ABSTRACT

Title of Dissertation: THE DEVELOPMENT OF A COMMUNITY INFORMED CUMULATIVE STRESSORS AND RESILIENCY INDEX (CSRI) TO EXAMINE ENVIRONMENTAL HEALTH DISPARITIES AND DISEASE RISK IN SOUTH CAROLINA

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Communities with environmental justice (EJ) issues usually have disparities in exposure to chemical and non-chemical stressors and health status compared to other communities without underlying EJ issues. Improving cumulative risk assessment (CRA) screening tools and models can provide the necessary information needed to reduce health disparities and create more resilient communities. To address these gaps in EJ science, this dissertation has three specific aims: 1) Identify perceptions of environmental and resilience factors that may influence health among African-Americans in North Charleston, South Carolina (SC) (Study 1), 2) Develop a Cumulative Stressors and Resiliency Index (CSRI) used to rank risk in SC (Study 2), and 3) Examine associations

between CSRI scores and risk of asthma hospitalizations/emergency department (ED) visits in SC (Study 3).

Community stakeholders (N=18) participated in key-informant interviews and completed a 26-item paper survey in study one. Interviews were transcribed and coded, while mode, frequencies, and percentages were calculated for each indicator based on its ability to influence health. Statistical tests performed in study two included a Principal Component Analysis (PCA), one-way analysis of variance (ANOVA), and linear regression performed in SAS Enterprise Guide 7.1. Choropleth maps were also developed in ArcMap 10.5. We concluded by calculating descriptive statistics by Environmental Affairs (EA) region, Spearman's rank-order correlation, one-way ANOVA, and negative binomial regression analyses in study three.

Many of the indicators (61%) were rated as extremely high priority items and included environmental hazards, sociodemographic attributes, and factors that may influence resiliency. CSRI scores ranged from 7.4 – 64.0 with a mean score of 29.1. Statistically significant differences in CSRI scores were evident by EA region ($p < 0.0001$) and a one-unit increase in the percentage of non-white populations per census tract projected to increase CSRI scores by roughly 6.1%. The CSRI was not able to predict risk of asthma hospitalizations/ED visits as hypothesized.

Overall, we demonstrated that identifying and addressing chemical and non-chemical stressors and resiliency gaps in areas impacted by environmental injustice may lead to overall improvements in community resilience. We anticipate this work will be used as a blueprint to build more resilient and equitable communities in SC.

THE DEVELOPMENT OF A COMMUNITY INFORMED CUMULATIVE STRESSORS AND RESILIENCY INDEX (CSRI) TO EXAMINE ENVIRONMENTAL HEALTH DISPARITIES AND DISEASE RISK IN SOUTH CAROLINA

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Dissertation submitted to the Faculty of the Graduate School of the
University of Maryland, College Park in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy
2017

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DEDICATION

I dedicate this dissertation to my loving and supportive husband Charles Naney, parents Frederick and Dr. Carolyn Burwell, grandmother Louise Burwell, and son William Naney. I also dedicate this dissertation to God; the one who allowed me to overcome all of the obstacles I encountered throughout this process and make it to the finish line.

ACKNOWLEDGEMENTS

I would like to thank my dissertation committee chair, advisor, and mentor, Dr. Sacoby M. Wilson, for his guidance and support in helping me achieve my academic and professional goals. I would also like to thank Dr. Robin Puett for the significant role she played on my dissertation committee and her genuine mentorship over the years. I further acknowledge and thank my other committee members for all of their hard work and support throughout this process: Dr. Amir Sapkota, Dr. Xin He, Dr. Donald Milton, Dr. Paul Turner, and Dr. Sharon M. Desmond. Furthermore, I would like to thank the community members from North Charleston, South Carolina for their participation in this research. I would like to thank my amazing friends (Dr. LaShanta Rice, Jessica Montresor-Lopez, Dr. Amanda Lowe Dubose, Rianna Murray, Chaka Burnett, Angela Cordova, and Tonja Sease) and siblings (Monica Burwell Bowles and Frederick Burwell, III) for encouraging me throughout my journey. Lastly, I thank my husband Charles Naney who gave me the prayers, support, love, and space I needed to complete my dissertation.

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LIST OF ABBREVIATIONS

ATSDR – Agency for Toxic Substances and Disease Registry

BLL – Blood Lead Level

CAFO – Concentrated Animal Feeding Operation

CalEPA – California Environmental Protection Agency

CBO – Community-based Organization

CBPR – Community-based Participatory Research

CCRAB – Charleston Community Research to Action Board

CDC – Centers for Disease Control and Prevention

CEHII – Cumulative Environmental Hazards Inequality Index

CEHI – Cumulative Environmental Hazards Index

CEVA – Cumulative Environmental Vulnerability Assessment

C-FERST – Community-Focused Exposure and Risk Screening Tool

CO – Colorado

COMR – Community-owned and Managed Research

CPS – Collaborative Problem-Solving Model

CRA – Cumulative Risk Assessment

CRI – City Resilience Index

CRI - Coastal Community Resilience Index

CRJ – Commission for Racial Justice

CSRI – Cumulative Stressors and Resiliency Index

CVD – Cardiovascular Disease

dl - Deciliter

DPM – Diesel Particulate Matter

EJ – Environmental Justice

EJGAT – Environmental Justice Geographic Assessment Tool

EJSEAT – Environmental Justice Strategic Enforcement Screening Tool

EJ IWG – Interagency Working Group on Environmental Justice

FAO – Food and Agriculture Organization

GCI – Green City Index

GAO – General Accounting Office

HIA – Health Impact Assessment

HPSA – Health Professional Shortage Areas

HRSA – Health Resources and Services Administration

HRI – Hazard Resilience Index

HI – Health Index

IMR – Infant Mortality Rate

IOM – Institute of Medicine

IRB – Institutional Review Board

JIBC – Justice Institute of British Columbia

km – Kilometer

LAMC – Lowcountry Alliance for Model Communities

LBW – Low birth weight

LULUs – Locally Unwanted Land Uses

LUSTs – Leaking Underground Storage Tanks

m – Meter

MAUP – Modifiable Areal Unit Problem

MIAEH – Maryland Institute for Applied Environmental Health

MD – Maryland

NAAQS – National Ambient Air Quality Standards

NATA – National-Scale Air Toxics Assessment

NC – North Carolina

NDVI – Normalized Difference Vegetation Index

NEJAC – National Environmental Justice Advisory Council

NIMBY – Not-In-My-Back-Yard

NO_2 – Nitrogen Dioxide

OR – Oregon

PA – Pennsylvania

ppb – Parts-Per-Billion

PHS – Public Health Service

PIBBY – Place-In-Blacks-Back-Yard

$PM_{2.5}$ – Particulate matter <2.5 micrometers in diameter

O_3 – Ozone

ODPHP – Office of Disease Prevention and Health Promotion

RCI – Resilience Capacity Index

RRI – Rural Resilience Index

SC – South Carolina

SD – Standard Deviation

SES – Socioeconomic Status

SVI – Social Vulnerability Index

THRIVE – Tool for Health and Resilience in Vulnerable Environments

TRI – Toxic Release Inventory

TSDFs – Treatment Storage and Disposal Facilities

TX – Texas

UCC – United Church of Christ

UMD – University of Maryland

Urban HEART – Urban Health Equity Assessment and Response Tool

USC – University of South Carolina

USDA – United States Depart of Agriculture

USDHHS – United States Department of Health and Human Services

USEPA – United States Environmental Protection Agency

Virginia Commonwealth University – VCU

WERA – West End Revitalization Association

WHO – World Health Organization

WI – Wisconsin

YPLL – Years of Potential Life Lost

μg – Micrograms

CHAPTER 1

DISSERTATION OUTLINE

This dissertation has been divided into seven informative chapters that commence with an introduction section (Chapter 1). Chapter 1 contains a brief synopsis of why "place" matters, meaning that certain aspects of one's environment (biological, chemical, physical, and social) may negatively impact their health. We further discuss the populations most burdened by environmental stressors, legislation enacted to protect vulnerable groups, and gaps in assessment tools used to examine the cumulative impacts of environmental exposures and chronic disease risk. We also present our three specific aims and their corresponding research question that will be addressed throughout subsequent chapters. Chapter 2 is the background section and serves as an extension to the introduction in Chapter 1. This chapter provides a detailed review of the literature in the following topic areas: 1) EJ Defined, 2) History of the EJ Movement, 3) EJ Theory, 4) EJ Science, 5) EJ and Resilience, 6) EJ and Community Engagement, 7) CRA, 8) Cumulative Impact Assessment and EJ Indices, and 9) Resilience Indices. We also present a cumulative risk assessment and resiliency conceptual framework that guides the work in subsequent chapters and can be used as a model for future CRA research.

Chapter 3 coincides with Specific Aim #1 and includes a draft of a manuscript entitled, "Perceptions of Environmental Stressors and Building Resiliency in a Community with Environmental Justice Issues" that has been submitted to *Qualitative Research*. This chapter highlights the importance of citizen scientists in CRA research by drawing upon the expertise of EJ stakeholders in North Charleston, SC to identify perceptions of environmental and resilience factors that may perpetuate or mitigate health inequalities in their respective neighborhoods. Through our qualitative assessment, we collected information that allows us to gain a better understanding of how to address environmental stressors and resilience gaps among EJ populations that may lead to substantial improvements in overall community resilience. This chapter was organized into standard manuscript headings and lays the groundwork for the development of our community informed Cumulative Stressors and Resiliency Index (CSRI) described in Chapter 4.

Similar to Chapter 3 in organizational structure, Chapter 4 is also a complete draft of a manuscript that was submitted for peer-review to *Environmental Health Perspectives* entitled, "The Development of a Cumulative Stressors and Resiliency Index to Examine Environmental Health Risk: A South Carolina Assessment". This chapter details the process of developing a novel CSRI that may be used to rank the burden of pathogenic characteristics that impact health at the census tract level in SC. Building upon current CRA and EJ indices, this chapter introduces an assessment tool that combines environmental exposures, sociodemographic characteristics, and resiliency buffers into a score that more accurately examines environmental risk and vulnerability. While this CSRI was only applied to census tracts in SC, these indices show great promise in becoming a gold standard for CRA at the population level.

Chapter 5 includes an application of the CSRI to predicting asthma hospitalizations/ED visits across the state of SC at the census tract level. Specifically, chapter 5 is a draft of our final manuscript entitled, "Examining the Associations between a Cumulative Stressors and Resiliency Index (CSRI) and Risk of Asthma Hospitalizations in South Carolina" that will be submitted for peer review to the *Journal* *of Exposure Science and Environmental Epidemiology*. The purpose of this chapter was to examine the association between the CSRI and asthma hospitalizations/ED visits, as well as determine whether our index could be used as a model to predict the risk of asthma hospitalizations/ED visits. Lastly, Chapter 6 is a culmination of our work where we provide an overall synopsis of dissertation chapters 3-5. Specifically, we emphasize major study findings, discuss the strengths and limitations of our work, and consider the public health implications.

CHAPTER 2

BACKGROUND

Research showing that *"Your zip code may be more important to health than your genetic code"* (Ritchie, 2013) has begun to transform the way that we conceptualize and approach eliminating health disparities. Our environment is multifaceted as it relates to health, not only encompassing all physical, chemical, and biological factors that are external to a person, but the social and cultural aspects as well (World Health Organization [WHO], n.d.a). Moreover, our environment may consist of salutogenic and pathogenic factors that embody the "the creation or origins of health" and "creation or origins of disease", respectively (Antonovsky, 1987; Macdonald, 2005; Wilson, 2009). Salutogenesis refers to anything in an individual's social, economic, and emotional environment that promotes health and well-being while pathogenesis represents the environmental stressors in one's environment that may undermine health (Antonovsky, 1987; Macdonald, 2005; Wilson, 2009).

Additionally, environmental stressors do not work independently and are often additive and/or multiplicative in nature; thereby creating cumulative impacts that may lead to adverse health outcomes over time. The challenges involved in assessing the combined effects of neighborhood and individual characteristics has stimulated discourse in the way to accurately analyze the cumulative impacts of environmental stressors. Specifically, these challenges include defining relevant geographic landscapes, identifying significant neighborhood attributes, specifying the influence of individual-level variables, incorporating the exposome, combining appropriate research designs, and avoiding reductionism in the way that neighborhood factors are incorporated into disease causation models and analyses (Diez Roux, 2001).

Populations of color and economically disadvantaged individuals have historically been the subgroups disproportionately affected by the cumulative impact of stressors because they often have the greatest exposure to environmental hazards in their neighborhoods (Burwell-Naney, 2013; Rice et al. 2014; Wilson et al., 2012a; Wilson et al., 2013; Wilson et al., 2014) and may lack the health-promoting infrastructure or resiliency buffers that are necessary to counteract the health implications of such exposures. Community health resilience (CHR) may be defined as "the ability of a community to use its assets to strengthen public health and healthcare systems and to improve the community's physical, behavioral, and social health to withstand, adapt to, and recover from adversity" (US Department of Health and Human Services [US DHHS)], 2015). Without these safeguards in place, communities may be more likely to have higher mortality rates of stroke, hypertension, cancer, diabetes, and heart disease when compared to their White and more affluent counterparts (Massey, 2004; Morello-Frosch, Zuk, Jerrett, Shamasunder & Kyle, 2011).

In a concerted effort to protect vulnerable populations against exposures to environmental hazards, President Bill Clinton signed Executive Order 12898 in 1994 to address environmental justice (EJ) issues in communities of color and low-income groups (United States Environmental Protection Agency [USEPA], 1994). Since the signing of this executive order, the USEPA has developed guidelines for conducting cumulative risk assessments (CRAs) that consider multiple stressors and exposure pathways that impact health, especially among poor and underserved communities that bear the brunt of these exposures. Embedded in the CRA definition lies a comprehensive framework requiring: 1) planning, 2) scoping and problem formulation, 3) risk analysis, and 4) risk characterization, all of which serve to characterize environmental hazards that are unique to specific communities (Barzyk, S. Wilson, & A. Wilson, 2015; Callahan & Sexton, 2007; USEPA, 2003b). Assessing the combined effects of stressors is challenging since researchers must consider the time-related facets of multiple exposures, intrinsic and extrinsic factors of vulnerability, sub-populations of at-risk individuals with increased exposures, and psychosocial stress that may result from non-chemical stressors (i.e., crime, residential segregation, heavy traffic).

Unfortunately, this research has traditionally not accounted for resilience factors that may mitigate the impact of exposure to chemical and non-chemical stressors. In a time when the use of a traditional single pollutant model has become obsolete (Callahan & Sexton, 2007), researchers have begun to identify innovative strategies to assess cumulative risk in a way that more accurately total exposures. Several studies have attempted to develop tools that may be used to quantify the negative impacts of environmental stressors on vulnerable communities by creating screening tools with indices, community assessment maps, or a combination of the two metrics (Huang & London, 2012; Rodriquez & Zeise, 2017; Su et al., 2009); however, many of these tools do not have the capacity to address cumulative stressors from a precautionary lens (Alexeeff et al., 2010). Many of these tools also fail to consider measures of resilience that may have the ability to counteract the cumulative impacts of multiple environmental stressors (Davis, Cook, & Cohen, 2005).

Alleviating the cumulative burden of environmental stressors and low resiliency in communities would be especially important for conditions such as asthma, since air pollution (Diette, McCormack, Hansel, Breyesse, & Matsui, 2008; Guamieri & Balmes, 2014) and neighborhood-level social conditions (i.e., low socioeceonomic status [SES], community violence, stress, and social networks) (Schreier & Chen, 2008; Williams, Sternthal & Wright, 2009) are factors that have been associated with higher rates of asthma morbidity. Asthma is a chronic respiratory condition often characterized by airway obstruction, hyper-responsiveness, and inflammation that may produce symptoms of cough, wheezing, chest tightness, shortness of breath (Dougherty & Fahy, 2009). With approximately 4 million people suffering from asthma in the US and 1.6 million emergency department visits with asthma as the primary diagnosis in 2013 (Centers for Disease Control and Prevention [CDC], 2017), researchers have tried to develop predictive models to identify individuals who may have an increased risk for an asthma event.

Specifically, studies have attempted to design models that predict the development of asthma in children and have been inaccurate (Luo, Nkoy, Stone, Schmick, & Johnson, 2015) or excluded important environmental factors that are known to be associated with asthma despite their ability to predict or rule out asthma development (Smit et. al, 2015). Nevertheless, there is still a need to explore the association between additional environmental factors and risk of asthma hospitalizations in an effort to predict the combination of exposures that may precede a severe asthma attack. While we cannot modify some of the risk factors for asthma (i.e., atopy, gender, allergies, and family history of asthma), we can reduce the risk for other environmentally driven factors that may exacerbate asthma such as stress, obesity, air pollution, violence, and absence of social networks.

This study comes at a point in time when the field of environmental health is at a crossroads with its current metrics for assessing the cumulative impacts of stressors and need a more comprehensive approach that allows us to better examine environmental vulnerability, resiliency, and disease risk particularly in the environmental justice context. To address this current research gap, the long-term goal of this study is to develop a community-informed cumulative stressors and resiliency index (CSRI) that quantifies the impact of environmental exposures and resiliency buffers at the census tract level. We hypothesize that our cumulative risk assessment (CRA) tool will have the capacity to detect environmental vulnerability and health risks at an earlier stage in the disease development process based on exposures to environmental hazards, sociodemographic attributes, and resilience factors that may buffer the negative impacts of various stressors. We apply our CRA tool to specific health outcomes to determine how well the environmental-based CSRI predicts asthma hospitalizations in SC. Our existing community-university partnership between the University of Maryland (UMD), College Park and the Charleston Community Research to Action Board (CCRAB) in North Charleston, South Carolina (SC) has worked collectively to address the following aims:

- ***Specific Aim #1: Identify perceptions of environmental and resilience factors that may influence health among African-Americans in North Charleston, SC.***

- Research Question 1: What are the perceptions of environmental and resilience factors that may influence health among African-Americans in North Charleston, SC?
- Research Question 2: What environmental factors most influence health in North Charleston, SC communities?
- Research Question 3: Are there differences between community perceptions of factors that may influence health and actual factors that have been implicated in the literature?

- ***Specific Aim #2: Develop a cumulative stressors and resiliency index (CSRI) comprised of environmental exposures and resilience factors that may be used to rank risk and vulnerability at the census tract level.***
  - Research Question 4: What indicators can be used to examine and quantify the cumulative burden of environmental stressors and resiliency in communities at the census tract level?
  - Research Question 5: Are there differences in the cumulative impact of environmental stressors and resiliency by census tract based on CSRI scores?
- ***Specific Aim #3: Examine the association between CSRI scores and risk of asthma hospitalizations/emergency department (ED) visits at the census tract level.***
  - Research Question 6: Is there an association between CSRI scores and increased risk of asthma hospitalizations in SC?

This study is innovative because we used a mixed-methods approach to develop a new metric for identifying the cumulative impacts of environmental stressors at the census tract level that included measures of resiliency. Not only did we use a holistic approach to measure the various stressors (e.g., chemical and non-chemical), we also incorporated decision science to identify community perceptions of environmental stressors and resiliency buffers to determine whether their responses were similar to those cited in the literature as drivers of health disparities. In addition, we allowed community members to prioritize each environmental stressor in regards to health so that we could incorporate the most appropriate measures in the CSRI. This study is also innovative because we included new indicators of resiliency that have not been previously used in other cumulative impact assessment tools. Our CSRI places greater emphasis on resiliency buffers than other cumulative impact assessment tools, which is especially important since communities impacted by EJ issues may not always be able to evade stressors in their local environment.

We anticipate our CSRI will have an impact beyond SC and become a gold standard for scoring and ranking environmental stressors and disease risk at the national level. In addition, we used our CSRI indicators to develop an environmental-based regression model that may be associated with the risk of asthma hospitalizations in a region heavily impacted by asthma morbidity and mortality. To date, there has been no other attempt to capture more of the environmental stressors and resiliency buffers that may influence the risk of an asthma event. While studies have been conducted examining predictive models for asthma hospitalizations (Gorelick, Scribano, Stevens, Schultz, & Shults, 2008; Grineski, 2009; Ram, Zhang, Williams, & Pengetnze, 2015), none have used our combination of environmental stressors and resiliency variables estimate disease risk.

2.1 Environmental Justice Defined

Environmental Justice (EJ) has increasingly become integrated into various programs, policies, and research initiatives (Clinton, 1994). Though the 17 Principles of Environmental Justice originated at the First National People of Color Environmental Leadership Summit in 1991, President Bill Clinton's 1994 signing of Executive Order 12898 caused federal agencies to develop actionable strategies that promote EJ principles in communities overburdened by environmental pollution. It states, "…each Federal agency shall make achieving environmental justice part of its mission by identifying and addressing, as appropriate, disproportionately high and adverse human health or environmental effects of its programs, policies, and activities on minority populations and low-income populations in the United States and its territories and possessions…" to officially address environmental and human health conditions in communities of color and economically disadvantaged areas (Clinton, 1994).

Despite some differences in the language used to define environmental justice, equality has been at the forefront of activists and environmental justice researchers interested in protecting vulnerable populations overburdened by environmental stressors. Dr. Bunyan Bryant provides one of the most widely recognized definitions of environmental justice:

> *Environmental justice is served with is served when people can realize their highest potential, without experiencing the 'isms.' EJ is supported by decent paying and safe jobs; quality schools and recreation; decent housing and adequate health care; and democratic decision-making and personal empowerment. It may occur in communities where both cultural and biological*

> *diversity are respected and highly revered and where distributed justice prevails* (Bryant, 1995).

The U.S. Environmental Protection Agency (EPA) has formulated a less expansive yet highly utilized definition:

> *The fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies. Fair treatment means that no group of people should bear a disproportionate share of the negative environmental consequences resulting from industrial, governmental and commercial operations or the execution of federal, state, local and tribal programs and policies* (USEPA, n.d.a).

The U.S Department of Agriculture (USDA) is another federal agency that has developed a definition:

> *Environmental Justice means that, to the greatest extent practicable and permitted by law, all populations are provided the opportunity to comment before decisions are rendered on, are allowed to share in the benefits of, are not excluded from, and are not affected in a disproportionately high and adverse manner by, government programs and activities affecting human health or the environment* (United States Department of Agriculture [USDA], 1997).

Some states such as California codified environmental justice in legislation using the following definition:

The fair treatment of people of all races, cultures, and incomes with respect to the development, adoption, implementation, and enforcement of environmental laws, regulations and policies (California Energy Commission, 2017).

Since the emergence of the environmental justice movement, the interpretation and breadth of EJ has expanded beyond an initial focus on inequalities regarding the distribution of environmental hazards to include other issues like gender inequalities and disparities in transportation, housing, and education (Bullard, Mohai, Saha, & Wright, 2007; Perez et al. 2015). The scope of EJ has also broadened to include topics like climate change, climate justice, and local food and energy that tend to focus on sustainable materialism (Schlosberg, 2013). The evolution of the scope of EJ further demonstrates how both environment and nature are necessary to achieve the social justice that is the nucleus of the EJ movement. Since injustices are not independent, our treatment of nature is an important component of justice that should be incorporated into the purview of EJ (Schlosberg, 2007).

2.2 History of the Environmental Justice Movement

A series of events may have served as a catalyst for the EJ movement, beginning with the Civil Rights Act of 1964 that was signed into law by President Lyndon Johnson. This law promoted racial equality by addressing discrimination in federally assisted programs, businesses, and employment; segregation in schools and other public places; and voting rights. Dr. Martin Luther King, Jr. played a pivotal role in this legislative reform known as the "Civil Rights Movement" and spent the latter years of his life eliminating barriers to achieving racial equality such as poverty, unemployment, lack of education, and the shortage of economic opportunity in the African-American community. Before Dr. Martin Luther King Jr.'s death in 1968, he traveled to Memphis, Tennessee to assist African-American sanitation workers in a strike against their employer for safer working conditions, improved pay and benefits, and union recognition (Bullard, 1994; Bullard & Johnson, 2000). Though novel at the time, this event unofficially marked the beginning of an Environmental Justice Movement that was solidified in the 1980s among African-American protestors in Warren County, North Carolina (NC).

In 1982, the Warren County Citizen Group protested the construction of a landfill in their community that would store soil contaminated with polychlorinated biphenyls (PCBs) (Bullard, 2000; Bullard & Waters, 2005; Geiser & Waneck, 1994). Warren County had the highest percentage of African-Americans (63.7%) and one of the lowest per capita incomes ($6,984) in the state, where African-Americans typically accounted for 24.2% of the state's population and the per capita income was $9,283 (Bullard, 2000). The specific site selected for the landfill within Warren County was Afton, which was not the most feasible location since the water table was located only 5-10 feet below the surface and many of the residents relied on wells as their source of drinking water (Bullard, 2000; Geiser & Waneck, 1994). Exposure to PCBs could result in reproductive dysfunction, neurological and developmental defects in children exposed in utero, increased cancer risk, and other endocrine and digestive system effects (US Public Health Service, The Agency for Toxic Substances and Disease Registry, USDHHS, & USEPA, n.d.). Despite potential health concerns, Warren County protesters were not able to prevent construction of the landfill in their community but negotiated the following: 1) no additional landfills could be built in Warren County, 2) well water must be monitored for PCBs, and 3) residents must be monitored for PCBs (Bullard, 2002; Geiser & Waneck, 1994). The Warren County protest left a lasting impact on the EJ movement by demonstrating how communities could organize against environmental injustices to influence environmental decision-making and policy.

The aforementioned events sparked an investigation by the US General Accounting Office (GAO) in 1983 who was tasked with determining the correlation between the distribution of landfills and the racial and economic composition of the communities hosting the industrial facilities in the USEPA's Region IV states (USGAO, 1983). While Region IV has eight southeastern states, the landfills were found in Alabama (1), North Carolina (1), and South Carolina (2) counties. In the official report entitled *"Siting of Hazardous Waste Landfills and their Correlation with Racial and Economic Status of Surrounding Communities"*, African-Americans were the dominant racial group who resided in three of the four communities hosting the hazardous waste landfills. Moreover, 26% of the population living in these communities had incomes below the national poverty level and most identified as African-American (USGAO, 1983).

The U.S General Accounting Office's report was followed by a similar study conducted by the Commission for Racial Justice (CRJ) of the United Church of Christ (UCC) in 1987 called *"Toxic Waste and Race in the United States"*. This study was the first to examine the association between race and the treatment, storage, and disposal of toxic on the national scale (CRJ, 1987). In geographies hosting multiple sites or the largest hazardous waste facilities, the percentage of people of color was more than three times higher than in communities with no facilities (38% and 12%, respectively) (CRJ, 1987). Populations of color were disproportionately burdened by the presence of hazardous waste facilities with three out of every five African-American or Hispanic-Americans residing in communities with uncontrolled toxic waste sites. The pattern of environmental injustice across the US was now evident, and subsequent conferences, summits, and research studies provided further support for the claims outlined in the *"Toxic Waste and Race in the United States"* report (1987).

In desperate need of solutions, Drs. Bunyan Bryant and Paul Mohai organized the Conference on Race and the Incidence of Environmental Hazards at the University of Michigan's School of Natural Resources in 1990 (Konisky, 2015; Bunyan & Mohai, 1992). Similar efforts to resolve EJ concerns were made by the Agency for Toxic Substance and Disease Registry (ATSDR) in collaboration with the US Centers for Disease Control (CDC) when they sponsored the "National Minority Health Conference: Focus on Environmental Contamination". There were also significant books that were published entitled, *We Speak for Ourselves: Social Justice, Race, and the Environment* and *Dumping in Dixie: Race, Class, and Environmental Quality,* that highlighted the role of impacted communities in addressing EJ issues and the related conflict experienced by African-Americans living in the South (Bullard, 2000; Bullard & Alston, 1990).

The following year, the First National People of Color Leadership Summit was held in Washington, D.C. where activists met to develop the 17 Principles of Environmental Justice. These principles are based on the following attributes: 1) interdependence to Mother Earth, 2) respect of cultures, languages, and beliefs about the natural world and our role in healing ourselves, 3) ensuring environmental justice, 4) promoting economic alternatives that would contribute to environmentally safe livelihoods, 5) and securing political, economic, and cultural liberations that has been denied for centuries, resulting in the poisoning of communities, land, and genocide of people (First National People of Color Environmental Leadership Summit Delegates, 1996).

With the 17 Principles of Environmental Justice in place, the USEPA established an Office of Environmental Justice in 1992 to use as an organizational platform to combat environmental injustice across its ten regions. The USEPA then expanded their organizational infrastructure in 1993 to include a National Environmental Justice Advisory Council (NEJAC) tasked with providing advice and recommendations on EJ issues from the perspective of the multiple stakeholders involved (USEPA, n.d.b.). In 1994, the USEPA partnered with other federal sponsors to host a "Symposium on Health Research and Needs to Ensure Environmental Justice" to continue the discussion on eliminating environmental inequalities. That same year also marked the signing of Executive Order 12898 by President Clinton, which ultimately institutionalized EJ within federal agencies and focused efforts on communities that are typically victimized by EJ (Clinton, 1994). Moreover, a Federal Interagency Working Group on Environmental Justice (EJ IWG) representing the 17 agencies and White House offices was established under the Executive Order to oversee the implementation of agency specific strategic plans that would improve the quality of life of communities overburdened by environmental hazards.

Approximately 20 years after the establishment of Executive Order 12898, under the leadership of Administrator Lisa Jackson, the USEPA decided to incorporate EJ into every aspect of its programs, policies, and activities through a new strategic plan known as Plan EJ 2014. Plan EJ 2014 was characterized by the following foundational elements: 1) protecting the environment and health in overburdened communities, 2) empowering communities to take action to improve their health and environment, and 3) establish partnerships with local, state, tribal, and federal governments and organizations to achieve healthy and sustainable communities (USEPA, 2010). Most of the USEPA's strategies to advance EJ have been accomplished and they recently achieved their goal of creating a Community-Focused Exposure and Risk Screening Tool (C-FERST) to assist with identifying and prioritizing environmental and public health issues in communities across the nation (USEPA, 2016a).

2.3 Environmental Justice Theory

The environmental justice concept is predicated on certain groups hosting a disproportionate share of environmental hazards in their respective communities. Though these communities are typically non-white and/or low-income, some scientists believe that there is little or no evidence that supports the existence of environmental inequalities based on sociodemographic factors (Anderton et al., 1994; Anderton, Anderson, Oakes, & Fraser, 1994; Atlas, 2002; Bowen, Salling, Haynesy, & Cyran, 1995).

Meanwhile, other scholars have devised a theoretical construct known as the "minority move-in" hypothesis that may account for the differential distribution of hazardous waste sites among non-white and economically underserved populations (Mohai & Saha, 2015; Pais, Crowder, & Downey, 2014; Pastor, Sadd, & Hipp, 2001).

Specifically, environmental inequalities of this nature may be deconstructed into three categories that include: 1) economic, 2) sociopolitical, and 3) racial factors. Some industries may strategically elect to site their facility in areas that have lower property values and operational costs, which may also be an area populated by predominately non-white and low-income residents (Boone & Madorres, 1999; Daniels & Friedman, 1999; Mohai & Saha, 2007; Rhodes, 2003). In contrast, minority move-in hypothesis may be described as an area where property values and quality of life have declined in such a way that drives white and affluent populations out and non-white and low-income families in who are enticed by affordable housing prices (Mohai & Saha, 2007; Pastor, Sadd, & Hipp, 2001). Even if affordable housing does not incentivize populations of color, other underlying factors such as housing segregation may limit their ability to move away from LULUs (Mohai & Bryant, 1992; Mohai & Saha, 2007; Morello-Frosch & Jesdale, 2006; Morello-Frosch & Lopez, 2006; Szasz & Meuser, 2000).

Disparities in environmental hazards may also exist due to sociopolitical factors, where communities of color often have less political influence and resources than their counterparts to lobby against the siting of these facilities in their neighborhoods (Camacho, 1998; Cole & Foster, 2001; Mohai & Saha, 2007; Saha & Mohai, 2005). When white populations exercise their political voice to prevent environmental hazards from surfacing in their communities, they may inadvertently force these facilities into communities with less political capital perpetuating a cycle of distributional injustice (Camacho, 1998; Cole & Foster, 2001; Saha & Mohai, 2005; Mohai & Saha, 2007). This phenomenon is known as “not-in-my-back-yard” (NIMBY), where white or more affluent populations may object to the siting of LULUs in their community, thereby driving these facilities towards more vulnerable groups (Bullard, 2000; Gerrar, 1993). Exclusionary practices in zoning, deed assignment, and land-use planning that promote NIMBYism may further reinforce the concept "place-in-blacks-back-yard" (PIBBY) (Bullard, n.d.; Spencer, 2008). Environmental racism may occur in concert with the aforementioned economic and sociopolitical factors since populations of color have been perceived as asserting the least amount of opposition when industry or government proposes the siting of LULUs in their communities (Bullard & Wright, 1986; Saha & Mohai, 2005; Mohai & Saha; 2007). Racial inequalities expressed in other areas such as education, employment, health care, and planning and zoning policies may also indirectly limit the autonomy that non-white populations have over what occurs in their environment.

Additional studies have proposed interrelated theories that may further explain inequalities in the distribution of environmental hazards. Specifically, a study conducted in Southern California demonstrated the role of White privilege in driving environmental discrimination and disparities in urban development (Pulido, 2000). Discriminatory practices in land using planning and zoning have further precipitated differential exposures to neighborhood stressors and limited the presence of health promoting infrastructure in communities of environmental justice (Maantay, 2001; Wilson, 2009; Wilson, Hutson, & Mujahid, 2008). The implications of inequitable development are catastrophic, since the quality of one's neighborhood environment may be directly linked with health. For example, residing in disadvantaged neighborhoods based on certain physical attributes (i.e., availability of recreational resources and healthy food locales) has been associated with increased cardiovascular disease risk (Diez Roux, Kershaw, &

Lisabeth, 2008). Similarly, there are neighborhood features in the social environment (i.e., crime, social cohesion, and collective efficacy) that are associated with hypertension, obesity, and other health risk behaviors (Wilson, Hutson, & Mujahid, 2008).

Several studies have also found a relationship between environmental health disparities and segregation that may perpetuate health inequalities among populations of color (Jacobs, 2011; Morello-Frosch & Jesdale, 2006; Morello-Frosch & Lopez, 2006; Rice et al., 2014). Racial segregation, known as "the physical separation of the races in residential contexts", has been influenced by the following factors: 1) discriminatory housing practices, 2) white resistance to integration, 3) dismantled political system, 4) exclusionary land use and zoning ordinances, 5) workplace discrimination, and 6) inequities in industrial development (Morello-Frosch & Jesdale, 2006; Morello-Frosch & Lopez, 2006; Orfield, 2005; Williams & Collins, 2001).

2.4 Environmental Justice Science

2.4.1 Burden Disparities

The Industrial Revolution was marked by a rise in the factory system and urban living, where many workers had to move into the cities where the factories were located due to limited transportation infrastructure (Sreenivasan, 2009). Over time this historical convenience has become a modern encumbrance, as landmark studies have brought national attention to racial and income inequalities in the distribution of environmental waste facilities (Bullard & Alston, 1990; CRJ, 1987; Mohai & Bryant, 1992). The populations most burdened by the presence of industrial facilities are typically non-white and economically disadvantaged groups who host many of these environmental hazards in their communities (Bullard, 2000; CRJ, 1987; Mohai & Saha, 2007). For example, a study conducted in Metropolitan Charleston, SC documented burden disparities in the distribution of Toxic Release Inventory (TRI) facilities, where every 1% increase in the White population decreased the number of TRI facilities by roughly 6 and low SES was associated with a higher number of these facilities at the census tract level (Wilson et al., 2012a). These findings were validated by the findings of an analogous study conducted in Maryland (MD), where the percentage of non-white and poverty populations were higher in TRI host census tracts than non-host census tracts (Wilson et al., 2014a).

While the type of locally unwanted land use (LULUs) may vary, the relationship between environmental hazards and overburdened populations has consistently been cited throughout the literature. Another study in SC found that out of the 29.5% of African-Americans living in the state, over 50% percent lived in census tracts hosting a Superfund site. Similarly, over 50% of the 14.2% of the population living below poverty in SC resided in a Superfund host census tract (Burwell-Naney et al., 2013). Regarding leaking underground storage tanks (LUSTs), African-Americans were more likely to live in LUST host census tracts (29.86) compared to non-host tracts (23.87) in SC (Wilson et al., 2013). The disparity was greater among low-income groups, where populations living below poverty were 38% more likely to reside in host census tracts (33.06) instead of non-host census tracts (28.40) (Wilson et al., 2013). Additional studies have documented the disproportionate location of hazardous waste landfills across the United States, demonstrating that three of the largest sites were located in African-American communities that represented 40% of the landfill capacity for the entire nation (Guana, 1995; GAO, 1983).

While the previously mentioned studies present evidence of environmental inequalities, some researchers refute the idea that environmental injustice exists. For example, Anderton et al. found no statistically significant difference in the mean percentage of African-Americans hosting hazardous waste treatment, storage, and disposal facilities (TSDFs) (14.54) compared to non-host tracts (15.20) (Anderton, Anderson, Oakes, & Fraser, 1994). The authors did find statistically significant differences among Hispanic residents and populations living below the poverty line, where the methodology was based on comparing the 408 census tracts that contained TSDFs with the remaining 31,595 non-host census tracts for all variables (Anderton, Anderson, Oakes, & Fraser, 1994). Another study conducted by the Social and Demographic Research Institute (SADRI) at the University of Massachusetts examined disparities in the siting of the same commercial hazardous waste facilities as those in the first national EJ study performed by the United Church of Christ CRJ entitled "Toxic Wastes and Race in the United States" (CRJ, 1987). The SADRI study reported conflicting results, finding no statistically significant differences among non-white populations residing in host census tracts compared to non-host tracts, but SES disparities were present (Been, 1995).

When exploring environmental inequalities, one must consider the most appropriate unit of analysis and the definition that will be used to determine whether inequalities exist (Downey, 2005). The modifiable areal unit problem (MAUP) refers to the issue of aggregating data using differing scales and/or boundaries at a single scale that may affect the results (Mennis, 2002; Wong, 1996). The discrepancies between the SADRI and CRJ studies exemplify the MAUP, in that the SADRI performed their analysis at the census tract level and the CRJ used zip codes. Been revisited findings from previous studies at the census tract level for 1994 to analyze sociodemographic variables for 600 TSDF host census tracts in relation to 60,000 TSDF non-host tracts (1995). She found no statistical significance for percent African-American but the percentage of Hispanics, combined non-white populations, and lower income groups tended to live in TSDF host tracts (Been, 1995). It is important to note that the results from the Been study corresponded with some of the findings from both the CRJ and SADRI studies, demonstrating that even differences in comparison populations may impact notions of environmental inequality (Downey, 2005).

The methods that are employed to examine burden disparities of various environmental stressors are important since that may have a significant impact on study findings. One of the early methods used to assess this type of disparity is the unit-hazard coincidence approach, where researchers select a geographic unit of analysis (census tract or zip code) and determine whether the hazard is present (Been, 1995; CRJ, 1987; Goldman & Fitton, 1994) or not present. In addition, the sociodemographic characteristics are compared between the geographic units to elucidate distribution disparities related to race/ethnicity and SES. Based on the results, it is assumed that the populations comprised in the geographic unit reside closest to the environmental hazard and have the greatest burden compared to groups not living in the unit. This approach is limited because it does not take into account the proximity to the hazard or variations in size of the hazard in each geographic unit (Mohai & Saha, 2007). Other studies have found distribution disparities using the distance-based approach (i.e., buffers), which requires mapping the location of the environmental hazards and creating distance bands around each facility (Burwell-Naney et al., 2013; Chakraborty & Armstrong, 1997; Hamilton & Viscusi, 1999; Mohai & Bryant, 1992; Pastor, Sadd & Hipp, 2001; Pollock & Vittas, 1995; Saha & Mohai, 2005; Wilson et al., 2012a; Wilson et al., 2013; Wilson et al., 2014). Once the distance bands have been established, sociodemographic characteristics are then compared to determine whether certain groups are differentially burdened by LULUs.

