being that block group's with relatively low median household income represent the path of least resistance and/or market forces will allocate resources as to create a greater concentration of polluters in their communities.

The positive relationship between population density and emission density was also expected considering that urban areas tend to have a greater number of $PM_{2.5}$ point sources located in them and would in turn have greater $PM_{2.5}$ emissions. The negative coefficient reported for percent of a block group's population that is African American is opposite than expected if one flows the environmental justice reasoning. According to the environmental justice model, block groups with a greater percent of their population that is African American would presumably have less representation in land use decision, have lower incomes, be more susceptible to discrimination, and be less involved in environmental activism. As a result, block groups with a greater percent of their population being African American would have more $PM_{2.5}$ emitters located in them and would therefore have greater emission density. As regression A showed, block groups with a greater percent of their population do have more $PM_{2.5}$ emitters located in them, yet regression B indicates that this does not mean they will also have a greater emission density. This unexpected incongruity is puzzling and may be a result of either the assumption that greater $PM_{2.5}$ emitter point source density correlating with greater emission density being wrong, or the possibility of outliers affecting the data. The validity of these two possibilities will be discussed later.

For regression B, the key independent variable was also median household income. Median household income reported a coefficient of -.0000087, which implies that with all other variables held constant if a block group's median household income decreases by $10,000, annual emissions of $PM_{2.5}$ is expected to increase by 8.7 tons per km^2. This relationship is in agreement with the hypothesis that median household income and emission density are inversely correlated, and the ratio seems very plausible in terms how much income is required to create a significant change in $PM_{2.5}$ emission density. Percent of a block group's population that is African American reported a coefficient of -

0.07. This coefficient implies that a 10% increase in the percent of block group's population that is African American may reflect a decrease of annual PM2.5 emission by 7 tons per km^2. The coefficient reported for population density is .000085, which suggests an annul increase 8.5 tons of PM2.5 emissions per km^2 if population density increases by 1,000 people per square kilometer.

The results for regression B, which uses $PM_{2.5}$ emission density as the dependent variable, are far less conclusive than regression A that uses $PM_{2.5}$ emitter point source density as the dependent variable. The results for regression B reported that the key independent variable, median household income, has a t-stat of –3.85 and a p-value of .00012. Though these are statistically significant results, and the hypothesis that North Carolina block groups with lower median household income will have a greater $PM_{2.5}$ emission density than North Carolina block groups with higher median household income is supported, neither the percent of a block group's population that is African American nor population density yielded statistically significant relationships with $PM_{2.5}$ emission density. The percent of a block group's population that is African American yielded a t-stat of –0.40 and a p-value of 0.69, while population density yielded a t-stat of 1.12 and a p-value of .263. These are not close to being statistically significant results. Thus, it cannot be inferred that North Carolina block groups with a greater percent of their population being of African American decent will have less PM2.5 emissions than block groups with a smaller percentage of their population being African American. Further, it can not be inferred that a North Carolina block group's with a greater population densities will have a greater $PM_{2.5}$ emission density than North Carolina block groups with smaller population densities.

Correlation Analysis

	PM2.5 emission density	*PM2.5 Point Source Density*	*Median Household Income*	*% of Pop. African American*	*Population Density*
PM2.5 emission density	1				
PM2.5 Point Source Density	0.256169	1			
Median Household Income	-0.05723	-0.10955	1		
% of Pop. African American	0.024411	0.104132	-0.43558	1	
Population Density	0.017727	0.088671	-0.05934	0.319233	1

The above correlation analysis gives insight into the strength of the relationship between each of the independent variables and the dependent variables. According to the results, none of the independent/confounding variables are dependent on one another. The established benchmark for variable dependency, or multicollinearity, is .80 (or -.80). It is particularly important that no two variables have a stronger correlation than .80 because it would skew the results. Multicollinearity can skew the regression results because the two variables would be so correlated to each other that the regression equation would not be able to distinguish what value it should attribute to each of the independent variables in relation to the dependent variable. The presented data reports that the two most correlated independent variables are median household income and percent of a block group's population that is African American at -.44, which is high but safely above the -.80 benchmark. Considering African Americans historically make less money than Caucasian's, as discussed in the environmental justice conceptual model, it is expected that percent of the population that is African American and median household income would have such a strong inverse relationship.