2.4.2 Exposure Disparities

Burden disparities in the distribution of LULUs may also be indicative of exposure disparities related to pollutants emitted from these facilities. When assessing exposure, one must consider the magnitude, frequency, and duration of exposure to a chemical or non-chemical stressor as well as characteristics that are unique to the population being exposed. There are several sources, pathways, and routes of exposure that may introduce some uncertainties in assessment; however, one constant observation that has been documented in the literature shows that non-white and low SES populations have differential exposures to environmental hazards (Faber & Krieg, 2002; Massey, 2004). Not only do these groups disproportionately host LULUs in their communities, they are often located in closer proximity to pollution sources than their White and more affluent counterparts. Specifically, studies have demonstrated that populations of color and low-income groups tend to reside closer to Toxic Release Inventory (TRI) facilities (Wilson et al., 2012a), leaking underground storage tanks (LUSTs) (Wilson et al., 2012b;

Wilson et al., 2013), Superfund sites (Burwell-Naney et al., 2013; Maranville, Ting, & Zhang, 2009), brownfields (Paull, 2008), and residential traffic (Boehmer, Foster, Henry, & Woghiren-Akinnifesi, 2013), thus, having a greater exposure to the chemical releases concomitant with these hazards.

Many of these studies have relied on proximity analysis methods to postulate exposure disparities; however, this approach is limited in its ability to account for chemical release characteristics, meteorological conditions, and time activity patterns (Stuart, Mudhasakul, & Sriwatanapongse, 2009) in regards to air pollution exposures. Nevertheless, the proximity assumption is supported by several studies that found significant associations between proximity of residential location to pollution sources and health outcomes. For example, Boehmer et al. demonstrated that roughly 4% (11.3 million persons) of the total US population lives within 150 meters (m) of a major highway and may have an increased risk of adverse health outcomes that are often associated with air pollution exposures (i.e., cardiovascular disease mortality, non-asthmatic respiratory symptoms, impaired lung) (Boehmer et al., 2013). For example, rheumatoid arthritis (De Roos, Koehoorn, Tamburic, Davies, & Brauer, 2014), risk of childhood cancers (Crosignani et al., 2004), asthmatic exacerbations (Brown et al., 2012), and adverse pregnancy outcomes (Brender, Maantay, & Chakraborty, 2011) are a few health conditions associated with proximity to roadways.

Based on prior research, an increase in exposure risk may subsequently increase disease risk. As a result, communities impacted by EJ issues may be even more susceptible to health effects associated with traffic-related air pollution. Several studies have demonstrated a general link between exposure to traffic emissions and adverse health effects such as all-cause mortality (Hart, Rimm, Rexrode, & Laden, 2013), cardiovascular mortality (Raaschou-Nielsen et al., 2012), cardiovascular disease (Stockfelt et al., 2017), impaired lung function (Anderson, Thundiyil, & Stolbach, 2012), respiratory distress (Health Effects Institute, 2010), and asthma (Gruzieva et al., 2013). However, predominately non-white and low-income communities are disproportionately exposed to traffic-related pollution and other environmental hazards that may increase their risk of an adverse health outcome (Brender, Maantay, & Chakraborty, 2011; Pratt, Vadali, Kvale, & Ellickson, 2015). Additional studies have corroborated disparate exposures to environmental hazards negatively affect health in communities impacted by EJ issues. For example, differential exposures to traffic-related air pollution during winter have been associated with higher proportions of preterm births among economically disadvantaged and African-American mothers (Ponce, Hoggatt, Wilhelm, & Ritz, 2005). Moreover, disparities in exposures to sources of lead, cadmium, and mercury increased the risk of chronic kidney disease among non-white and low-income populations (Said & Hernandez, 2015).

Despite the contaminant or hazard, exposure disparities are not solely limited to chemical stressors. Exposures to non-chemical stressors, such as structural factors or psychosocial conditions, may also disproportionately impact populations of color and those of low socioeconomic position. For example, studies have indicated that populations impacted by EJ issues are overly exposed to fast-food outlets and convenience stores and have less access to healthy food sources than their respective counterparts (Evans et al., 2015; Franco, Diez Roux, Glass, Caballero, & Brancati, 2008; A. Hilmers, D. Hilmers, & Dave, 2012; Walker, Keane, & Burke, 2010). Low access to grocery stores combined with high access to unhealthy food outlets may influence the ability of these populations to make dietary choices that promote a healthy body weight (Evans et al., 2015; A. Hilmers, D. Hilmers, & Dave, 2012; Walker, Keane, & Burke, 2010). Not only has low access to grocery stores been associated with obesity, studies have also shown a link between lack of access to healthy food options and increased risk for CVD (Castillo, et al. 2013; Treuhaft & Karpyn, n.d.; Weintraub, Kelley, Bozdech & Yen, 2016), diabetes (Castillo, et al. 2013; National Research Council, 2009; Treuhaft & Karpyn, n.d.), and cancer (Treuhaft & Karpyn, n.d.; USDA, 2009).

Non-white communities may also experience higher rates of crime, exposures to tobacco and alcohol advertisements, as well as dilapidated housing conditions that may negatively influence health outcomes (Gee & Sturges, 2004). For example, studies have indicated how differential exposures to violent crime (Messer, Kaufman, Dole, Savitz, & Laraia, 2006a) and residential segregation (Kramer, Cooper, Drews-Botsch, Waller, & Hogue, 2010) may contribute to racial disparities in preterm and very pre-term births. Exposure to violent crime has also been associated with an increased risk of cardiovascular outcomes (Churr & O'Campo, 2015) and physical inactivity (Kneeshaw-Price et al., 2015). The disproportionate burden of violent crime amongst predominantly non-white populations is often explained by factors such as poverty, unemployment, education inequalities, residential segregation, social organization, and female headship (Steffensmeier, Ulmer, Feldmeyer, & Harris, 2010; Ulmer, Harris, & Steffensmeier, 2012; US Department of Housing and Urban Development [HUD], 2016)

Current and future smoking decisions amongst adolescents are linked with tobacco advertisements (Braverman & Aaro, 2004), and the communities most targeted by these tobacco-marketing strategies are economically disadvantaged and non-white communities (Henriksen, Schleicher, Dauphinee, & Fortmann, 2012; Lee, Henriksen, Rose, Moreland-Russell, & Ribisl, 2015; Seidenberg, Caughey, Rees, & Connolly, 2010; Siahpush et al., 2016). The long-term health effects associated with cigarette smoking include: 1) cancer, 2) precancerous lesions, 3) CVD, 4) respiratory disease, 5) eye disease, 6) rheumatoid arthritis, 7) reduced effectiveness of tumor necrosis factor-alpha inhibitors, and 8) bone health (Committee on the Public Health Implications of Raising the Minimum Age for Purchasing Tobacco Products, et al., 2015; USDHHS, 2014).

Non-chemical stressors may also work synergistically with chemical stressors to increase one's susceptibility to traditional environmental hazards and promote adverse health outcomes. For example, one study examined how exposures to violence may affect susceptibility to traffic-related air pollution in regards to the onset of childhood asthma (Clougherty et al., 2007). Specifically, one standard deviation (SD) (4.3 parts-per-billion [ppb]) increase in exposure to nitrogen dioxide (NO_2) in children exposed to violence above the median had 1.63 times the risk of developing asthma (Clougherty et al., 2007). Additional disparities may stem from differential exposures to biological stressors (i.e., pathogens), radiological stressors (i.e., radionuclides), odors, and noise, vibration, and congestion (Casey et al., 2017; Stillo & Gibson, 2017; USEPA, 2003b; Wing et al., 2008).

2.4.3 Health Disparities

Environmental health disparities are multifaceted in nature, meaning they can be further deconstructed into subcategories of infrastructure disparities, unhealthy land uses, planning and zoning inequities, disparate exposures to chemical and nonchemical neighborhood stressors, and insufficient salutogenic resources that may cultivate "riskscapes" (Morello-Frosch & Jesdale, 2006; Morello-Frosch & Lopez, 2006; Morello-Frosch & Sadd, 2001). When susceptible populations encounter adverse exposures, health disparities may be expressed as differences in cardiovascular disease (Graham, 2015), cancer (Massetti, Thomas, & Ragan, 2016), respiratory disease (Schraufnagel et al., 2013), diabetes (Gaskin et al., 2014), reproductive and developmental health (Sutton et al., 2012), mortality rates (Gee & Payne-Sturges, 2004), life expectancy (Williams & Sternthal, 2010), infant mortality rates (Lorch & Enlow, 2016), and mental health status (Alegria, Green, McLaughlin, & Loder, 2015). Studies have shown that only 10-30% of the variance in cancer and other chronic disease outcomes can be explained by genetic factors while the other 70-90% is primarily due to the environment (Juarez et al., 2014).

Environmental health disparities may be further complicated by race/ethnicity since populations of color are more likely to reside in riskscapes or areas that are overburdened by environmental stressors (i.e., TRI facilities, LUSTs, brownfields, heavily trafficked roadways, Superfund sites, and concentrated animal feeding operations [CAFOs]) (Boehmer et al., 2013; Burwell-Naney et al., 2013; Cushing et al., 2015; Mohai, Lantz, Morenoff, House, & Mero, 2009; Mohai & Saha, 2007; Nicole, 2013; Wing & Wolf, 2000). The increased exposure to environmental hazards is often accompanied by a greater exposure to social stressors such as poverty, racial discrimination, crime, malnutrition, and substance abuse (Adler & Rehkopf, 2008; Morello-Frosch, Zuk, Jerrett, Shamasunder, & Kyle, 2011). When considered synergistically, environmental and social stressors have the potential to exacerbate health disparities in communities of color and low socioeconomic status.

Cardiovascular disease (CVD) is a debilitating condition often marked by disparity since socioeconomically disadvantaged populations and persons of color experience higher rates of CVD mortality than their respective counterparts (Ski, King-Shier, & Thompson, 2014). Specifically, African-Americans had a 2-fold higher death rate from major CVDs than Whites in populations aged 20 – 64. Some studies have attributed racial/ethnic disparities in CVD risk to differences in SES (Karlamangla, Merkin, Crimmins, & Seeman, 2010; Kurian & Cardarelli, 2007; Winkleby, Kraemer, & Ahn, 1998) while others have focused more on biological and behavioral risk factors (i.e., diabetes, hypertension, high cholesterol, and physical inactivity) as the culprit (Baruth et al., 2011; Kaplan & Keil, 1993; Morello-Frosch, Zuk, Jerrett, Shamasunder, & Kyle, 2011).

Additional disparities in CVD may be credited to differential exposures to environmental contaminants. For example, studies have indicated that exposures to $PM_{2.5}$, ultrafine particles, polyaromatic hydrocarbons (PAHs), and metals are associated with an increase in CVD morbidity and mortality (Du, Xu, Chu, Guo, & Wang, 2016; O'Toole, Conklin, & Bhatnagar, 2008; Poursafa et al., 2017). These contaminants are typically emitted from automobiles and industrial facilities, which are also the sources of environmental hazards that disproportionately impact communities of color and low SES groups (Houston, Li, & Wu, 2014; Mohai, Lantz, Morenoff, House, & Mero, 2009), thereby further contributing to disparities in CVD.

Asthma is also a condition characterized by disparity since the burden of disease is more prevalent in certain non-white populations and economically disadvantaged groups. Hospitalization and mortality rates for asthma are three times higher among African-Americans compared to Whites, and Puerto Ricans have the highest rates of asthma attacks and deaths (National Heart, Lung, and Blood Institute, 2012). This trend is present in children as well, where the prevalence of asthma among Puerto Ricans (19.2%) or African-Americans (12.7%) is higher than among Whites (8%) or Mexican Americans (6.4%) (Forno & Celedon, 2012). While health care policies, provider factors, and individual/family factors may contribute to disparities in asthma, various aspects of one's environment may also influence asthma rates. Specifically, low-income communities have housing that is more likely to have above average exposures to asthma triggers such as dust mites, mold spores, mildew, rodent allergens, and cockroach allergens (Canino, McQuaid, & Rand, 2009; Krieger, Song, Takaro, & Stout, 2000; Sheehan et al., 2010). Air pollution exposures may also contribute to the development of asthma throughout childhood and adolescence (Gehring et al., 2015), and comparable to CVD, EJ populations may have greater exposure to air pollution than their counterparts (Clark, Millet, & Marshall, 2014; Miranda, Edwards, Keating, & Paul, 2011; Morello-Frosch, Zuk, Jerrett, Shamasunder, & Kyle, 2011). Other environmental stressors associated with asthma morbidity are exposures to passive cigarette smoke and stress resulting from exposures to violent crime, both of which disproportionately impact non-white groups (Canino, McQuaid, & Rand, 2009; Eldeiraw et al., 2016; Forno & Celedon, 2012).

Cancer is another disease that impacts all racial/ethnic and SES groups, but African-Americans have the highest overall incidence (504.1/100,000) and mortality (238.8/100,000) rates for cancer among men and women (National Cancer Institute [NCI], 2008). Several studies have documented significant differences in cancer risk among non-white populations due to environmental exposures to air toxics. One study found that African-American concentrated census tracts had a 6% higher cancer risk burden than predominately White census tracts (Chunrong, James, & Kedia, 2014). Specifically, the unequal distribution of industrial facilities and major roads in African-American communities accounted for the relative and absolute disparity in cancer risk respectively. Similar findings have been corroborated by other cancer risk studies in the Harris County, TX (Linder, Marko, & Sexton, 2008), SC (Rice et al., 2014; Wilson et al., 2015a), Maryland (MD) (Apelberg, Buckley, & White, 2005), California (CA) (Morello-Frosch, Woodruff, Axelrad, & Caldwell, 2000) and various metropolitan areas (Morello-Frosch & Jesdale, 2006), illustrating how disproportionate exposures to environmental toxicants may drive cancer-related health disparities.

Research has also suggested that environmental exposures may contribute to health disparities in low birth weight (LBW) and preterm births. Aside from the risk of infant mortality, babies of LBW may factor into health disparities due to their increased risk of impaired cognitive development (Shenkin, Starr & Deary, 2004), coronary heart disease, hypertension, and noninsulin dependent diabetes throughout the life course (Osmond & Barker, 2000). In addition, African-American women have the highest rates of low (13.18) and very low (2.94) birth weight, which is significantly greater than any other racial/ethnic group (Martin, Hamilton, Osterman, Curtis, & Mathews, 2013).

Statistics for preterm births are similar to those for low and very LBW, where the preterm birth rate is higher among babies born to African-African mothers.

Additionally, researchers found that traffic-derived air pollution in low SES neighborhoods during winter was associated with the highest proportion of preterm births compared to middle and high SES neighborhoods (Ponce, Hoggatt, Wilhelm, & Ritz, 2005). Furthermore, previous research has confirmed the disparate relationship between air pollution exposure and LBW rates among non-white mothers (Morello-Frosch, Jesdale, Sadd, & Pastor, 2010; Woodruff, Parker, Kyle, & Schoendorf, 2003). While, other work has demonstrated how exposures to psychosocial stressors may lead to higher LBWs or preterm deliveries in populations of color (Rich-Edwards & Grizzard, 2005). Regardless of the health outcome, higher exposures to environmental and psychosocial stressors exacerbate health disparities between groups of different racial/ethnic identity and SES.

2.4.4 Infrastructure/Ecosystem Disparities

Infrastructure and ecosystem level disparities may exist in park/green space, healthcare, and healthy food access. Studies have indicated that physical activity may significantly improve health outcomes by lowering an individual's risk for the following conditions: 1) heart disease (Myers, 2003), 2) stroke (Gallanagh, Quinn, Alexander, & Walters, 2011), 3) type 2 diabetes (Colberg et al., 2010), 4) depression (Strawbridge, Deleger, Roberts, & Kaplan, 2002), 5) hypertension (Diaz & Shimbo, 2013), 6) osteoporosis (Warburton, Nicol, & Bredin, 2006), and 7) some cancers (Brown, Winters-Stone, Lee, & Schmitz, 2012). While the benefits of regular exercise are known, only

48% of adults meet the CDC's 2008 physical activity guidelines of at least 150 minutes of moderate-intensity aerobic physical activity throughout the week, 75 minutes of vigorous-intensity activity throughout the week, or a combination of moderate and vigorous activity (CDC, 2015). Despite slight differences in the amount of activity required for each age group, inadequate levels of physical activity for all populations may still vary by region, race/ethnicity, and socioeconomic status. Individuals residing in southeastern states are more likely to be less physically active than those residing in other regions of the country (Cohen et al., 2013; Segal, Rayburn, Martin, 2015). Regarding race/ethnicity, there is a higher percentage of non-Hispanic Whites (50.1%) who met the 2008 guidelines for aerobic physical activity through leisure-time activity when compared to their non-Hispanic African-American (37.0%) and Hispanic (35.9%) counterparts (Schoenborn, Adams, & Peregoy, 2013). Men (50.4%) are typically more active than women (42.1%) while younger adults are more likely to meet the physical activity requirements compared to older populations (Schoenborn, Adams, & Peregoy, 2013). Socioeconomic factors may also impact activity levels, where populations with a household income above the poverty level are more likely to meet fitness guidelines than those with an income at or near the poverty level (Schoenborn, Adams, & Peregoy, 2013).

While environmental justice science has traditionally focused on spatial disparities of LULUs, more recent studies have focused on differences in environmental amenities due to the impact that they have on health. Specifically, health disparities may be perpetuated when communities lack access to salutogenic infrastructure such as parks or green space, healthy food outlets, or health care resources. For example, green space has been associated with a reduced risk of cardiovascular disease (Richardson, Pearce, Mitchell, & Kingham, 2013) and mental health outcomes (Maller, Townsend, Pryor, Brown, & St Leger, 2006; Richardson, Pearce, Mitchell, & Kingham, 2013), less stress (Chiesura, 2004), and lower odds of obesity among populations residing within 300 meters of the green space (Toftager et al., 2011). Despite the benefits of having green space, studies have consistently shown disparities in access among low-income and non-white populations that may be more pronounced in segregated cities (Saporito & Casey, 2015)

Independent from green space access, urban tree canopy has been associated with better overall health mediated by lower overweight/obesity (Bell, Wilson, & Liu, 2008) and increased social cohesion (Holtan, Dieterien, & Sullivan, 2014; Ulmer et al., 2016). Tree canopy has been further linked with better mental health, where one study found a 25% increase in the proportion of neighborhood tree cover was associated with a 1-point decrease in Depression Anxiety and Stress Scales (DASS) scores (higher scores represent poorer mental health) (Beyer et al., 2014). In addition, a 10% increase in tree canopy in Baltimore, MD was associated with a 12% decrease in crime (Troy, Grove, & O'Neil-Dunne, 2012). The same relationship between tree canopy cover and lower crime rates has been affirmed in other cities such as Portland, Oregon (OR), Austin, Texas (TX) (Snelgrove, Michael, Waliczek, & Zajicek, 2004), Philadelphia, Pennsylvania (PA) (Wolfe & Mennis, 2012), Milwaukee, Wisconsin (WI) (Heynen, Perkins, & Roy, 2006).

Having access to parks is also critical in providing individuals with opportunities to engage in physical activity, since populations that reside close to parks are three times more like to meet daily exercise recommendations compared to those who live further than walking distance (Giles-Corti et al., 2005; Wendel, Downs, & Mihelcic, 2011). Moreover, access to parks and park cleanliness have been associated with lower body mass index (BMI) among adults after adjusting for neighborhood characteristics that may negatively impact one's use of parks (i.e., homicides and walkability) (Stark et al., 2014). Proximity to parks has also been associated with high mental health status (Sturm & Cohen, 2014), improved quality of life, and reductions in self-reported stress (Hartig, Mitchell, de Vries, & Frumkin, 2014), depressive symptoms, and interpersonal violence (Barrett, Miller, & Frumkin, 2014). Other studies demonstrated ecosystem level benefits of parks that include the following: 1) mediate the urban heat island effect, 2) reduce concentration of air toxics, 3) preserve animal habitats, 4) filter water pollutants, and 5) reduce stress on stormwater systems (Boone, Buckley, Grove & Sister, 2009; Gunawardena, Wells, & Kershaw, 2017; Konijnendijk, Annerstedt, Nielsen, & Maruthaveeran, 2013).

The benefit of parks to health are known, but several inconsistencies in the literature regarding access has made it difficult to disentangle the populations that are most impacted by environmental disamenities. For example, a few studies have documented more traditional EJ findings with non-white and economically disadvantaged populations having lower access to parks (Boone, Buckley, Grove, & Sister, 2009; Garcia & White, 2006; Estabrooks, Lee, & Gyuresik, 2003; Wolch, Wilson, Fehrenbach, 2005) while others argue that no racial or income disparities exist (Abercrombie et al., 2008). Additional studies have indicated that racial and economic differences in park access may vary by geography. Specifically, a study explored the equitable distribution of parks in Pueblo, Colorado (CO) and Macon, Georgia (GA) based on the spatial clustering of park access scores and corresponding sociodemographic measures. In Macon, parks were actually more accessible in areas with non-white and lower income populations while park access in Pueblo, CO favored White and more affluent subgroups (Talen, 1997). Additional studies observed racial/ethnic and economic disparities in park access (Garcia & White, 2006; Wen, Zhang, Harris, Holt, & Croft, 2013) as well introduced similar inequalities in park characteristics (i.e., cleanliness, percent tree canopy, amenities, facilities) (Bruton & Floyd, 2014; Engelberg et al., 2016). Other communities found disparities in park size among White and non-white populations, where a higher proportion of African-Americans had greater access to parks (≤400 m) than Whites in Baltimore, MD, but Whites had access to more acres of park land in MD and Los Angeles, CA (Boone, Buckley, Grove, & Sister, 2009; Sister, Wolch, & Wilson, 2010). Moreover, studies have shown parks located in areas with a high percentage of non-white populations or economically disadvantaged groups are more likely to be of lower quality and have fewer amenities (Moore, Diez Roux, Evenson, McGinn, & Brines, 2008; Suminski et al., 2012; Vaughan et al., 2013).

While White and affluent populations tend to have greater access to green space (Wolch, Byrne, & Newell, 2014), other research has noted differing trends in urban areas compared to more rural landscapes. For example, areas with a higher percentage of poverty were associated with less green space access in urban and suburban communities while rural communities had increased green space access in economically disadvantaged areas (Wen, Zhang, Harris, Holt & Croft, 2013). Additional studies have supported the previously mentioned findings of less green space in lower-income areas (Astell-Burt, Feng, Mavoa, Badlands & Giles-Corti, 2014; Garcia & Strongin, 2010). When measuring park and green space accessibility, it is important to note that there are several strengths and weaknesses embedded in each approach that may account for some of the conflicting results. There may also be strengths and weakness associated with improving green space access. For example, many of the aforementioned studies have focused on the benefits of having access to green space, parks, or tree canopy cover in relation to health and wellness. However, creating new green space may result in green gentrification and displacement of residents who traditionally lack access to green space (Cole, Lamarca, Connolly, & Anguelovski, 2017; Gould & Lewis, 2012; Wolch, Byrne, & Newell, 2014). "Green gentrification" is a term that has been used to describe the gentrification processes that may occur when an environmental amenity is created or restored in a community (Gould & Lewis, 2012; Wolch, Byrne, & Newell, 2014).

Unlike the differences reported for park and green space access, disparities related to healthcare access are more consistent with other EJ studies that illuminate stark inequalities among non-white and economically disadvantaged groups. African-Americans already have a higher disease risk than their White counterparts for several chronic conditions, including diabetes (Signorello, et al., 2007), stroke (Howard, Labarthe, Hu, Yoon, & Howard, 2007), coronary heart disease (Leigh, Alvarez, & Rodriguez, 2016), hypertension (Lackland, 2014), heart failure (Sharma, Colvin-Adams, & Yancy, 2014), acquired immune deficiency syndrome (AIDS) (CDC, 2017), and human immunodeficiency virus (HIV) (Mead et al., 2008). In addition to having poor health outcomes, African-Americans have the highest mortality rates in the US (The Henry J. Kaiser Family Foundation, 2017) and a life expectancy that is six times shorter than Whites at birth (Collins, Tenney, & Hughes, 2002). Collectively, non-white populations tend to have lower access to health care than Whites and are less likely to acquire preventive or specialty services that may contribute to improvements in health (Mead et el., 2008).

The negative impacts of poverty on health are also significant, with mortality rates among low-income populations being highest for most of the primary causes of death (e.g., infectious, nutritional, cardiovascular, metabolic diseases, cancers, and injuries) (Mansfield & Novick, 2012). Poverty may also increase one's susceptibility to disease due to the effects that chronic stress poses on the body's immune system (Blair et al., 2011; Brunner & Marmot, 2006; Schulz et al., 2012), which may further perpetuate health disparities. Psychosocial stress (i.e., overcrowding, racial discrimination, economic deprivation, crime) may also lead to changes in immune system function that predisposes individuals to adverse health conditions (Gee & Payne-Sturges, 2004; McEwen & Tucker, 2011), and low SES and non-white populations often have increased exposures to psychosocial stress (Adler & Snibbe, 2003; Quinn, Kaufman, Siddiqi, & Yeatts, 2010). These differential exposures and heightened vulnerability may be compounded by disparities in health care access and insurance coverage, which also disproportionately impacts more African-Americans and Hispanics than Whites (Derose, Gresenz, & Ringel, 2011; Hayes, Riley, Radley, & McCarthy, 2015; Kirby & Kaneda, 2013).

Additional studies have presented barriers in access to care that may be explained by geography, language barriers, and availability of transportation or other support services. For example, one study found that African-Americans and rural populations were burdened by a longer travel time than White and urban residents when seeking medical services (Probst, Laditka, Wang, & Johnson, 2007), which may deter these populations from routinely pursuing healthcare. There are also geographical disparities in healthcare access related to SES that my cause economically disadvantaged communities to have lower quality care than more affluent communities. For instance, research has shown that revascularization rates among patients hospitalized with myocardial infarction (MI) were higher in economically advantaged communities than low-income communities due to their ability to perform coronary reperfusion at their hospitals (Fang & Alderman, 2004). After adjusting for confounders that impact access to care, Latino populations with limited proficiency in English had fewer physician visits when compared with their Latino counterparts who spoke English as their native language (Derose & Baker, 2000).

Though healthcare access inequalities contribute to health disparities, low access to nutritious food options may further contribute to these notable differences. Most chronic diseases have been associated with a lower consumption of healthy foods (i.e., fruits and vegetables) (Mead, 2008; Boeing et al., 2012); however, not all communities have access to stores that provide the foods necessary to lower disease risk. Specifically, studies have shown that fruit and vegetable consumption may lower one's risk for cardiovascular disease (Dauchet, Amouyel, Hercberg, & Dallongeville, 2006; He, Nowson, Lucas & MacGregor, 2007; He, Nowson, & MacGregor, 2006; Dauchet, Amouyel, & Dallongeville, 2005; Hartley et al., 2013), certain types of cancer (Boeing et al., 2012), and all-cause mortality (Wang, 2014). The benefits associated with these foods are overshadowed by areas known as food deserts, which is a designation given to urban and rural areas that lack access to healthy and affordable foods (US Department of Agriculture [USDA], 2017).

A food desert designation is assigned at the census tract level and accounts for populations who are economically disadvantaged with low access to healthy food retail outlets (Beaulac, Kristjansson, & Cummins, 2009; Larson, Story, & Nelson, 2009; USDA, 2016). Areas with a higher proportion of low-income or African-American groups are more likely to be classified as food deserts (Dutko, Ver Ploeg, & Farrigan, 2012) since they have fewer supermarkets that offer a variety of affordable and healthy food options (Moreland, Wing, Diez Roux, & Poole, 2002; Treuhaft, & Karpyn, n.d.; Walker, Keane, & Burke, 2010). For example, one study found no supermarkets located in predominately African-American communities in Brooklyn, New York (NY) (Moreland & Filomena, 2007). In addition to the distributional inequities, fewer stores in these communities carried fresh produce compared to those found in mostly White neighborhoods (Moreland & Filomena, 2007).

Several studies have theorized the origin of food deserts, one of which is deeply rooted in economic segregation and concomitant changes in the sociodemographic composition in inner cities. Post War World II policies provided incentives for homeownership among White populations that allowed them to migrate from inner cities to suburban areas as African-Americans began to move into the city (Alwitt & Donley, 1997; Blackwell, 2014; Zenk et al., 2005). This phenomenon, known as “white flight”, led to decreases in median household income in inner cities that forced the closure of various businesses and supermarkets (Alwitt & Donley, 1997; Blackwell, 2014; Zenk et al., 2005). Another theory is that supermarkets located in the suburbs enticed consumers with their higher quality foods, greater variety, lower prices, and longer business hours (Guy, Clarke, & Eyre, 2004). As a result, supermarkets began to expand and smaller neighborhood stores closed thereby allowing access to favor those with a car or the ability to use public transportation (Guy, Clarke, & Eyre, 2004). Still there are other factors that may be considered as barriers to having healthy food options accessible, such as the difficulty of finding a large plot of land to build a supermarket since it is more profitable to divide the property to sell in smaller fractions (Alwitt, Donley, 1997; Walker, Keane, & Burke, 2010).

Many studies have focused on how food deserts may contribute to health disparities since populations in these food environments may have little or no access to healthy food outlets (Stack, 2015; Treuhaft & Karpyn, n.d.; Walker, Keane, & Burke, 2010); however, "food swamps" may best describe the current food environment since they consider the contribution of unhealthy food outlets as well (Anderson Steeves, Martins, & Gittelsohn, 2014; Bridle-Fitzpatrick, 2015; Fielding & Simon, 2011; Luan, Law, & Quick, 2015). Food swamps are not necessarily deprived of food resources, but may be defined as areas with low access to healthy food outlets (i.e., grocery stores and supermarkets) and high access to unhealthy food outlets (i.e., fast-food restaurants and convenience stores) (Bridle-Fitzpatrick, 2015). The paucity of supermarket access has fostered an environment that may exposes residents to more high-energy dense foods often found at fast food restaurants and convenience stores (Drewnowski & Specter, 2004). Some studies have begun to explore inequalities in the distribution of these pathogenic food outlets and found that high-energy dense foods are more available in non-white and economically disadvantaged neighborhoods (Block, Larson, Story, & Nelson, 2009; A. Hilmers, D. C. Hilmers, & Dave, 2012).

Previous research has found an association between fast-food outlet density and unhealthy lifestyles (Hollands, Campbell, Gilliland, & Sarma, 2014), increased risk of obesity, and low self-efficacy of eating healthy foods (Block, Scribner, & De Salvo, 2004; Li, Harmer, Cardinal, Bosworth, & Johnson-Shelton, 2009). Another study found that fast-food outlet density was positively associated with BMI, particularly among economically disadvantaged populations located at 0.5, 1.0, and 2.0 mile road network buffers (Reitzel et al., 2014). In addition to fast-food outlets, convenience stores have also been associated with negative health outcomes related to mortality, diabetes, and obesity rates (Ahern, Brown, & Dukas, 2011). Disparities in food access remain a critically important environmental justice issue, since greater exposure to healthy and high-energy dense foods can influence health promoting or debilitating decisions.

2.5 Environmental Justice and Resilience

Resilience terminology exceeds contextual and disciplinary boundaries (Magis, 2010; Stoddard et al., 2013; Wulff, Donato, & Lurie, 2015), initially dating back to the 1970s where Gordon used the term to describe a spring's ability to store energy and deflect elastically without breaking or succumbing to deformation (Community & Regional Resilience Institute, 2013). A few years later the term resilience began to surface in varying iterations in the community domain and has since evolved to the definition that will be referenced throughout this work as, "the ability of a community to use its assets to strengthen public health and healthcare systems and to improve the community's physical, behavioral, and social health to withstand, adapt to, and recover from adversity" (USDHHS, 2015).

Regardless of the language used to describe resiliency, there are five quintessential concepts that are inherent in the definition and may contribute to a community's ability to recover from a disaster: 1) attribute, 2) continuing, 3) adaptation, 4) trajectory, and 5) comparability (Community & Regional Resilience Institute, 2013). Based on these concepts, resilience should be intrinsic within a community, communities should be able to adapt to adverse situations with a positive outcome, and communities should be comparable based on their ability to adapt to a stressor (Community & Regional Resilience Institute, 2013).

The community resilience definition that embodies the five concepts and best articulates the hardships that communities may encounter daily is described as "the ability of a community to use its assets to strengthen public health and healthcare systems and to improve the community's physical, behavioral, and social health to withstand, adapt to, and recover from adversity" (USDHHS, 2015). Since communities are unique entities with varying needs, it is important to use an approach that addresses community resilience from a local perspective that may indirectly affect change on a higher level. In fact, studies have shown that prioritizing and meeting the needs of a community's most vulnerable populations may foster macro-level improvements in overall resilience (Chandra et al., 2013; Wulff, Donato, & Lurie, 2015). This ideology is particularly important in EJ communities where predominately non-white and economically disadvantaged residents often bear the brunt of cumulative exposures to chemical and non-chemical stressors. When vulnerable communities lack resiliency, they may be more likely to have higher mortality rates for stroke, hypertension, cancer, diabetes, and heart disease when compared to their White and more affluent counterparts (Massey, 2004; Morello-Frosch et al., 2011).

Consequently, a dose-response relationship may exist between exposure to the stressors and allostatic load that can promote a heightened level of vulnerability (Theall, Drury, & Shirtcliff, 2012). Since vulnerability is a function of exposure to risk and resilience as demonstrated by the following equation, any changes in resilience and/or exposure may ultimately be reflected in vulnerability (Food and Agriculture Organization [FAO], n.d.).

$$V_i = f(exposure_{risk}, R_i)$$

Though vulnerability and resilience are different yet complimentary in nature, research suggests that future studies integrate both concepts into one assessment tool (Miller et al., 2010). A recent study attempted to connect the two concepts by measuring community resilience and social vulnerability across US counties and found that the most vulnerable counties were also the least resilient (Bergstrand et al., 2015). This study affirms the relationship between resiliency and vulnerability, and further demonstrates the significance of including both concepts in community assessments to obtain a more complete profile of human health and environmental risk.

To effectively respond to stressors and become resilient, communities must have available assets and an ability to use them so they can function during and/or after a disturbance (Longstaff, Armstrong, Perrin, Parker, & Hidek, 2010). Several measures have been developed to quantify resilience, but they are limited in their ability to capture community resilience (Windle et al., 2011) or have mainly focused on disaster resilience

(Ostadtaghizadeh et al., 2015). The resilience capacity index (RCI) assesses resilience in metropolitan areas based on their ability to cope with prospective challenges related to regional economic, sociodemographic, and community connectivity capacity (Building Resilient Regions Network, n.d.). Unfortunately, the RCI focuses more on socio-environmental factors. Since the RCI was designed as a metropolitan level assessment, it does not measure resiliency in areas that may lack more health promoting resources like rural areas or smaller cities.

The Tool for Health & Resilience In Vulnerable Environments (THRIVE) is one resiliency tool that allows communities to determine ways to improve health and safety and promote health equity by exploring components of the social-cultural environment (people), physical environment (place), and economic environment (equitable opportunity) (Prevention Institute, n.d.). THRIVE captures important components of the physical environment where community members and other stakeholders can score and prioritize questions related to air, water, and soil quality; access to transportation; access to parks and green space; access to health promoting services; and access to pathogenic products and services. Nevertheless, THRIVE does not directly measure environmental stressors and assets in a way that would allow resiliency to be quantified and compared across communities.

The Coastal Resilience Index is another resiliency tool designed to aide community leaders in evaluating whether their respective communities will continue to function at an acceptable capacity after a disaster occurs. This tool is more of a self-assessment used to identify areas that a community may become more resilient and determine the resources that should allocated to these communities to improve resiliency

(Sempier, Swann, Emmer, Sempier, & Schneider, 2010). While the Coastal Resiliency Tool was never designed to compare the results with other communities, it can be used to examine changes in resiliency within communities measured on a scale of low, medium, or high resiliency. Communities may select a relevant disaster for their self-evaluation; however, they must assess their level of resiliency based on the following categories: 1) critical infrastructure and facilities, 2) transportation issues, 3) community plans and agreements, 4) mitigation measures, 5) business plans, and 6) social systems (Sempier, Swann, Emmer, Sempier, & Schneider, 2010). The Coastal Resiliency Tool was specifically designed for evaluating resiliency to storms and other natural disasters, but it is not equipped to measure resiliency in response to a community's ability to withstand exposures to cumulative environmental stressors (chemical and non-chemical) that may negatively impact health over time.

The City Resilience Index (CRI) uses four overarching dimensions to evaluate resilience in multiple cities: 1) health and well-being, 2) economy and society, 3) infrastructure and environment, and 4) leadership and strategy (Arup & The Rockefeller Foundation, 2015). The four dimensions are comprised of 12 goals (three per dimension) and 52 comprehensive indicators cities can use to achieve resiliency. The assessment consists of qualitative and quantitative questions that may be used to evaluate a city's current resiliency profile and inform their trajectory towards a more resilient future (Arup & The Rockefeller Foundation, 2015). The CRI does consider an array of indicators that are important in achieving community resiliency, such as adequate education for all, appropriate land use and zoning, actively engaged citizens, adequate access to healthcare services, safe and affordable housing, and sufficient affordable food supply (Arup & The

Rockefeller Foundation, 2015). However, the results cannot be compared to other cities, the indicators are somewhat subjective, and the number of indicators may make this assessment cumbersome and difficult to for communities to achieve resiliency.

The Rural Resilience Index (RRI) is another tool designed to evaluate community resiliency to disasters that occur in more rural or remote areas. The RRI is comprised of multiple dimensions that fall within categories of community resources and disaster management (Cox & Hamlen, 2015; Justice Institute of British Columbia [JIBC], n.d.). The community resources section whether communities have high or low resilience based on the following characteristics: 1) close-knit and involved, 2) self-sufficient and resourceful, 3) diverse in skills, knowledge and fostering tradition, 4) strong health and social support system, 5) strong local leadership and governance, 6) stable and sustainable, 7) adequate services and utilities, and 8) administrative services support our community (Cox & Hamlen, 2015; JIBC, n.d.). In contrast, the disaster management section focuses on the following resiliency attributes: 1) disaster aware, 2) prepared for disaster, 3) structures are protected, 4) farms, commercial livestock, working animals and pets are protected, 5) comprehensive disaster plan, 6) involved in ongoing disaster planning, 7) adequate first response capacity, and 8) adequate emergency medical response capacity (Cox & Hamlen, 2015; JIBC, n.d.).

While the RRI is a comprehensive resiliency assessment tool, each characteristic is rated subjectively as “yes” or “no” and the results cannot be quantified due to the qualitative nature of the tool. Specifically, there is no way to determine variance between or within communities since the measures for each dimension are “high resilience”, “low resilience”, “need more info”, and “not applicable”. Nevertheless, the Hazard Resilience

Index (HRI) can be used in conjunction with the RRI to assess community resilience to local hazard-risk priorities (JIBC, 2015). Specifically, the HRI tool allows communities to identify their strengths, assets, and vulnerabilities through the lens of 17 categories of potential disasters. Some of the categories in the HRI are related to accidents, various natural hazards, food shortages, terrorism, diseases, structural challenges, and nuclear events (JIBC, 2015).