Regression A yielded a relatively low R square of .02. The R square measures how well the regression equation explains the variation in the dependent variable ($PM_{2.5}$ emitter point source density). In other words, the R square is a measurement of the variation around the mean explained by all of the independent variables. The reported R square of .02 suggests that all the confounding variables together explain 2% of the variation in block group's $PM_{2.5}$ point source density.

Summary and Implications of Results:

There are many interesting results from both the GIS maps as well as the regression analyses. From the regression maps it could be seen that there are greater concentrations of PM2.5 point sources in block groups with lower median household income. In addition a relationship between the location of emitters with population density and percent of the population that is African American could be seen. However, the relationship between $PM_{2.5}$ emitter locations with population density and race are not as clear as the relationship with median household income. These results are then mirrored in regression A, with all three independent variables holding statistically significant relationships in line with the environmental justice conceptual model.

While a major source of $PM_{2.5}$ emissions is cars, it could not be included in the regression model because this is a non-point source and therefore could not be proven statistically. Yet, the GIS maps indicate that block groups of lower socioeconomic status are generally located in closer proximity to major transportation networks, especially in cities. From the maps it can be seen that major transportation networks are often buffered by block groups of lower socioeconomic and minority status. Having a major freeway such as I-40 running through a community would lower property values in the same way that a major polluter would. When a major road is created in a community the households with the greatest income and social mobility will be able to move, while low-income household may be forced to live next to this type of pollution source because it is the only place where rents are cheap enough. The probability and significance of this relationship should be explored because it also has many economic and environmental equity implications.

In regression A, emitter point source density held a statistically significant negative relationship with median household income. Though causality between the two variables cannot be assumed, the environmental justice reasoning that either initial discriminatory decisions or market forces have led to the inequitable distribution are plausibly rational explanations. In addition, the percent of a block group's population that is African American held a statistically significant inverse relationship with PM2.5 point source density. This result, as well as the correlation between median household income and percent of the population that is African American of only -.43, implies an inequitable concentration of PM2.5 point sources in block groups with a relatively high African American population that can not be fully explained by the fact that African Americans have significantly lower incomes. Racist decisions during the siting of PM2.5 emitters cannot be inferred from these results. However, the environmental justice conceptual model provides a logical explanation for this inequitable distribution. The environmental justice reasoning being that there is both overt and institutionalized discrimination in siting decision as well as various social and market forces that result in

African American making significantly less income than Caucasians, which restricts them from equal access non polluted communities.

The relationship between race and the location of $PM_{2.5}$ point sources is troubling, and studies showing a clear difference in lung health between Caucasians and African American mirror this disproportionate exposure to $PM_{2.5}$ emitters. A 2002 study estimated 3.4 million African Americans currently had asthma and that African Americans have the highest asthma prevalence of any racial/ethic group. [45] In addition, the American Lung Association reports that current asthma prevalence rate among Blacks is 38 percent higher than that for Caucasians, and African Americans are 3 times more likely to die from asthma than Caucasians.[46] While African Americans have similar smoking habits as Caucasians (22% vs. 24% respectively in 2002) and have lower overall exposure to tobacco smoke, they are more likely to develop and die from lung cancer.[47] Black men are also at least 50 percent more likely to develop lung cancer and 36 percent more likely to die from lung cancer than Caucasian men.[48] There are presumably many variables that affect the significantly higher instance of decreased lung health in African Americans, and it cannot be inferred from this study's results that there is causation between the inequitable concentrations of PM2.5 point sources in communities with greater African Americans population. However, PM2.5 has been proven cause

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[45] Perlin SA, Sexton K, Wong DW. An examination of race and poverty for populations living near industrial sources of air pollution. J Expo Anal Environ Epidemiol. 1999, Jan-Feb; 9(1):29-48; Perlin SA, Wong DW, Sexton K. Residential proximity to industrial sources of air pollution: interrelationships among race, poverty, and age. J Air Waste Mange Assoc. 2001 Mar;51(3); 406-2

[46] American Lung Association, http://www.lungusa.org/site/pp.asp?c=dvLUK9O0E&b=35976

[47] Surveillance, Epidemiology, and End Results Program, 1975-2001, Division of Cancer Control and Population Sciences, National Cancer Institute. http://www.lungusa.org/site/pp.asp?c=dvLUK9O0E&b=35976

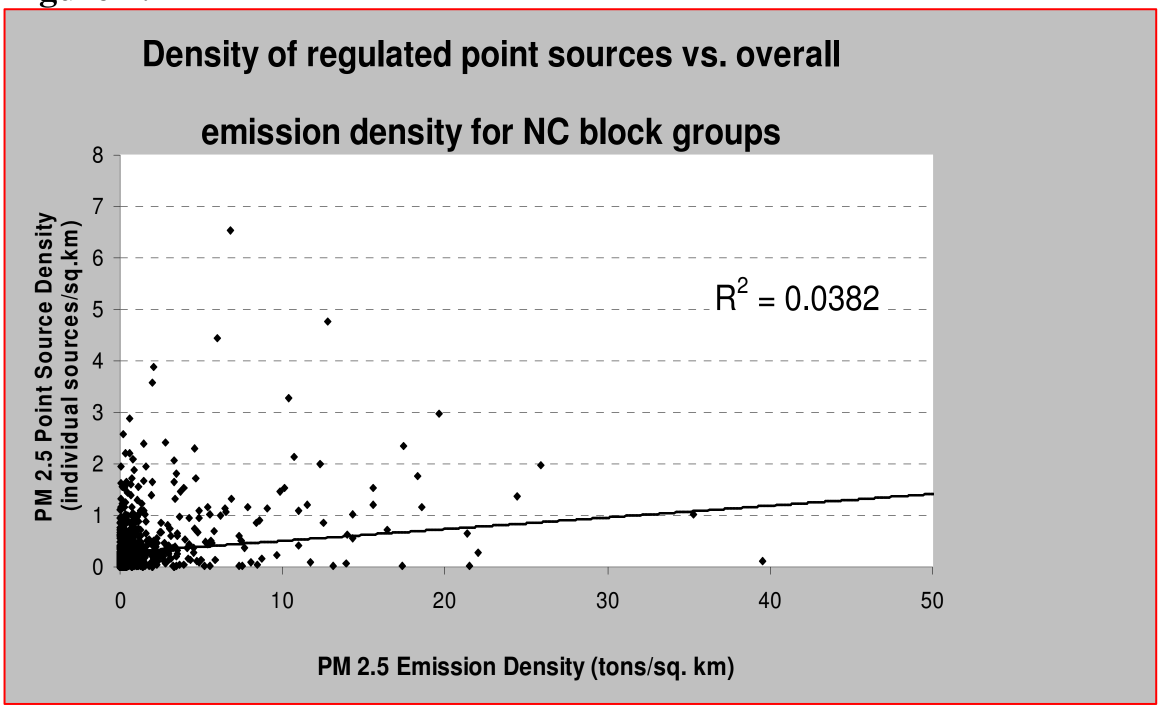
[48] Surveillance, Epidemiology, and End Results Program, 1975-2001, Division of Cancer Control and Population Sciences, National Cancer Institute. http://www.lungusa.org/site/pp.asp?c=dvLUK9O0E&b=35976

significant health problems, and the relationship between the location of PM2.5 point sources, race, and decreased health should be further explored.

The results in regression B, which used PM2.5 emission density as the dependent variable, are not as conclusive. Though median household income yielded a statistically significant positive relationship with PM2.5 emission density in line with environmental justice reasoning, neither population density nor percent of block group's population that is African American yielded significant results. The disparity between the results in regression A and B are puzzling; however, there are two possible reasons for the discrepancy. Essentially, the earlier assumption that an increase in PM2.5 emitter point source density is strongly correlated with an increase in PM2.5 emission density is not fully sound; and this is a result of economic and health factors placing electric utilities and other large polluters in very sparsely populated block groups, which are then acting as outliers and skewing the data.

It was assumed that areas with greater $PM_{2.5}$ emitter point source density would also have greater $PM_{2.5}$ emission density because more emitters would result in more economic activity that is creating $PM_{2.5}$ emissions as waste, and therefore there would be greater $PM_{2.5}$ emissions. However, this assumes that all emitters are relatively equal, and this is not the case. Figure 7 is shows the relationship between PM2.5 point source density and PM2.5 emission density. From this graph it can be seen that the two variables are not strongly correlated. The R-square of .038 reports that the two variables only explain 3.8% of the variation between one another, and the earlier correlation coefficient of .26 between the two variables is not strong enough to infer a close relationship. The Depending on the economic activity, some emitters expel far more $PM_{2.5}$ than others. For example an electric utility company can easily emit much greater amounts of $PM_{2.5}$ than multiple small textile factories of paper mills. Yet, all of these types of industries are given the same value of 1 in the $PM_{2.5}$ emitter point source indicator, and is weakness of the model.