2.6 Environmental Justice and Community Engagement

Community engagement has been recognized as an integral strategy in connecting the community's expertise with research on exposures to environmental stressors and tackling environmental health problems. Since residents experience a multitude of exposures to chemical and non-chemical stressors in their neighborhoods, community engagement is a necessary approach that may strengthen research efforts on cumulative environmental risks (Alexeeff et al., 2010; National Environmental Justice Advisory Council [NEJAC] Cumulative Risks/Impacts Work Group, 2004; Nweke, 2011). Recently, community engagement has become a critical component in promoting resilience by having various stakeholders working with communities to safeguard against health disparities (Morton & Lurie, 2013). Community-based EJ organizations have also relied on community-engaged research, such as community-based participatory research (CBPR) (Horowitz, Arniella, James, & Bickell, 2004; Simonds, Wallerstein, Duran, & Villegas, 2013; Tapp, White, Steuerwald, & Dulin, 2013), the collaborative problem solving (CPS) model (USEPA, 2008; S. M. Wilson, O. R. Wilson, Heaney, & Cooper, 2007), and community-owned and managed research (COMR) (Heaney et al., 2011;

Heaney, S. M. Wilson, & O. R. Wilson, 2007), to address environmental and health inequalities in their neighborhoods.

One of the most common community-engaged research approaches is CBPR, where community members and stakeholders are equitably involved in all aspects of the research process from inception of the topic to interpretation of the results (Israel et al., 2005; Israel, Eng, Schulz, & Parker, 2005; Wallerstein & Duran, 2010). After a topic of community importance has been decided, the partners work collectively using knowledge and taking actions to affect social change that may improve health (Israel et al., 2003; Israel, Eng, Schulz, & Parker, 2005; Wallerstein & Duran, 2010). The specific principles of CBPR involve: 1) acknowledging the community as a unit of identity, 2) building upon community strengths and resources, 3) promoting mutual learning among partners, 4) achieving a balance between research and action that benefits science and community needs, 5) emphasizing the value in community-defined problems, 6) promoting a cyclical and iterative process to develop sustainable partnerships, 7) disseminating results to all partners, and 8) a long-term commitment from all partners (Holkup, Tripp-Reimer, Salois, & Weinert, 2004; Israel et al., 2005; Israel, Schulz, Parker, & Becker, 1998). These principles have essentially allowed public health research to evolve from the researcher-driven enterprise of "community-based research" to a partnership approach that is rooted in equal participation from the community (Israel, Schulz, Parker, Becker, & Community-Campus Partnerships for Health, 2001; Simonds, Wallerstein, Duran, Villegas, 2013; Strickland, 2006).

CBPR plays an important role in reducing health disparities, and several studies have demonstrated the effectiveness of this approach in solving health and environmental problems found in communities of environmental injustice (O'Fallon & Dearry, 2002; Strickland, 2006; Wallerstein & Duran, 2006). For example, CBPR has been used to address environmental issues related to the siting of a new port terminal in North Charleston, SC (Burwell-Naney et al, 2017; Wilson et al., 2014a); health implications associated with goods movement activities in California (Garcia et al., 2013), cancer disparities in Central Appalachia (Behringer, Mabe, Dorgan, & Hutson, 2009), asthma exacerbations from indoor and outdoor pollutants in Detroit, Michigan (Parker et al., 2013), and exposures to multiple pollution sources in Buffalo, New York, to name a few. The USEPA has also recognized community engagement as a critical component of environmental research and have required that CRA grants include CPBR in their proposals (NEJAC, 2004; Payne-Sturges et al., 2015). While there are a few limitations to this research strategy, most cases have resulted in the development of useful interventions, an atmosphere of mutual benefits, trust building, overcoming communication and partnership barriers, and finding solutions to local health problems (Heaney, S. M. Wilson, & O. R. Wilson, 2007).

Alternatively, the West End Revitalization Association (WERA) created the COMR model that highlights the community's ability and capacity to develop, manage, and sustain their own research projects (Heaney et al., 2011; Heaney, S. M. Wilson, & O. R. Wilson, 2007). This community engagement strategy differs from CBPR in that the COMR model requires that the CBO be funded to operate as the principal investigator (PI) and project manager instead of a university or government partner (Heaney, S. M. Wilson, & O. R. Wilson, 2007; O. R. Wilson, Bumpass, O. M. Wilson, & Snipes, 2008). Typically, a university or government partner is involved in the research process as a consultant, but the CBO takes on the responsibility of selecting their own consultants, managing and leveraging funds, and owning the databases. The WERA successfully applied the COMR model to address a lack of basic amenities due to the dusty dead-end streets, *E. coli* contaminated drinking water, failed septic tanks, and foul odors from the sewage treatment plant in communities of EJ in Mebane, NC (O. R. Wilson, Bumpass, O. M. Wilson, & Snipes, 2008). This CBO also managed to thwart the North Carolina Department of Transportation's (NCDOT) plans to build the 119-bypass through two of the African-American communities. As indicated by the WERA's experience, COMR can be used to improve environmental conditions in communities exposed to multiple hazards. However, this approach is most effective in EJ and CRA research when a community has a high level of organizational capacity specifically personnel and infrastructure in place to sustain project activities over a long period of time (O. R. Wilson, Bumpass, O. M. Wilson, & Snipes, 2008).

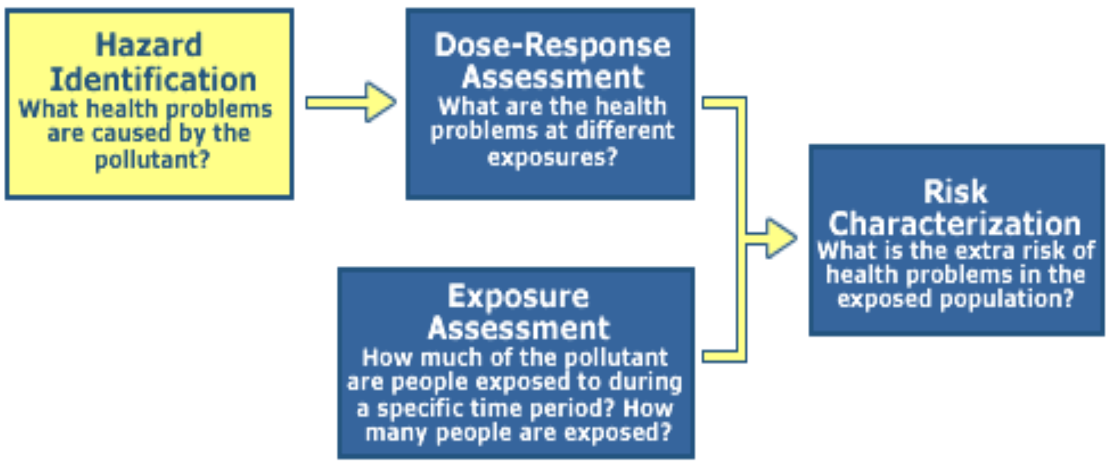
The CPS model is a community-based stakeholder engagement approach created by USEPA that is comprised of the following seven elements: 1) issue identification, community vision, and strategic goal setting, 2) community capacity-building and leadership development, 3) consensus building and dispute resolution, 4) multi-stakeholder partnerships and leveraging of resources, 5) constructive engagement by relevant stakeholders, 6) sound management and implementation, and 7) evaluation, lessons learned and replication of best practices (USEPA, 2008; S. M. Wilson, O. R. Wilson, Heaney, & Cooper, 2007).

This approach is based on the work performed by ReGenesis, a community-based organization, organized to address and revitalize brownfields and Superfund sites that were located in predominately African-American and low-income neighborhoods of Spartanburg, SC. In addition to the concerning rates of cancer, respiratory illness, reproductive problems, and mortality in the area, these Spartanburg residents also suffered from poor infrastructure (i.e., transportation, water, and sewer) and lacked access to medical care economic opportunities that may have increased community resilience (Barzyk, S. Wilson, & A. Wilson, 2015; USEPA, 2003a; USEPA, 2008). Because of the studies supporting the value of the CPS model in facilitating environmental and social change, the NEJAC has promoted the use of this model in research intended to reduce cumulative risk in communities with multiple chemical and non-chemical stressors (NEJAC, 2004).

2.7 Cumulative Risk Assessment

To better understand ways to eliminate environmental injustice and reduce health disparities, we must consider the combined risks of chemical and non-chemical stressors on various populations over time. Previously, a single-chemical risk assessment approach was used to identify threats to human health through hazard identification, dose-response-assessment, exposure assessment, and risk characterization (Figure 1) (USEPA, 2003b; USEPA, 2017). When conducting a single-chemical risk assessment, a specific chemical was often examined to determine its unique exposure pathways, media, or endpoints. The problem with this assessment methodology, particularly in EJ communities, is that it lacks the capacity to evaluate multidimensional problems inclusive of chemical, biological, and social stressors that may be modified when operating collectively (Rhodes, 2003). The need for a cumulative risk assessment methodology was apparent so that traditional risk assessment approaches could withstand the challenges of a complex and changing environment.

Figure 1. The Four Step Risk Assessment Process



The USEPA responded to the gap in methodology in 2003 when they established a *Framework for Cumulative Risk Assessment* to guide the process of understanding compounded risks to human health from multiple environmental stressors. Cumulative risk assessment is defined as:

> *An analysis, characterization, and possible quantification of the combined risks to health or the environment from multiple agents or stressors* (Barzyk, S. Wilson, & A. Wilson, 2015; Sexton, 2012; USEPA, 2003b).

The essential components of CRA are that it accounts for multiple stressors, considers interactions between various stressors, and focuses on how a multitude of stressors may impact populations versus individuals (Sexton, 2012; Sexton & Linder, 2010; USEPA, 2003b). Other factors that may be incorporated into CRAs are the different environmental media as well as durations, pathways, and /or routes of exposure that may have a bearing on risk. Multiple effects may also be taken into consideration, risks may be quantified from multiple stressors, non-chemical stressors (i.e., noise, violent crime, low access to green space, healthcare, and healthy foods) may be included in the assessment, as well as concepts of vulnerability (Sexton, 2012; Sexton & Linder, 2010; USEPA, 2003b).

The factors that distinguish CRAs from conventional risk assessment methods may also be considered benefits of this particular approach; however, there are still several challenges that need to be addressed. Specifically, characterizing multiple stressors with varying toxicities and pathways that lack a common endpoint may pose a challenge in CRA (Barzyk, S. Wilson, & A. Wilson, 2015; Williams, Dotson, & Maier, 2012). Another challenge of CRAs involves incorporating non-occupational and occupational exposures due to the variability in workplace stressors, interaction mechanisms, and duration of potential exposures. The use of non-chemical stressors may also be problematic since there is not always a consistent metrics in place to measures these exposures across populations (Williams, Dotson, & Maier, 2012). When there are metrics for non-chemical or even chemical stressors, there may still be challenges in obtaining data at the same unit of analysis and time period. In addition, quantifying the interactions between chemical and non-chemical stressors and determining the dose-response relationship for disease outcomes (Lewis, Sax, Wason, & Campleman, 2011; Williams, Dotson, & Maier, 2012).

As a result, there are certain "best practices" that may be implemented to overcome some of the challenges of CRAs while still fulfill the requirements of this approach. For example, the purpose and objectives of the CRA should be clearly defined, achievable, and measurable (Barzyk, S. Wilson, & A. Wilson, 2015). In addition, key community and non-community stakeholders should inform some aspects of the CRA process and specific roles and responsibilities of respective partners may also be defined during this step (Barzyk, S. Wilson, & A. Wilson, 2015; Payne-Sturges et al., 2015). Once the scope (i.e., temporal, spatial, receptors, and quantification plan) has been determined, a conceptual model may be used to identify relationships between various stressors and assets that may impact risk. Methods are applied to rank the stressors and the results are used to prioritize solutions, particularly in high-risk communities (Barzyk, S. Wilson, & A. Wilson, 2015). The final steps of a CRA involve summarizing the analysis plan and evaluating whether risk management efforts were effective, efficient, and equitable (Barzyk, S. Wilson, & A. Wilson, 2015; Sexton & Linder, 2010).

2.8 Cumulative Impact Assessment and Environmental Justice Indices

With the recent addition of a "social determinants of health" topic area incorporated into the Healthy People 2020 initiative (USDHHS, 2016), the need for standardized tools and methodologies that can be used to comprehensively examine environmental conditions that may lead to negative health outcomes has become more apparent. Over the past few decades, most of the risk assessment research conducted at the USEPA has involved single chemical agents, specific sources or their respective category, single exposure pathways, routes of exposure, different environmental media, as well as health endpoints (Callahan & Sexton, 2007; Sexton, 2012). These risk assessment techniques failed to account for multiple exposures to both chemical and nonchemical stressors, and thereby ignited a paradigm shift from traditional risk approaches to the development of innovative methods and assessment tools that measure cumulative risk.

Not only should these novel methods and assessment tools capture cumulative impacts, they must also have the ability to characterize inequalities and potential exposures to multiple environmental hazards (Su et al., 2009). Several cumulative impact assessment and EJ indices have been constructed over the years to quantify risk at varying geographic locations and scales, there is still more work to be done to create an index that incorporates decision analysis, multiple risk quantification, and a consistent CRA process that ranges from defining a purpose to the evaluation of results from risk reduction action (Barzyk, S. Wilson, & A. Wilson, 2015). We examine a few of the cumulative impact assessment and EJ indices below:

2.8.1 EJView

EJView, formerly known as the Environmental Justice Geographic Assessment Tool (EJGAT), was created by the USEPA in 2005 as a public tool for identifying prospective EJ communities. This tool allows the use to generate detailed reports and includes the following data layers that can be mapped at various geographic levels: 1) community-based USEPA grants, 2) sites reporting to the USEPA, 3) water monitoring stations, 4) places, 5) nonattainment areas for select NAAQS, 6) health, 6) demographics, and 7) boundaries and water features (Table 1). While this tool allows users to characterize a specific location by mapping the above layers, it still lacks the algorithmic complexity that is required to designate an area as an EJ community. Specifically, the tool's inability to display demographic characteristics simultaneously makes it difficult to determine the racial and economic composition of a particular region in one search (Frederick, 2013).

Other weaknesses that have been reported on EJView are: 1) the tool lacks the capacity to capture comparative risks between non-white racial groups, 2) differentiating between the severity of environmental risks cannot be done using the same interface, and 3) more emphasis is placed on risks at the local level making this tool less equipped to handle national assessments (Fredericks, 2013). Though EJView includes a variety of important variables that can be mapped for a specific area, it still excludes a method for quantifying the risks in each community to make meaningful comparisons or prioritize communities based on their level of risk. Despite several efforts to improve this tool in 2010, EJView was finally replaced by EJSCREEN in 2015 as the public's new EJ mapping tool.

Table 1. EJView Map Layers

EJView	
Community-based EPA Grants	• EJ Grants • CARE Grants • Brownfield Grants
Sites Reporting to EPA	• Hazardous Waste (RCRA Info) • Air Emissions (AFS) • Water Dischargers (PCS/ICIS) • Toxic Releases (TRI) • Superfund (CERCLIS) • Brownfields (ACRES)
Water Monitoring Station	• USGS Water Monitors (NWIS) • EPA Water Monitors (STORET)
Places (GNIS)	• Schools • Hospitals

	• Worship Places
Nonattainment Areas	• Ozone 8-Hour (1997 Standard) • Lead (2008 Standard) • $PM_{2.5}$ Annual (1997 Standard) • $PM_{2.5}$ 24-Hour (2006 Standard)

Health	• Cancer and Noncancer (2005)
	  ○ Cancer Risk by Tract
	  ○ Cancer Risk by County
	  ○ Respiratory Risk by Tract
	  ○ Respiratory Risk by County
	  ○ Neurological Risk by Tract
	  ○ Neurological Risk by County
	• Infant Mortality Rate (2004)
	• Low Birth Weight Rate (2004)

Demographics (SF1) 2010	• Population Density 2010 • Minority (%) 2010 • Age <18 Years (%) 2010 • Female (%) 2010 • Renter (%) 2010
Demographics (ACS) 2010	• Population Density (People/Square Mile) • Per Capita Income • Below Poverty (%) • Education <12G (%) • HS Diploma Only (%) • College Degree (%) • Age <18 Years (%) • Homes Pre-1950 (%) • Speak English <Well (%) • Female (%) • Rental Units (%) • Minority (%)
Demographics 2000	• Population Density (People/Square Mile) • Per Capita Income • Below Poverty (%) • Education <12G (%) • HS Diploma Only (%) • College Degree (%) • Age <18 Years (%) • Homes Pre-1950 (%) • Speak English <Well (%) • Female (%) • Rental Units (%) • Minority (%)

Boundaries and Water Features	• Neighborhood Points • Neighborhood Boundaries • Impaired Streams • Impaired Water Bodies • Streams • Water Bodies • Watershed (HUC12) • Railroads • 2002 Freight (Kilotons) • Health Service Areas • Congressional Districts • Urban Areas • City Boundaries • Federal Lands • Zip Codes • Counties • States

2.8.2 EJSEAT

In contrast to EJView, the USEPA's Office of Enforcement and Compliance Assurance (OECA) created the Environmental Justice Strategic Enforcement Screening Tool (EJSEAT) for internal use only. The purpose of this screening tool is to identify priority communities that may be overburdened be environmental hazards and other public health concerns (NEJAC, 2010). The EJSEAT consists of demographic, environmental, health, and compliance indicators that are analyzed for census tracts in each state (Table 2). The scores in EJSEAT are calculated using an algorithm, where the data are ranked within each indicator category, summed, and averaged for all of the census tracts. Summing and finding the mean for the data across the four indicator groups is the method used to derive the cumulative EJSEAT score for each census tract. Nevertheless, only the census tracts with scores in the top 10 and 20 percent of the state are designated as EJ areas of concern. The EJSEAT's ability to quantify and prioritize risk by census tract has significantly increased the utility of this screening tool compared to EJView.

Though EJSEAT was an internal assessment tool; the NEJAC was tasked with making recommendations to improve the ability of the tool to capture EJ communities. NEJAC found limitations with the health data since it was only available at the county level. The lack of spatial granularity limited the utility of the tool for making locally-relevant assessments. They ultimately suggested either discarding the health variable from the analysis or giving it a lesser weight than the other indicators (NEJAC, 2010). For the compliance indicator category, NEJAC proposed using facility density instead of compliance due to the variation in how regulatory violations and inspections are enforced across states. NEJAC also recommended a restructuring of the indicator categories into two groups (social vulnerability and environmental burden) and warned against the use and limitations of the tool that could be helpful for other agencies creating EJ screening tools. For example, they mentioned EJSEAT focused more on air quality for their environmental indicators and how it should not be used as an assessment tool (Table 2). They also mentioned how EJSEAT should bring resources instead of stigma to EJ areas of concern that are identified by the tool. Moreover, they found EJSEAT was limited to data points collected on a national scale and suggested they supplement the data with community specific information (NEJAC, 2010). Regardless of these limitations, designing a screening or assessment tool is an evolutionary process that will continue to improve over time.

Table 2. EJSEAT Indicators

EJSEAT	
Demographic Indicators (2000 Census)	• Persons Below the Poverty Line (%) • Persons >25 Years Old, no HS Diploma (%) • Persons <5 Years Old (%) • Persons >64 Years Old (%) • Households Linguistically Isolated (%) • Minorities (African American, Native American, or Pacific Islanders) (%)
Environmental Indicators (NATA, RSEI)	• NATA Risk • NATA Neurological and Respiratory Hazard Index • NATA Non-Cancer Diesel PM • $PM_{2.5}$ Concentration • Ozone Concentration (8-Hour Average) • Average RSEI Risk-Related Score for Federally Permitted Industrial Facilities in the Census Tract
Health Indicators[a]	• Rate of Infant Mortality • Rate of Low Birth Weight
Compliance Indicators	• Number of FRS Facilities Per Square Mile • Computed Measure of Inspections • Computed Measure of Violations • Computed Measure of Formal Actions

2.8.3 EJSCREEN

EJSCREEN is a more recent tool that uses publicly available data and allows the public to access the raw data files (USEPA, n.d.c.). EJSCREEN serves as a replacement to EJView and has incorporated many of the recommendations suggested by NEJAC to meet both the needs of the USEPA and the public. Specifically, the USEPA uses EJSCREEN to inform community-engaged outreach, develop retrospective reports of

EPA work, improve geographically based initiatives, and implement programs related to permitting, enforcement, compliance, and those that are voluntary (USEPA, n.d.c.).

EJSCREEN is characterized as an EJ screening and mapping tool that includes a web-based GIS component so that the indices for a particular block group or census tract can be calculated and visually represented by color coded maps. EJSCREEN is currently the most innovative index that has been released due to the following factors: 1) accessible to the public, 2) has enhanced mapping capabilities, 3) can generate reports for selected area, 4) has ability to make comparisons between selected area and state, EPA region, and/or nation, 5) and the data can be analyzed at the block group or census tract level. This screening tool consists of 11 environmental indicators, 6 demographic indicators, and 11 EJ Indexes (Table 3).

EJSCREEN uses a multiplicative approach to calculate a cumulative impact score: 11 environmental indicators x (demographic index for selected area – average demographic index for US) x block group population) (USEPA, n.d.c.). The demographic index for each area is calculated by taking the mean of the percent poverty and minority indicators ([%Poverty + % Minority] /2). In regards to health measures, EJSCREEN incorporates the EPA's National-Scale Air Toxics Assessment (NATA) data for cancer and respiratory health effects that is based on chronic exposures to outdoor sources of pollution. NATA was developed by the USEPA as an air toxics screening tool for prioritizing pollutants and emission sources across larger geographic areas (USEPA, n.d.d). Nevertheless, the integration of NATA data into EJSCREEN presents a few challenges since the data cannot be used to determine specific risk values at the census tract level or smaller geographic scales. As a result, there is no way to analyze exposure-disease relationships or track the impact of EJ-related decisions on health at the neighborhood level.

There are additional limitations with EJSCREEN. For example, EJSCREEN was developed to demonstrate transparency in the way the USEPA makes decisions regarding communities that have been designated as potential areas of environmental injustice (USEPA, n.d.c.). EJSCREEN has similar limitations as many other indices in that they must use national level datasets to make comparisons between states. While the ability to compare EJSCREEN scores across states is important, this function does not allow states to select datasets that may not be collected in other states and could better reflect public health concerns in their respective state. Furthermore, many of the data points are only a proxy for environmental exposures that may lead to adverse health outcomes, which may introduce uncertainty in the EJSCREEN scores.

Another limitation of this screening tool is that it was never designed to perform a detailed CRA and it does not include an exhaustive list of all environmental health issues that impact EJ communities. Though EJSCREEN is not a CRA tool, research has demonstrated the utility of CRAs in informing EJ-related policy decisions (Sexton & Linder, 2010). CRAs follow a more systematic and impartial process that that could be beneficial when identifying prospective communities of environmental injustice, but a more salient attribute of CRAs is that they integrate various chemical and non-chemical stressors into their analysis that are not found in EJSCREEN. EJSCREEN has the potential to become a more comprehensive screening tool while maintaining its original functionality if it integrates more social or non-chemical stressors into the index instead of primarily focusing on environmental and sociodemographic indicators. There is still a great need for EJSCREEN; however, the development of newer screening tools that follow the CRA approach and can detect disparities in environmental exposures by race and income may cause this tool to become less effective in identifying high-risk populations.

Table 3. EJSCREEN Indicators

EJSCREEN	
Environmental Indicators	• $PM_{2.5}$ (ug/m^3 Annual Average) • Ozone (Summer Average ppb 8-Hour Concentration) • NATA Diesel PM (ug/m^3) • NATA Air Toxics Cancer Risk (Lifetime Cancer Risk from Inhalation of Air Toxics) • NATA Respiratory Hazard Index (Ration of Exposure Concentration to Health-Based Reference Concentration) • Lead Paint Indicator (% Pre-1960s Housing) • Traffic Proximity and Volume (Daily Traffic Count/Distance to Road) • Proximity to National Priority List (NPL) Sites (Count [AADT] within 500 m/ Distance in m) • Proximity to Risk Management Plan (RMP) Facilities (Count within 5 km or Nearest Beyond 5 km/ Distance in km) • Proximity to Treatment Storage Disposal Facilities (TSDFs) (Count within 5 km or Nearest Beyond 5 km/ Distance in km) • Proximity to Major Direct Water Dischargers (Count within 5 km or Nearest Beyond 5 km/ Distance in km)
Demographic Indicators	• Minority Population (%) • Low-Income (%) • Linguistically Isolated • <HS Education (%) • <5 Years Old (%) • >64 Years Old (%)
EJ Indexes	• NATA Air Toxics Cancer Risk • NATA Respiratory Hazard Index • NATA Diesel PM (DPM) . $PM_{2.5}$ • Ozone • Lead Paint Indicator • Traffic Proximity and Volume

	• Proximity to RMP Sites • Proximity to TSDFs • Proximity to NPL Sites • Proximity to Major Direct Water Dischargers

2.8.4 CalEnviroScreen 3.0

CalEnviroScreen 3.0 is the most recent version of the California Communities Environmental Health cumulative impact assessment tool that was released in September 2016 as an update to CalEnviroScreen 2.0 (Faust et al., 2016). This screening tool was primarily developed for use by the California Environmental Protection Agency (CalEPA) and its respective boards, departments, and offices (Rodriguez & Zeise, 2017) to identify vulnerable communities across the state that are disproportionately impacted by multiple pollution sources to inform policy and prioritize mitigation activities (Cushing et al., 2015). Since its inception, the CalEnviroScreen tool has been modified including adding new indicators, updating datasets, adjusting the geographic scale of analysis (reflected in transition from CalEnviroScreen 1.1 to 2.0 only), and revising the methods used to measure some of the indicators (Office of Environmental Health Hazard Assessment [OEHHA], 2016). CalEnviroScreen 3.0 consists of 20 indicator variables that grouped into the following four domains: 1) exposures, 2) environmental effects, 3) sensitive populations, and 4) socioeconomic factors (Table 4). The indicator variables from the four domains are furthered simplified into a pollution burden and population characteristics category to calculate the cumulative impact score.

The cumulative impact calculation uses additive and multiplicative measures to initially weight, sum, and then multiply (total pollution burden x population characteristics) variables from both categories the to obtain the final score. The formula is one of the strengths of this cumulative impacts assessment tool since it is based on a widely accepted concept of risk analysis that multiplies threat by vulnerability to obtain risk (risk = threat * vulnerability) (Faust et al., 2016). Another strength of this tool is the comprehensiveness of California's health and environmental data repositories that allow them to capture information on various indicators that are not possible in other state or national indices. Though the CalEnviroScreen and other cumulative impact indices cannot include all environmental exposures that impact health, their tool could be improved by including a resiliency component, segregation measures, or other environmental stressors known to have significant impacts on health.

Table 4. CalEnviroScreen 3.0 Indicators

CalEnviroScreen 3.0	
Exposures	• Ozone (Concentration) • $PM_{2.5}$ (Concentration) • Diesel PM (Emissions) • Pesticide Use (Pounds/Square Mile) • Toxic Releases (RSEI Toxicity-Weighted Releases) • Traffic (Density) • Drinking Water Contaminants (Concentration)
Environmental Effects	• Cleanup Sites (Weighted Sites) • Groundwater Threats (Weighted Sites) • Hazardous Waste Facilities/Generators (Weighted Sites) • Impaired Water Bodies (Number of Pollutants) • Solid Waste Sites/Facilities (Weighted Sites and Facilities)
Sensitive Populations	• Cardiovascular Disease Emergency (Emergency Department Visits for Heart Attacks) (Rate per 10,000) • Asthma Emergency Department Visits (Rate per 10,000)

	• Low Birth-Weight Infants (%)
Socioeconomic Factors	• Educational Attainment (%) • Linguistic Isolation (%) • Poverty (%) • Unemployment (%) • Rent-Adjusted Income

2.8.5 Cumulative Environmental Hazards Inequality Index (CEHII)

The Cumulative Environmental Hazard Inequality Index (CEHII) was developed to characterize socioeconomic and race/ethnicity based inequalities that could ultimately be utilized to estimate the impact of cumulative environmental hazards across communities (Su et al., 2009). The CEHII originated from the Concentration Index (CI), which is an assessment tool that examines concentration curves to determine whether socioeconomic inequalities exist within a health sector by temporal points or country. However, the CEHII is an expansion of the CI that incorporates a magnitude of inequalities for environmental hazards (Su et al., 2009). CEHII defines inequality as twice the area of the inequality curve in relation to the inequality line, where a positive curve represents census tracts with a higher percentage of certain racial/ethnic groups and low SES populations that have a lower burden of environmental hazards. In contrast, the negative curve illustrates the opposite effect and represents tracts with a higher burden of hazards. The index measures hazards such as ambient concentrations of fine particulates ($PM_{2.5}$), nitrogen dioxide (NO_2), and estimates of cancer risk based on modeled diesel particulate matter (DPM) concentrations (Table 5). The environmental hazards are combined into a multiplicative or additive model using the cumulative proportion of the study population in the area ranked by race/ethnicity and SES (Sexton & Linder, 2011; Su et al., 2009).

The CEHII was applied to areas of Los Angeles County, where environmental inequalities were confirmed among predominately non-white and low-income communities. Furthermore, the disparities among sociodemographic groups were more pronounced when the multiplicative model was used to estimate cumulative hazards instead of the additive model alternative. While the authors suggest that other measures of environmental hazards could be added (i.e., water pollution, traffic density, noise, access to supermarkets, proximity to industrial emissions sources) (Su et al., 2009), the current version of the model is not as comprehensive in examining the cumulative impact of multiple hazards due to its environmental focus. Despite some limitations, incorporating social stressors and additional environmental stressors into this model appears promising as we continue to improve the methodology for conducting cumulative impact assessments.

Table 5. CEHII Indicators

Cumulative Environmental Hazard Inequality Index (CEHII)	• Non-white Population (%) • Population Under Twice the Poverty Level (%) • Nitrogen Dioxide (NO_2) (ppb) • Fine Particulate Matter ($PM_{2.5}$) ($\mu g/m^3$) • Diesel Particulate Matter (DPM) (cancer risk per million)

2.8.6 Urban Health Equity Assessment and Response Tool (Urban HEART)

Another assessment tool that considers SES differences is the World Health Organization's (WHOs) Urban Heart Health Equity Assessment and Response Tool Urban HEART, which uses a global approach to collectively identify health inequalities within or across cities and action-based solutions to alleviate those disparities (World Health Organization [WHO], n.d.b.). Since its initial launch in 2008, there have been roughly 50 countries that have been trained in the use of Urban HEART. There were two major indicator groups that have been categorized as health outcomes and determinants of health, where health outcomes refer to disease specific outcomes (i.e., mortality/morbidity standardized by 100,000 people) and summary indicators such as infant mortality rate (WHO, n.d.b.). The determinants of health have been further divided into four core indicators related to the following: 1) physical environment and structural aspects such as access to safe drinking water and sanitation, 2) social and human development that involves access to education and health care, 3) economic factors that stem from employment opportunities and potential for generating income, and 4) governance that allows the public to be fully engaged in decision making processes and inform government spending on healthcare services (Table 6). The Urban HEART's output for the indicators is represented by color-coded profiles that illustrate the cities with the highest inequalities.

There are 12 Urban HEART core indicators that cities or neighborhoods within cities can adopt based on the availability of the data and global relevance of each variable in urban areas (WHO, 2010). The data for the assorted indicators can be further deconstructed into population (i.e., age or sex), location (i.e., neighborhood or city district), and socioeconomic group (i.e., income or education) (Sexton & Linder, 2011), which is an important feature to include when making decisions about vulnerable subgroups. There are also strongly recommended and optional indicators that different cities can use to customize the assessment tool in way that is most appropriate for their locale. The interchangeability of the indicators and the urban focus of Urban HEART may introduce several strengths and weaknesses. For example, Urban HEART is an assessment resource that prioritizes health disparities in urban areas of developed and developing countries, so it is unable to capture health disparities information in more rural regions of the world.

While this assessment tool has established core indicators that can be compared across multiple cities in developed and developing countries, the scope of this tool is broad and may not necessarily reach the level of granularity that is required to capture cumulative stressors in developed countries versus developing countries. For example, cities in the US may suffer less from physical environment and infrastructure issues such as poor sanitation and would be better served with an indicator that captures traffic density. The ability to interchange indicators is built in to this tool; however, you lose the ability to make meaningful comparisons across cities if different indicators are being incorporated into the assessment.

Table 6. Urban Heart Core, Strongly Recommended, and Optional Indicators

Urban Health Equity Assessment and Response Tool (Urban HEART)	
Core Indicators	
Health Care Outcome: Summary Indicator	• Infant Mortality
Health Outcomes: Disease Specific Indicators	• Diabetes • Tuberculosis (TB) • Road Traffic Injuries

Social Determinants of Health: Physical Environment and Infrastructure	• Access to Safe Water • Access to Improved Sanitation
Social Determinants of Health: Social and Human Development	• Completion of Primary Education • Skilled Birth Attendance • Fully Immunized Children • Prevalence of Tobacco Smoking
Social Determinants of Health: Economic	• Unemployment
Social Determinants of Health: Governance	• Government Spending on Health
Strongly Recommended Indicators	
Health Outcomes: Summary Indicators	• Under-Five Mortality • Maternal Mortality • Life Expectancy at Birth
Health Outcomes: Disease Specific Indicators	• Morbidity and Mortality for: All Cancers, Cardiovascular Disease, Respiratory Disease, HIV/AIDS, Homicide, Mental Illness
Social Determinants of Health: Physical Environment and Infrastructure	• Households Served by Municipal Solid Waste Management System • Solid Fuel Use • Work-Related Injuries
Social Determinants of Health: Social and Human Development	• Literacy • Underweight Children • Overweight and Obesity • Breastfeeding • Teenage Pregnancy • Physical Activity
Social Determinants of Health: Economic	• Poverty • Women in Workforce • Secure Tenure
Social Determinants of Health: Governance	• Voter Participation • Insurance Coverage
Optional Indicators	
Social Determinants of Health: Physical Environment and Infrastructure	• Alcohol Outlets • Green Spaces
Social Determinants of Health: Social and Human Development	• Domestic Violence • Low Birthweight

Social Determinants of Health: Economic	• Slum Population • Informal Employment
Social Determinants of Health: Governance	• Government Spending on Education

2.8.7 Cumulative Environmental Vulnerability Assessment (CEVA)

The CEVA was first developed as a tool to assist regulators and advocates define EJ communities by identifying areas with the highest level of environmental hazards and social vulnerability (Huang & London, 2012). Specifically, this assessment tool combines variables from a Cumulative Environmental Hazards Index (CEHI), Social Vulnerability Index (SVI), and Health Index (HI) (reference index) to increase the accuracy of profiling EJ communities at the census block group level (Table 7). The CEHI and SVI variables were captured at the block group level with the exception of the NATA data that had to be converted from census tract to block group. The HI data was available at the zip code level and was converted to block group so that all variables were in the same unit of analysis. The overall assessment tool was designed using the collaborative research model, where a university-based team partnered with a coalition of EJ and health advocates for contextual input and gained insight from different methods in the literature (Huang & London, 2012).

The CEVA was used in California's San Joaquin Valley (SJV), where the results indicated that the SVI was significantly correlated with the CEHI (0.296) and HI (0.231) respectively, but the relationship was not significant between the CEHI and HI (Huang & London, 2012). Moreover, this study demonstrated that urban landscapes had the highest vulnerability for environmental and social measures, and environmental and social vulnerability were present in rural areas among non-white and low SES populations who live near agriculture and industrial facilities (Huang & London, 2012).

While the findings did characterize EJ communities in the SJV that were primarily based on high, medium, and low categories for CEHI and SVI, there were still several limitations that need to be addressed in future assessment tools. The authors mentioned that the NATA dataset excluded diesel sources in the assessment of cancer risk and propose to include transportation volume data in future research (Huang & London, 2012). Additional limitations included the following: 1) lacks available or appropriately scaled data for variables that may be linked with adverse health conditions, 2) unable to assess areas smaller than a block group, 3) focuses more on the presence or absence of point sources instead of emissions concentrations and the fate or toxicity of each pollutant, 4) incapable of accounting for time activity patterns on a larger geographic scale, and 5) lacks the functionality to capture absolute measures of exposure (Huang & London, 2012).

Table 7. CEVA Indicators

Cumulative Environmental Vulnerability Assessment (CEVA)	
Cumulative Environmental Hazards Index (CEHI)	• Toxic Release Inventory Sites • Refineries • Hazardous Waste Treatment, Storage and Disposal Facilities • Chrome Platters • Total Amount Agri. Pesticide Application Per 1 $Mile^2$ • National-scale Air Toxic Assessment
Social Vulnerability Index (SVI)	• Percent of People Younger Than 5 or Older Than 60 • Locations of Health Care Facilities • Percent of Population in Poverty • Percent of People of Color

	• Percent of People Older Than 25 Without a High School Diploma
Health Index (HI)	• Low Birth Weight Rate • Years of Potential Life Lost Before Age 65 • Asthma Hospitalization Rate Ages 0-19

2.8.8 Community-Focused Exposure and Risk Screening Tool (C-FERST)

The USEPA launched a screening tool called the Community-Focused Exposure and Risk Screening Tool (C-FERST) designed to support EJ research efforts to identify communities that are differentially impacted by environmental exposures and have higher risks for negative health outcomes. C-FERST has mapping and report generation capabilities that capture environmental concentration indicators, human exposure estimates, health risk estimates, and demographic, social, and economic indicators (Table 8). This screening tool was built in response to the needs of EJ communities, pressing environmental issues, and current tools that were not adequately measuring the burden of cumulative stressors. C-FERST allows users to characterize the cumulative impact of multiple environmental stressors and identify at-risk communities, examine environmental problems and differential impacts within communities, and assess the effectiveness of risk reduction actions (Zartarian et al., 2011). The USEPA's main regional offices were the primary users of C-FERST, but it has since been extended to public and environmental health professionals and the general public.

Community users and USEPA staff are consistently reviewing the C-FERST so that they can continue to find ways to improve and build upon the current version to meet the needs of EJ communities. Two case study communities in Milwaukee, Wisconsin informed the initial development of C-FERST; however, pilot projects conducted in other major US cities have aided in bringing the tool to its present form. The unique qualities that distinguish C-FERST from other risk screening tools is that it organizes EPA information and science in a way that connects to other tools to aid in the environmental assessments process (Zartarian et al., 2011). Secondly, it serves as a source for providing and communicating the USEPA's best environmental exposure information while promoting collaborative research opportunities to fill any current gaps in the data (Zartarian et al., 2011).