Figure 7:

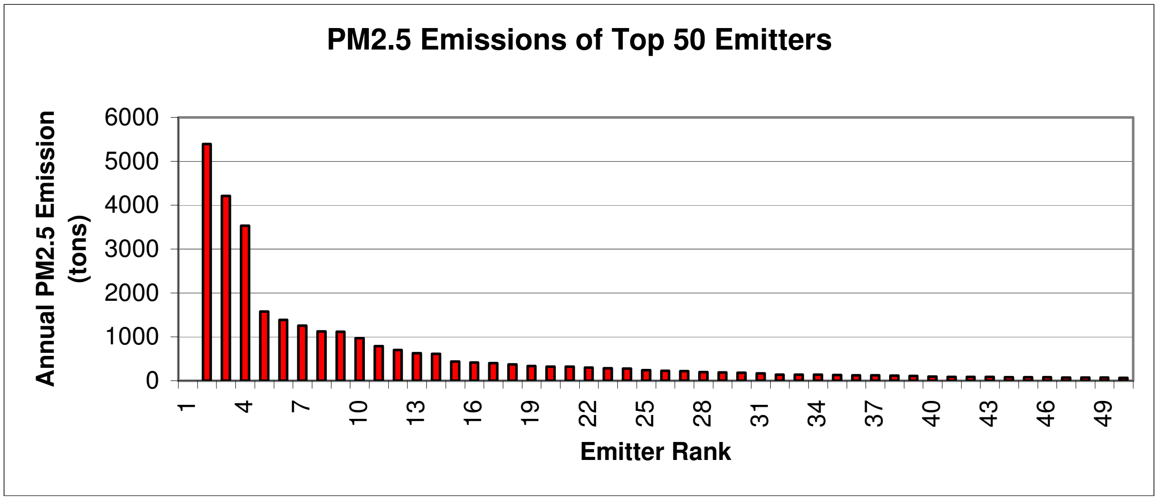


Another explanation for the discrepancy between regression A and B is that it is unacceptable to have very large polluters, such as electric utilities, located in highly urbanized areas as because all communities regardless of socioeconomic status or race will feel the effects. Thus, all communities use their political and economic powers to ensure theses types of polluters are not located in harmful range of their families. As a result, the largest polluters are generally placed in rural areas where their risk impacts are reduced. Though the wealthiest are probably the most active at dispelling large polluters from urban areas, it happens that their understandable act of selfishness also helps the greater good.

The lack of a strong correlation between block groups with high PM2.5 emitter point source densities and block groups with high PM2.5 emission densities could be the result of electric utilities acting as outliers on the data because they have the ability to apply very great health costs on society. Of the 10 largest PM2.5 emitters in the North Carolina, 9 of them are electric utilities. As can be seen in figure 8 below, the top 3 polluters have very large total annual $PM_{2.5}$ emissions, and all three are also electric utilities. Together top 3 facilities account for 35% percent of the total fine particulate emissions in NC, from EPA regulated point sources.[49] If an electric utility supplier was purely interested in economic efficiency and profit maximization, and was also given the choice of siting location for a plant void of health, political, and social constraints, the supplier would presumably place the electric utility in the closest possible proximity to industrialized urban centers where population densities are the greatest. Yet, because electric utilities are such large PM2.5 emitters and are therefore significant health hazards, and electricity transportation costs have become relatively negligible, society wants utility plants located in rural areas where they will affect the least amount of people.

[49] Calculated from EPA's Air Quality System Database, which can be accessed at http://www.epa.gov/air/data/geosel.html

Figure 8:



[50]

In order, the 3 greatest PM2.5 emitters in North Carolina are Cp&L's Roxboro electric utilities facility located in Person county, Duke Power's Belews Creek electric utility facility located in Stokes county, and Duke Power's Marshal electric utility facility located in Catawba county. All three of these electric utilities are located in block groups with population densities well below the state's averages (see figure 9). The Cp&L plant is located in a block group with a population density of 11.1 people per square kilometer, Belews Creek in a block group with 17.18 people per square kilometer, and the Marshal plant in a block group with 24.46 people per square kilometer. The average population density for North Carolina block groups is 386.3 people per square kilometer, and the median is 151.76 people per square kilometer.[51] The explanation that the largest polluters are located in areas of very low population density in order to minimize the negative externalities of their emissions is supported by the fact that the 3 largest emitters in North Carolina are also located in block groups with very low population density. This fact also

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50 Calculated from EPA's Air Quality System Database, http://www.epa.gov/air/data/geosel.html

51 See appendix 2 for descriptive statistics

helps explain why population density yielded a statistically significant relationship in regression A but not regression B.

Figure 9:

	CP& L Roxboro	Belews Creek	Marshal Plant	NC Average	State Median
Pop. Density (people per km^2)	11.1	17.8	24.46	386.3	151.7
% of pop. African American	32%	60%	2.8%	22%	12%

While the fact that the state's major polluters are located in sparely populated block groups helps explain why population density did not yield a statistically significant relationship with PM emission density, it does not explain why percent of the population that is African American did not yield statistically significant results with PM2.5 emission density. The Cp&L plant is located in a block group that is 32% African American, Belews Creek in a block group that is 60% African American, and the Marshal plant in a block group that is 2.8 % African American. The average percent of the population that is African American for North Carolina block groups is 22%, and the median is 12% (see figure 9).[52] Both the Cp&L plant and Belews Creek plant are located in block groups with African American populations well above the state's norm, while the Marshal plant is located in a block group that's African American population is well below the state norm. The fact that there are large polluters located in areas that are both predominantly African American and Caucasian could explain why there is not a statistically significant relationship between race and PM2.5 emission density. This

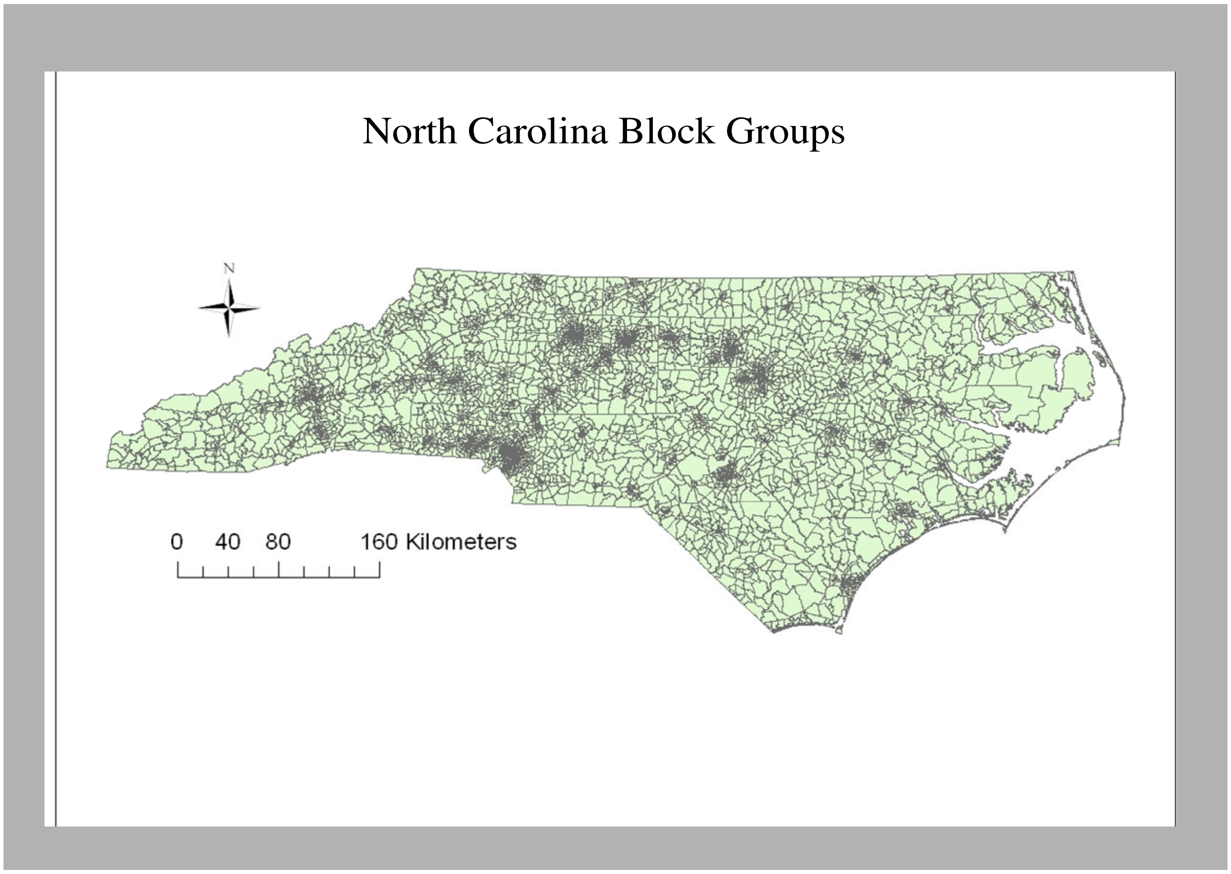
[52] See appendix 2 for descriptive statistics