Table 8. C-FERST Indicators

Community-Focused Exposure and Risk Screening Tool (C-FERST)	
Environmental Concentration Indicators	• Acetaldehyde (μg/m^3) • Acrolein+ (μg/m^3) • Arsenic (μg/m^3) • Benzene (μg/m^3) • Butadiene (μg/m^3) • Chromium (μg/m^3) • Diesel PM (μg/m^3) • Formaldehyde (μg/m^3) • Lead (μg/m^3) • Naphthalene (μg/m^3) • PAH (μg/m^3)
Human Exposure Estimates Indicators	• Acetaldehyde (μg/m^3 Annual Avg. in Human Breathing Zone) • Acrolein+ (μg/m^3 Annual Avg. in Human Breathing Zone) • Arsenic (μg/m^3 Annual Avg. in Human Breathing Zone) • Benzene (μg/m^3 Annual Avg. in Human Breathing Zone) • Butadiene (μg/m^3 Annual Avg. in Human Breathing Zone) • Chromium (μg/m^3 Annual Avg. in Human Breathing Zone) • Diesel PM (μg/m^3 Annual Avg. in Human Breathing Zone) • Formaldehyde (μg/m^3 Annual Avg. in Human Breathing Zone)

	• Lead ($\mu g/m^3$ Annual Avg. in Human Breathing Zone) • Naphthalene ($\mu g/m^3$ Annual Avg. in Human Breathing Zone) • PAH ($\mu g/m^3$ Annual Avg. in Human Breathing Zone)
Health Risk Estimates Indicators	Cumulative Air Toxics Cancer Risk (Risk Per One Million Persons) • Acetaldehyde Cancer Risk (Risk Per One Million Persons) • Arsenic Cancer Risk (Risk Per One Million Persons) • Benzene Cancer Risk (Risk Per One Million Persons) • Butadiene Cancer Risk (Risk Per One Million Persons) • Chromium Cancer Risk (Risk Per One Million Persons) • Formaldehyde Cancer Risk (Risk Per One Million Persons) • Naphthalene Cancer Risk (Risk Per One Million Persons) • PAH Cancer Risk (Risk Per One Million Persons) Cumulative Air Toxics Non-Cancer Respiratory Risk (Hazard Quotient) • Acetaldehyde Non-Cancer Respiratory Risk (Hazard Quotient) • Acrolein Non-Cancer Respiratory Risk (Hazard Quotient) • Chromium Non-Cancer Respiratory Risk (Hazard Quotient) • Diesel PM Non-Cancer Respiratory Risk (Hazard Quotient) • Formaldehyde Non-Cancer Respiratory Risk (Hazard Quotient) • Naphthalene Non-Cancer Respiratory Risk (Hazard Quotient) Cumulative Air Toxics Non-Cancer Neurological Risk (Hazard Quotient) • Lead Non-Cancer Neurological Risk (Hazard Quotient)
Demographic, Social and Economic Indicators	• Minority (%) • Below Poverty Level (%) • Low Income (<2x Poverty Level) (%) • Less than Age 5 Years (%) • Less than 18 Years (%) • >64 Years (%) • >= 25 Years with Less than a HS Degree • Linguistically Isolated Households (%) • Population American Indian and Alaskan Native (%) • Population American Indian and Alaskan Native Below Poverty (%)

2.8.9 Social Vulnerability Index (SVI)

The Social Vulnerability Index (SVI) was a tool created by the Agency for Toxic Substances and Disease Registry (ASTDR) to assist local decision-makers with identifying communities that may need additional support in responding to emergency situations related to outbreaks, natural disasters, and chemical exposures. The SVI ranks vulnerability at the census tract level using indicators from the following four domains: 1) socioeconomic status (SES), 2) household composition & disability, 3) minority status & language, and 4) housing & transportation (ATSDR, 2016) (Table 9). Since the scope of the SVI is emergency-based, it lacks the capacity to quantify a community's daily level of vulnerability that may be attributable to cumulative exposures to environmental hazards and low access to health promoting resources. According to the ASTDR, this tool is best used to create evacuation plans for vulnerable populations, estimate supplies (i.e., food, bedding, medicine, and water) needed in emergencies, designate community funding for emergency preparedness, identify shelters, allocate appropriate numbers of emergency responders, and determine the communities in need of long term support to recover from an emergency incident (ASTDR, 2016).

Table 9. SVI Indicators

Social Vulnerability Index (SVI)	
Socioeconomic Status	• Below Poverty • Unemployed • Income • No High School Diploma

Household Composition & Disability	• Aged 65 or Older • Aged 17 or Younger • Civilian with a Disability • Single-Parent Households
Minority Status & Language	• Minority • Speak English "Less than Well"
Housing and Transportation	• Multi-Unit Structures • Mobile Homes • Crowding • No Vehicle • Group Quarters

2.8.10 Green City Index (GCI)

The Green City Index (GCI) was developed as an environmental quality assessment tool for major cities and is comprised of 16 quantitative and 14 qualitative indicators (Table 10). These indicators may span the following categories depending on the particular region of the city being evaluated and accompanying challenges: 1) CO_2 emissions, 2) energy, 3) buildings, 4) land use, 5) transport, 6) water and sanitation, 7) waste management, and 8) air quality and environmental governance. Over 120 cities have been evaluated by the Green City Index worldwide, with Europe leading as the region with the highest number of participating cities (n=30) (Siemens, 2012). Regarding the scoring criteria, a city may receive an overall index ranking as well as a ranking for each of the eight individual categories expressed as a numerical value or performance band.

For example, there are five possible performance bands that can be assigned to cities within a particular region (Asia, Africa, and Latin America) that range from "well below average" to "well below average". Among Asian cities eligible for this style of ranking, Singapore was the only city that performed “well above average” classification while Karachi was the sole recipient of the “well below average” band (Siemens, 2012). In Latin American regions, Curitiba had the highest performance ranking while Guadalajara and Lima shared the lowest ranking of “well below average” for environmental quality. There were no recipients of the highest performance band in the African region; however, Dar es Salaam and Maputo scored “well below average” (Siemens, 2012).

In contrast to the performance band evaluation technique, there are some regions like the US, Canada, and Europe that can use numerical values to measure environmental quality within their major cities. Specifically, Copenhagen ranked highest (87.31) in environmental quality among 30 European cities whereas Kiev had the lowest score (32.33) (Siemens, 2012). The US and Canadian estimates were similar to those found in Europe, where San Francisco, CA was considered the highest-ranking city (83.8) for environmental quality among 27 total US and Canadian cities (Siemens, 2012). In contrast, Detroit, MI had the lowest ranking score for environmental quality (28.4) (Siemens, 2012). Regardless of the format (numerical versus categorical bands) used to rank cities, the Green City Index does include policy indicators that may account for disparities in environmental quality among major cities. Some of the policies included in the Green City Index relate to clean air, water efficiency and treatment, land use, transportation congestion reduction, energy efficient buildings, clean and efficient energy, and CO_2 reduction. A few studies have noted the importance of evidence-based public health policies and their ability to significantly impact health status when enacted and enforced (Brownson, Chriqui, & Stamatakis, 2009; CDC, 2011).

While the GCI has been innovative in its inclusion of policy indicators, there are still a few limitations that would prevent this index from becoming a standardized cumulative impacts assessment tool. For example, this index uses environmental data compiled on a global scale where many of the cities may not have access to the same type of information. Therefore, comparing environmental quality scores across cities that are included in the index may present a challenge if they are not located in the same region. This index exclusively focuses on major cities and cannot be used to draw comparisons about environmental quality in more rural areas of the US. Since capturing other types of environmental stressors (i.e., poverty, segregation, access to health services) are not in line with the original purpose of the GCI, it could never be used a comprehensive environmental assessment tool that reflects all domains of the environment. The GCI also fails to measure ozone and $PM_{2.5}$ concentrations, which are variables that are often incorporated into environmental health screening or risk assessment tools due to their strong association with adverse health outcomes (Grant & Bell, 2010; Hime, Cowie, & Marks, 2015; Jerrett et al., 2009; Szyszkowicz & Rowe, 2016).

Table 10. GCI Indicators

Green City Index (GCI)	• CO_2 Emissions Per Unit of GDP • CO_2 Emissions Per Person • CO_2 Reduction Strategy • Electricity Consumption Per Unit of GDP • Electricity Consumption Per Person • Clean and Efficient Energy Policies • Green Spaces • Population Density • Urban Sprawl • Number of LEED Certified Buildings • Energy Efficient Building Standards • Energy Efficient Building Incentives • Share of Workers Traveling by Public Transit, Bicycle,

	or Foot • Public Transport Supply • Average Commute Time from Residence to Work • Green Transport Promotion • Congestion Reduction Policies • Water Consumption Per Capita • Water System Leakages • Water Quality Policy • Stormwater Management Policy • Percent of Municipal Solid Waste Recycled • Waste Reduction Policies • NO_x Emissions • PM_{10} Emissions • Clean Air Policy • Green Action Plan • Green Management • Public Participation in Green Policy

2.9 Resilience Indices

2.9.1 Resilience Capacity Index (RCI)

The Resilience Capacity Index (RCI) was designed to examine a region's ability to adapt to potential challenges that may arise of in the future (Building Resilient Regions, n.d.). It consists of 12 equally weighted indicators that measure regional economic, socio-demographic, and community connectivity capacity across metropolitan areas of the US (Table 11). These regions are then separated by quintiles into very high, high, medium, low, and very low resilience categories based on their capacity to recover from a stress event (Building Resilient Regions, n.d.). A z-score is assigned to each metropolitan area to account for disparities in the indicator metrics and is used to further rank metropolitan area. Though the RCI includes several variables that are important for resiliency, it excludes certain environmental stressors that may influence community resilience. The RCI is also limited by its ability to measure resiliency in only metropolitan areas.

Table 11. RCI Indicators

Resilience Capacity Index (RCI)	
Economic Indicators	• Income Equality • Economic Diversification • Regional Affordability • Business Environment
Sociodemographic Indicators	• Educational Attainment • Without Disability • Out of Poverty • Health-Insured
Community Connectivity Indicators	• Civic Infrastructure • Metropolitan Stability • Homeownership • Voter Participation

2.9.2 Tool for Health & Resilience In Vulnerable Environments (THRIVE)

THRIVE is a comprehensive resiliency tool that allows communities to determine ways to improve health and safety and promote health equity by exploring components of the social-cultural environment (people), physical environment (place), and economic environment (equitable opportunity) (Prevention Institute, n.d.). THRIVE captures various aspects of the physical environment that seem to be lacking in the RCI. This tool allows community members and other stakeholders to score and prioritize the following topics: 1) air, water, and soil quality; 2) access to transportation; 3) access to parks and green space; 4) access to health promoting services; and 5) access to pathogenic products and services (Table 12). Nevertheless, THRIVE does not directly measure environmental stressors and assets in a way that would allow resiliency to be quantified and compared across communities.

Table 12. THRIVE Indicators

Tool for Health & Resilience In Vulnerable Environments (THRIVE)	
People	• Social Networks & Trust • Participation & Willingness to Act for the Community Good • Norms & Culture
Place	• What's Sold & How it's Promoted • Look, Feel & Safety • Parks & Open Space • Getting Around • Housing • Air, Water & Soil • Arts & Cultural Expression
Equitable Opportunity	• Education • Living Wages & Local Wealth

2.9.3 Coastal Community Resilience Index (CRI)

The CRI is another resiliency tool designed to aide community leaders in evaluating whether their respective communities will continue to function at an acceptable capacity after a disaster occurs. This tool is more of a self-assessment used to identify areas that a community may become more resilient and determine the resources that should allocated to these communities to improve resiliency (Sempier, Swann, Emmer, Sempier, & Schneider, 2010). While the CRI tool was never designed to compare the results with other communities, it can be used to examine changes in resiliency within communities measured on a scale of low, medium, or high resiliency.

The CRI allows communities to self-evaluate resiliency based on a bad storm or future storm scenario. Communities can then assess resiliency based on the following categories: 1) critical infrastructure and facilities, 2) transportation issues, 3) community plans and agreements, 4) mitigation measures, 5) business plans, and 6) social systems (Table 13) (Sempier, Swann, Emmer, Sempier, & Schneider, 2010). Check marks are tallied for each of the six categories that correspond to a percentage, and the percentages further correspond to the low, medium, and high resiliency ratings. Since the CRI is storm specific, it is not equipped to measure resiliency in response to a community's ability to withstand exposures to cumulative environmental stressors (chemical and non-chemical) that may negatively impact health over time.

Table 13. Coastal CRI Indicators

Coastal Community Resilience Index (CRI) Indicators	
Critical Infrastructure and Facilities	• Wastewater treatment system • Power Grid • Water Purification System • Transportation/Evacuation Routes • City Hall or Other Local Government Building(s) • Police Station or Other Law Enforcement Building(s) • Fire Station(s) • Communications Main Office or Substations • Emergency Operation Center • Evacuation Shelter(s) • Hospital (s) • Critical Record Storage
Transportation Issues	• Will primary bridge(s) be out for less than one week? • Will roads blocked by storm debris (trees, wrack) be cleared in less than one week? • Will washouts (roads) be passable in less than one week? • Will flood-areas (tunnels, roads in low-lying areas) be operational within one week? • Is public transportation available to assist evacuation of residents unable to evacuate on their own?

	• Is there more than one evacuation route? • Is there a plan for post-storm traffic management?
Community Plans and Agreements	• Participate in the FEMA Community Rating System? • Use an early flood warning system? • Have a certified floodplain manager? • Have planning commissioner(s) with formal training in planning? • Have a planning staff with credentials from the American Institute of Certified Planners (AICP)? • Have a FEMA-approved and state EMS-approved mitigation plan? • If you have an approved mitigation plan, has it been revised in the past two years? • Have Memorandums of Understanding (MOUs) or Memorandums of Agreement (MOAs) with neighboring communities to help each other during times of disaster? • Have a comprehensive plan or strategic plan that addresses natural disasters? • Have a floodplain manager or planner who participates in the following organizations: - Association of State Floodplain Managers or State Floodplain Management Association? - American Planning Association (APA) or state APA chapter? - American Society of Civil Engineers (ASCE) or state or local section of ASCE? - American Public Works Association? • Have first-hand experience with disaster recovery within the last 10 years? • Have a communication system to use before, during and after a disaster?
Mitigation Measures	• Elevation of residential, nonresidential buildings, or infrastructure to National Flood Insurance Program standards for your community* • Relocation of buildings and infrastructure from flood-prone areas • Flood-proofing of nonresidential structures • Education programs about mitigation options for your community • Acquisition of repetitive loss structures, infrastructure, or property • Incentives-based mitigation measures • Adoption of the most recent International Building Codes • Hiring certified building inspectors • Staffing an adequate number of people to enforce building codes

	• Have completed or planned shoreline restoration projects for critically eroding areas • Require the protection and maintenance of sensitive coastal habitats, ecosystems, and natural features (dunes, barrier islands, salt marshes, mangroves) • Have undeveloped public lands, such as parks, forests or preserves in the coastal high hazard areas (V-zone on FIRM map)
Business Plans	• Generators • Backup options for basic needs (water, sewer, food, and communications) • Plans to bring in staff to help reopen the business (considering impacts to staff) • Plans for restocking • Plans for ice distribution
Social Systems	• Strong faith-based networks (counted on during a disaster) • Cultural identity (unified Hispanic, Asian or other ethnic communities) • Neighborhood associations support members in times of need • Business cooperative or working relations (industries that employ many residents, Chamber of Commerce, other business-related networks, etc.) • Strong civic organizations (Kiwanis Club, Rotary Club, etc.)

2.9.4 City Resilience Index (CRI)

The City Resilience Index (CRI) uses four overarching dimensions to evaluate resilience within cities: 1) health and well-being, 2) economy and society, 3) infrastructure and environment, and 4) leadership and strategy (Table 14) (Arup & The Rockefeller Foundation, 2015). The four dimensions are comprised of 12 goals (three per dimension) and 52 comprehensive indicators cities can use to achieve resiliency. The assessment consists of qualitative and quantitative questions that may be used to evaluate a city's current resiliency profile and inform their trajectory towards a more resilient future (Arup & The Rockefeller Foundation, 2015). The CRI does consider an array of indicators that are important in achieving community resiliency, such as adequate education for all, appropriate land use and zoning, actively engaged citizens, adequate access to healthcare services, safe and affordable housing, and sufficient affordable food supply (Arup & The Rockefeller Foundation, 2015). However, the results cannot be compared to other cities, the indicators are somewhat subjective, and the number of indicators may make this assessment cumbersome and difficult to obtain resiliency.

Table 14. CRI Indicators

City Resilience Index (CRI)		
Dimensions	Goals	Indicators
Health & Wellbeing	• Minimal Human Vulnerability • Diverse Livelihoods & Employment • Effective Safeguards to Human Health & Life	• Safe and Affordable Housing • Adequate Affordable Energy Supply • Inclusive Access to Safe Drinking Water • Effective Sanitation • Sufficient Affordable Food Supply • Inclusive Labour Policies • Relevant Skills and Training • Local Business Development and Innovation • Supportive Financing Mechanisms • Diverse Protection of Livelihoods Following a Shock • Robust Public Health Systems • Adequate Access to Quality Healthcare • Emergency Medical Care • Effective Emergency Response Services

Economy & Society	• Collective Identity & Community Support • Comprehensive Security & Rule of Law • Sustainable Economy	• Local Community Support • Cohesive Communities • Strong City-Wide Identity and Culture • Actively Engaged Citizens • Effective Systems to Deter Crime • Proactive Corruption Prevention • Competent Policing • Accessible Criminal and Civil Justice • Well-Managed Public Finances • Comprehensive Business Continuity Planning • Diverse Economic Base • Attractive Business Environment • Strong Integration with Regional and Global Economies
Infrastructure & Environment	• Reliable Mobility & Communications • Effective Provision of Critical Services • Reduced Exposure & Fragility	• Secure Technology Networks • Reliable Communications Technology • Effective Transport Operation & Maintenance • Diverse and Affordable Transport Networks • Adequate Continuity for Critical Assets and Services • Diligent Maintenance • Retained Spare Capacity • Flexible Infrastructure Services • Effective Stewardship of Ecosystems • Robust Protective Infrastructure • Effectively Managed Protective Ecosystems • Appropriate Codes, Standards and Enforcement • Comprehensive Hazard and Exposure Mapping
Leadership and Strategy	• Effective Leadership	• Appropriate Government

	& Management • Empowered Stakeholders • Integrated Development Planning	Decision-Making • Effective Co-Ordination with Other Government Bodies • Proactive Multi-Stakeholder Collaboration • Comprehensive Hazard Monitoring and Risk Assessment • Comprehensive Government Emergency Management • Adequate Education for All • Widespread Community Awareness and Preparedness • Mechanisms for Communities to Engage with Government • Comprehensive City Monitoring and Data Management • Consultative Planning Process • Appropriate Land Use and Zoning • Robust Planning Approval Process

2.9.5 Rural Resilience Index (RRI)

The Rural Resilience Index (RRI) is another tool designed to evaluate community resiliency to disasters that occur in more rural or remote areas. The RRI is comprised of multiple dimensions that fall within categories of community resources and disaster management (Table 15) (Cox & Hamlen, 2015; Justice Institute of British Columbia [JIBC], n.d.). The community resources section whether communities have high or low resilience based on the following characteristics: 1) close-knit and involved, 2) self-sufficient and resourceful, 3) diverse in skills, knowledge and fostering tradition, 4) strong health and social support system, 5) strong local leadership and governance, 6) stable and sustainable, 7) adequate services and utilities, and 8) administrative services support our community (Cox & Hamlen, 2015; JIBC, n.d.).

In contrast, the disaster management section focuses on the following resiliency attributes: 1) disaster aware, 2) prepared for disaster, 3) structures are protected, 4) farms, commercial livestock, working animals and pets are protected, 5) comprehensive disaster plan, 6) involved in ongoing disaster planning, 7) adequate first response capacity, and 8) adequate emergency medical response capacity (Cox & Hamlen, 2015; JIBC, n.d.). While the RRI is a comprehensive resiliency assessment tool, each characteristic is rated subjectively as "yes" or "no" and the results cannot be quantified due to the qualitative nature of the tool. Specifically, there is no adequate method to examine the variation between communities since the measures for each dimension are "high risk", "low risk", "need more info", and "not applicable". Individual communities can still internally monitor changes in resiliency over time if their ratings change from high to low risk or low to high risk. Nevertheless, the RRI and many of the other resiliency tools would benefit from a more quantitative rating system that would allow for comparisons between different communities and evaluations of statistically significant differences in resiliency within communities over time.

Table 15. RRI Indicators

Rural Resilience Index	
Community Resources	• Our community is close knit and involved • Our community is self-sufficient and resourceful • Our community is diverse in skills, knowledge and culture • Our community has a strong health and social support system

	• Our community has strong local leadership and governance • Our community is stable and sustainable • Our community has adequate services and utilities • Regional governance and services support our community • Our community is disaster aware
Disaster Management	• Our community is prepared for disaster • Our community structures are protected • Our livestock, animals and farms are protected • Our community has a comprehensive disaster plan • Our community is involved in ongoing disaster planning • Our community has adequate first response capacity • Our community has adequate medical response capacity

2.9.6 Hazard Resilience Index (HRI)

The Hazard Resilience Index (HRI) was also developed by the JIBC and can be used in conjunction with the RRI to assess community resilience to local hazard-risk priorities (JIBC, 2015). Specifically, the HRI tool allows communities to identify their strengths, assets and vulnerabilities through the lens of 17 categories of potential disasters. Some of the categories in the HRI are related to accidents, various natural hazards, food shortages, terrorism, diseases, structural challenges, and nuclear events (Table 16) (JIBC, 2015). The HRI uses comprehensive categories to assess resiliency as previously mentioned, but it has the same limitations in its rating system as the RRI.

Table 16. HRI Indicators

Hazard Resilience Index (HRI)	
Accidents	• Air Plane Crashes • Marine Accidents • Motor Vehicle Crashes • Train Derailments

Astronomical	• Asteroid, Comets, and Meteor Crashes • Geomagnetic and Lonospheric Storms • Space Object Crashes
Atmospheric	• Blizzards • Climate Change • Drought – Natural and Human Caused • Extreme Cold • Fog • Frost Hailstorms • Hear Waves • Hurricanes • Ice Fogs, Ice Storms, and Freezing Rain • Lake-Effect Storms • Lightning and Thunderstorms • Microbursts • Sea Storms and Sea Surges • Seiche • Snowstorms • Tornadoes and Waterspouts • Windstorms
Conflictual Social Action	• Conflictual Social Action
Contamination	• Air Pollution • Soil Contamination • Water Contamination
Dam Failure and Structural Collapse	• Dam Failure • Structural Collapse – Buildings • Structural Collapse – Transportation
Diseases	• Animals – Air & Water • Animals – Human Transmitted • Animals – Animal Transmitted • Human – Air and Water Transmitted • Human – Animal Transmitted • Human – Human Transmitted • Human – Food Transmitted • Plants – Human Controlled • Plants – General • Plants and Pest Infestations
Earthquakes, Tsunamis & Volcanos	• Earthquakes • Tsunamis • Volcano-Ash Falls, Projectiles and Lateral Blasts, Pyrochlastic Flows and Lava Flows

Fires	• Brush, Bush and Grass Fires • Community Structural Fires • Community Interface Fires • Forest Fires or Wildfires • Peat Bog Fires
Food Shortages	• Food Shortages: For Communities that Depend Mostly on Local Food for Sustenance • Food Shortages: For Communities that Depend Mostly on Food Grown Elsewhere Sustenance
Geological Hazards	• Dust and Sand Storms • Erosions, Deposition and Desertification • Expansive Soils • Gravitational Mass Movement (Landslides) • Gravitational Mass Movement (Landslides): Debris Avalanches, Debris Flows and Torrents – Natural • Land Subsidence and Sinkholes • Submarine Slides
Hazardous Material Spills, Explosions and Oil Pipeline and Gas Leaks	• Gas Explosions and Gas Leaks • Mine Explosions • Oil Pipe-Line Leaks • Other Explosions • Hazardous Material Spill – On Site • Hazardous Material Spill – Air Transport • Hazardous Material Spill – Marine Transport • Hazardous Material Spill – Land Transport • Hazardous Material Spill – Rail Transport
Hydrological Hazards	• Avalanches – Natural & Human Caused • Flash Floods • Ice Jam Floods • Local Floods • Rain Storm Floods • Snow Melt Floods • Glaciers • Icebergs, Sea Ice and Icefloes • Lake Outbursts
Nuclear Failure	• Nuclear Accidents

Power and Water Outages	• Power Outages • Water Outages
Riots	• Riots
Terrorism	• Terrorism – General • Terrorism – Biological • Terrorism – Chemical • Terrorism – Cyber Terrorism • Terrorism – Explosives and Bombs • Terrorism – Nuclear

2.10 Environmental Stressors and Resiliency Conceptual Framework

An exposome layer encapsulates our environmental stressors and resiliency conceptual framework (Figure 2), which is a concept first defined in 2005 as the totality of life-course environmental exposures from conception onwards (Wild, 2005). The exposome concept considers the complexity of multiple environmental exposures and responses to chemical stressors, nonchemical stressors, microbiome metabolites, and infectious agents at varying levels and scales (Cui, 2016). Within the exposome, we demonstrate how exposures to environmental stressors, perceptions of environmental stressors, and resiliency factors may work collectively to impact allostatic load (i.e., stress) at varying levels (i.e., individual, family, and community).

Allostatic load simply refers to the cumulative biological tax on the body from physiological responses to daily stressors (Sexton & Linder, 2011). Consequently, a dose-response relationship may exist between exposures to environmental stressors and allostatic load that can promote vulnerability or risk (Theall, Drury, & Shirtcliff, 2012). This conceptual framework takes into account the relationship between cumulative environmental exposures, allostatic load, and disease onset, which may be influenced by an individual's valuation of exposure and their accompanying physiological and psychological responses to a stressor (Adler, 2009). Allostatic load has been associated with damaging health behaviors (i.e. alcohol and tobacco abuse), cardiovascular disease, and mortality, which may further proliferate health disparities among vulnerable populations (Beckie, 2012).

Social and environmental stressors play a critical role in perpetuating health disparities (Clougherty & Kubzansky, 2009; Gee & Payne-Sturges, 2004; Morello-Frosch, Zuk, Jerrett, Shamasunder, & Kyle, 2011) due to their contribution to chronic individual stress and allostatic load (Logan & Barksdale, 2008; Morello Frosch & Shenassa, 2006; Sexton & Linder, 2011). A stressor is considered as any perceived or actual threat to an individual that has the capacity to disrupt homeostasis and cause stress (Schneiderman, Ironson, & Siegal, 2005). While most people experience acute stress in response to a stressful event over the life course, chronic stress may be more problematic because it may increase one's risk for several health problems like CVD (Torpy, Lynm, & Glass, 2007), neurologic and psychiatric diseases (Davis, Holmes, Pietrzak, & Esterlis, 2017), Parkinson's disease (Austin, Ameringer, & Cloud, 2016), multiple sclerosis (Mohr, Hart, Julian, Cox, & Pelletier, 2004), eating disorders (Yau & Potenza, 2013), addictions (Sinha, 2001), post-traumatic stress disorder (PTSD) (McFarlane, 2010), and sleeping complications (Oken, Chamine, & Wakeland, 2015).

In our conceptual framework, we explore several physical and social factors that may be pathogenic or health repressing. Race/ethnicity is one factor that may exacerbate the negative effects of environmental stressors (pathogens) (Gee & Payne-Sturges, 2004; Morello-Frosch, Zuk, Jerrett, Shamasunder, & Kyle, 2011) on health while resiliency buffers (e.g., salutogens) may counteract the body's physiological and psychological response to stressors and promote health (Davis, Cook, & Cohen, 2005). We illustrate the relationships between these concepts to illustrate how perceptions of exposures may contribute to stress and adverse health outcomes.

2.10.1 Environmental Exposures

Built Environment Stressors

Brownfields

According to the USEPA, a brownfield is defined as the expansion, redevelopment, or reuse of a property that may contain hazardous substances or pollutants. Several studies have documented the negative impact of brownfields on human health (Ding, 2006; Litt, Tran, & Burke, 2002; Tang, 2013). For example, one study found brownfields were strongly associated with 'not good health', limiting long-term illness, and premature all-cause mortality (Bambra et al., 2014). Moreover, communities with larger plots of brownfield land had a higher morbidity rate compared to those with a smaller proportion of brownfield land after controlling for relevant confounders (Bambra et al., 2014).

Diesel PM Concentration

Diesel PM is a complex mixture of acetaldehyde, acrolein, benzene, 1,3-butadience, formaldehyde, and polycyclic aromatic hydrocarbons (PAHs) that comprise diesel exhaust (USEPA, 2002). The sources of diesel PM include emissions from trucks, buses, cars, locomotives, ships, and heavy-duty equipment. When inhaled, diesel PM may cause irritation of the eyes, nose, and throat (USEPA, 2002), as well as increase one's risk for lung cancer (Silverman, 2017), exacerbations of asthma (McEntee & Ogneva-Himmelberger, 2008), neurological effects (Kilbum, 2000), and inflammation (Xu et al., 2013).

Lead Paint (% pre-1960s housing)

Lead-contaminated house dust from lead paint found in older homes is the major source of lead exposure among children in the US (CDC, 2017). Children are especially vulnerable to lead exposures since they have more hand-mouth behaviors and spend time on dusty floors, have a higher absorption rate than adults in their gastrointestinal tract, and their blood-brain barrier and detoxification systems are less developed (Abelsohn & Sanborn, 2010; Kennedy, Lordo, Sucosky, Boehm, & Brown, 2014). While there is no safe blood lead level (BLL) in children, a reference level of 5 microgram per deciliter (μg/dl) is being used to identify individuals who have been exposed to lead and require case management (CDC, 2012a; WHO, 2016a). Exposure to lead is associated with developmental neurotoxicity in children, reproductive dysfunction in adults, as well as toxicity to the kidneys, blood, and endocrine systems in both children and adults (Sanborn, Abelsohn, Campbell & Weir, 2002; WHO, 2016a). Sources of lead exposure may include: 1) lead-based paint in older homes, 2) contaminated soil, 3) groundwater and surface water near industrial and mining areas, 4) drinking water when lead pipes or plumbing fixtures corrode, 5) outdoor air (i.e., aviation fuel, industrial emissions, metal processing), 6) food (i.e., lead-glazed pottery or porcelain containers), and 7) manufactured products (i.e., toys, jewelry, cosmostics) (President's Task Force on

Environmental Health Risks and Safety Risks to Children, 2016; Sanborn, Abelsohn, Campbell & Weir, 2002).

LUSTs

LUSTs are defined as leaking tanks or underground piping connected to a tank that has a minimum of 10% of its total volume located underground (Wilson et al., 2012b; Wilson et al., 2013; USEPA, n.d.e.). These tanks may contain carcinogenic compounds such as benzene, where exposure via water contamination may lead to increased bleeding and decreased immune function (USDHHS, Public Health Service [PHS], Agency for Toxic Substances and Disease Registry [ATSDR], 2007). Other non-carcinogenic contaminants (i.e., toluene, ethylbenzene, xylene, petroleum, etc…) found in LUSTs may lead to kidney or liver damage, lung dysfunction, hearing loss, eye irritation, memory loss, difficulty breathing, and fatigue (GAO, 2007); ATSDR, 1999; Wilson et al., 2013).

Ozone Concentrations

Ozone is considered an odorless gas that contains three oxygen atoms, and may be further classified into two different types: 1) stratospheric and 2) ground-level. While stratospheric O_3 serves as a protective layer around the Earth's surface that blocks ultraviolent radiation, ground-level O_3 is detrimental to human health and the environment (USEPA, n.d.f.). Nitrogen oxides (NO_x) and VOCs react in the presence of sunlight and heat to create this greenhouse gas. Exposure to ozone has been associated increased frequency of asthma attacks (Kim et al., 2011), aggravation of lung diseases

(Strom, Alfredsson, Malmfors, & Selroos, 1994), airway irritation, inflammation, and difficulty breathing (Chen, Kuschner, Gokhale, & Shofer, 2007; USEPA, n.d.f.). Exposure to ozone has also been associated with an increase in stroke and cardiopulmonary hospitalizations (Carlsen, Forsberg, Meister, Gislason, & Oudin, 2013), but the relationship has been refuted in other studies (Montresor-Lopez, et al., 2016). The USEPA has set National Ambient Air Quality Standards (NAAQS) for O_3 at 75 parts per billion (ppb) averaged over an 8-hour period in order to protect the most vulnerable populations from negative health outcomes (USEPA, n.d.g).

$PM_{2.5}$ Concentrations

$PM_{2.5}$ is a complex mixture of compounds found in the atmosphere that contains elemental and organic carbon, crustal materials (soil and ash), nitrates, and sulfates. Unlike other geographic areas in the US, $PM_{2.5}$ concentrations are mostly comprised of sulfates and carbon (Sallis & Glanz, 2009) in the southeastern region of the nation. While there are several sources of $PM_{2.5}$ that result from combustion and industrial activity (i.e., power plants, wood burning, motor vehicles, and coal and oil related activities), the main source is automobile traffic (Molnar, Gortmaker, Bull & Buka, 2004; Sallis & Glanz, 2009).

In an effort to protect the public's health and traditionally vulnerable subpopulations (e.g., asthmatics, children, and the elderly), the USEPA has set NAAQS for $PM_{2.5}$ where concentrations should not exceed 12 ug/m^3 over the course of a year (annual mean averaged over three years) and 35 ug/m^3 over a 24-hour period (98^{th} percentile averaged over a three-year period) (Lovasi, Hutson, Guerra, & Neckerman, 2009; USEPA, n.d.g.). Despite the implementation of these federal standards, there is a wealth of research that has shown a positive association between $PM_{2.5}$ exposure and adverse health outcomes. Specifically, $PM_{2.5}$ exposure has been associated with premature mortality (Wang et al., 2015), heart disease (Du, Xu, Chu, Guo, & Wang, 2016), heart attacks (Cesaroni et al., 2014), stroke (Scheers, Jacobs, Casas, Nemery, & Nawrot, 2015), low birth-weight (Ebisu & Bell, 2012), respiratory diseases (Xing, Xu, Shi, & Lian, 2016), and asthma exacerbation (Orellano, Quaranta, Reynoso, Balbi, & Vasquez, 2017). Exposure to $PM_{2.5}$ is also associated with heart disease mortality (Ueda, Nitta, & Ono, 2009) and increased risk for hospital admissions and emergency department visits related to cardiometabolic conditions (Kloog, Coull, Zanobetti, Koutrakis, & Schwartz, 2012).

Toxic Release Inventory (TRI) Facilities

TRI facilities are considered industry sectors that may manufacture, process, or use any of the more than 650 toxic chemicals that may pose a threat to human health or the environment (USEPA, n.d.h.). The facilities are mandated to report the amount of toxic chemicals that they release into the air or water, or may dispose of in a landfill to the USEPA based on the size of the facility. Studies have documented the harmful effects that these releases may pose on human health, such as an increase in total (Hendryx & Fedorko, 2011) and cardiovascular morality outcomes (Hendryx, Luo, & Chen, 2014). Furthermore, populations exposed to TRI releases may also have an increased risk of low birth weight (Porter, Kent, Su, Beck, & Gohlke, 2014), asthma (Legot, London, Shandra, & Rosofsky, 2011), and cancer (Choi, Shim, Kaye, & Ryan, 2006). The literature also shows that TRI facilities are disproportionately located in low-income areas and among populations of color (Pastor, Sadd, & Morello-Frosch, 2004; Wilson et al., 2012a).

Toxic Releases from Facilities

Toxic chemicals released into the environment from various industrial activities may negatively impact human health and the environment. Specifically, toxic releases from industrial sources have been linked with a higher risk of infant mortality (Currie & Schmieder, 2008); respiratory (i.e., asthma) and neurological diseases (Legot, London, Rosofsky, & Shandra, 2012), and cancer (Luo, Hendryx, & Ducatman, 2011). Of the 25.45 billion pounds of production-related waste managed across various TRI facilities in 2014, 3.9 billion pounds were disposed or released into the air, land, and water (USEPA, 2016b). Many of these toxic chemicals are exorbitantly released in predominately non-white and economically disadvantaged communities (Collins, Munoz, & JaJa, 2016; Faber & Krieg, 2002; Johnson, Ramsey-White, & Fuller, 2016).

Superfund Sites

Superfund sites are abandoned hazardous waste sites that the USEPA has deemed as a significant threat to human and environmental health (USEPA, n.d.i.). While many of these sites have been placed on the UEPA's National Priorities List (NPL) for cleanup, there are still sites that contain chemicals (i.e., volatile organic compounds [VOCs], mercury, polycyclic aromatic hydrocarbons [PAHs], dioxin) that may result in long-term health effects if exposed. Exposure to these contaminants may result in an increased risk for the following health outcomes: 1) birth defects, 2) diabetes, 3) urinary tract disorders, 4) eczema, 5) impaired speech and hearing, 6) anemia, 7) stroke, and 8) decreased immune function (Burwell-Naney et al., 2013; Currie, Greenstone, & Moretti, 2011; Kouznetsova, Huang, Ma, Lessner, & Carpenter, 2007; Lybarger, 1998; Sergeev & Carpenter, 2010).

Traffic Density

Traffic congestion is considered a significant issue, particularly in urban communities, since high traffic density may equate to the release of more motor vehicle emissions. Heavily trafficked roadways have been linked to a number of adverse health outcomes, including increased risk of asthma exacerbation (Brown et al., 2012), cardiac and pulmonary mortality (Brugge, Durant, & Rioux, 2007), additional hospital admissions (Cook, deVos, Pereira, Jardine, & Weinstein, 2011), and exacerbated respiratory symptoms (US Department of Transportation [USDOT], 2007). Studies have shown economically disadvantaged and non-white populations are disproportionately exposed to traffic and may have a higher risk for the aforementioned adverse health outcomes (Pratt, Vadali, Kvale, & Ellickson, 2015; Rowangould, 2013).

Alcohol Outlets

Research has shown that persons with greater access to alcohol facilities are more likely to consume unhealthy quantities of alcohol and have a hospital visit related to anxiety, stress, or depression (Pereira, Wood, Foster, & Haggar, 2013). Moreover, another study indicated alcohol-related hospitalizations and mortality were significantly higher in communities with a higher density of alcohol outlets (Richardson, Hill, Mitchell, Pearce, & Shortt, 2015). Other studies have shown that a higher density of alcohol outlets is associated with higher rates of violence, crime, drunk driving accidents, and pedestrian injuries (Campbell et al., 2009; Pacific Institute, n.d.).

Land-Use Planning and Zoning

Land using planning and zoning practices have played a role in escalating differential exposures to neighborhood stressors and reducing the presence of health promoting infrastructure in communities with EJ issues (Maantay, 2001; Rossen & Pollack, 2012; Wilson, 2009; Wilson, Hutson, & Mujahid, 2008). The implications of inequitable development are catastrophic since the quality of one's neighborhood environment has direct links with health. For example, residing in disadvantaged neighborhoods that lack health-promoting attributes (i.e., availability of recreational resources and healthy food locales) has been associated with an increased for cardiovascular disease, asthma, and cancer (Diez Roux, 2006; Rossen & Pollack, 2012; Wilson, Hutson, & Mujahid, 2008). Similarly, the social environment or neighborhood contextual factors (i.e., crime, social cohesion, and collective efficacy) have been linked with hypertension (Morenoff et al., 2007), obesity (Burdette, Wadden, & Whitaker, 2006), and risky health behaviors (i.e., smoking) (Mmari et al., 2014).

Housing Quality

Housing quality is extremely important for health and well-being due to its ability to contribute to various adverse health conditions. Not only are physical conditions (i.e., ventilation, heat, cold, lighting) important, there are also chemical, biological, and social conditions to consider as factors that may impact health (Jacobs, 2011). Specifically, substandard housing conditions have been associated with asthma, lead poisoning, respiratory problems, injuries, and mental health issues (Bashir, 2002; Hood, 2005; Krieger & Higgins, 2002; Northridge, Ramirez, Stingone, & Claudio, 2010). Like many other social environmental stressors, the individuals most burdened by moderate and severe substandard housing conditions are African-American and Hispanic populations (Hood, 2005; Jacobs, 2011).