explanation is not complete, and the relationship between the largest emitter and socioeconomic status should look at.

Based upon spatial and multiple regression analysis of census block group data and pollution emissions records, it is clear that the location of fine particulate matter point sources in North Carolina block groups is significantly related to the socioeconomic indicators median household income, race, and population density. On average, block groups with lower household incomes and relatively greater African American populations have more industrial point sources of fine particulate mater located in them than block groups that are relatively more affluent and have a greater Caucasian population. Thus, an inequitable distribution of fine particulate point sources in North Carolina can be inferred. Though causality between the socioeconomic indicators and the location of PM2.5 point sources can not be inferred, the fact that the relationships are statistically significant supports the environmental justice reasoning that there are various market forces as well as discriminatory social forces limiting creating this inequitable distribution.

Possible policy actions aimed at alleviating this inequitable distribution might be a more diligent health surveillance of high-risk populations including low-income and/or African American families, more stringent emission standards for PM2.5 emitters, and a more progressive tax structure. A more diligent health surveillance of low income and/or African American populations would allow for greater understanding of the health affects associated with greater proximity to PM2.5 point sources. More stringent emission standards for PM2.5 emitters could be emplaced to lower overall PM2.5 emissions below noxious levels. A more progressive tax structure would work to redistribute income before taxation from the wealthiest households, which are predominantly Caucasian, to households of lower income status, which include most African American families. The result of income redistribution would presumably be an equalization of wealth between classes and races, which would translate into more equal spatial mobility as well.

Appendix 1:



Appendix 2: Descriptive Statistics:

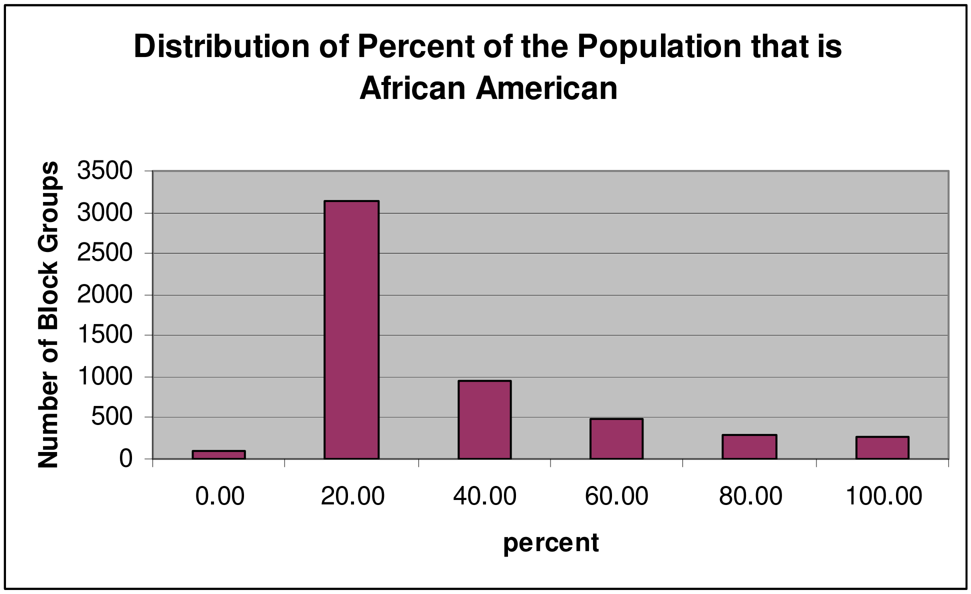
	Percent Black	Population density	Median household income
Mean	22%	386.281557	42804.75727
Standard Error	0.003492791	7.246265726	255.691332
Median	12%	151.763208	40072
Mode	0	None	40000
Standard Deviation	25%	525.5915892	18545.99577
Sample Variance	0.064182038	276246.5187	343953959.2
Kurtosis	1.316569277	25.81679527	14.87833771
Skewness	1.431775757	3.305381704	2.547242009
Range	100	9261.33551	242445
Minimum	0	1.069346949	5952
Maximum	100%	9262.404857	248397
Sum	1181.500552	2032227.271	225195828
Count	5261	5261	5261
Confidence Level(95.0%)	0.006847323	14.20569404	501.2613347

Descriptive Statistics

Point_den		*PM_conc*	
Mean	0.066357	Mean	0.299783
Standard Error	0.004641	Standard Error	0.037768
Median	0	Median	0
Mode	0	Mode	0
Standard Deviation	0.336636	Standard Deviation	2.739419
Sample Variance	0.113324	Sample Variance	7.504415
Kurtosis	710.3535	Kurtosis	797.4175
Skewness	19.97689	Skewness	24.71048
Range	14.58245	Range	109.9525
Minimum	0	Minimum	0
Maximum	14.58245	Maximum	109.9525
Sum	349.1017	Sum	1577.157
Count	5261	Count	5261
Largest(1)	14.58245	Largest(1)	109.9525
Smallest(1)	0	Smallest(1)	0

Appendix 3:

Appendix 4:



Distribution of Percent of the Population that is African American
Number of Block Groups
3500
3000
2500
2000
1500
1000
500
0
0.00
20.00
40.00
60.00
80.00
100.00
percent

Bibliography

Anderton, Douglas L., Andy B. Anderson, John Michael Oakes, Michael R. Fraser. 1994. "Environmental Equity: The Demographics of Dumping." Demography 31(2): 229-248

Anderton Douglas L., Andy B. Aderson, John Michael Oakes, and Michael Fraser, Elenour W. Weber, and Edward J. Calabrese, " Hazardous Waste Facilites: 'Environemtal Equity' Issues in Metropolitan Areas," Evaluation Review (vol. 18, no.2), pp. 123-40. 1994.

Been, Vicki, Locally Undesirable land uses in minority neighborhoods: Disproportionate siting or market dynamics? *Yale Law Journal*, 1994.

Bullard, Robert D., *Dumping in Dixie: Race, Class and Environmental Quality*. Boulder, CO: Westview Press, 1994.

Bullard, Robert D. (ed.), *Unequal Protection: Environmental Justice and Communities of Color.* San Francisco: Sierra Club, 1994.

Bryant, Bunyan, *Environmental Advocacy: Working for Economic and Environmental Justice*, Ann Arbor, MI, 2002.

Bryant, Bunyan, and Paul Mohai (eds.), *Race and the Incidence of Environmental Hazards: A Time for Discourse*. Boulder, CO: Westview Press, 1994.

Buzzelli, Jerrett, Burnett, and Finklestein. *Spatiotemperal perspectives on Air Pollution and Environmental Justice in Hamilton, Canada, 1985-1996,.* Annals of the Association of American Geographers, 93 3 (3), 2003, pp. 557-573

Cole, Luke W., and Sheila R. Foster. *From the Ground Up: Environmental Racism and the Rise of the Environmental Justice Movement.* New York: New York University Press, 2001.

Camacho, David E., ed. 1998. *Environmental Injustices, Political Struggles: Race, Class, and the Environment*. Durham, NC: Duke University Press.

Dunlap, Riley E. , and Rik Scarce. 1991. "Poll Trends: Environmental Problems and Protection." The Polls 55.4: 651-672.

Foreman, Christopher H. Jr., *The Promise and Peril of Environmental Justice*, Washington, DC: Brookings Institution, 1998.

Gergely, Leise, "A GIS Investigation of Environmental Racism Using Toxic Emission and US Census Data" Fall 04'

Hurley, Andrew. 1995. *Environmental Inequalities: Class, Race, and Industrial Pollution in Gary, Indiana, 1945-1980.* Chapel Hill: University of North Carolina Press.