Social Environment Stressors

Educational Attainment

Several studies have documented the relationship between educational attainment and health (North Carolina Institute of Medicine, 2009; Telfair & Shelton, 2012; Zimmerman, Woolf, & Haley, 2014), meaning that populations with more education have lower morbidity and mortality rates (Adler & Newman, 2002; Baker, Leon, Greenaway, Collins, & Movit, 2011; Hahn & Truman, 2015; North Carolina Institute of Medicine, 2009). In fact, populations with a higher level of educational attainment have lower morbidity or mortality for stroke, high cholesterol, ulcers, asthma, hypertension, diabetes, and high cholesterol (Choi et al., 2011; CDC, 2012b; Eisner, Katz, Yelin, Shiboski, & Blanc, 2001; Telfair & Shelton, 2012). Individuals with lower education may be more likely to participate in risky behaviors (i.e., smoking, drinking) (Pampel, Krueger, & Denney, 2010) and evade healthy behaviors related to diet and exercise (Darmon & Drewnowski, 2008; Zimmerman, Woolf, & Haley, 2014). Since educational attainment is closely linked with income, less educated populations may be more likely to live in economically disadvantaged communities that lack access to health-promoting resources (Virginia Commonwealth University [VCU] & Robert Wood Johnson Foundation, 2014; Zimmerman, Woolf, & Haley, 2014).

Linguistically Isolated

Linguistic isolation is important in our examination of environmental and social stressors. Populations who speak limited English may delay medical care since they may lack information on symptoms or services that are available to them for disease prevention or maintenance (Shi, Lebrun, & Tsai, 2009). Linguistically isolated populations may be exposed to racial discrimination due to language barriers, which is a phenomenon that has been associated with low SES, poor quality of life, and stress (Gee & Ponce, 2010).

Long-Term Unemployment

Regarding unemployment status, several studies have shown that unemployed individuals have worse psychological and physical health than those who are currently employed (McKee-Ryan, Song, Wanberg, & Kinicki, 2005; Nichols, Mitchell, & Lindner, 2013; Pharr, Moonie, & Bungum, 2012). Not only does unemployment create psychological distress for the unemployed, it may also create a domino effect of poor health and violence at the family and at the community level. Unemployed individuals are more likely to delay health care services than the employed due to the financial burden, and were less likely to have access to health care that may be required to maintain their well-being (Pharr, Moonie, & Bungum, 2011).

Low-Income (% poverty)

The negative impacts of poverty on health are substantial, with mortality rates among low-income populations being highest for almost all major causes of death (e.g., infectious, nutritional, cardiovascular, metabolic diseases, cancers, and injuries) (Kawachi, Kennedy, Lochner, & Prothrow-Stith, 1997; Mansfield & Novick, 2012). Poverty may also increase one's susceptibility to disease due to the adverse effects of chronic stress on the body's immune system (Brunner & Marmot, 2006; Ziol-Guest, Duncan, Kalil, & Boyce, 2012). Economically disadvantaged groups may be more susceptible to disease due to their disproportionate exposures to chemical and non-chemical stressors (Evans & English, 2002; Massey, 2004; Morello-Frosch, 2011). In addition, they may reside in communities overburdened by disamenities (i.e., fast-food outlets, convenience stores) (Block, Scribner, & DeSalvo, 2004; A. Hilmers, D. C. Hilmers, & Dave, 2012) and lack the resources necessary (i.e. green space, supermarkets) necessary to counteract negative environmental exposures (Astell-Burt, Feng, Mavoa, Badland, & Giles-Corti, 2014).

GINI Index

The Gini coefficient is a quantitative measure of income inequality within a population that may range from zero to one, where zero indicates that all individuals have equal income and one represents perfect inequality (Damgaard, n.d.). Several studies suggest income inequality may be associated with health and well-being (Kaplan, Pamuk, Lynch, Cohen, & Balfour, 1996; Pickett & Wilkinson, 2015; Rowlingson, 2011). Specifically, income inequality biologically presents as chronic stress in the body and is also associated with low levels of trust and social cohesion (Pickett & Wilkinson, 2015). Not only does income inequality impact stress levels, it may also negatively influence life expectancy and infant mortality (Nowatzki, 2012). Other studies have reported evidence of residual effects of income inequality over the life course by demonstrating how adult health may be adversely impacted by income inequality experienced during childhood (Gupta, de Wit, & McKeown, 2007; Lillard, Burkhauser, Hahn, & Wilkins, 2014; Warren, 2016).

Violent Crime

Research has shown violent crime may be associated with poor mental health (Curry, Latkin, & Davey-Rothwell, 2008; Freeman, Smith, & New South Wales, 2014). One study found neighborhood violent crime was associated psychological distress through the following indirect pathways: 1) the community's perceptions of neighborhood disorder and 2) actual violence experienced in the neighborhood (Curry, Latkin, & Davey-Rothwell, 2008). In addition to the impacts on mental health, exposure to violent crime may also be associated with birth outcomes such as small for gestational age (Masi, Hawkley, Piotrowski, & Pickett, 2007), low birth weight, and preterm birth (Messer, Kaufman, Dole, Herring, & Laraia, 2006).

Residential Segregation

Several studies have noted the relationship between environmental health disparities and segregation that may perpetuate health inequalities among populations of color (Jacobs, 2011; Kramer & Hogue, 2009; Morello-Frosch & Jesdale, 2006; Morello-Frosch & Lopez, 2006; Rice et al., 2014). Segregation has been associated with an increased risk of negative health outcomes, such as mortality (Yang & Matthews, 2015), preterm birth (Messer, Laraia, & Mendola, 2009), low-birth weight (Debbink & Bader, 2011), asthma (Pearlman et al., 2006), CVD (Kershaw & Albrecht, 2015), cancer (Morello-Frosh & Jesdale, 2006), and sexually transmitted infections (STIs) (Kramer & Hogue, 2009). This increased risk for adverse health conditions is likely attributable to the disproportionate distribution of environmental hazards in predominately non-white and low-income communities (Gee & Payne-Sturges, 2004: Massey, 2004; Morello-Frosch, Zuk, Jerrett; Shamasunder, & Kyle, 2011; Wilson et al., 2012a; Wilson et al., 2012b). The Dissimilarity Index is one method of representing segregation and may be defined as the amount a group's population percentage would have to change in a small area to have the same percentage of the respective group in a larger geographical area. While there are several other dimensions of segregation (i.e., unevenness, exposure, clustering, concentration, and centralization), the Dissimilarity Index is still considered the best overall measure of segregation due to the ease of computation and interpretation, its tractable properties, and invariance with respect to the relative number of non-white subgroups (Massey, 2012).

2.10.2 Resilience Buffers

In our conceptual framework, we introduce resilience buffers that may counteract physiological and psychological responses to the cumulative impacts of environmental stressors at the community level. Resiliency generally refers to one's ability to withstand, adapt to, or recover from adversity, which can occur at both an individual and/or community level. Community resiliency refers to "the ability of a community to use its assets to strengthen public health and healthcare systems and to improve the community's physical, behavioral, and social health to withstand, adapt to, and recover from adversity" (USDHHS, 2015). To effectively respond to stressors and become resilient, communities must have available assets that are accessible so they can function during and/or after a disturbance (Longstaff, Armstrong, Perrin, Parker, & Hidek, 2010). These assets may include health-promoting infrastructure (i.e., healthy food outlets, green space, health care facilities) that are necessary to counteract cumulative impacts of multiple environmental stressors (Wilson, 2009; Hutson & Wilson, 2011; Morello-Frosch, Zuk, Jerrett, Shamasunder, & Kyle, 2011; Sexton & Linder, 2011). When vulnerable communities lack resiliency, they may be more likely to have higher mortality rates for stroke, hypertension, cancer, diabetes, and heart disease when compared to their White and more affluent counterparts (Do, et al., 2008; Massey 2004; Morello-Frosch et al. 2011). We examine the following resilience buffers that may stimulate stress and lead to health disparities.

Access to Exercise Facilities

Being physically active may significantly improve health outcomes by lowering an individual's risk for the following conditions: 1) heart disease, 2) stroke, 3) type 2 diabetes, 4) depression, and 5) some cancers (CDC, 2016; Press, Freestone, & George, 2003; Warburton, Nicol, & Bredin, 2006). While gyms or health clubs are often an underutilized resource for physical activity, there are still approximately 58,000,000 people in the US who use the gym for their exercise needs (Static Research Brain Institute, 2016). There are some discrepancies in whether the presence of a fitness facility in a community equates to an active lifestyle (Ding, Sallis, Kerr, Lee, & Rosenberg, 2011; Feng, Glass, Curriero, Stewart, & Schwartz, 2010); however, a dearth of these facilities in a region may provide residents with less of an opportunity to be physically active.

For example, one study found that participants with access to exercise facilities (≥4) in their buffer zones (measured within 1,000m line-based road network) spent approximately 5 additional minutes performing moderate to vigorous physical activity per day and a 69% higher odds of meeting recommendations for physical activity (Eriksson, Arvidsson, & Sundquist, 2012). Nevertheless, populations who perceive their communities as unsafe may be less likely to participate in outdoor fitness activities (i.e., playing, walking, or running around the neighborhood) (Sallis & Glanz, 2009; Molnar, Gortmaker, Bull, & Buka 2004; Lovasi, Hutson, Guerra, & Neckerman, 2009) and would benefit from improved access to exercise facilities. Moreover, non-white and lower-income tracts were significantly more likely to not have recreational facilities in their neighborhoods than their White and more affluent counterparts (Moore, Diez Roux, Evenson, McGinn, & Brines, 2008; Powell, Slater, Chaloupka, & Harper, 2006).

Access to Green Space

Green space has been associated with a reduced risk of cardiovascular disease (Jennings & Gaither, 2015; Richardson, Pearce, Mitchell, & Kingham, 2013; WHO, 2016b) and mental health outcomes (Lee, Jordan, & Horsley, 2015; Richardson, Pearce, Mitchell, & Kingham, 2013; Shanahan et al., 2016), as well as type 2 diabetes mellitus (Astell-Burt, Feng, & Kolt, 2014; Dalton et al., 2016; WHO, 2016b). Access to green space has also been associated with lower odds of obesity among populations residing within 300m of the green space (Toftager, 2011). Park and green space access may also promote individual resiliency and well-being due to the social interactions that may occur there (Jennings, Larson, & Yun, 2016; Lee, Jordan, & Horsley, 2015). Without access to parks, individuals may lack opportunities to engage in physical or social activity and ultimately reduce their risk of most adverse health outcomes.

Access to Grocery Stores

Several chronic diseases have been associated with a lower consumption of healthy foods (i.e., fruits and vegetables) (Boeing et al., 2012; Mead, 2008; Wang et al., 2014); however, not all communities have access to groceries stores that may provide the foods necessary to lower risk for diseases such as CVD (Liu et al., 2000), cancer (Boeing et al., 2012), and hypertension (Borgi, et al., 2016). Specifically, areas that have higher poverty levels or a greater percentage of African-Americans are more likely to be designated as a food desert (Dutko, P, Ver Ploeg, M, & Farrigan, 2012; Rodney, 2015; Walker, Keane, & Burke, 2010). According to the USDA, food deserts are considered urban and rural areas that lack access to healthy and affordable foods (USDA, n.d.). A food desert is typically assigned at the census tract level and contains populations who are economically disadvantaged with low access to healthy food retail outlets (Cole, 2012; Cummins & Macintyre, 2002; USDA, n.d.; Walker, Keane, & Burke, 2010). Aside from inadequate access to healthy foods, some of the barriers to increasing healthy dietary behaviors among low-income communities include 1) high prices for healthy food, 2) poor quality of available healthy foods, and 3) lack of quality retail stores nearby (Evans et al., 2015). Nevertheless, eliminating the aforementioned barriers by improving access and availability of healthy foods may ultimately reduce nutrition-related health disparities among non-white communities (Celentano, 2009; Satia, 2009).

Access Primary Healthcare

Studies have demonstrated an association between increased primary care availability and better health outcomes (Chang, Stukel, Flood, & Goodman, 2011), as well as the necessity of primary care services to counteract the negative impact that lower socioeconomic conditions may have on health (Shi, 2012). For example, one study demonstrated how access to healthcare significantly increased the odds of CVD prevention among Latino adults (Alcala et al., 2015).

Access to Mental Healthcare

Mental health is so intricately linked with physical health in that one can cause the other (WHO, 2014). Studies have indicated associations between poor mental health and increased risk of new cardiovascular events following a myocardial infarction (Nielsen, Vestergaard, Christensen, Christensen, & Larsen, 2013), increased risk of stroke (Lambiase, Kubzansky, & Thurston, 2014), as well as a decreased risk of asthma control and quality of life (Lavoie et al., 2005). As a result, improving mental health would ultimately lead to increases in physical health and well-being (WHO, 2014).

Homeownership

There are several studies that demonstrate the positive social impacts of homeownership. For example, homeownership may lead to a creation of wealth, which may promote higher rates of civic engagement and improvements in health due to one's ability to afford quality healthcare (Grinstein-Weiss et al., 2010; Harkness and Newman, 2002; Rohe & Lindblad, 2013). Homeownership also fosters residential stability, which indirectly leads to increased academic performance among children and social capital in adults (Rohe & Lindblad, 2013). Moreover, homeownership may allow individuals to reside in communities with better schools, social conditions, and physical environments (Rohe & Lindblad, 2013) with less crime (Ni & Decker, 2009).

Health Insurance Coverage

Uninsured populations have worse health outcomes compared to the insured because they may be less likely to receive preventive services or screenings (i.e., pap smears, mammograms, prostate screening, colon screening, etc) that could reduce the likelihood of needless conditions (Bernstein, Chollet, & Peterson, 2010). The uninsured may also have less access to certain health care services that promote disease management, which may lead to increased disease severity, more emergency department visits, greater short-term reductions in health, and longer recovery times (Bernstein, Chollet, & Peterson, 2010; National Immigration Law Center, 2014; ODPHP, n.d.c). The disparities in health insurance coverage are evident by gender, age, and race/ethnicity, where a higher percentage of males are insured, young adults (18 – 34) have twice the uninsured rate as older adults (45 – 64), and Hispanic and non-Hispanic Blacks have higher uninsured rates compared with Asian/Pacific Islanders and Whites (CDC, 2011a; Kirby & Kaneda, 2010; Sohn, 2017).

Despite disparities the abovementioned disparities, there is evidence of a positive relationship between health insurance status and health-related outcomes (Institute of Medicine [IOM], 2002; Sommers, Gawande, & Baicker, 2017). For example, having health insurance may cause individuals to receive more preventive and screening services that may ultimately lead to improvements in health (Institute of Medicine [IOM], 2002; Sommers, Gawande, & Baicker, 2017). This is particularly important for diseases like cancer (i.e., breast, prostate, or colorectal cancer), where uninsured patients are more likely to die prematurely than patients with insurance due to the delay in diagnosis (Marwick, 2002; Sommers, Gawande, & Baicker, 2017). Health insurance coverage has also been associated with reductions in mortality (Wilper et al., 2009; Woolhandler & Himmelstein, 2017).

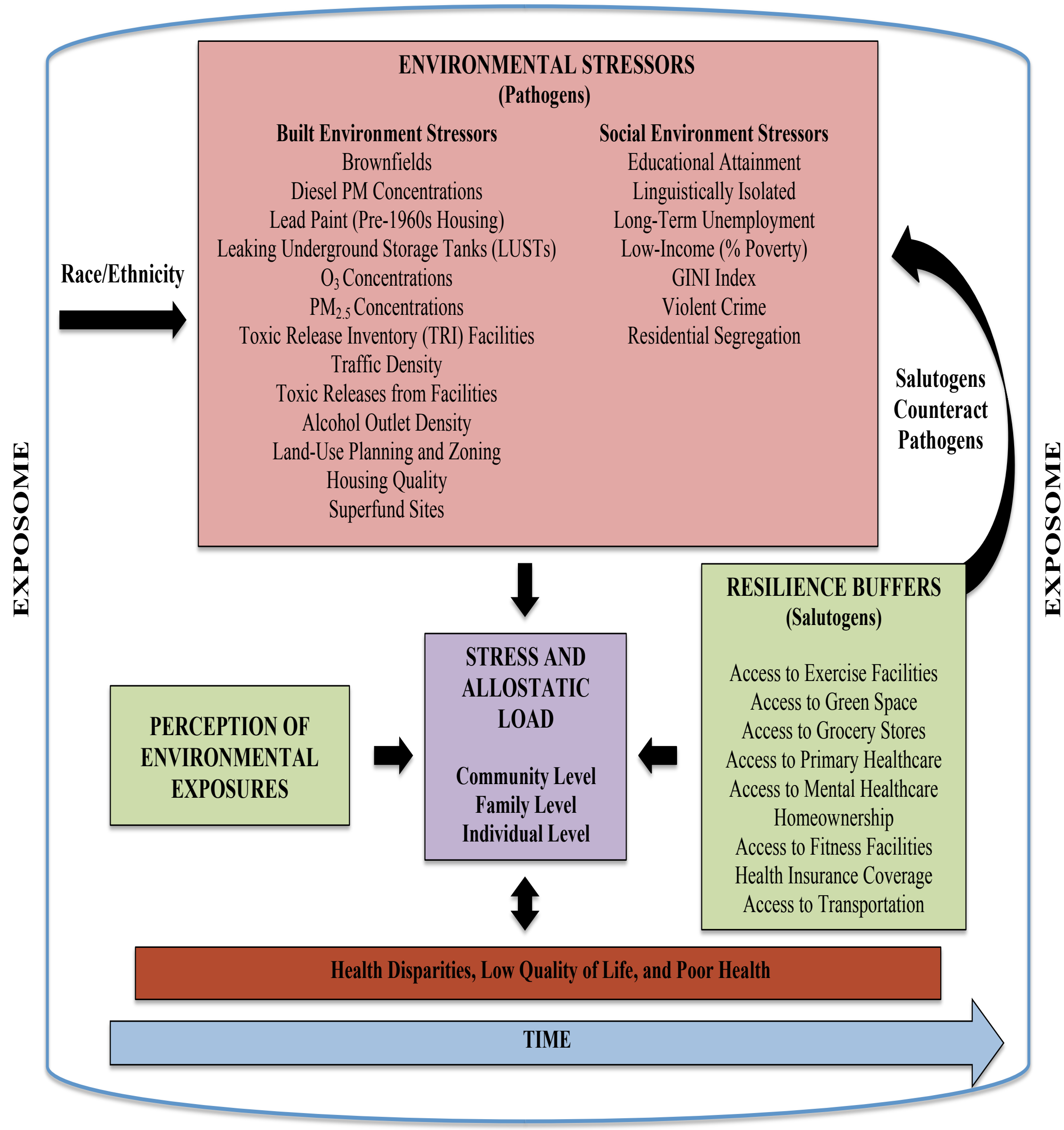
<u>**Access to Transportation**</u>

Studies have indicated populations with access to transportation where they live and work may influence active commuting behaviors such as walking, cycling, or using public transit in combination with walking or cycling (Dalton, Jones, Panter, & Ogilvie, 2013; Djurhuus, Hansen, Aadahl, & Glumer, 2014; Victoria Transport Policy Institute, 2010). Moreover, access to these alternative forms of transportation have been shown to cause direct and indirect benefits to health such as reductions in traffic emissions, increases in physical and mental health, and improved access to health care services and healthy food (CDC, 2011b; Litman, 2013; Rissel, Curac, Greenaway, & Bauman, 2012; Victoria Transport Policy Institute, 2010). When communities lack health-promoting amenities (i.e., supermarkets, healthcare, green space), accessible transportation may be an important solution in creating sustainable communities that connect people with resources (USEPA, 2013).

2.10.3 Perception of Environmental Exposures

Perceptions of exposure are a salient aspect of the cumulative stressors and resiliency conceptual framework due to the relationship with physiological stress. While some environmental exposures directly affect the stress response (i.e., exposure to air toxics) (Oeder et al., 2015), other environmental stressors may also induce a physiological response due to the way that they are perceived and processed (Oken, Chamine, & Wakeland, 2014; Peek, Cutchin, Freeman, Stowe, & Goodwin, 2009). For example, one study demonstrated how community perceptions of health risks related to environmental exposures to a petrochemical complex in Texas City, Texas (TX) were associated with interleukin-6 and viral reactivation biological markers of stress (Peek, Cutchin, Freeman, Stowe, & Goodwin, 2009). The brain's perception of an environmental stimulus as a stressor may be moderated by one's memory or previous experiences, current physiological state, traits, and genotype. Once the brain perceives the environmental stimuli as negative, it signals the autonomic nervous system (ANS), hypothalamo-pituitary-adrenal (HPA) axis, immune system, and gene expression as part of the stress activation process affecting the body (Oken, Chamine, & Wakeland, 2014). Perceptions of environmental stressors may differ by race/ethnicity, where non-white populations may exhibit greater levels of environmental concern or higher perceptions of environmental risks than their White counterparts (Chakraborty, Collins, Grineski, & Maldonado, 2017; Jones & Rainey, 2006). Greater perceptions of environmental risk coupled with disproportionate exposures to environmental hazards make non-white populations especially vulnerable to stress and adverse health outcomes.

Figure 2. Environmental Stressors and Resiliency Conceptual Framework



CHAPTER 3

PERCEPTIONS OF ENVIRONMENTAL STRESSORS AND BUILDING RESILIENCY IN A COMMUNITY WITH ENVIRONMENTAL JUSTICE ISSUES

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Dr. Robin Puett is an associate professor with the Maryland Institute for Applied Environmental Health (MIAEH) at the University of Maryland, College Park. Her research and teaching interests are in the areas of environmental and spatial exposure assessment and epidemiology. Dr. Puett's research has mainly explored the relationship of ambient air pollution exposures with chronic disease (i.e. cardiovascular disease and diabetes) and mortality. Ongoing and future research in this area delves more deeply into the biological pathways involved, susceptible subpopulations and important potential modifiers of these relationships, such as diet and physical activity.

Dr. Xin He is an associate professor in Epidemiology and Biostatistics. His current research focus is on longitudinal data analysis, time-to-event data analysis, nonparametric and semiparametric methods, as well as applications in epidemiology, environmental health, and biomedical studies.

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3.1 Abstract

This study identified perceptions of environmental and resilience factors that may perpetuate or mitigate health inequalities in North Charleston, SC. Environmental justice community stakeholders (n=18) were recruited to participate in key informant interviews consisting of 7 face-to-face questions and a 26-item cumulative stressors and resiliency index (CSRI) paper survey. Interviews were transcribed and coded, while mode, frequencies, and percentages were calculated for each indicator based on its ability to influence health. Approximately 61% of the indicators were rated as extremely high priority items and included environmental hazards, sociodemographic attributes, and factors that may influence resiliency. Social support, faith, increasing environmental awareness; maintaining a healthy diet, generational advantage, and upholding/encouraging a positive attitude were most mentioned as resilience factors that allow residents to adapt to negative characteristics in their environment. Understanding and addressing environmental stressors and resiliency gaps in areas impacted by environmental injustice may lead to improvements in community resilience.

Key Words: Resilience, Environmental Justice (EJ), Cumulative Stressors and Resiliency Index (CSRI), North Charleston, Environmental Health, Risk Perceptions, Community Stakeholders, Key Informant Interviews

3.2 Introduction

In recent years, studies have illustrated the role of social and environmental stressors in driving environmental health disparities (Clougherty & Kubzansky, 2009; Gee & Payne-Sturges, 2004; Morello-Frosch, Zuk, Jerrett, Shamasunder, & Kyle, 2011). The cumulative impact of these stressors is particularly evident in communities affected by environmental justice (EJ) issues, where predominately non-white and economically disadvantaged populations have traditionally experienced differential exposure pollution emitted from local environmental hazards and are more likely to exhibit higher rates of morbidity and mortality (Sexton & Linder, 2011). These communities often lack health-promoting infrastructure (i.e., healthy food outlets, green space, health care facilities) necessary to counteract cumulative impacts of multiple environmental stressors (Wilson, 2009; Hutson & Wilson, 2011; Morello-Frosch, Zuk, Jerrett, Shamasunder, & Kyle, 2011; Sexton & Linder, 2011). The compounded effect of this double disparity creates a positive dose-response relationship between exposures to cumulative neighborhood stressors and allostatic load (Mair, Cutchin, & Peek, 2011; Theall, Drury, & Shirtcliff, 2013). Allostatic load has been associated with damaging health behaviors (i.e., alcohol and tobacco abuse), cardiovascular disease, and mortality, which may further proliferate health disparities among vulnerable populations (Beckie, 2012).

While studies have documented mechanisms of environmental disease onset and its connection with stress (Zeliger, 2015), the cumulative impact these factors have on health may vary based on exposure levels, one's valuation of exposure, and accompanying physiological and psychological responses (Adler, 2009). To effectively respond to stressors and become resilient, communities must have available assets and an ability to apply them so they can function during and/or after a disturbance (Longstaff, Armstrong, Perrin, Parker, & Hidek, 2010). The U.S. Department of Health & Human Services (USDHHS) defines community health resilience (CHR) as "the ability of a community to use its assets to strengthen public health and healthcare systems and to improve the community's physical, behavioral, and social health to withstand, adapt to, and recover from adversity" (USDHHS, 2015). Much of the resilience work to date has transcended contextual (i.e., natural disasters, violence, and injury) and disciplinary boundaries (Magis, 2010; Wulff, Donato, & Lurie, 2015); still, more resiliency studies are needed in overburdened communities to improve their capacity to thrive when exposed to acute and chronic stressors.

Addressing and prioritizing health, wellness, and preparedness needs of a community's most vulnerable populations may ultimately foster macro-level improvements in resilience (Wulff, Donato, & Lurie, 2015). To explore these issues, the purpose of this study was to utilize the expertise of EJ stakeholders in North Charleston, SC to identify perceptions of environmental and resilience factors that may perpetuate or mitigate health inequalities in their neighborhoods. We will present information regarding the perceptions of environmental and resilience factors that may influence health, elucidate environmental factors that most influence health in North Charleston communities, and examine differences between community perceptions of factors that may impact health and factors documented in the literature. The insight gained from EJ stakeholders will inform a new cumulative stressors and resiliency index (CSRI) and an accompanying resilience buffer measure that more accurately represents exposure risk in vulnerable communities across the state of South Carolina.

3.3 Methods

Study Area

Study participants were recruited from North Charleston, SC to participate in one on one in-person interviews using a convenience-sampling scheme. This site was selected due to our existing community-university partnership with the Low Country Alliance for Model Communities (LAMC) and Charleston Community Research to Action Board (CCRAB), community-based organizations (CBOs) established to address EJ and health issues that affect disadvantaged populations of color in the North Charleston region of SC (Wilson, Campbell, Dalemarre, Fraser-Rahim, & Williams, 2014). These CBOs are part of the Charleston Area Pollution Prevention Partnership (CAPs) which includes UMD-College Park; SC Department of Health and Environmental Control (SCDHEC); University of South Carolina (USC)-Columbia; and the following local communities: Accabee, Union Heights, Chicora-Cherokee, Howard Heights, Windsor Place, Five Mile, and Liberty Hill (Wilson, Campbell, Dalemarre, Fraser-Rahim, & Williams, 2014). The cornerstone of the partnership is built on the community-based participatory research (CBPR) framework and the U.S. Environmental Protection Agency's (USEPA) EJ collaborative problem-solving model (USEPA, 2008; Minkler & Wallerstein, 2008).

Eligibility

Individuals were eligible to participate in the study if they met the following criteria: 1) African-American, 2) $\geq$18, 3) currently reside in North Charleston, and 4) have lived in North Charleston for at least one year. The eligibility questionnaire lasted no longer than eight minutes and consisted of four main questions with additional follow-up inquiries on medical conditions, health insurance and employment status, highest level of education completed, median household income, and previous participation in a community meeting or activity. Eligible community members were contacted subsequently via phone to schedule a time to perform their key informant interview at the LAMC office and as a reminder of their appointment. Those who were eligible to participate in the study received a $25 VISA gift card and refreshments. The Institutional Review Board (IRB) at UMD-College Park approved the research approach and corresponding study materials.

Instrumentation

The research team reviewed several versions of key informant interview questions and cumulative stressors survey before it was piloted on individuals in North Carolina (NC) (n = 4) and Virginia (VA) (n = 8) with demographic characteristics similar to the target population in North Charleston, SC. Based on feedback received from research team and community members in both states, we made minor revisions to the study instruments that ultimately reduced the time required to complete the key informant interviews and improved the clarity of the questions.

The key informant interview consisted of a 7-question face-to-face interview embedded with a 26-item paper survey instrument that used a 5-point Likert scale. We asked 5 pre-survey questions during the audio recorded interview that addressed factors contributing to ill health, negative and positive things in the environment that may impact health, one's ability to be resilient in response to negative environmental stimuli, and requirements for improving resiliency in their respective environment. A professional transcription company transcribed the 18 key informant interviews. Two members of the research team conducted the coding through deductive reasoning separately, searched for major themes in the codebook, performed a second thematic review using a more inductive reasoning approach, and then compared findings to create a final dataset using group consensus.

The survey consisted of 26 questions that spanned several domains (physical and social) of the environment. The survey items were selected from other EJ and environmental vulnerability metrics as well as scientific literature. Survey items were defined and answered using a 5-point Likert scale, from 1 = "not at all a priority" (NP) to 5 = "extremely high priority" (EHP). The study participants were instructed to mark the box that best described the level of priority that should be assigned to each indicator based on its ability to improve health in their community. Each participant was provided with the following example prior to beginning the survey:

> *"Example for indicator 1: Think about your community. If there are not many fitness facilities nearby for you to exercise to improve your health, this may be a higher priority item. If there are fitness facilities nearby to exercise, this may be marked as lower priority item in improving health in your community."*

Frequencies, corresponding percentages, and modes were calculated for the CSRI survey indicators. To determine which environmental indicators had the greatest impact on health in North Charleston neighborhoods, we selected indicators on the survey that were marked HP and/or EHP by ≥50% of the population.

3.4 Results

Twenty eligibility questionnaires were administered and 18 individuals participated in the study, thereby creating a low nonresponse rate of 10% (n=2). Participant ages ranged from 35 to 86 years ($\bar{x}$ = 57, M = 63) and there were more female (56%) than male (44%) participants (Table 17). The racial composition of participants was primarily African-American (94%) with one individual racially identifying as a Hawaiian Native. Study participants mainly resided in the Union Heights community (67%) and had participated in at least one LAMC or CCRAB (78%) meeting and/or event. Educational attainment ranged from having less than a high school education (6%) to holding a Master's degree (28%), with most of the study population having at least some college (78%) (Table 17). The study population contained more unemployed (56%) than employed (44%) individuals; however, the unemployed participants were mostly retirees. The mode for household income for most participants (67%) was ≤ $39,000 per year. The majority of participants had health insurance (89%) and a few had been diagnosed with hypertension, diabetes, asthma, arthritis, and elevated cholesterol by a doctor or other health professional.

In the cumulative stressors survey, approximately 61% of indicators were rated as an EHP item based on the highest percentage of participants selecting EHP (Table 18). These items included a combination of environmental hazards (e.g., brownfields, ozone, $PM_{2.5}$, superfund sites, and toxic releases from facilities), sociodemographic attributes (i.e., educational attainment, health insurance coverage, and long-term unemployment), and factors that may influence resiliency (i.e., access to transportation and violent crime). Findings were inconsistent for primary care HPSAs (mode=HP/EHP) and diesel particulate matter (mode=HP/EHP); however, the most extreme disparity in responses was for density of alcohol outlets (mode=LP/EHP). After selecting the indicators on the survey that had ≥50% of the participants mark HP and/or EHP, only density of alcohol outlets (45%), linguistically isolated (28%), and non-white populations (44%) were not considered main factors that impact health in the community (Table 18). Sixty-five percent of the 18 study participants who responded to the question rated low-income as an extremely high priority item in their community.

Data saturation for key informant interviews was achieved with 18 interviews, meaning we reached a point where there was enough data to replicate the study and no new information was being obtained to address our research questions (Fusch & Ness, 2015). Participants were initially asked, "What are some things that may contribute to ill health, such as diabetes, high blood pressure, cancer, stroke, asthma, and heart disease to name a few?". Unhealthy diet, environmental exposures, physical inactivity, genetics, and not seeking routine medical care were among the leading responses mentioned. As they reflected on the second question, "What is something negative in your environment, if anything, that may cause you to develop ill health?"; 94% of the study participants voiced concerns regarding environmental hazards located in their community.

According to the respondents, "proximity to industrial operations, chemical manufacturing plants, and highways" were the consensus nuisances. Participant's remarks included, "it's very odorous coming down 26", "noise pollution … here we have a main road and constant noises", and "just the air quality in the environment … we have been surrounded by industrial places for quite a while". Another participant explained, "we had quite a few plants in the area … some cleanup has been done to it, but not something – not extensive cleanup, so it has left the soil contaminated". The same participant further mentioned, "the dumping of the waste material and stuff from the plants into the river causing problems with the fish".

The third question was, "When considering some of the negative things that may exist or have occurred in your environment, what has allowed you to withstand hardships, adapt to stress, or in other words be resilient?". Based on the responses, "faith", "I try to have a good diet", "knowledge, you know, being able to understand what we're up against, what we are facing", "complacency because you just adjust or adapt to foul odors, to the infrequent bouts of mist – chemical mist in the air … people just become used to them and accept them", "self-motivation", "being around loved ones", and "knowing there's another generation behind me, knowing that someone has to, how would I say, voice concerns" were some of the majors factors that contributed to community resiliency.

The study participants were also asked, "What is something positive in your environment, if anything, that may lower your risk of developing ill health?". Some of the participants thought that having social support was a positive factor in their environment, and one person mentioned "I have my girls that I be around. Some people don't have nobody around.". Several others mentioned, "we try to keep the neighborhood clean", "eating proper foods and exercising", "I see the community organizations collaborating to improve the quality of life of residents", "the community monitors that we are using now that, you know, to detect thing", and "attending meetings and things that you could see what's actually going on in the community".

The fifth question was, “What is something that you need in environment, if anything, to improve your ability to withstand hardships, adapt to stress, or in other words be resilient?”. Most people expressed the need to become better informed as a community member on “what the potential substances are – the sources, precautions we should take to protect ourselves, and also, knowledge of the easy observable conditions that indicate exposure”. Others mentioned “closer medical facilities … where people can go without having to pay, those who can’t afford it” and “a place where we can get fresh vegetables and fresh fruit in our neighborhood”. Developing new community infrastructure and having more access to green space or places to exercise were also prominent responses.

When asked the post-survey question, “What do you believe should be added to the list of environmental indicators, if anything, and why?”, most of the respondents said nothing (44%) while others described indicators that measure soil quality, programs to support wellness among youth and seniors, mortality rates, zoning, social support, technology, community participation on environmental issues, and communication and awareness between community, city, and state level officials should be added in some capacity. The final question posed was “What do you believe should be removed from the list of environmental indicators, if anything, and why?”, most participants stated nothing (67%). There were four participants whose responses were inconclusive; however, density of alcohol outlets and residential segregation were mentioned as items to remove.

3.5 Discussion

This study aimed to elicit the expertise of residents in North Charleston, SC impacted by environmental injustice to determine their perceptions of environmental stressors and resilience factors that may catalyze health disparities in their neighborhoods to inform the development of a CSRI tool. We further ranked and identified environmental factors that most influence health in the community and compared the perception of these factors with those implicated in the literature. The results from the cumulative stressors survey showed participants viewed several of the environmental indicators (61%) as an EHP item in their community. The overabundance of environmental hazards in communities impacted by environmental injustice is not a new concept (UCC, 1987), but decades later our cumulative stressors survey indicates these populations are still vastly burdened by multiple hazards in their community such as air pollution (i.e., ozone, $PM_{2.5,}$ toxic releases from facilities, diesel PM), toxic release inventory facilities (TRI), and brownfields, to name a few. Studies suggest mitigating hazards has much to do with equity and justice in managing resources (Morrow, 2008), which ultimately calls for a paradigm shift of building resilient communities with health-promoting infrastructure to neutralize the effects of various environmental stressors.

The study participants also exhibited extensive knowledge of factors that contribute to ill health that corroborated with the following determinants of health categories: 1) individual behavior, 2) social factors, 3) health services, and 4) biology and genetics (Office of Disease Prevention and Health Promotion [ODPHP], 2017). Almost all (94%) of the participants in our study mentioned some form of an environmental hazard as a negative stressor in their environment that may contribute to ill health. These results were similar to those found in a cancer risk study conducted in Metropolitan Charleston, SC, where residents perceived exposures to negative environmental conditions (i.e., air, water, and soil pollution, hazardous wastes) were a serious threat to health (Rice, Brandt, Hardin, et al., 2015). Additional studies conducted in North Charleston over the years confirm disparities in hazard distribution in the community (Burwell-Naney et al., 2013; Rice et al., 2014; Wilson et al., 2012a; Wilson et al., 2013). According to participant, “there’s companies that think about what they can profit, but they really don’t think about the neighborhood”. A positive dose-response relationship exists between exposures to cumulative neighborhood stressors and allostatic load (Mair, Cutchin, & Peek, 2011; Theall, Drury, & Shirtcliff, 2012), thereby perpetuating a cycle of health disparities among vulnerable populations (Beckie, 2012).

Several of the participants attributed resiliency to one of these factors: 1) social capital, 2) services and institutions, 3) built environment, and 4) structural (Davis, Cook, & Cohen, 2005). Specifically, participants mentioned various resilience themes such as social support, upholding/encouraging a positive attitude (i.e., social capital); faith, civic infrastructure, collaborative organizations, increasing environmental awareness (i.e., services and institutions); maintaining a healthy diet, exercise (built environment), and generational advantage (i.e., structural). Within the generational advantage theme, one resident conveyed deeply rooted cultural beliefs that may have a major impact on the African-American community:

> “I think another part that helps me with it is knowing some of the oppositions being an African-American, what our forefathers has went through … and even

> though what we're going through, I think it's a little less … and I think within me, I can do more."

Though four participants mentioned complacency as a resilience factor, studies have shown that this perspective may be counterproductive in achieving community resilience and could result in inaction or poor adaptation in response to a stressor (Amundsen, 2012; Lansford, Covarrubias, & Miller, 2016).

When considering the many resilience buffers that were mentioned, the study participants still perceived they lacked essential resources that would improve their ability to become resilient. Their response was consistent with other studies that emphasize the importance of having robust resources (i.e., physical infrastructure, economics, civil society, and governance) and a high adaptive capacity to develop resilient community ecosystems (Longstaff, Armstrong, Perrin, Parker, & Hidek, 2010). For example, participants stated they needed more access to green space or places to exercise, grocery stores that sell healthy foods, healthcare services, better transportation systems, and new community infrastructure to improve resilience.

Becoming better informed as a community member was another theme that surfaced as a need to improve resiliency. A participant even suggested having a community newsletter to circulate information. In addition, another participant believed that establishing a chain of command to report environmental hazards would further improve resiliency in their community. Several participants also mentioned the aforementioned resources, monitoring, and training as something positive in their community that may lower their risk for ill health.

The existing CAPs partnership creates opportunities for the participants to learn more about their environment through the EJRADAR online mapping tool (Wilson et al., 2015b), environmental monitoring, and environmental health workshops. Since community partnerships are critical to strengthening community resilience (Chi, Williams, Chandra, et al., 2015), the CAPs partnership can be used a venue to address resiliency deficits in North Charleston.

Though we gained valuable information from our key informants, there were a few limitations. One limitation commonly associated with interviews is how the researcher's presence may introduce bias in the participants' responses (Creswell, 2003); however, this phenomenon was less apparent in the CSRI survey when interviewees had an opportunity to complete the survey paper-based survey individually. As with all qualitative studies, our small population size did not allow our results to be generalizable to a larger population. Furthermore, our use of a convenience-sampling scheme limited the representativeness of our sample of African-American adults in North Charleston. Since we were unable to recruit participants from Liberty Hill, we were unable to achieve a representative sample of our target study population. While the cumulative stressors survey was used to inform the indicators and weights of the CSRI, we realize that the perceptions of environmental stressors and the priority level that the study participants assigned to each variable may not be extrapolated to other populations. Despite our use of verbal cues in the cumulative stressors survey, we did not test for construct validity or reliability in the first rendition of our original survey, which may have influenced the results of the study.

Despite the limitations, there were notable strengths observed while performing the key informant interviews that included our ability to collect important data from community-engaged stakeholders in a convenient and inexpensive manner. We captured information regarding perceptions of environmental stressors and resilience factors that will be used to inform the development of a comprehensive CSRI designed to quantify and assess environmental risk in SC communities. Moreover, this study was an opportunity to strengthen our longstanding relationship with local residents and raise awareness about environmental and resilience factors that may impact health among our study participants.

3.6 Conclusion

Our study suggests that living near various environmental hazards had the most bearing on what EJ populations perceived as a negative aspect of their environment that causes ill health. Since communities impacted by environmental injustice are not always able to evade exposures to chemical and non-chemical stressors in their environment, it is critical to focus on the resilience factors that may buffer the effects of the stressors and thereby reduce allostatic load. The presence of social support, individual environmental awareness, faith, upholding/encouraging a positive attitude and healthy diet, and generational advantage should be incorporated into interventions aimed to improve resiliency in communities impacted by environmental injustice. Future studies will focus on the design and application of the CSRI as a risk assessment tool to identify resilience deficits in vulnerable communities across SC. We will also determine how to incorporate the study participants' suggestions for new indicators (i.e., zoning, soil quality, mortality rates, and programs to support wellness for youth and seniors) into the CSRI and work with additional stakeholders to devise strategies that strengthen resilience in North Charleston. In addition, we will revise the cumulative stressors survey from this study to include validity and reliability measures and qualifying statements so that it can be administered to a larger population.

3.7 Acknowledgements

We would like to thank the community members from North Charleston, SC for their participation in the study, as well as LAMC for allowing the research team to use their facility to implement the study. We would also like to thank Mr. Charles Naney and Dr. Carolyn Burwell for their assistance in conducting the key informant interviews, and Dr. Amanda Lowe-DuBose for being the secondary coder for the qualitative analysis.

3.8 Declaration of Conflicting Interests

There were no potential conflicts of interest to report for this study.

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3.10 Manuscript 1 Tables

Table 17. Descriptive Characteristics of North Charleston, SC Interviewees (n=18)

Variables	Frequency (%)
Age (x = 57)[a]	
30 – 39	1 (6)
40 – 49	2 (11)
50 – 59	3 (17)
60 – 69	9 (50)
70 – 79	1 (6)
80 – 89	1 (6)
No Response	1 (6)
Gender	
Male	8 (44)
Female	10 (56)
Race and Ethnicity	
African American	17 (94)
Hawaiian Native	1 (6)
Community	
Union Heights	12 (67)
Liberty Hill	0
Chicora – Cherokee	4 (22)
Accabee	2 (11)
North Charleston Resident	
Yes	16 (89)
No	2 (11)
Zip Code[a]	
29405	15 (83)
29410	1 (6)
29483	1 (6)
29418	1 (6)
Medical Conditions	
Yes	11 (61)
No	7 (39)
Type of Medical Conditions[b]	
Hypertension	3
Diabetes	5
Asthma	2
Arthritis	1
Elevated Cholesterol	3
Other	4

Health Insurance	
Yes	16 (89)
No	2 (11)
Education[a]	
< High School Education	1 (6)
High School Graduate	3 (17)
GED or Equivalent	0
Some College	2 (11)
Associate's Degree	5 (28)
Bachelor's Degree	5 (28)
Master's Degree	2 (11)
Professional or Doctoral Degree	0
Income[a]	
< $9,999	3 (17)
$10,000 - $19,000	3 (17)
$20,000 - $29,000	2 (11)
$30,000 - $39,000	4 (22)
$40,000 - $49,000	0
$50,000 - $59,000	1 (6)
$60,000 - $69,000	5 (28)
Employment	
Yes	8 (44)
No	10 (56)
Participation in LAMC or CCRAB Meeting/Event	
Yes	14 (78)
No	4 (22)

[a]Due to rounding, some of the numbers may not add up to 100%.
[b]Interviewees had multiple or no medical conditions, which does not allow us to calculate a percentage for each health outcome.

Table 18. Cumulative Stressors and Resiliency Index (CSRI) Survey Results from North Charleston, SC Study Participants

Environmental Indicators	Not at all a priority (%) 1	Low priority (%) 2	Medium Priority (%) 3	High Priority (%) 4	Extremely High Priority (%) 5	Mode[c]
Access to exercise facilities	0	0	0	10 (56)	8 (44)	HP
Access to green space	0	0	4 (22)	10 (56)	4 (22)	HP
Access to public transportation	0	4 (22)	5 (28)	3 (17)	6 (33)	EHP
Brownfields[a]	0	0	1 (6)	7 (39)	10 (56)	EHP
Density of alcohol outlets[a]	3 (17)	5 (28)	2 (11)	3 (17)	5 (28)	LP/EHP
Diesel particulate matter (PM) concentrations[a]	0	0	2 (11)	8 (44)	8 (44)	HP/EHP
Educational attainment	0	0	2 (11)	3 (17)	13 (72)	EHP
Food swamps	0	2 (11)	0	4 (22)	12 (67)	EHP
Health insurance coverage	0	0	0	7 (39)	11 (61)	EHP
Health professional shortage areas (mental health)	0	0	2 (11)	12 (67)	4 (22)	HP
Health professional shortage areas (primary care)	1 (6)	0	5 (28)	6 (33)	6 (33)	HP/EHP
Lead paint (% pre-1960s housing) [a]	0	1 (6)	1 (6)	9 (50)	7 (39)	HP
Leaking underground storage tanks (LUSTs)	0	0	3 (17)	8 (44)	7 (39)	HP
Linguistically isolated	4 (22)	2 (11)	7 (39)	3 (17)	2 (11)	MP

Long-term unemployment	0	0	2 (11)	7 (39)	9 (50)	EHP
Low-income (% poverty) [ab]	0	0	3 (18)	3 (18)	11 (65)	EHP
Non-white population[a]	2 (11)	2 (11)	6 (33)	6 (33)	2 (11)	MP/HP
Ozone (O_3) concentrations	0	0	1 (6)	6 (33)	11 (61)	EHP
Particulate matter 2.5 ($PM_{2.5}$) concentrations	0	0	3 (17)	6 (33)	9 (50)	EHP
Residential segregation	2 (11)	1 (6)	4 (22)	8 (44)	3 (17)	HP
Superfund sites	1 (6)	1 (6)	2 (11)	6 (33)	8 (44)	EHP
Toxic release inventory (TRI) facilities	0	0	3 (17)	8 (44)	7 (39)	HP
Traffic density[a]	0	0	3 (17)	12 (67)	3 (17)	HP
Toxic releases from facilities[a]	0	0	4 (22)	6 (33)	8 (44)	EHP
Violent crime	0	0	2 (11)	7 (39)	9 (50)	EHP
Vulnerable populations (children <10 and elderly >65)	0	1 (6)	6 (33)	9 (50)	2 (11)	HP
Total[a]	13 (3)	19 (4)	73 (16)	177 (38)	185 (40)	N/A

[a]Due to rounding, some of the numbers may not add up to 100%.
[b]Low-income (% poverty) is missing one vote (n = 17).
[c]LP = Low priority, MP = Medium priority, HP = High priority, EHP = Extremely high priority

CHAPTER 4

THE DEVELOPMENT OF A CUMULATIVE STRESSORS AND RESILIENCY INDEX TO EXAMINE ENVIRONMENTAL HEALTH RISK: A SOUTH CAROLINA ASSESSMENT

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Running Title: Cumulative Stressors and Resiliency

4.1 Abstract

Background: Many communities across South Carolina (SC) are differentially burdened by pollution and suffer from environmental health disparities. As result, we need better approaches to understand and mitigate risk.

Objectives: Our objective was to develop a cumulative stressors and resiliency index (CSRI) that may be used to rank risk at the census tract level in SC.

Methods: We performed a Principal Component Analysis (PCA) on each variable subcategory to reduce our proposed indicators to 20 variables reflecting environmental stress and resiliency in communities impacted by environmental injustice. CSRI scores (0 - 100) were computed at the census tract level. High- risk (HR) census tracts were identified as CSRI scores in the 90th percentile. We performed a one-way analysis of variance (ANOVA) on CSRI scores by Environmental Affairs (EA) region and linear regression for percent non-white and CSRI scores. Choropleth maps were developed in ArcMap 10.5 using natural breaks to visualize spatial relationships.

Results: CSRI scores ranged from 7.4 – 64.0. The mean CSRI score for SC was 29.1, which was lower than the mean score for Upstate (35.2) and Midlands (31.7) regions. The one-way ANOVA results indicated a statistically significant difference in CSRI scores by EA region ($p < 0.0001$) except when the Lowcountry was compared to the Pee Dee region [95% CI: -1.53, 2.68]. Based on the regression model results, a one-unit increase in the percentage of non-white populations per census tract would increase CSRI scores by roughly 6.1%.

Conclusion: The results of our study support the inclusion of resilience factors in environmental justice (EJ) assessments.

Key Words: stressors, index, resilience, South Carolina, environmental justice, risk, disparities, environmental health

4.2 Introduction

Research showing that *"Your zip code may be more important to health than your genetic code"* (Ritchie, 2013) has begun to transform the way we conceptualize and approach context and place in eliminating health disparities, particularly environmental health disparities. Cumulative risk assessment (CRA) is a methodology developed in response to the need to organize and analyze information from real life situations that can be used to examine, characterize, and quantify risk posed to human health based on exposures to multiple environmental stressors (Callahan & Sexton, 2007) that can drive health disparities. CRA may be distinguished from traditional human risk assessment methods based on the following factors: 1) CRA risk analysis may include proxies of exposures instead of absolute or quantitative estimates of health risk, 2) exposures are determined from the combined effects of a particular agent or stressor, 3) population-based assessments are performed that examine individual and community exposures to multiple stressors, and 4) non-chemical stressors are incorporated into the assessment of risk (Barzyk, S. Wilson, & A. Wilson, 2015). Moreover, CRA methods can account for interaction effects between stressors and vulnerability and susceptibility factors that are inherent in certain populations. CRA provides a framework for the development of new cumulative impact assessment and environmental justice (EJ) screening tools that could be used to quantify risk and prioritize need to inform action-based solutions.

The US Environmental Protection Agency (USEPA) has created various EJ tools over the years such as EJView (formerly known as the Environmental Justice Geographic Assessment Tool [EJGAT]), EJSCREEN (replaced EJView), Environmental Justice Strategic Enforcement Screening Tool (EJSEAT), and Community-Focused Exposure and Risk Screening Tool (C-FERST). These tools were designed to identify and prioritize problems in communities that may be overburdened by environmental stressors and related health risks. CalEnviroScreen 3.0 is a cumulative impact assessment tool developed to identify vulnerable communities across the state that are disproportionately impacted by multiple pollution sources to inform policy and prioritize mitigation activities in the state of California (Cushing et al., 2015). The Cumulative Environmental Hazards Inequality Index (CEHII) (Su et al., 2009), Urban Heart Equity Assessment and Response Tool (Urban Heart) (World Health Organization [WHO], n.d.), Cumulative Environmental Vulnerability Assessment (CEVA) (Huang & London, 2012), Social Vulnerability Index (SVI), and Green City Index (GCI) are other tools that can evaluate an aspect of environmental or social vulnerability.

Cumulative risk assessment and EJ screening tools have become very effective in identifying inequalities and population clusters impacted by environmental injustice. Specifically, populations of color and economically disadvantaged groups have been disproportionately affected by the cumulative impact of stressors because they often have the greatest exposure to environmental hazards in their communities (Burwell-Naney et al., 2013; Rice et al., 2014; Wilson et al., 2012a; Wilson et al., 2013; Wilson et al., 2014). They may also lack or have limited access to green space, fitness facilities, health care, and grocery stores, which are all resources known to promote health and well-being (Hutson & Wilson, 2011; Wilson, 2009; Wilson, 2010). Without salutogenic infrastructure or necessary resiliency buffers in place, these already overburdened populations may not be equipped to counteract the adverse health effects associated with exposure to environmental stressors. While some conceptual models for CRA have captured the impact of salutogenic conditions on health (Linder & Sexton, 2011), this factor has not been systemically integrated into CRA screening tools in a way that demonstrates how resiliency can alter risk and provide a more accurate evaluation of community vulnerability.

Community health resilience (CHR) is defined as "the ability of a community to use its assets to strengthen public health and healthcare systems and to improve the community's physical, behavioral, and social health to withstand, adapt to, and recover from adversity" (US Department of Health and Human Services [US DHHS], n.d.). A population's physical and mental health as well as social and economic determinants of health may have a significant impact on community resilience (Castleden, McKee, Murray, & Leonardi, 2011). Since communities are unique entities with varying needs, it is important to address community resiliency at the meso-level that may indirectly affect change at other levels of organization. Specifically, Wulff and colleagues (2015) mentioned the importance of prioritizing and meeting the needs of a community's most vulnerable populations to foster macro-level improvements in overall resilience. When vulnerable communities lack resiliency, they may be more likely to have higher mortality rates for stroke, hypertension, cancer, diabetes, and heart disease when compared to their White and more affluent counterparts (Massey, 2004; Morello-Frosch, Zuk, Jerrett, Shamasunder, & Kyle, 2011).

Furthermore, there are several measures that have been developed to quantify resilience, but they are either less applicable to the concept of community resilience (Windle, Bennett, & Noyes, 2011) or have been used only in disaster resiliency tools (Ostadtaghizadeh, Ardalan, Patson, Jabbari, & Khankeh, 2015). The resilience capacity index (RCI) assesses resilience in metropolitan areas based on their ability to cope with prospective challenges related to regional economic, sociodemographic, and community connectivity capacity (Building Resilient Regions Network, n.d.), but it focuses more on socio-environmental factors. Since the RCI was designed as a metropolitan level assessment, it does not measure resiliency in areas that may lack more health promoting resources like rural areas or smaller cities.

Perhaps a more representative instrument is the Tool for Health & Resilience In Vulnerable Environments (THRIVE). THRIVE allows communities to determine ways to improve health and safety and promote health equity by exploring components of the social-cultural environment (people), physical environment (place), and economic environment (equitable opportunity) (Prevention Institute, n.d.). THRIVE captures important components of the physical environment where community members and other stakeholders can score and prioritize questions related to air, water, and soil quality; access to transportation; access to parks and green space; access to health promoting services; and access to pathogenic products and services. Nevertheless, THRIVE does not directly measure environmental stressors and assets in a way that would allow resiliency to be quantified and compared across communities.

Despite current efforts to design and refine CRA and resiliency assessment tools, there is more work needed to create an index that can quantify risk based on a community's exposure to environmental stressors and resiliency buffers that may mitigate the impact of risk. The purpose of this study was to develop a cumulative stressors and resiliency index (CSRI) hybrid measure comprised of environmental exposures and resilience factors that may be used to rank risk at the census tract level.

We apply the CSRI to South Carolina (SC) to determine which indicators can be used to examine the cumulative burden of environmental stressors and resiliency in SC communities and assess the difference in CSRI scores by census tract. Moreover, we assess potential disparities in CSRI scores by region and race/ethnicity.

4.3 Methods

Overview

In order to comprehensively assess the burden of environmental health stressors and their impact on various subpopulations when accounting for factors of resilience, we designed a CSRI that may be used to: 1) quantify risk at the census tract level, 2) identify and prioritize low-resiliency populations with limited health promoting resources, 3) create community profiles of stressors and assets, and 4) provide state and local governments with a standardized tool that promotes transparency when making decisions to address environmental injustice. The CSRI screens for cumulative risk based on the multiplicative relationship between chemical and non-chemical stressors and resiliency factors that may buffer the effect of environmental exposures, hence creating a more accurate risk calculation. While environmental exposures and resiliency buffers are the primary categories represented in the risk formula, these categories may be further deconstructed into subcategories of environmental exposures, environmental hazards, pathogenic factors, and salutogenic factors (Figure 3). Salutogenic factors refer to features of the environment that are physical, economic, natural, social, or spiritual that may foster health and wellness (Antonovsky, 1987; MacDonald, 2005; Wilson, 2009). In contrast, pathogenic factors include various aspects of the built and social environment that may increase vulnerability and negatively impact health sustainability, and resiliency (Wilson, 2009).

Approach

To effectively respond to stressors and become resilient, communities must have available assets and an ability to apply them so they can function during and/or after a disturbance (Longstaff, Armstrong, Perrin, Parker, & Hidek, 2010). The relationship between environmental stressors and resiliency buffers is embedded in our hybrid CSRI index where we calculate a risk score for each census tract. Specifically, we multiply environmental stressors (environmental exposures + environmental hazards) by the resiliency buffers (pathogenic factors + salutogenic factors) (Figure 4) to determine the overall CSRI score. A multiplicative approach was used to calculate the CSRI scores since a higher prevalence of stressors may increase a community's susceptibility to the impacts associated with pollution exposures (Clougherty & Kubzansky, 2009). Our calculation was modified (Figure 4) based on the following risk formula used by emergency response organizations (Brody, Di Bianca, & Krysa, 2012) as well as the California EPA (Faust et al., 2017) in their cumulative impact assessment tool:

Risk = Threat x Vulnerability

Our formula uses resiliency buffers instead of vulnerability since we focus more on individual-level and community-level assets and take into account the inverse of common pathogenic factors that influence vulnerability so that they become protective against environmental exposures. Though vulnerability and resilience are different yet complimentary in nature, research suggests that future studies integrate both concepts into one assessment tool (Miller et al., 2010). A recent study attempted to connect the two concepts by measuring community resilience and social vulnerability across US counties and found the most vulnerable counties were also the least resilient (Bergstrand, Mayer, Brumback, & Zhang, 2015). This study affirms the relationship between resiliency and vulnerability, and further demonstrates the significance of including both concepts in community assessments to obtain a more complete risk profile.

Indicators

We initially selected 26 indicators for the CSRI informed by the following processes: 1) data collected from key informant interviews that provided information on environmental health and resiliency concerns that affect communities impacted by EJ issues and 2) variables in the literature known to have a positive (resiliency buffers) or negative (environmental stressors) association with adverse health outcomes. We then created a list of possible CSRI indicators (Table 19). Afterwards, we used principal component analysis (PCA) to systematically construct the final list of CSRI indicators using SAS Enterprise Guide v 7.1. Principal component analysis does not make assumptions regarding the causal structure of the variables, but it is a variable reduction procedure used to capture indicators that explain most of the variance among the observed variables. Other studies have documented the use of this procedure in reducing the number of factors included in an index (Bergstrand, Mayer, Brumback, & Zhang, 2015; Cutter, Boruff, & Lynn Shirley, 2003).

The Proc Factor statement was used in SAS Enterprise Guide version 7.1 to perform the PCA using all environmental stressor and resiliency buffer variables. We performed a separate PCA for all four subcategories and entered each variable into the model based on our findings from a previous study where African-American residents in North Charleston, SC prioritized EJ issues impacting their community (Burwell-Naney et al., [under review]). For example, the highest percentage of residents ranking an indicator as an extremely high priority was entered into the PCA model first, followed by the next highest ranking variable within a respective subcategory. Any indicator that accounted for > 10% of the total variance among the observed variables in a subcategory was a candidate for the final CSRI. For this stage of the research, we used the following equation:

$$Proportion = \frac{\text{Eigenvalue for the component of interest}}{\text{Total eigenvalues of the correlation matrix}}$$

where the denominator (total eigenvalues of the correlation matrix) is equal to the total number of variables (N=26) being analyzed (O'Rourke & Hatcher, 2013). The 26 proposed indicators were reduced to 20 and included in the equation to calculate the CSRI scores for each census tract (Table 20).

Indicators were assigned a score from 0 – 1 in increments of 0.25 based on a census tract's percentile range and represented a community's rank for each stressor or resiliency factor (Table 21). For example, a census tract with a high mean concentration of diesel PM would receive a higher score that was closer to 1; while, a census tract with a low mean concentration of diesel PM would be ranked closer to zero. Each census tract could receive a score of 0, .25, .50, .75 and 1 that would correspond with percentiles calculated from state estimates. The environmental hazard indicator scores corresponded with four groups that were developed based on a census tract's distance to a specific hazard. We decided not to use the weighting method for our environmental hazards indicators that was previously applied in the CalEnviroScreen 3.0 tool (Faust et al., 2017) since we still need to consider how to appropriately weight the resiliency buffers in a way that may accurately counteract the environmental hazards. The CSRI scores could range from 0 – 100 (Table 21), where low scores were indicative of low risk/high resiliency census tracts and high scores represented high risk/low resiliency census tracts.

4.4 Results

Study Area

Cumulative Stressors and Resiliency Index scores were calculated for census tracts in South Carolina, a state located in the southeastern region of the US that spans approximately 30,061 square miles and is often characterized by rural and urban landscapes. South Carolina is divided into four Environmental Affairs (EA) regions that provide local support to the communities located within their boundaries: 1) Upstate, 2) Midlands, 3) Pee Dee, and 4) Lowcountry. The Upstate region covers the northwest quadrant of SC, Midlands covers the center of the state from York to Barnwell counties, Lowcountry covers the south quadrant, and Pee Dee contains the northeast region of the state. In addition, SC has 1,103 census tracts that equate to 3,059 block groups and 181,901 blocks (US Census Bureau, nda). South Carolina census tracts (15) assigned to bodies of water (9900s) and those with little or no residential population (9800s) were excluded from analysis (US Census Bureau, n.d.b). Two additional census tracts were excluded that had no residential population (45027960202, and 45061920301), thereby reducing the total number of census tracts in the study area to 1,088.

The population consists of approximately 4,625,364 residents with 153.9 persons/square mile (US Census Bureau, n.d.c). The population is mostly non-Hispanic White (66.2%), followed by non-Hispanic Black (27.9%) and Hispanic/Latino (5.1%). The state's median household income was $45,483, roughly $8,400 lower than the median income for the US ($53,889) (US Census Bureau, n.d.c). While, the percentage of persons below poverty level in SC (16.6%) exceeds the US average (13.5%).

Analysis

We calculated CSRI scores for the 1,088 census tracts that were populated in the state. The indicator data were obtained from various publicly available websites, requested from an agency, or purchased from a vendor. Since our indicators were available at different geographic units of analysis, we used a crosswalk to convert the data to the appropriate scale using SAS Enterprise Guide version 7.1. The datasets were linked with SC census tracts and percentiles were calculated based on the raw scores for each indicator (Table 22). The percentiles for each census tract were assigned a value ranging from 0-1, and the value was incorporated into the final CSRI calculation. Census tracts were assigned a score of 0 if they had a raw score of 0 for the respective indicator while census tracts with scores in the <25th percentile range (excluding 0) received a score of 0.25. Census tracts in the >25th – 50th percentile were scored as 0.50, those at the >50th - <75th percentile receive a score of 0.75, and any census tract at the >75th percentile range were scored as 1. The indicator representing 'access to grocery stores' was scored as either 1 or 0 to represent a low access or non-low access tract, respectively. For environmental exposures, environmental hazards, and pathogenic factor subcategories, being in the lower percentile represented lower exposures. Regarding the salutogenic factors, being in the lower percentile meant that a census tract had greater access to grocery stores, more fitness facilities, higher education, more health insured individuals, and was not designated as a Health Professional Shortage Area (HPSA) or was a HPSA with a lower need for primary health professionals in the area.

The scores assigned to each percentile were summed for environmental stressors and resiliency buffers, which were then multiplied to compute the final CSRI score (Table 22). We also calculated descriptive statistics on the mean (M), standard deviation (SD), minimum, and maximum values of CSRI scores for the state and four EA regions. In addition, we calculated CSRI scores that were in the 90^{th} percentile for the state and EA regions to represent high-risk (HR) census tracts. Any census tract that had a CSRI score ≥ to the 90^{th} percentile of the state was a HR community, meaning they have high exposures to environmental stressors and low resiliency. We also performed a one-way analysis of variance (ANOVA) to determine whether mean differences exist in CSRI scores by EA region.

Choropleth maps were created using ArcMap 10.5 to illustrate the spatial relationship between CSRI scores (Figure 5) and the percentage of non-white populations (Figure 6) across the state. Each map contained five classes using natural breaks, thereby illustrating variations between the highest and lowest class of the variables of interest. We also tested the relationship between populations of color and CSRI scores by performing linear regression to assess whether there are racial/ethnic disparities in cumulative exposures to environmental stressors and resiliency buffers at a significance level of 0.05 (Table 24). Within the linear regression model, percent non-white was the independent variable while CSRI score was the dependent variable.

We present a combination of descriptive statistics, PCA, one-way ANOVA, and linear regression results to justify our systematic selection of indicators examine environmental health disparities. Our results indicate select environmental stressors and resiliency factors can be combined into a hybrid assessment tool to estimate cumulative risk in SC communities. Using our criteria for selecting indicators for the final CSRI model, there were 17 indicators that explained ≥10% of the total variance for their respective subcategory (Table 20). Traffic density (4.8%), toxic releases from TRI facilities (6.4%), and LUSTs (3.6%) did not meet the ≥10% variance criteria in the PCA procedure; however, they were still included in the index due to their impact on health and presence in other EJ assessment tools (i.e., CalEnviroScreen 3.0, EJSEAT).

Five of the eight pathogenic indicators met the inclusion criteria, which caused us to remove linguistic isolation (8.7%), Gini index (5.1%), and LBW (3.9%) variables from the final CSRI. The salutogenic subcategory also had five of the eight variables meet the inclusion criteria, thereby excluding mental health services (8.5%), access to green space (5.4%), and homeownership (4.7%). While possible CSRI scores for each census tract ranged from 0-100, the actual scores ranged from 7.4 – 64.0 and represented communities in the Lowcountry and Upstate regions, respectively (Table 23). The mean CSRI score for the state was 28.0, which was lower than the mean score for Upstate (33.9) and Midlands (30.2) regions (Table 23).

After performing a one-way ANOVA, our findings indicated there was a statistically significant difference in CSRI scores by EA region ($p < 0.0001$) (Table 24).

The Tukey's Studentized Range (HSD) test calculated more specific regional comparisons and results indicated that significant differences in CSRI scores only applied to certain regions. When comparing the Lowcountry to Pee Dee region, there was no statistically significant difference in mean CSRI scores since the 95% confidence intervals (CIs) [-1.53, 2.68] overlapped. All other regional comparisons remained significant in the HSD test at an alpha level of 0.05. The linear regression model containing percent non-white populations and CSRI scores was also statistically significant at an alpha level of 0.05 ($p < 0.0001$). Specifically, we found a one-unit increase in the percentage of non-white populations increased CSRI scores by roughly 6.1% at the census tract level (Table 24).

Results from the choropleth maps (Figures 5 and 6) demonstrate the highest scores were found in areas containing the highest percentage of populations of color. The red areas on the CSRI map represent tracts close to or within the 90^{th} percentile for CSRI scores (≥43.8) in the state. These HR tracts are primarily located in more densely populated counties such as Charleston, Florence, Greenville, Spartanburg, Anderson, and York. The census tract with the highest CSRI score (64.0) and hence the lowest resiliency was detected in the Upstate region in Greenville, County, SC. In contrast, the census tract with the lowest CSRI score and high resiliency (7.4) is located in Berkeley County, SC in the Lowcountry region. Despite the spectrum of CSRI scores, many of the HR census tracts in the map were geographically adjacent to tracts with lower risk and higher resiliency.

4.5 Discussion

This study was designed to address the lack of scientific studies that include resiliency as a protective factor in mitigating the impacts of exposure to environmental stressors in communities impacted by environmental injustice. In response to this gap, we developed a novel CSRI hybrid measure comprised of environmental exposures and resilience factors that may be used to rank risk at the census tract level in South Carolina. We systematically reduced 26 variables to 20 indicators that have been cited in the literature and affirmed by community stakeholders as those that may contribute to environmental stress and resiliency. Though many of our variables have been used in other EJ screening tools, we incorporated a unique combination of environmental stressors and community assets into one model that has repeatedly been omitted from CRA tools (Barzyk, Wilson, & Wilson, 2015). For example, we used pathogenic indicators such as 'segregation' and 'violent crime' paired against salutogenic factors like 'access to primary healthcare' and 'access to grocery stores' to buffer the negative impacts of the stressors. Cumulative Risk Assessment tools that only consider pathogenic factors may overestimate risk and provide an inaccurate account of communities' needs to strengthen resiliency.

Not only were we able to determine that there was a direct relationship between the percentage of non-white populations residing in a census tract and CSRI scores, we also identified HR census tracts with CSRI scores in the 90th percentile for the state that would benefit from a risk reduction plan. For example, there were two census tracts in the Lowcountry region with similar population sizes and over a four-fold difference in CSRI scores (11.3 vs. 52.6). The high resiliency census tract was predominately white (76.0%)

and had the following characteristics: 1) ample access to grocery stores (non-food desert), 2) highly insured (25th percentile), 3) no alcohol outlets (excluding grocery stores, restaurants, and other establishments selling alcohol) or fitness facilities, 4) low crime and unemployment rate (25th percentile) 5) moderate access to primary healthcare (50th percentile; HPSA designation with a lower need for health professionals based on the HPSA score), 6) high educational attainment (25th percentile), and 7) high poverty (100th percentile), and 8) no fitness facilities. Despite the high percentage of poverty (83.1%), low educational attainment (29%), lack of fitness facilities nearby, HPSA designation, and the exposures to environmental stressors (e.g. TRI facilities ≤2.5 km and toxic releases) in this census tract, risk remained low.

In contrast, the low resiliency census tract was predominately non-white (88.0%) with the subsequent characteristics: 1) no grocery stores nearby (food desert) or fitness facilities, 2) low insured population and educational attainment (75th percentile), 3) high alcohol outlet density (100th percentile), 4) high crime (75th percentile), 5) high unemployment rates (75th percentile), 6) low access to primary healthcare (75th percentile) and 7) low poverty (25th percentile). This census tract had a lower poverty rate (39.0%) than the other tract and similar outcomes for $PM_{2.5}$ and ozone concentrations (25th percentile), but their resiliency factors could not offset enough of the environmental stressors to have an overall impact on the cumulative score. This census tract was also located near TRI facilities, Superfund sites, LUSTs, and brownfields (≤2.17 km), which may contribute to some of the differences in overall CSRI scores. Nevertheless, we believe that the interaction between resiliency factors and environmental stressors requires further exploration to determine the exact combination of salutogens required to significantly reduce the effects of exposures to environmental hazards.

While CRA is an iterative process, there are still actionable solutions that can be implemented to reduce environmental health disparities. Our CSRI tool may be used in a decision-making capacity to prioritize needs of specific communities based on the individual assessment of the indicators before they were combined into a cumulative index. However, we also see this tool as an opportunity create sister communities in the four EA regions in South Carolina. Our map of the CSRI scores indicates that low resiliency communities are often located adjacent to high resiliency or lower risk communities, which means that these communities could partner together in their risk reduction activities and provide support to each other in areas of weakness to build healthy community ecosystems. Since studies have shown that prioritizing and meeting the needs of a community's most vulnerable populations may lead to macro-level improvements in overall resilience (Wulff, Donato, & Lurie, 2015), we believe that partnering high resiliency communities with lower resiliency communities may be the solution to mitigating environmental health disparities and improving health across the state.

Despite our efforts to follow CRA principles in our study, there were limitations. Our CSRI tool may be used to rank the burden of pathogenic and salutogenic characteristics that impact health at the census tract level, but the results only serve as a proxy for actual exposures and risk. We selected variables that were mostly derived from publicly available datasets so that our CSRI scores would be comparable to census tracts in other states; however, a few of the variables required a license to gain data access (i.e., fitness facilities, alcohol outlets). Some entities may not have the resources to obtain access to these data sets.

In addition, we could not include all possible measures of environmental exposure in our index or capture every exposure during the exact same time period. For example, most of our indicators were collected from ACS from 2011-2015, but the ozone, $PM_{2.5}$, and RSEI concentrations represented 2010 estimates and hazards data (i.e., Superfund sites, TRI facilities, LUSTs) were variable years (Table 20). Though we used community stakeholder feedback to populate the PCA in our variable selection process, the PCA results were still driven by the order in which the variables were loaded. Therefore, we found that it was important to engage communities most impacted by EJ issues to inform the variable selection process so that the index was reflective of community-specific problems. Since our population was primarily comprised of African-American, low-middle income, urban residents; the variables selected for the CSRI may not reflect the priorities in communities with a differing racial, economic, or geographic demographic.

Another limitation of the study involved converting the data to the same geographic unit. Since a few of the original 26 variables were only available at the county level (e.g., violent crime, low birth weight, traffic density), we had to apply county level estimates to all census tracts within the corresponding county. In addition, census tract level air pollution concentrations had to be estimated from a few monitors located in densely populated areas. Extrapolating this data may have introduced misclassification and conditional bias. Using various crosswalks to get the data at the same level and combining those numerous datasets into one cumulative index already introduces error that may be compounded by error embedded in the individual datasets used for each variable (i.e., missing data, sampling error).

In future studies, we plan to explore other variables that could be used in the CSRI and further improve the methodology used to analyze the impact of salutogenic and pathogenic environmental characteristics on community health. In addition to exploring other methods and variables (i.e., land use, soil quality, mortality rates, and wellness support programs), we will examine weighting classifications that appropriately reflect the level of impact each variable may contribute to environmental stress and resiliency. We also plan to examine the association between CSRI scores and risk of asthma hospitalizations at the census tract level, which is an approach that will be applied to other health issues in the state (i.e., stroke and type 2 diabetes). We will also perform this analysis in other states in Region IV of the USEPA (i.e., North Carolina and Tennessee) to determine the utility of the tool beyond the borders of SC.

4.6 Conclusion

This study demonstrates that a CRA tool embedded with salutogenic and pathogenic factors is a viable method for screening risk and community resiliency. Finding racial/ethnic disparities in CSRI scores and HR census tracts located in more urban landscapes is not necessarily novel; however, our index allowed us to identify a blueprint for targeting communities that have low resiliency. A resilient community is one that can use its assets to strengthen public health systems in a way that may improve various dimensions of health, hence, allowing communities to withstand, adapt to, and recover from adversity (USDHHS, 2015). Our study results support this concept of a resilient community, and indicate that resiliency factors may be more important in reducing risk than attempting to eliminate exposures to environmental hazards. Although we encountered a few limitations, we anticipate our findings will be used by federal, state, and local agencies to prioritize actionable solutions in areas of concern to create more resilient, equitable, and healthy communities.

4.7 Acknowledgements

We would like to thank Mr. Charles Naney for his support on data management and analysis related activities. Moreover, we would like to thank Qi Yang from the UMD GIS and Geospatial Services Center for his support with GIS and all of the agencies that provided us with data for the CSRI variables.

4.8 Conflict of Interest

The authors declare no conflict of interest in this study.

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Table 19. Proposed CSRI indicators (N=26)

Environmental Stressors	**Resiliency Buffers**
Environmental Exposures • Diesel Particulate Matter (PM) Concentrations • Lead Paint (% Pre-1960s Housing) • Ozone Concentrations • $PM_{2.5}$ Concentrations • Traffic Density • Toxic Releases from Facilities	*Pathogenic Factors* • Linguistically Isolated • Low Birth Weight • Long-Term Unemployment • Low-Income (% Poverty) • Gini Index • Violent Crime • Access to Alcohol Outlets • Residential Segregation (Dissimilarity Index)
Environmental Hazards • Brownfields • Superfund Sites • Toxic Release Inventory (TRI) Facilities • Leaking Underground Storage Tanks (LUSTs)	*Salutogenic Factors* • Access to Green Space • Access to Mental Healthcare • Access to Primary Healthcare • Access to Grocery Stores • Access to Fitness Facilities • Educational Attainment • Health Insurance Coverage • Homeownership

Table 20. Finalized CSRI Indicators Obtained from Secondary Data

Subcategory	Indicator (PCA Variance %)	Definition	Data Source (Year)
Environmental Exposures	Diesel PM Concentrations (15.7)	Measure of the mean concentration of diesel pollution in the air released from trucks, buses, trains, ships, and heavy-duty equipment.	National-scale Air Toxics Assessment (NATA) (2011)
	Lead Paint (% Pre-1960s Housing) (10.0)	Measure of the percentage of older homes in an area that may still have lead paint.	US Census American Community Survey (ACS) (2011-2015)
	Ozone Concentrations (40.6)	Measure of the mean concentration of annual mean ozone releases in the air from cars, trucks, buses, oil refineries, factories, and consumer products (paints, cleaners, and solvents).	SC Department of Health & Environmental Control (SCDHEC) (2010)
	$PM_{2.5}$ Concentrations (22.4)	Measure of the mean concentration of annual mean fine particulates releases in the air from cars, power plants, wood burning, and coal and oil related activities.	SCDHEC (2010)
	Traffic Density (4.8)	Measure of the amount of vehicle miles traveled in an area per day.	SC Department of Transportation (SCDOT)
	Toxic Releases from Facilities (6.4)	Measure of the mean concentration of toxic substances released into the air from various industries in the area.	US Environmental Protection Agency (EPA) Risk-Screening Environmental Indicators (RSEI) Model (2010)
Environmental Hazards	Brownfields (51.0)	Measure of expansion, redevelopment or reuse of a property within a specified distance (0.5, 1.0, and 5.0km) that may contain toxic substances.	NETROnline database populated by ACRES (last updated 2009-2013)

	Superfund Sites (26.5)	Measure abandoned hazardous waste sites within a specified distance (0.5, 1.0, and 5.0km) that may still contain toxic substances.	National Institutes of Health TOXMAP NPL Final Status (1989-2009; last updated 2016)
	TRI Facilities (18.9)	Measure of industries releasing toxic substances within a specified distance (0.5, 1.0, and 5.0km) .	National Institutes of Health TOXMAP (2014)
	LUSTs (3.6)	Measure of leaking tanks or underground piping within a specified distance (0.5, 1.0, and 5.0km).	NETROnline database populated by ACRES (last updated 2009-2011)
Pathogenic Factors	Long-Term Unemployment (17.4)	Measure of the percentage of persons aged 16 and older who have been out of work for at least 6 months and are eligible for employment in an area.	ACS (2011-2015)
	Low-Income (% Poverty) (27.3)	Measure of the percentage of persons who live below the poverty level in an area.	ACS (2011-2015)
	Violent Crime (13.6)	Measure of the rate of non-negligent manslaughter, forcible rape, robbery, and aggravated assault offenses in an area per 1,000 people.	SC Law Enforcement Division (SLED) (2010)
	Access to Alcohol Outlets (12.2)	Measure of the number of places (NAICS code 445310) that sell alcohol in an area per 10,000 people ≥21 years of age.	Hoovers Company Information (2014-2016)
	Residential Segregation (Dissimilarity Index) (11.9)	Measure of the evenness with which two groups are distributed across a geographic area that make up a larger area.	ACS (2011-2015)
Salutogenic Factors	Access to Primary Healthcare (HPSAs) (11.1)	Measure of a shortage of primary health care providers in an area based on HPSA scores that indicate the level of need.	(HRSA) Data Warehouse (last updated date 2002 - 2015)

	Access to Grocery Stores (19.1)	Measure of areas with low access to grocery stores within a 1 and 10-mile range for urban and rural areas, respectively.	United States Department of Agriculture (USDA) Food Access Research Atlas (2010)
	Access to Fitness Facilities (11.7)	Measure of the number of fitness facilities (NAICS code 713940) nearby per 10,000 people.	Hoovers Company Information (2014-2016)
	Educational Attainment (24.6)	Measure of the percentage of persons aged 25 and older who graduated from high school in an area based on the population of residents ≥25.	ACS (2011-2015)
	Health Insurance Coverage (15.0)	Measure of the percentage of persons who have health insurance in an area.	ACS (2011-2015)

Table 21. Range of Possible Scores for Various Stages of CSRI Calculation

Categories	Subcategories	Indicator Range	Subcategory Range	Category Range	CSRI Score Range
Environmental Stressors	Environmental Exposures	0-1	0-6	0-10	0-100
	Environmental Hazards	0-1	0-4		
Resiliency Buffers	Pathogenic Factors	0-1	0-5	0-10	
	Salutogenic Factors	0-1	0-5		

Table 22. Sample CSRI Calculation for a Census Tract.