Hershkowitz, Allen, *Bronx Ecology*, Washington, D. C., Island Press, 2002.

Hofrichter, Richard, ed., Toxic Struggles: *The Theory and Practice of Environmental Justice.* Philadelphia: New Society Publishers, 1993.

Jarrett, Michael and Richard T. Burnett, "*A GIS- Environmental Justice Analysis of Particulate Air Pollution in Hamilton, Canada*." Environment and Planning A 2001, Volume 33, pg. 955-973

Jerrett M, Eyles J, Cole D, Reader S. 1997. "*Environmental Equity in Canada: an Empirical Investigation Into the Income Distribution of Pollution In Canada*." Environment and Planning A 29 1777-1800

Jocobson, M.Z. "Atmospheric Pollution: History, Science and Regulation," Cambridge University Press, New York (2002)

Mohai, Paul. 1995. "The Demographics of Dumping Revisited: Examining the Impact of Alternate Methodologies in Environmental Justice Research." Virginia Environmental Law Journal 14: 615-652.

McMaster R, Leit H, Sheppard E, 1997. "*GIS-based Environmental Equity and Risk Assessment: Methodological Problems and Prospects"* Cartography and Geographic Information Systems 24, pg 172-189.

Perlin SA, Sexton K, Wong DW. An examination of race and poverty for populations living near industrial sources of air pollution. J Expo Anal Environ Epidemiol. 1999, Jan-Feb; 9(1):29-48; Perlin SA, Wong DW,

Pulido, Laura. 1996. "A Critical Review of the Methodology of Environmental Racism Research." Antipode 28(2), pp. 142-59.

Sexton K, Adgate J L. 1999. "Looking at Environmental Justice From an Environmental Health Perpecitive" Journal of Exposure Analysis and Environmental Epidemiology 9, pg. 3-8

Sexton K. Residential proximity to industrial sources of air pollution: interrelationships among race, poverty, and age. J Air Waste Mange Assoc. 2001 Mar;51(3); 406-8

Szasz, Andrew, *EcoPopulism: Toxic Waste and the Movement for Environmental Justice*, Minneapolis, MN: U. of Minnesota Press, 1994.

United Church of Christ. 1987. Toxic Waste and Race in the United States: A National Report on the Racial and Socioeconomic Characteristics of Communities with Hazardous Waste Sites. New York: United Church of Christ.

Vittles, Elliot M. and Philip H. Pollock, III. "*Poverty, Pollution, and Solid and Hazardous Waste Siting: How Strong are the Links?*" Florida Center For Hazardous Waste Management

U.S. Census Bureau, Current Population Survey, 2000

http://www.epa.gov/ttn/oarpg/naaqsfin/pmhealth.html

Bullard, Robert D., It's Not Just Pollution"
http://www.ourplanet.com/imgversn/122/bullard.html

http://edugreen.teri.res.in/explore/air/smog.htm

Carlin, John: "Environmental Externalities in Electric Power Markets: Acid Rain, Urban Ozone, and Climate Change" www.eia.doe.gov/cneaf/pubs_html/rea/feature1.html

North Carolina Economic Review 2002, North Carolina Department of Commerce, Policy Research, and Planning Division;
http://cmedis.commerce.state.nc.us/econdata/review/NC_Economic_Review.pdf

U.S. Census Bureau, *Statistical Abstract of the United States 2004-2005*

North Carolina 2000 Census Data: http://data.osbm.state.nc.us/profiles/mini/04037.pdf

US Census Bureau (2000)
http://www.ncruralcenter.org/databank/trendpage_Population.asp

EPA www.epa.gov/otaq/transp/conform/conf-regs.htm

Selected Appendixes: 2000. Summary Social, Economic, and Housing Characteristics. 2000 Census of Population and Housing

http://www.census.gov/geo/www/tiger/block.html

EPA's Air Quality System Database can be accessed at
http://www.epa.gov/air/data/geosel.html

American Lung Association,
http://www.lungusa.org/site/pp.asp?c=dvLUK9O0E&b=35976

Surveillance, Epidemiology, and End Results Program, 1975-2001, Division of Cancer Control and Population Sciences, National Cancer Institute.
http://www.lungusa.org/site/pp.asp?c=dvLUK9O0E&b=35976