	Environmental Stressors				Resiliency Buffers			
	Environmental Exposures (6)		**Environmental Hazards (4)**		**Pathogenic Factors (5)**		**Salutogenic Factors (5)**	
CSRI Components	Raw Score	Indicator Score	Raw Score	Indicator Score	Raw Score	Indicator Score	Raw Score	Indicator Score
	Ozone 0.031 ppm	0.50	Brownfields N/A	0	Poverty 64.2%	0.75	Education 19.0%	1.00
	$PM_{2.5}$ 10.3 $\mu g/m^3$	0.25	Superfund 1.63 km	0.75	Unemployment 2.9%	0.25	Grocery Stores 1	1.00
	Diesel PM 0.61 $\mu g/m^3$	1.00	TRI Facilities 2.50 km	0.50	Violent Crime 6/1,000 residents	0.75	Health Insurance 22.0%	0.75
	Lead Paint 55.0%	1.00	LUSTs 2.17 km	0.75	Alcohol Outlet Density 3.1/10,000 residents ≥21 years of age	0.75	Fitness Facilities 3/10,000 residents	0.25
	Toxic Releases Mean RSEI Score 0.88	0.25			Residential Segregation -0.0	0.50	Primary Healthcare Mean HPSA score 7	0.25
	Traffic Density (1890000 VMT per sq mi)	0.50						
Subcategory Totals	(0.50 + 0.25 + 1.00 + 1.00 + 0.25 + 0.50) = 3.50		(0 + 0.75 + 0.50 + 0.75) = 2.00		(0.75 + 0.25 + 0.75 + 0.75 + 0.50) = 3.00		(1.00 + 1.00 + 0.75 + 0.25 + 0.25) = 3.25	
Category Totals (Range 0-10)	3.50 + 2.00 = 5.50				3.00 + 3.25 = 6.25			
CSRI Calculation (Potential Range 0-100)	**5.50 x 6.25 = 34.4**							

Table 23. CSRI Descriptive Statistics

Region (Census Tracts)	Mean Score (SD)[a]	Minimum	Maximum	High Risk[b] Scores
South Carolina (1,088)[d]	29.1 (10.2)	7.4	64.0	≥ 43.8
Upstate (324)	35.2 (9.1)	13.5	64.0	≥ 46.9
Midlands (316)	31.7 (9.3)	12.0	58.1	≥ 43.8
Pee Dee (206)	22.6 (7.4)	10.5	52.5	≥ 31.5
Lowcountry (242)	23.2 (8.1)	7.4	54.4	≥ 33.8

[a]Standard Deviation; [b]90th percentile score; [C]Fifteen census tracts were excluded due their census assignment to bodies of water (9900s) or those with little or no residential population (9800s, 45027960202, and 45061920301)

Table 24. One-Way ANOVA and Linear Regression Results

One –Way ANOVA					
Variable	SS	Df	MS	F	*p*
Region	31308.5	3	10436.2	139.8	<0.0001[a]
Linear Regression					
Variable	Coefficient		Standard Error		*p*
Non-white * CSRI	6.1		1.3		<0.0001 [a]

[a]*p* is statistically significant at alpha level 0.05

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Figure 3. Primary and Subcategories of the CSRI

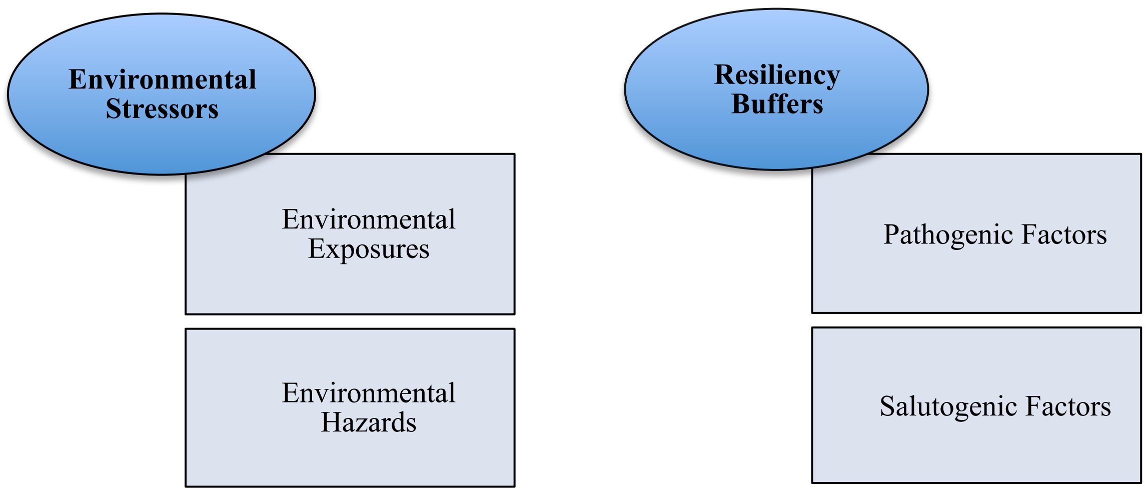


Figure 4. CSRI Calculation for Estimating Risk in SC Census Tracts

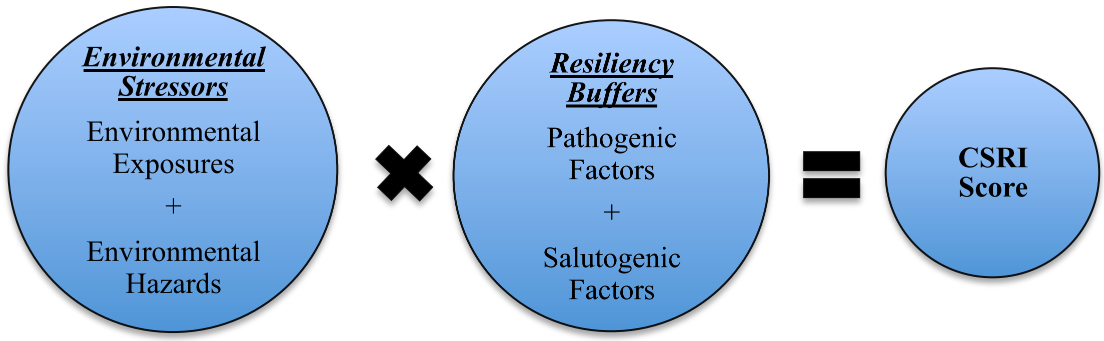
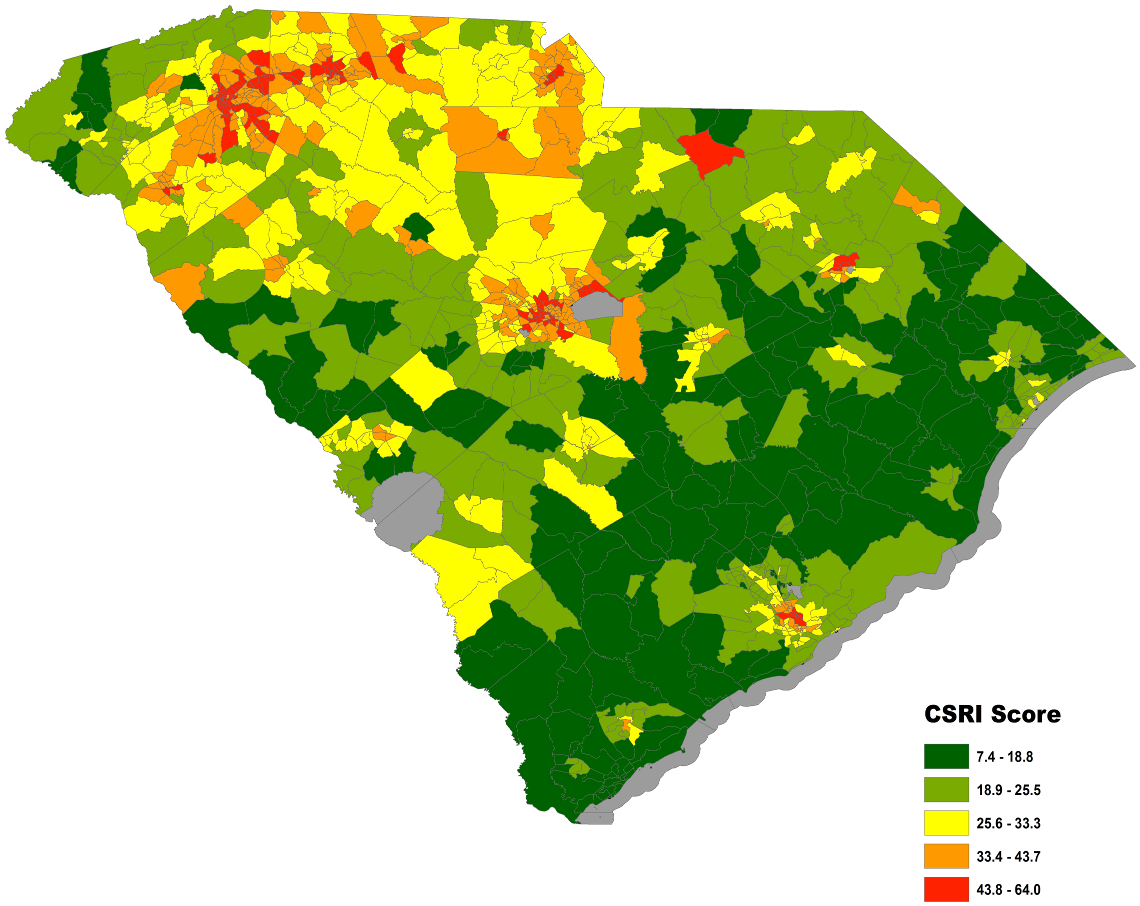
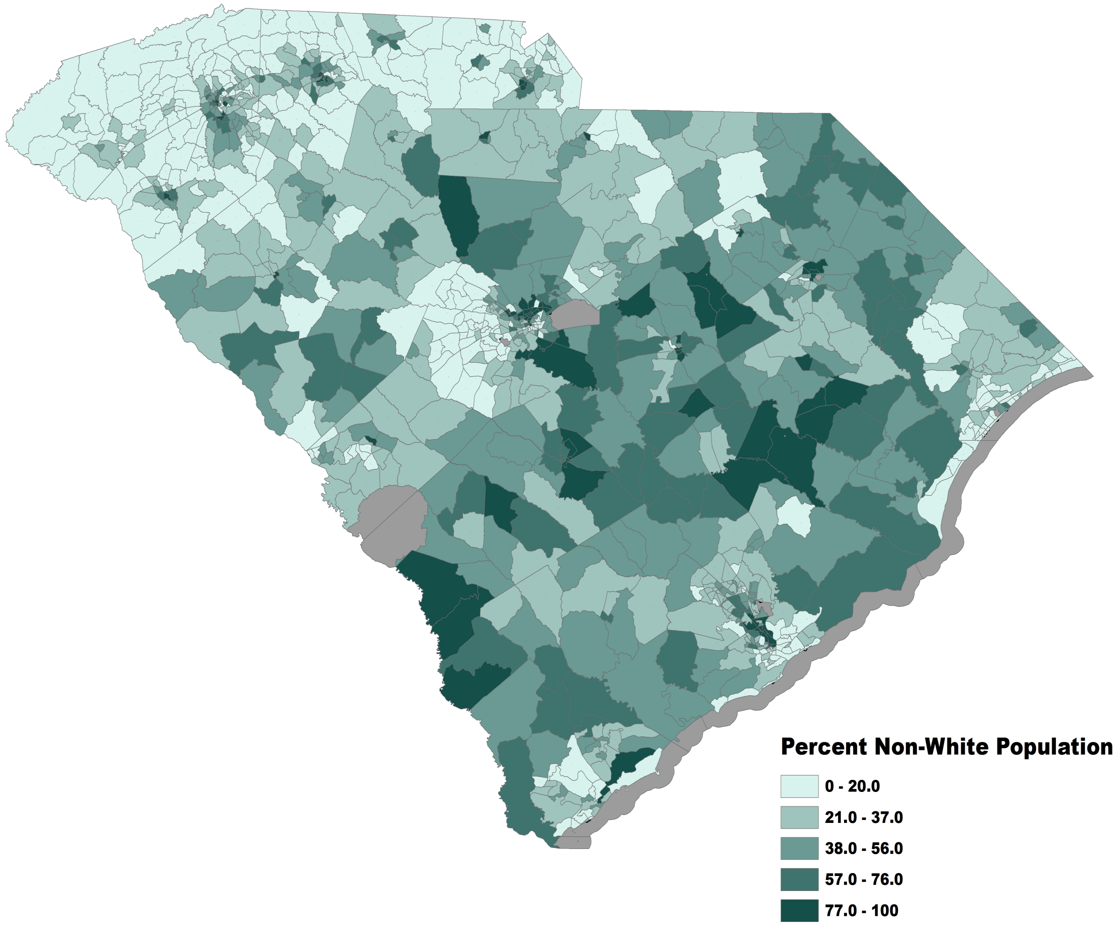


Figure 5. Choropleth Map of CSRI Scores by Census Tract



[a]Fifteen census tracts (marked in grey) were excluded due their census assignment to bodies of water (9900s) have little or no residential population (9800s, 45027960202, and 45061920301).
[b]CSRI scores range from low risk to high risk based on a community's combined load of environmental stressors and resiliency buffers. The highest class of CSRI scores (43.8 – 64.0) represents communities in the 90[th] percentile for risk or those classified as "high risk".

Figure 6. Choropleth map of Percent Non-white Population by Census Tract



[a]Fifteen census tracts (marked in grey) were excluded due their census assignment to bodies of water (9900s) have little or no residential population (9800s, 45027960202, and 45061920301) .

CHAPTER 5

EXAMINING THE ASSOCIATION BETWEEN A CUMULATIVE STRESSORS AND RESLIENCY INDEX AND RISK OF ASTHMA HOSPITALIZATIONS IN SOUTH CAROLINA

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5.1 Abstract

Considering combined impacts of chemical and non-chemical stressors on disease processes is particularly important for asthma, since various aspects of the physical and social environment may exacerbate symptoms and negatively impact disease management. This study examines the association between a pilot Cumulative Stressors and Resiliency Index (CSRI) and risk of asthma hospitalizations/emergency department (ED) visits in South Carolina (SC) communities to help reduce severe asthmatic events. Asthma hospitalization/ED visit data was obtained from the SC Revenue and Fiscal Affairs Office (SC RFAO) on patients diagnosed with asthma (ICD-9: 493) in 2010. We applied exclusion criteria that resulted in 32,738 cases and calculated corresponding descriptive statistics using SAS Enterprise Guide 7.1. Spearman's rank-order correlation, one-way Analysis of Variance (ANOVA), and negative binomial regression analyses were also performed. We found a weak negative correlation ((r = -0.13; p <0.0001) between CSRI scores and asthma hospitalization/ED visits. Moreover, a one-unit increase in CSRI scores decreased asthma hospitalizations/ED visits by roughly 1% (0.010) at the census tract level. While an unexpected relationship existed between the CSRI and risk of asthma hospitalizations/ED visits, this study highlights the importance of integrating CRA methods when selecting models for disease outcomes heavily influenced by environmental factors.

Key Words: exposure modeling, disease, population based studies, environmental monitoring

5.2 Introduction

To better understand ways to eliminate environmental injustice and reduce health disparities, it is important to consider the combined impacts of chemical and nonchemical stressors on disease processes (Clougherty & Kubzansky, 2009; Gee & Payne-Sturges, 2004; Morello-Frosh, Zuk, Jerrett, Shamasunder, & Kyle, 2011; Solomon, Morello-Frosch, Zeise, & Faust, 2016). This phenomenon is especially relevant for respiratory diseases such as asthma, where aspects of the physical and social environment may exacerbate symptoms and negatively impact disease management. Asthma is an inflammatory disease of the airways often characterized by shortness of breath, wheezing, coughing, and chest tightness (South Carolina Department of Health and Environmental Control [SCDHEC]). When an asthmatic event occurs, the airway becomes inflamed and muscles bands surrounding the airway wall tighten to the point of restricting airflow (National Heart, Lung, and Blood Institute, 2014). There are certain environmental, behavioral, and genetic risk factors known to contribute to the pathogenesis of asthma or may exacerbation symptoms in individuals with a previous asthma diagnosis. These risk factors include: 1) having a blood relative with asthma, 2) being overweight, 3) having another allergic condition, 4) being a smoker, 5) exposure to air pollution, 6) exposure to secondhand smoke, and 7) exposure to occupation triggers (Mayo Clinic, 2016; Subbarao, Mandhane, & Sears, 2009; Toskala & Kennedy, 2015).

An asthmatic event may range in severity from disrupting sleep or work responsibilities to being admitted to the emergency department (ED) or hospital, which may reduce productivity (i.e., school and work absences) (Asher & Pearce, 2014; CDC, 2011c; Ismaila, Sayani, Marin, & Su, 2013). This loss of productivity creates a significant economic burden on the nation's healthcare resources of roughly $56 billion (CDC, 2011c; Barnett & Nurmagambetov, 2011; SCDHEC, 2015). The economic encumbrance of asthma stems from the nearly 25.7 million total cases found nationwide, which also includes the 7.0 million children previously diagnosed with asthma as of 2010 (Akinbami et al., 2012). While asthma is a nondiscriminatory condition, the burden of disease disproportionately impacts populations of color and economically disadvantaged subgroups (Bryant-Stephens, 2009; Forno & Celedon, 2009; The Asthma and Allergy Foundation of America & The National Pharmaceutical Council, 2005). For example, data from 2008 – 2010 indicates populations of Puerto Rican descent had the highest prevalence of asthma (16.1%) when compared to Caucasians (7.7%), followed by persons identifying with multiple racial groups (14.1%) African-Americans (11.2%), and American Indians or Alaskan Natives (9.4) (Akinbami et al., 2012). African-Americans also have a higher asthma emergency department (ED) visit and hospitalization rate (per 100 persons with asthma than their Caucasian counterparts (Akinbami et al., 2012). The prevalence of asthma is higher among economically disadvantaged groups, ranging from 7.3% in populations with incomes ≥200% of the poverty level to 11.2% in those with incomes <100% of the poverty level (Akinbami et al., 2012).

Differential exposures to various chemical and non-chemical stressors may also perpetuate asthma disparities (Shmool et al., 2014; Solomon, Morello-Frosch, Zeise, & Faust, 2016; Yonas, Lange, & Celedon, 2012). Studies have consistently indicated that non-white and lower income populations have differential exposures to environmental hazards (Massey, 2004; Morello-Frosch, Zuk, Jerrett, Shamasunder, & Kyle, 2011; Pratt, Vadali, Kvale, & Ellickson, 2015). Specifically, lower income populations are more likely to reside in housing with above average exposures to asthma triggers such as dust mites, mold spores, mildew, rodent allergens, and cockroach allergens (Canino, McQuaid, & Rand, 2009; Pacheco et al., 2014; Williams, Sternthal, & Wright, 2009). Air pollution exposures may also contribute to the development of asthma throughout childhood and adolescence (Bowatte et al., 2015; Gehring et al., 2015; Khreis & Nieuwenhuijsen, 2017), where populations impacted by environmental injustice may have greater exposure to air pollution than their counterparts (Bell & Ebisu, 2012; Clark, Millet, & Marshall, 2014; Zou, Peng, Wan, Mamady, & Wilson, 2014). Other environmental stressors associated with asthma morbidity are exposures to passive cigarette smoke and stress resulting from exposures to violent crime (Canino, McQuaid, & Rand, 2009; Sternthal, Jun, & Wright, 2010), both of which disproportionately impact non-white groups (Forno & Celedon, 2012; Wright et al., 2004). While additional non-chemical stressors have the potential to modify the risk of an asthmatic exacerbation (i.e., segregation, access to healthy foods, access to healthcare resources, violence, alcohol) (Holsey, Collins, & Zahran, 2013; Sisson, 2007; Williams, Sternthal, & Wright, 2009), studies have shown there are resiliency factors related to adaptability (Mitchell, Murdock, & McQuaid, 2004), perceived self-control (Mitchell, Murdock, & McQuaid, 2004), and collective efficacy (Williams, Sternthal, & Wright, 2009) that may reduce one's risk of having a severe asthmatic event.

In an effort to reduce the proliferation of asthma disparities and the high mortality rates that may ensue, researchers have tried to develop prediction models to better identify individuals who have an increased risk for developing asthma (Grabenhenrich et al., 2014; Luo, Nkoy, Stone, Schmick, & Johnson, 2015) or an exacerbation that leads to hospitalization or an ED visit (Gorelick, Scribano, Stevens, Schultz, & Shults, 2008; Grineski, 2009; Ram, Zhang, Williams, & Pengetnze, 2015; Yurk et al., 2004). Many of these models are not representative of the multiple environmental triggers that may increase one's risk of an asthma exacerbation or resiliency factors that may decrease one's risk of an asthmatic event; therefore, using a cumulative risk assessment (CRA) approach may improve predictive models for asthma hospitalizations/ED visits.

With a CRA tool, one can organize and analyze information in a way that accounts for the interactive effects of biological, chemical, physical, and psychosocial stressors on human health (Sexton, 2012). A few CRA tools include health indicators in their model (i.e., CalEnviroScreen 3.0, Urban HEART, EJSCREEN), along with other environmental stressors, to quantify overall risk and vulnerability (Faust et al., n.d.; US Environmental Protection Agency {USEPA], n.d.c.; World Health Organization [WHO], 2010); however, they are still not entirely equipped to quantify risk for specific disease outcomes. One study used a multidimensional cumulative risk index (CRI) to predict asthma morbidity risk in children by analyzing variables such as environmental tobacco smoke (ETS), perceived discrimination, acculturation, poverty, neighborhood disadvantage, and children's asthma severity (Mitchell, Murdock, & McQuaid, 2004). Despite the success of this model, there were environmental exposures and potential protective factors not included (Castro-Rodriguez, Fomo, Rodriguez-Martinez, & Celedon, 2016). In contrast, another study included air pollution (e.g., nitrogen oxide, ozone, PM_{10}) and seasonality (e.g., humidity, vapor pressure, air temperature) measures in their model but excluded other environmental stressors and resiliency factors (Soviri, Reidpath, & Sarran, 2013).

One of the Office of Disease Prevention and Health Promotion (ODPHP) objectives in *Healthy People 2020* is to reduce asthma deaths, hospitalizations, and ED visits (ODPHP, n.d.). We anticipate our work may aid in achieving this goal and have designed a study to examine the association between a newly developed Cumulative Stressors and Resiliency Index (CSRI) and risk of asthma hospitalizations/emergency department (ED) visits in South Carolina (SC) communities to help reduce severe asthmatic events. The CSRI is a hybrid cumulative impact assessment tool designed in a previous study that examined the interactive effects of environmental stressors and resiliency buffers that may counteract the effects of adverse exposures (Burwell-Naney et al., [submitted]). We hypothesize that our environmental-based CSRI will be able to predict the risk of asthma hospitalizations/ED visits in SC communities. We further hypothesize there will be a direct relationship between CSRI scores and risk of asthma hospitalizations, demonstrating that populations with high exposure to environmental stressors and low resiliency may be more susceptible to severe asthma events. We posit this work will allow us to identify areas in SC that may need more asthma management resources, as well as elucidate the factors that may be contributing to increases in the risk of asthma hospitalizations/ED visits.

5.3 Materials and Methods

Study Area

South Carolina is a state located in the southeastern region of the US that spans approximately 30,061 square miles and is often characterized by rural and urban landscapes. Four environmental affairs (EA) regions divide the state into the following quadrants: 1) Upstate, 2) Midlands, 3) Pee Dee, and 4) Lowcountry. Moreover, SC has 1,103 census tracts that equate to 3,059 block groups and 181,901 blocks (US Census Bureau, n.d.a). Within the 1,103 census tracts are those that have been assigned to bodies of water (9900s) or have little or no residential population (9800s, 45027960202, and 45061920301). These 15 census tracts were excluded from the study, hence reducing the total number of census tracts in the study area to 1,088 (US Census Bureau, n.d.b).

According to the 2010 US Census Bureau, approximately 4,625,364 residents populate the state and there are 153.9 persons living per square mile (US Census Bureau, n.d.c). The population is mostly comprised of non-Hispanic Whites (66.2%), followed by non-Hispanic Blacks (27.9%) and Latinos (5.1%). The 2011 - 2015 trend of median household income was $45,483, which was roughly $8,400 lower than the US average ($53,889) (US Census Bureau, n.d.c). These differences in median household income are also reflected in poverty trends, where the percentage of persons below poverty level in SC (16.6%) exceeds the US estimate (13.5%).

In regards to asthma, the SC Department of Health and Environmental Control (SC DHEC) reported 311,539 adults and 102,440 children were diagnosed with asthma as of 2013 (SCDHEC, 2015). Asthma differentially affects populations ≤18 years of age in SC and is considered the most common chronic condition and leading cause of disability among children (SCDHEC, 2015). The following SC counties had the highest asthma hospitalization/ED discharge rates (160.3-282.1 per 10,000) among populations ≤18 years of age: 1) McCormick, 2) Newberry, 3) Chester, 4) Fairfield, 5) Marlboro, 6) Dillon, 7) Calhoun, 8) Clarendon, 9) Williamsburg, 10) Orangeburg, 11) Allendale, and 12) Hampton. When considering all age groups, asthma hospitalizations/ED visits were highest in young males (0-4 years of age) and middle age females (40-49 years of age) from 2011-2013 with close to 8,000 visits (SCDHEC, 2015).

Asthma Hospitalizations

Asthma hospitalization/ED visit data was obtained from the SC Revenue and Fiscal Affairs Office (SCRFAO) on patients who received an ICD-9 diagnosis code of 493 in a SC hospital or ED in 2010. The dataset consisted of other information regarding the date of diagnosis, race, age, gender, zip code, county of residence, and primary payor. Participants were excluded from the study if they met the following criteria: 1) non-resident of SC based on a five-digit zip code, 2) included missing data that did not allow the verification of SC residency, and 3) comprised missing data necessary to perform descriptive statistics for race, age/ethnicity, gender, and primary payor. Each asthmatic event was counted as a separate case regardless of whether an individual had a repeat hospitalization or ED visit in 2010. Other studies have used this approach of treating repeated asthma hospitalizations/ED visits as independent cases in their analysis (Soyiri, Reidpath, & Sarran, 2011). After applying the exclusion criteria, 32,738 cases of an asthma exacerbation remained in the study.

Cumulative Stressors and Resiliency Index (CSRI)

The CSRI is an innovative cumulative risk assessment tool that may be used to perform the following: 1) quantify cumulative environmental risk at the census tract level, 2) identify and prioritize low-resiliency populations with limited health promoting resources, 3) create community profiles of environmental stressors and assets, and 4) provide state and local governments with a standardized tool that promotes transparency when making decisions to address environmental injustice (Burwell-Naney et al., [submitted]. Community members impacted by EJ issues as well as current literature on environmental stressors and resiliency informed the CSRI; however, final variable selection was orchestrated using the principal components analysis (PCA) procedure in SAS Enterprise Guide 7.1. This procedure allowed us to include environmental stressors and resiliency buffer indicators that accounted for ≥10% variance, with the exception of Toxic Release Inventory (TRI) facilities and leaking underground storage tanks (LUSTs) variables. These two variables were included due to their impact on health and presence in other environmental justice (EJ) risk screening tools (i.e., EJSEAT, CalEnviroScreen 3.0). The CSRI is comprised of 20 indicators divided into four subcategories: 1) environmental exposures, 2) environmental hazards, 3) pathogenic factors, and 4) salutogenic factors (Table 25). While the methods for developing the CSRI are discussed in more detail elsewhere (Burwell-Naney, et al. [submitted]), we have provided the calculation below for calculating the overall score (Figure 27). CSRI scores range from 0 – 100, where higher scores equate to high risk and low resiliency and lower scores represent low risk and high resiliency.

Statistical Analysis

We obtained descriptive statistics by calculating percentages of asthma hospitalizations by gender, age, race/ethnicity, primary payor, and environmental affairs (EA) region using SAS Enterprise Guide 7.1 (Table 26). Additional statistics were calculated for age and EA regions to determine the mean and standard deviation (SD) values. Age (≤17, 18 – 64, ≥65) and primary payor (Medicaid, Medicare, Private) were collapsed into three categories for the regression analysis. Gender was recoded into two categories, (Male, Female) and the race/ethnicity variable (White, African American, Asian, American Indian, Other, and Hispanic) maintained its original category. A Spearman's rank-order correlation was calculated to determine whether a relationship exists between CSRI scores and asthma hospitalizations, including the strength (weak, medium, or strong) and direction (positive versus negative) of the relationship.

We used a one-way Analysis of Variance (ANOVA) test to examine differences in mean asthma hospitalizations by EA region. In addition, we performed negative binomial regression analyses at a significance level of 0.05 to determine the relationship between CSRI scores (independent variable) and risk of asthma hospitalizations (dependent variable). While Poisson regression is typically used to model count data, negative binomial regression was best suited for our analysis given the variance was considerably higher than the mean (i.e., overdispersion) (Soviri, Reidpath, & Sarran, 2011; Soviri, Reidpath, & Sarran, 2013). We controlled for potential confounding factors (e.g., gender, race/ethnicity, age, and primary payor) in our adjusted negative binomial regression model.

In addition, a choropleth map was created using ArcMap 10.5 to depict the following spatial relationships between CSRI scores and asthma hospitalizations/ED visits (Figure 8). The map contained five percentile categories generated by natural breaks, thereby illustrating variations between the highest and lowest percentile among the variables of interest. Specifically, the higher percentile categories in the map legend represented greater asthma hospitalizations/ED visits and areas that may have high environmental stress and low resiliency. In contrast, the lower percentile categories had fewer or no asthma hospitalizations/ED visits and low environmental stress and high resiliency.

5.4 Results

We present a combination of descriptive statistics, Spearman's rank-order correlation, one-way ANOVA, and negative binomial regression results to determine whether or not our hybrid CSRI model effectively predicted asthma hospitalizations and ED visits at the census tract level in SC. Asthma hospitalizations/ED visits were reported in 613 of the 1,088 populated census tracts in SC. There were 32,738 total asthma cases in our study and approximately 43.8% of those cases resided in the Midlands region (Table 26). The mean age for persons experiencing an asthma exacerbation was 47 and there were slightly more females (54.4%) than males (45.6%) who had been hospitalized or had an ED visit for asthma. There were also more Whites (58.7%) hospitalized for asthma than African-Americans (37.6%) and most of the population was insured by Medicare (34.4%), followed by commercial insurance (23.6%) and Medicaid (21.2%) (Table 26). Upon further analysis, the Spearman's rank-order correlation coefficient results demonstrate there was a very weak negative correlation between asthma hospitalizations/ED visits and CSRI scores at the census tract level (r = -0.13; p <0.0001) (Table 27).

Using one-way ANOVA, we found a statistically significant difference in asthma hospitalizations and ED visits by EA region (p <0.0001) (Table 27). The Tukey's Studentized Range (HSD) test results indicate significant differences in asthma exacerbation were consistent across all regions at an alpha level of 0.05. We also found similar results using negative binomial regression, where the unadjusted (p <0.0001) and adjusted models (p = 0.0003) were both statistically significant (Table 27). For the adjusted model, we found a one-unit increase in CSRI scores would decrease asthma hospitalizations and ED visits by roughly 1% (0.010) at the census tract level (Table 27). The spatial illustration of CSRI scores and asthma hospitalizations/ED visits (Figure 8) further demonstrates the relationship between our independent and dependent variables was non-existent. However, we observed a clustering of asthma hospitalizations/ED visits in more urban areas such as Charleston, Columbia, Florence, Greenville, and Spartanburg, SC.

5.5 Discussion

Our study aimed to examine the association between CSRI scores and increased risk of asthma hospitalizations/ED visits in SC communities. While we hypothesized our CSRI would be able to predict the risk of asthma hospitalizations/ED visits in SC communities, our results indicated otherwise. We first found a weak negative correlation ((r = -0.13; p <0.0001) between CSRI scores and asthma hospitalization/ED visits. The relationship is contrary to what we would expect given many of the variables in the CSRI either exacerbate or mediate the effects of asthma.

For example, studies have shown that exposures to $PM_{2.5}$ (Guarnieri & Balmes, 2014; Mirabelli, Vaidyanathan, Flanders, Qin, & Garbe, 2016; Yip, Pearcy, Garbe, & Truman, 2011), ozone (Guarnieri & Balmes, 2014; Soyiri, Reidpath, & Sarran, 2011), and diesel PM (McCreanor et al., 2007) may exacerbate asthma. Our CSRI also includes contextual aspects of the social environment (e.g., segregation, violent crime, socioeconomic status [SES]) (Eldeirawi et al., 2016; Gupta et al., 2010; Williams, Sternthal, & Wright, 2009) and other factors representing direct and/or indirect complications to asthma management like alcohol (Sisson, 2007) and lack of access to necessary healthcare resources or health insurance (Holsey, Collins, & Zahran, 2013).

One possible explanation for our findings is that there may have been collinearity between some of the individual independent variables in the CSRI. However, this should not be much of an issue in this study since the 20 independent variables are combined into one score and we used a variable selection procedure (PCA) (Tu, Kellett, Clerehugh, & Gilthorpe, 2005). In addition, some of the census tracts may have included outliers for asthma hospitalizations/ED visits since an individual with multiple hospital/ED visits during the study period were counted as a separate case. These outliers may have influenced the correlation coefficient and slope of the regression line in a way that weakened the relationship between the predictor and outcome variable. Results from the negative binomial regression (-0.010) were also conflicting, since we would expect that a one-unit increase in CSRI scores would increase asthma hospitalizations/ED visits at the census tract level. Specifically, we would anticipate that persons diagnosed with asthma would have an increased risk of an exacerbation if they resided in a census tract with high environmental stress and low resiliency. As part of a sensitivity analysis (data not shown), we performed an additional analysis using 10 years (2001-2011) of asthma hospitalization/ED visit data to examine whether a larger dataset would provide a more precise estimate that reflected the relationship between our independent and dependent variable. Nevertheless, we still found a negative estimate that was relatively similar to the results presented in this study.

Our study had a few limitations. For example, our CSRI did not include indoor environmental factors that may be associated with asthma like exposures to residential pesticides (Doust et al., 2014; Hernandez, Parron, & Alarcon, 2011) and indoor air pollution (Breysse, 2010). We also did not include weatherization (i.e., insulation, sealing leaks and ducts, inspecting heating/cooling systems) as a resiliency factor, which is known to improve indoor air quality and reduce triggers that would exacerbate asthma (Rose, Hawkins, Tonn, Paton, & Shah, 2015). Additionally, we had to perform a crosswalk to transform zip code level asthma hospitalizations/ED visits to census tract level estimates, which may reduce the accuracy of the case locations compared to having specific addresses for each case. Moreover, our current dataset may have underestimated the number of asthma hospitalizations/ED visits per census tract since we are unable to account for individuals seeking care outside of the state. While some census tracts may have several hospitalizations/ED visits for the same individual, our study was more concerned about the exacerbation event instead of distinguishing between the unique number of individuals with an exacerbation. There were also a few limitations within the index related to using crosswalks to combine data from varying geographic units of analysis, using variables collected within different time periods, and having to perform kriging with limited data points for air pollution variables (i.e., ozone, $PM_{2.5}$).

Asthma may not have been the best health outcome to use since asthma hospitalizations/ED visits may be influenced by access to and use of health care services to receive asthma medications, disease management plans, and insurance coverage (Kuhn et al., 2015; Markovitz & Andresen, 2006; Ungar et al., 2011). In cases of persistent asthma, children with at least one asthmatic exacerbation in the previous year have a twofold risk of having another exacerbation despite use of controller medications (Covar et al., 2008; Forno & Celedon, 2012). As a result, populations with an asthmatic hospitalization or ED visit may be more susceptible to asthma triggers than the general population based on genetics instead of increased exposures to environmental stressors and/or high community resiliency. Furthermore, some of the asthma hospitalizations/ED visits may have been attributable to an acute exposure to air pollution (i.e., ozone, pollen, $PM_{2.5}$) (Osborne, et al., 2017; Sheffield, Zhou, Shmool, & Cloughtery, 2015; Tian et al., 2017) and not the cumulative effects of the variables in our index. Using asthma incidence or prevalence data would have been more appropriate than hospitalization/ED visit data so we could prospectively or retrospectively determine whether the CSRI could be used to predict the risk of disease onset. In addition, using incidence data for asthma would allow us to establish more of a cause-effect relationship between the predictor (environmental stressors and resiliency buffers) and outcome (asthma) variables.

To make our model more specific to our outcome of interest, we plan to add individual CSRI indicators into the negative binomial regression model at a time to determine the best combination of environmental factors and resiliency buffers that can be used to accurately predict disease risk or other measures of health. Specifically, we plan to use the CSRI variables to predict life expectancy, quality of life, and years of potential life lost (YPLL). Life expectancy is a measure of the average number of years lived by members of the populations and is an indicator of mortality (Merrell, 2013). Quality of life is a multidimensional measure that may be categorized into the five domains: 1) physical well-being, 2) material well-being, 3) social well-being, 4) emotional well-being, and 5) developmental activity (Felce & Perry, 1995). Quality of life is an indicator of morbidity that may be assessed for overall health or disease specific scales (i.e., cancer, CVD, rheumatological, respiratory, and neurological conditions (Bowling, 2001; Hornigold et al., 2012). YPLL is an estimate of the average years a person would have lived if they did not die prematurely (Gardner & Sanborn, 1990). This morbidity measure can measure specific causes of death (Gardner & Sanborn, 1990; Marshall, 2004).

5.6 Conclusion

While our study was the first to use a CRA approach in disease modeling, our CSRI was ineffective in predicting risk of asthma hospitalizations/ED visits in SC. Despite the shortcomings of our model, there is still a need to design more environmental-based models to predict the risk of severe asthmatic events since asthma is a condition that is heavily influenced by environmental factors that are both pathogenic and salutogenic in nature. By improving environmental-based predictive models for various disease outcomes or other measures of health, we can better inform disease management and prevention strategies that will allow us to create resilient communities and ultimately reduce heath disparities.

5.7 Acknowledgements

We would like to thank the SC Revenue and Fiscal Affairs Office for providing the asthma data and Mr. Charles Naney for his support on data management and analysis related activities.

5.8 Conflicts of Interest

There are no competing financial interests in relation to this work.

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5.10 Manuscript 3 Tables

Table 25. CSRI Indicators (N=20)

Environmental Stressors	**Resiliency Buffers**
Environmental Exposures • Diesel Particulate Matter (PM) Concentrations • Lead Paint (% Pre-1960s Housing) • Ozone Concentrations • $PM_{2.5}$ Concentrations • Traffic Density • Toxic Releases from Facilities	*Pathogenic Factors* • Long-Term Unemployment • Low-Income (% Poverty) • Violent Crime • Access to Alcohol Outlets • Residential Segregation (Dissimilarity Index)
Environmental Hazards • Brownfields • Superfund Sites • Toxic Release Inventory (TRI) Facilities • Leaking Underground Storage Tanks (LUSTs)	*Salutogenic Factors* • Access to Primary Healthcare (HPSAs) • Access to Grocery Stores • Access to Fitness Facilities • Educational Attainment • Health Insurance Coverage

Table 26. Descriptive Statistics for Asthma Hospitalizations/ED Visits

Variables	**Geographic Area**				
	South Carolina	Lowcountry	Midlands	Pee Dee	Upstate
Total Cases	32,738	6,254	14,334	5,174	6,976
Mean Age (SD)	47 (27.2)	48 (26.7)	48 (26.9)	44 (27.5)	47 (27.8)
Age Range	0 - 106	0 - 101	0 - 106	0 - 104	0 - 104
Gender (%)					
Male	14,935 (45.6)	2,798 (44.7)	6,555 (45.7)	2,372 (45.8)	3,210 (46.0)
Female	17,800 (54.4)	3,456 (55.3)	7,776 (54.2)	2,802 (54.2)	3,766 (54.0)
Unknown	3 (0.010)	0	3 (0.021)	0	0
Race/Ethnicity (%)					
White	19,233 (58.7)	3,220 (51.5)	10,547 (73.6)	1,967 (38.0)	3,499 (50.2)
African American	12,294 (37.6)	2,814 (45.0)	3,189 (22.2)	3,067 (59.3)	3,224 (46.2)
Asian	64 (0.195)	5 (0.080)	43 (0.300)	5 (0.097)	11 (0.158)
American Indian	85 (0.260)	68 (1.09)	2 (0.014)	11 (0.212)	4 (0.057)
Other	386 (1.18)	89 (1.42)	140 (0.977)	48 (0.928)	109 (1.56)
Hispanic	672 (2.05)	57 (0.911)	413 (2.88)	76 (1.47)	126 (1.81)
Primary Payor (%)					
Self Pay	4,971 (15.2)	938 (15.0)	2,268 (15.8)	721 (13.9)	1,044 (15.0)
Medicare	11,262 (34.4)	2,236 (35.8)	4,924 (34.4)	1,660 (32.1)	2,442 (35.0)
Medicaid	6,930 (21.2)	1,182 (18.9)	2,848 (19.9)	1,332 (25.7)	1,568 (22.5)
Commercial Ins.	7,734 (23.6)	1,632 (26.1)	3,399 (23.7)	1,067 (20.6)	1,636 (23.5)
Workers Comp.	14 (0.043)	3 (0.048)	10 (0.070)	0	1 (0.014)
Indigent/Charitable Organization	688 (2.10)	83 (1.33)	499 (3.48)	74 (1.43)	32 (0.459)
Other Government	547 (1.67)	61 (0.975)	131 (0.914)	209 (4.04)	146 (2.09)
HMO	592 (1.81)	119 (1.90)	255 (1.78)	111 (2.15)	107 (1.53)

Table 27. Spearman's Rank-Order Correlation, One-Way ANOVA and Negative Binomial Regression

<table>
<tr><td colspan="6">Spearman's Rank-Order Correlation</td></tr>
<tr><td>Variable</td><td colspan="2">r</td><td colspan="3">p</td></tr>
<tr><td>CSRI Score and Asthma Hospitalizations/ED Visits</td><td colspan="2">-0.13</td><td colspan="3"><0.0001</td></tr>
<tr><td colspan="6">One-Way ANOVA</td></tr>
<tr><td>Variable</td><td>SS</td><td>Df</td><td>MS</td><td>F</td><td>p</td></tr>
<tr><td>EA Region</td><td>67974986.1</td><td>3</td><td>22658328.7</td><td>878.0</td><td><0.0001</td></tr>
<tr><td colspan="6">Negative Binomial Regression</td></tr>
<tr><td>Variable</td><td>Coefficient</td><td colspan="2">Standard Error</td><td colspan="2">p</td></tr>
<tr><td>CSRI Score</td><td>-0.008</td><td colspan="2">0.011</td><td colspan="2"><0.0001</td></tr>
<tr><td>CSRI Score * Age * Race/Ethnicity * Primary Payor</td><td>-0.010</td><td colspan="2">0.003</td><td colspan="2">0.0003</td></tr>
</table>

5.11 Manuscript 3 Figures

Figure 7. CSRI Calculation for Estimating Risk in SC Census Tracts

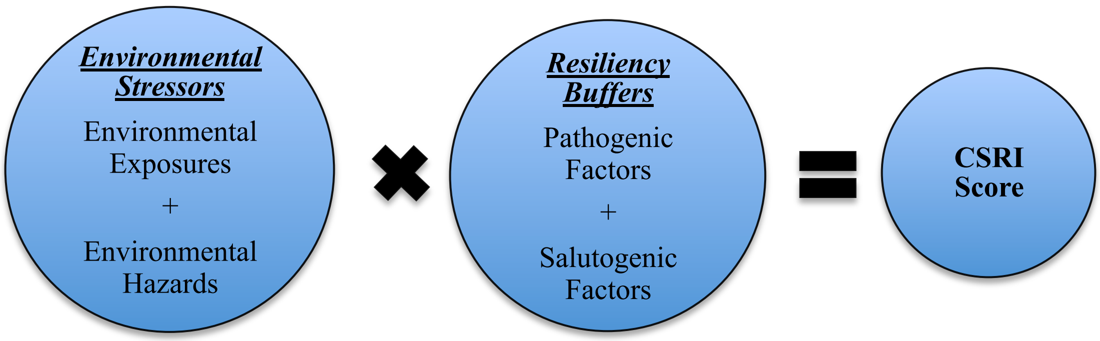
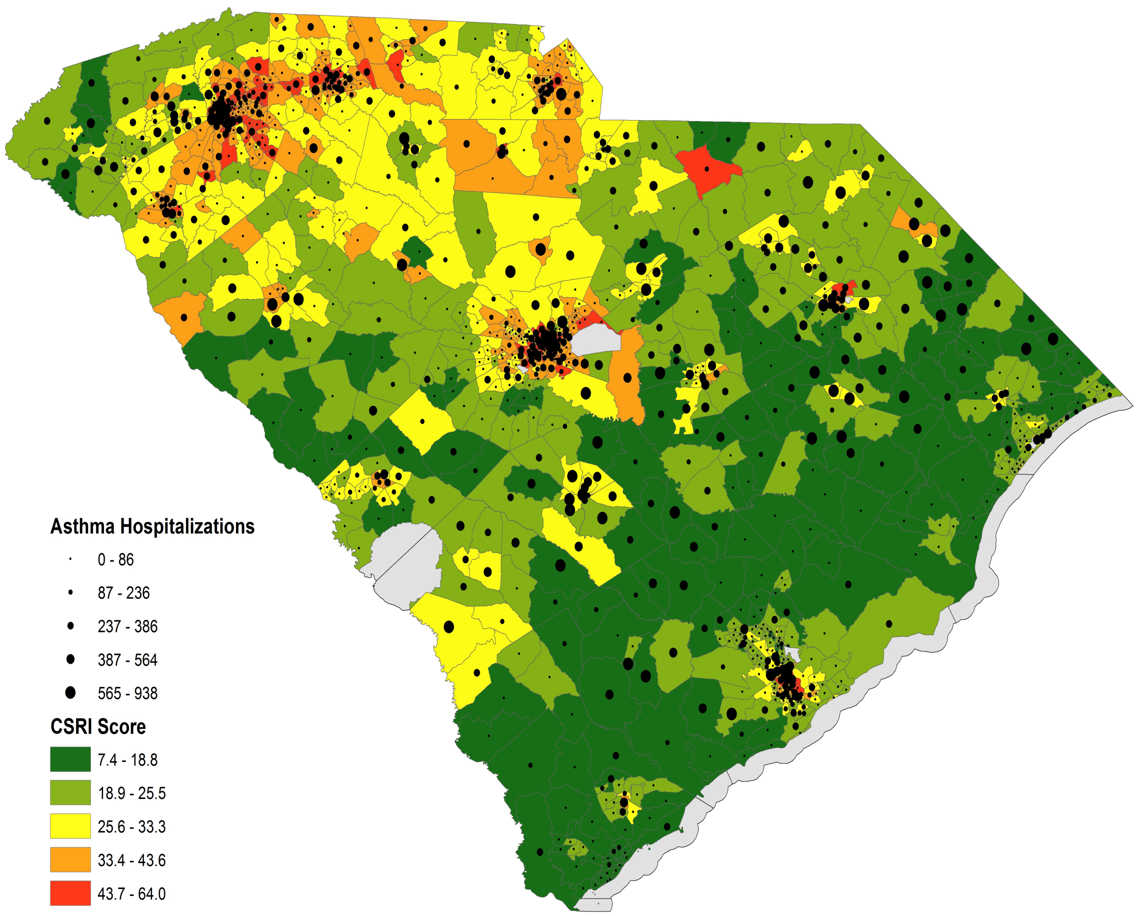


Figure 8. Map of CSRI Scores by Asthma Hospitalizations



CHAPTER 6

Synopsis, Strengths, Limitations, and Public Health Implications

This chapter provides a brief overview of our study findings and highlights the strengths and limitations of each individual study. In previous chapters we examined the literature to find support for the development of our study and presented evidence necessary to answer the research questions that correspond with our specific aims. We conclude with public health implications that provide a basis for future research studies on cumulative risk assessment (CRA) screening tools that account for community resiliency.

6.1 Specific Aim #1: Identify perceptions of environmental and resilience factors that may influence health among African-Americans in North Charleston, SC.

In our first study, we identified perceptions of environmental and resilience factors that may influence health among African-Americans in North Charleston, SC. When community stakeholders were asked their perceptions of negative aspects of their environment that may influence health, they (94%) mentioned traditional environmental hazards found in communities impacted by environmental injustice. For example, close proximity to industrial operations, chemical manufacturing plants, and highways; poor air quality; soil contamination; and water pollution that adversely affects fish health were some of the environmental concerns discussed during the key-informant interviews. The community stakeholders attributed their resiliency to social support, upholding/encouraging a positive attitude (i.e., social capital); faith, civic infrastructure, collaborative organizations, increasing environmental awareness (i.e., services and institutions); maintaining a healthy diet, exercise (built environment), and generational advantage (i.e., structural).

This study also focused on identifying environmental factors that most influenced health in North Charleston, SC. The environmental factors that most influenced health were those with ≥50% of the community stakeholders selecting HP, EHP, or a combination of the two categories as an indicator that would most influence health. Using the above criteria, alcohol outlet density, percent non-white population, and linguistically isolated indicators were not considered environmental factors that influenced health in North Charleston. The remaining 24 variables were reported as variables that were most influential in impacting health at the local level (Table 28).

Table 28. Highest Priority Environmental Stressor and Resiliency Indicators

Highest Priority Indicators (Total = 24)	
Access to exercise facilities	Superfund sites
Access to green space	Toxic releases from TRI facilities
Access to transportation	Violent crime
Brownfields	Low-income
Educational attainment	Ozone concentrations
Food swamps	$PM_{2.5}$ concentrations
Health insurance coverage	Diesel PM concentrations
Primary healthcare HPSA	Mental healthcare HPSA
Long-term unemployment	Lead paint
Traffic density	LUSTs
Violent crime	Segregation
Vulnerable populations	TRI facilities

We further examined differences between community perceptions of factors that may influence health and actual health-influencing factors as described in scientific literature. According to the participants' responses, there was no real difference in the perceptions of environmental factors that influence health and actual factors that have been implicated in the literature. Twenty-four of the 27 indicators were categorized as either a HP and/or EHP item. The mode for alcohol outlet density was divided between LP and EHP, while participants ranked percent non-white as a MP and HP item. Many of the participants ranked linguistically isolated as a MP, thereby believing that households containing adults with low English proficiency could still have some bearing on health.

When the study participants were asked “What do you believe should be added to the list of environmental indicators, if anything, and why?”, several of the respondents said nothing (44%). A few of the participants suggested that we keep the existing list and add indicators that measure the following factors: 1) soil quality, 2) programs that support wellness among youth and seniors, 3) mortality rates, 4) zoning, 5) social support, 6) technology, 7) community participation on environmental issues, and 8) communication and awareness between community, city, and state level officials. When asked, “What do you believe should be removed from the list of environmental indicators, if anything, and why?”, most of the participants (67%) stated that they would neither add or remove anything to the list while four of the responses were inconclusive. Access to alcohol outlets and residential segregation were the only variables that were mentioned as items to be removed despite the literature that links these variables with adverse health outcomes.

For example, persons with greater access to alcohol facilities are more likely to consume unhealthy quantities of alcohol and have a hospital visit related to anxiety, stress, and depression (Pereira, Wood, Foster, & Haggar, 2013), as well as assault injuries (Mai, Gruenewald, Ponicki, & Remer, 2013). Alcohol outlet density has also been associated with higher rates of violent crime despite the economic, racial, and age demographic of the community; however, the effect may be magnified in communities of color and economic disadvantage (Fone et al., 2016; Stewart, n.d.). Studies have also indicated that decreases in alcohol outlet density are associated with reductions in gonococcal infection rates (Cohen et al., 2006) and alcohol-related mortality (Spoerri et al., 2013), hence, demonstrating the relationship between alcohol outlets and poor health outcomes.

Several studies have noted the relationship between environmental health disparities and segregation that may perpetuate health inequalities among populations of color (Jacobs, 2011; Kramer & Hogue, 2009; Morello-Frosch & Jesdale, 2006; Morello-Frosch & Lopez, 2006; Rice et al., 2014). Segregation has been associated with an increased risk of negative health outcomes, such as mortality (Yang & Matthews, 2015), preterm birth (Messer, Laraia, & Mendola, 2009), low-birth weight (Debbink & Bader, 2011), asthma (Pearlman et al., 2006), CVD (Kershaw & Albrecht, 2015), cancer (Morello-Frosh & Jesdale, 2006), and sexually transmitted infections (STIs) (Kramer & Hogue, 2009). This increased risk for adverse health conditions is likely attributable to the disproportionate distribution of environmental hazards in predominately non-white and low-income communities (Gee & Payne-Sturges, 2004: Massey, 2004; Morello-Frosch, Zuk, Jerrett; Shamasunder, & Kyle, 2011; Wilson et al., 2012a; Wilson et al., 2012b).

6.1.1 Strengths

The strengths of this study certainly outweigh the limitations. Several studies have attempted to address perceptions of health by examining self-reported health status

(Mence, Chipperfield, Perry, 1999; Ruchiwit, Ruchiwit, Pawloski, & Curtin, 2012), susceptibility to health and safety risk factors (Weinstein, 1984), or have focused on how perceptions may influence a particular health behavior (Oyeyemi et al., 2014; Ries et al., 2008; Tanner et al., 2013) or outcomes (Webster & Heeley, 2010), but few have directly examined the perceptions of social and environmental stressors that may influence health. Our study not only assessed perceptions of environmental stressors in communities heavily impacted by environmental injustice, we also examined perceptions of resiliency factors that may positively influence health. We were also able to prioritize and bring attention to specific environmental stressors and resiliency factors influencing health in North Charleston. This information will be useful in assisting decision-makers and other stakeholders on how to proceed with community revitalization efforts.

Another strength is that our study community was part of a long-standing partnership that is a collaboration between the UMD-College Park, SCDHEC, USC-Columbia, LAMC, and the following CCRAB communities: Union Heights, Chicora-Cherokee, Rosemont, and Green Grove known as the Charleston Area Pollution Prevention Partnership (CAPs). This community-university partnership follows the CBPR framework, which is a collaborative research approach with demonstrated success in building trust between community and academic partners while increasing community empowerment, systems development, local capacity, and sustainability (Horowitz, Robinson, & Seifer, 2009; Minkler & Wallerstein, 2011; O'Fallon & Dearry, 2000; Wilson, Campbell, Dalemarre, Fraser-Rahim, & Williams, 2014). This community-university partnership was important because had already developed rapport and trust in the community, which allowed us to capture quality information from our study participants that was used to inform a larger study with significant public health implications.

6.1.2 Limitations

The limitations are more inherent in quantitative research for Specific Aim #1 and are not necessarily unique to our work. For example, our small population size did not allow our results to be generalizable to a larger population. We also used a convenience sampling scheme that limited the representativeness of our sample of African-American adults in North Charleston and the perceptions of environmental stressors and resiliency factors collected from the interviews and surveys. To address these issues in future studies, we could sample a larger population of persons impacted by EJ issues from different communities across the state. While our questions were pilot tested on a population similar to our study participants, our results may have been influenced by our failure to test for construct validity or reliability. Nevertheless, we can reword our questions in future versions of the survey so they are more clear and test for construct validity and reliability. Since our population was primarily comprised of African-American, low-middle income, urban residents; the variables selected for the CSRI may not reflect the priorities in communities with a differing racial, economic, or geographic demographic.

6.1.3 Public Health Implications

One of the public health implications of this study is that decision makers and other stakeholders at the federal, state, and local levels should engage more communities impacted by environmental injustice to elucidate perceptions of environmental stressors and resiliency factors. This is invaluable information since perceptions of environmental stressors are known to affect the disease onset process just as much as one's actual exposure to the stressor and related physiological and psychological responses (Adler, 2009). In addition, knowing the resiliency buffers in a specific community instead of focusing on just the negative aspects may inform action-based solutions to improve health when individuals are unable to escape the stressors in their physical and social environments.

6.2 Specific Aim #2: Develop a cumulative stressors and resiliency index (CSRI) comprised of environmental exposures and resilience factors that may be used to rank risk and vulnerability at the census tract level.

For this aim, we identified indicators that could be used to examine and quantify the cumulative burden of environmental stressors and resiliency in SC communities at the census tract level. We performed a Principal Component Analysis (PCA) to systematically select indicators used to examine cumulative risk and environmental health disparities. The PCA was informed by community stakeholders from Specific Aim #1 and resulted in the following CSRI indicators (Table 25):

Table 29. CSRI Indicators (Total = 20)

CSRI Indicators (Total = 20)	
Diesel PM concentrations	Low-income
Lead paint	Violent crime
Ozone concentrations	Access to alcohol outlets
$PM_{2.5}$ concentrations	Segregation
Traffic density	Access to primary healthcare
Toxic releases from TRI facilities	Access to grocery stores

Brownfields	Access to fitness facilities
Superfund sites	Educational attainment
TRI facilities	Health insurance coverage
LUSTs	Long-term unemployment

We quantified the cumulative burden of environmental stressors and resiliency in SC and found that CSRI scores ranged from 7.4 – 64.0 across census tracts. The lowest CSRI score was found in the Lowcountry EA region (7.4) while the highest score was identified from a census tract in the Upstate EA region (64.0). Census tracts with lower CSRI scores represented areas with low environmental stress and high resiliency, whereas tracts with higher CSRI scores were indicative of areas with high environmental stress and low resiliency. The results from this portion of the study revealed that there is a way to successfully create a CRA screening tool that quantifies risk based on environmental stressors and resiliency factors.

We also determined whether differences exist in the cumulative impact of environmental stressors and resiliency by census tract based on CSRI scores. We calculated a one-way ANOVA to examine differences in the cumulative impact of environmental stressors and resiliency for SC's Environmental Affairs (EA) regions. Our results indicated that there were statistically significant differences in CSRI scores by EA region ($p < 0.0001$); however, not all EA regions differed by CSRI score. Specifically, there was no statistically significant difference in mean CSRI scores between the Lowcountry and Pee Dee regions since the 95% confidence intervals (CIs) [-1.53, 2.68] overlapped. Some of the census tracts in the Midlands EA region had high-risk scores equivalent to the state (≥ 43.8) whereas census tracts in the Upstate EA region (≥ 46.9) exceeded the state's high-risk score based on percentiles calculated for each region.

Regional differences in census tract level CRSI scores exist and can be explored in more depth to determine which environmental stressors and resiliency factors are contributing to the disparities.

6.2.1 Strengths

There are several notable strengths that distinguish our work from previous studies. For example, our study is the first to design a hybrid CRA screening tool that includes environmental stressors and resiliency buffers. We also introduce a new calculation for measuring risk that considers the interaction between environmental stressors and resiliency factors that can reduce the overall contribution of stressors on risk (Risk = Environmental Stressors x Resiliency Buffers). Moreover, we partnered with community stakeholders from one of the most vulnerable areas in South Carolina to inform the CRA process since they have expertise on specific issues occurring in their community and can later assist with advocating and implementing strategies to reduce exposure disparities. Additionally, we detected areas of high-risk in SC that can be used for prioritizing intervention strategies and resources that will strengthen community resiliency. As result, we have information needed to create a blueprint of a resilient and sustainable community that can be used as a model in communities heavily impacted by EJ issues.

6.2.2 Limitations

While we were successful in quantifying risk and resiliency in SC communities and examining regional differences in CSRI scores, there were some limitations that we plan to address in future iterations of the CSRI when possible. Alternative methods could have been implemented to improve the accuracy of some of the indicators. For example, census tract level air pollution concentrations for $PM_{2.5}$ and ozone were estimated from a few monitors located in densely populated areas. Extrapolating this data may have introduced misclassification and conditional biases; therefore, we plan to use the USEPA's Hierarchical Bayesian Model (HBM) to estimate potential exposures to $PM_{2.5}$ and ozone concentrations per census tract. The HBM accounts for temporal and spatial variation in air pollution concentrations using a 12-km x 12-km grid to provide more accurate estimations of in areas that may be far from an air quality monitor (USEPA, 2010). In addition, this model also includes predicted air pollution concentrations from the USEPA's Community Multiscale Air Quality (CMAQ) model using the same 12-km x 12-km grid as the HBM (USEPA, 2010). The CMAQ model is comprised of emission, meteorology, and air chemistry-transport modeling components that allow this model to better predict $PM_{2.5}$ and ozone concentrations.

We selected variables that were mostly derived from publicly available datasets so that our CSRI scores would be comparable to census tracts in other states; however, a few of the variables required a license to gain data access (e.g. fitness facilities, alcohol outlets). Though some entities may not have the resources to obtain access to these data sets, one solution may be to partner with local universities who have access to the Hoovers online database. Including all possible measures of environmental exposure in our index was not feasible, but we were able to include indicators prioritized as a HP and/or EHP issue in communities impacted by EJ. Capturing all environmental exposures during the same time period and geographic unit of analysis may require greater change in data collection methods and consideration of how different variables will be analyzed together. Using various crosswalks to obtain the data at the same level and combining those numerous datasets into one cumulative index already introduces error that is compounded by the error that is embedded in collecting data for each variable. Some data collection challenges may be unavoidable, like when an area contains <5 cases and cannot be included in the analysis due to the low numbers.

Community stakeholder feedback from Specific Aim #1 was used to populate our PCA model to assist with our variable selection process. While engaging communities who have been impacted by EJ issues is a necessary component of CRAs, we only had a few stakeholders (N=18) provide information on environmental stressors and resiliency factors that most impact health in their community. We did achieve saturation with 18 study participants; however, we will need to survey more communities impacted by EJ issues in future iterations of the CSRI to improve the size and representativeness of our sample. In addition, our study population was primarily comprised of African-American, low-middle income, urban residents of North Charleston, SC who are impacted by EJ issues. Therefore, the CSRI may not reflect the priorities in communities with a differing racial, economic, or geographic demographic.

6.2.3 Public Health Implications

One major public health implication of this study involves building CRA screening tools that incorporate environmental stressors and resiliency factors that are necessary to more accurately examine community-level risk. To continue improving upon CRA screening tools, communities most impacted by EJ issues should always be involved to inform various aspects of the CRA process (Barzyk, S. Wilson, & A. Wilson, 2015). Further work is needed to explore equations and weighting factors that best represents the complex relationship between environmental stressors and resiliency buffers. In addition, public health entities should work collaboratively to standardize data collection methods (i.e., same geographic unit of analysis and year) in CRAs to improve the quality of risk estimates. Strengthening CRA screening tools in these ways will allow us to better identify high-risk areas, as well as create a blueprint of communities that are thriving to model less resilient communities after.

Action-based solutions for reducing risk should focus more on improving community resiliency since communities impacted by EJ issues are not always able to evade environmental stressors. Addressing resiliency in high-risk areas is known to foster macro-level improvements in overall community resiliency (Wulff, Donato, & Lurie, 2015), and some communities have already actively begun to strengthen resiliency in their most vulnerable neighborhoods. For example, Kansas City, Missouri has instituted a Green Impact Zone initiative to concentrate health-promoting resources in an area that has experience severe abandonment and economic decline (Mid-American Regional Council, 2017). They had community leaders inform the following priority areas to create more resilient and sustainable communities: 1) housing, 2) neighborhood capacity building, 3) outreach, 4) employment, 5) job training, 6) business development, 7) transportation infrastructure, and 8) energy and water conservation (Mid-American Regional Council, 2017).

The California Environmental Justice Alliance (CEJA) has also started a Green Zone Initiative in California that uses community input to inform the transformation of communities overburdened by EJ issues into those that are thriving. Their model involves three components: 1) identify overburdened communities through CRA tools, 2) advance visionary Green Zone policy, and 3) demonstrate the model on-the-ground with the seven overburdened communities that serve as anchor campaigns (California Environmental Justice Alliance, 2015). Minneapolis, Minnesota is another community that has recently introduced the Green Zone Initiative model decided to focus on the following areas: 1) equity, 2) displacement, 3) air quality, 4) brownfields and soil contamination, 5) housing, 6) green jobs, 7) food access, and 8) greening (Minneapolis Sustainability Office, 2017). The Green Zone Initiatives exemplify CRA at its best, where CRA screening tools can be used to identify high-risk communities that need resources to improve resiliency and sustainability.

6.3 Specific Aim #3: Examine the association between CSRI scores and risk of asthma hospitalizations/emergency department visits at the census tract level.

For specific aim #3, we examined the association between CSRI scores and risk of asthma hospitalizations/ED visits in South Carolina. We performed a Spearman's rank-order correlation coefficient test and our results demonstrated that there was a very weak negative correlation between asthma hospitalizations/ED visits and CSRI scores at the census tract level (r=-0.13; p <0.0001). We did find significant differences in asthma hospitalizations and ED visits by EA region (p<0.0001) that were consistent across all regions at an alpha level of 0.05. When constructing the negative binomial regression model, the unadjusted (p <0.0001) and adjusted models (p = 0.0003) were both statistically significant, but the results did not correspond with what we hypothesized.

For example, an increase in CSRI scores did not coincide with an increase asthma hospitalizations/ED visits in SC.

6.3.1 Strengths

While our CSRI could not predict the risk of asthma hospitalizations/ED visits, the study did have several strengths. To our knowledge, this study was the first to combine information gathered from a CRA screening tool to predict the risk of asthma hospitalizations/ED visits. This is particularly important since previous research has indicated that exposures to chemical and non-chemical environmental stressors may exacerbate asthma (Eldeirawi et al., 2016; Guarnieri & Balmes, 2015; Holsey, Collins, & Zahran, 2013; McCreanor et al., 2007). We were also the first to use environmental stressors and resiliency buffers in our asthma prediction model via the CSRI scores, which allowed us to emphasize the need for more disease prediction models that consider the above factors to improve accuracy in disease risk models. Another strength of our study is that we focused on one of the health outcomes (i.e., asthma) that was a priority concern for our North Charleston partners.

6.3.2 Limitations

One limitation of this study was our CSRI may have lacked variables that were more related to an asthma exacerbation since the index was not originally designed for use in a disease prediction model. For example, we did not include indoor environmental stressors associated with asthma like exposures to residential pesticides (Doust et al., 2014; Hernandez, Parron, & Alarcon, 2011) and indoor air pollution (Breysse et al., 2010; Golden & Holm, 2017). We also did not include weatherization (i.e., insulation, sealing leaks and ducts, inspecting heating/cooling systems) as a resiliency factor, which is known to improve indoor air quality and reduce triggers that would exacerbate asthma (Rose, Hawkins, Tonn, Paton, & Shah, 2015). We do not know if residential pesticides, indoor air pollution, or weatherization indicators would have replaced any of the current CSRI variables as a higher priority item, but accounting for indoor exposures will be an important component in our model.

Addressing some of these limitations may be difficult since SC does not have a comprehensive database with pesticide exposures or weatherization as seen in other states (i.e., California and Wisconsin, respectively). Nevertheless, we can improve our risk model by adding individual CSRI variables into the negative binomial regression model instead of using the CSRI score as the predictor variable. His new method would allow us to obtain the best combination of environmental factors and resiliency buffers that can be used to predict disease risk or another health indicator. Additionally, we had to perform a crosswalk to transform zip code level asthma hospitalizations/ED visits to census tract level estimates, which may slightly reduce the accuracy of the case locations. Overcoming this limitation would require us to have a specific address for each patient that can be geocoded to the correct census tract.

6.3.3 Public Health Implications

We believe that this study has major implications for incorporating aspects of CRA in disease risk models that can be used to screen for vulnerable populations with high environmental stress and low resiliency. Specifically, models used to examine risk of asthma hospitalizations/ED visits should include more environmental and resiliency factors that are specific to an asthmatic exacerbation. By designing more environmental-based predictive models for asthma, we can inform public health interventions that: 1) target high-risk communities with low resiliency, 2) reduce exacerbations and associated costs, 3) improve quality of life and productivity, and 4) decrease disparities and disease morbidity. Environmental-based prediction models may also be useful for other health measures aside from asthma like quality of life, life expectancy, and YPLL.

Environmental stressors and resiliency buffers would be a useful addition to Asthma Action Plans that are designed by physicians to assist patients with asthma management. These plans contain information on daily treatments, dose, and when to administer medication based on symptoms that correspond with green (doing well), yellow (asthma getting worse), and red (medical alert) zones (USDHHS, 2007). Asthma Action Plans include information on asthma triggers and ways to mitigate exposures to each trigger, but there is no mention of outdoor environmental stressors that may exacerbate asthma symptoms aside from pollen and outdoor mold. Not only should we expand the triggers in Asthma Control Plans to include environmental stressors, but we should also use this opportunity to link CRA screening tool data to Asthma Control Plan designations (green, yellow, or red) so that census tracts are color-coded based on their ability to trigger an asthmatic episode. This would allow patients to have a more comprehensive disease management plan that may prevent an asthma hospitalization/ED visit.

APPENDICES

Appendix A: University of Maryland IRB Approval Letter

DATE: November 17, 2015

TO: Kristen Burwell
FROM: University of Maryland College Park (UMCP) IRB

PROJECT TITLE: [760054-1] The Development of a Community Informed Cumulative Stressors Index to Examine Environmental Health Disparities and Disease Risk in South Carolina

REFERENCE #:
SUBMISSION TYPE: New Project

ACTION: APPROVED
APPROVAL DATE: November 17, 2015
EXPIRATION DATE: November 16, 2016
REVIEW TYPE: Expedited Review

REVIEW CATEGORY: Expedited review category # 5 & 7

Thank you for your submission of New Project materials for this project. The University of Maryland College Park (UMCP) IRB has APPROVED your submission. This approval is based on an appropriate risk/benefit ratio and a project design wherein the risks have been minimized. All research must be conducted in accordance with this approved submission.

Prior to submission to the IRB Office, this project received scientific review from the departmental IRB Liaison.

This submission has received Expedited Review based on the applicable federal regulations.

This project has been determined to be a Minimal Risk project. Based on the risks, this project requires continuing review by this committee on an annual basis. Please use the appropriate forms for this procedure. Your documentation for continuing review must be received with sufficient time for review and continued approval before the expiration date of November 16, 2016.

Please remember that informed consent is a process beginning with a description of the project and insurance of participant understanding followed by a signed consent form. Informed consent must continue throughout the project via a dialogue between the researcher and research participant. Unless a consent waiver or alteration has been approved, Federal regulations require that each participant receives a copy of the consent document.

Please note that any revision to previously approved materials must be approved by this committee prior to initiation. Please use the appropriate revision forms for this procedure.

All UNANTICIPATED PROBLEMS involving risks to subjects or others (UPIRSOs) and SERIOUS and UNEXPECTED adverse events must be reported promptly to this office. Please use the appropriate reporting forms for this procedure. All FDA and sponsor reporting requirements should also be followed.

All NON-COMPLIANCE issues or COMPLAINTS regarding this project must be reported promptly to this office.

Please note that all research records must be retained for a minimum of seven years after the completion of the project.

If you have any questions, please contact the IRB Office at 301-405-4212 or irb@umd.edu. Please include your project title and reference number in all correspondence with this committee.

Appendix B: Consent Form (Full)

Project Title	**Environmental Health Disparities, Community Resilience, and Disease Risk in South Carolina**
Purpose of the Study	*This research study is being led by Mrs. Kristen Burwell Naney (principal investigator) through the University of Maryland, College Park. We are inviting you to participate in this research study because you are an African-American adult (≥18) who currently lives in North Charleston, South Carolina (SC) and has been there for at least one year. The purpose of this research study is to use your knowledge as a community member to understand how you view environmental factors that may influence health outcomes in your neighborhood and your ability to overcome any hardships or stress that you may experience in your community. By using your feedback in this process, we will be able to create a new environmental stressors index that better represents the burden of negative exposures to environmental hazards and the resources that are available to offset some of the hazards across communities in SC.*
Procedures	*The procedures involve participating in a 45-minute in person key informant interview. You will be asked questions about your beliefs on environmental factors that may influence health in your community and your ability to withstand hardship and stress in your community. You will also be given a chance to rate the priority level that should be given to each environmental indicator based on how it impacts health in your community and provide feedback on whether any indicators should be removed or added. You will be provided with a list of terms and definitions for each indicator to review during the interview. Your responses will be audio recorded and are mandatory for participation; however, you will be given a unique identification number that you can use while speaking so that your name is never linked with your comments.*
Potential Risks and Discomforts	*Although there are no known risks to you for participating in this study, there is a possibility that you may find certain questions to be too personal or upsetting, but you do not need to respond to any questions that you do not want to answer.*
Potential Benefits	*There are no direct benefits from participating in this research. However, possible benefits include your contribution in creating a new index that may be used as a gold standard for scoring environmental stressors and health promoting resources on a state and national level.*

Confidentiality	*The researchers will make every effort to keep all of your information and responses confidential. Any potential loss of confidentiality will be minimized by storing data on an encrypted external hard drive, using a password protected database, on a password protected computer. The data will also be stored on an encrypted drive and only the principal investigator (Mrs. Kristen Burwell Naney), research team (Drs. Xin He, Donald Milton, Robin Puett, Amir Sapkota, and Sacoby Wilson), and research assistant will have limited access to the study information at all times. While a professional transcription company will transcribe your focus group responses, they will only have access to the audio recordings where everyone will be using their unique identification number to respond to questions instead of a name or any other personal information. We will keep all electronic data files from your focus group session for five years and at the end of that period, all files will be deleted from the computer.* *If we write a report or article about this research project, your identity will be protected to the maximum extent possible. Your information may be shared with representatives of the University of Maryland, College Park or governmental authorities if you or someone else is in danger or if we are required to do so by law.*
Compensation	*You will make $25 for your participation in the study and will be provided with refreshments.*
Right to Withdraw and Questions	*Your participation in this research study is completely voluntary and you may choose not to take part at all. If you decide to participate in this research study, you may stop participating at any time. If you decide not to participate in this study or if you stop participating at any time, you will not be penalized or lose any benefits to which you otherwise qualify.* *If you decide to stop taking part in the study, if you have questions, concerns, or complaints, or if you need to report an injury related to the research, please contact the principal investigator:* *Mrs. Kristen Burwell Naney* *PhD Candidate* *University of Maryland School of Public Health* *College Park, MD 20742*

	Phone: 617-637-5929 *kburwell@umd.edu* *Phone: 617-637-5929* *kburwell@umd.edu*
Participant Rights	*If you have questions about your rights as a research participant or wish to report a research-related injury, please contact:* **University of Maryland College Park** **Institutional Review Board Office** **1204 Marie Mount Hall** **College Park, Maryland, 20742** **E-mail: irb@umd.edu** **Telephone: 301-405-0678** *This research has been reviewed according to the University of Maryland, College Park IRB procedures for research involving human subjects.*
Statement of Consent	*Your signature indicates that you are at least 18 years of age; you have read this consent form or have had it read to you; your questions have been answered to your satisfaction and you voluntarily agree to participate in this research study. You will receive a copy of this signed consent form.* *If you agree to participate, please sign your name below.*
Signature and Date	**NAME OF PARTICIPANT [Please Print]**
	SIGNATURE OF PARTICIPANT
	DATE

Appendix C: Consent Form (Summary)

<u>Consent Form Summary:</u>

Title: Environmental Health Disparities, Community Resilience, and Disease Risk in South Carolina

Purpose: This research study is being led by Mrs. Kristen Burwell Naney through the University of Maryland, College Park (UMD). The purpose of this study is to understand how you view environmental factors that may influence health outcomes in your neighborhood and your ability to overcome any hardships or stress that you may experience in your community.

Procedures: You will be participating in a key informant interview where you will be asked questions about your beliefs on environmental factors that may be influencing health in your community. In addition, you will be given an opportunity to rate the priority level of each environmental indicator based on how it may improve health in your community. The interview will last roughly 45 minutes and all responses will be audio recorded.

Potential Risks: There are no known risks to you for participating in the study. There is a possibility that you may find certain questions to be too personal or upsetting, but you do not need to respond to any questions that you do not want to answer.

Potential Benefits: There are no direct benefits to participation in this research.

Confidentiality: All of your information will be kept confidential and stored on an encrypted hard drive. We will also use unique identification numbers throughout the key informant interview so that no personal information is audio recorded.

Compensation: You will receive a $25 VISA gift card for your participation.

Right to Withdraw: Your participation in this study is completely voluntary and you may withdraw at any time.

Contact Information: If you have any questions or concerns about the study, please contact the Institutional Review Board (IRB) Office or myself. You may find our contact information listed at the bottom of your copy of the consent form.

Appendix D: Community Recruitment Flyer

****SEEKING NORTH CHARLESTON, SOUTH CAROLINA COMMUNITY MEMBERS TO PARTICIPATE IN AN INTERVIEW****

What is the purpose of the study?

The University of Maryland (UMD), College Park is partnering with the Charleston Community Research to Action Board (CCRAB) and Lowcountry Alliance for Model Communities (LAMC) to conduct a research study called ***"Environmental Health Disparities, Community Resilience, and Disease Risk in South Carolina"*** to understand your view of environmental factors that may influence health outcomes and your ability to overcome any hardships or stress that you may experience in your community.

What will I be asked to do?

You will be able to participate in a 45-minute key informant interview at the LAMC office on environmental stressors in your community. ***Make $25 for your participation and enjoy light refreshments provided by the research team.***

Who can participate?

- African-Americans aged 18 and older who:
  - Reside in North Charleston, SC
  - Have lived in North Charleston, SC for at least one year

Who can I contact to participate or if I have any further questions?

- You may contact Mrs. Kristen B. Naney by:
  - Phone (617) 637-5929 or
  - Email kburwell@umd.edu

CCRAB/LAMC
(843) 693-3911
ccrabej@gmail.c

LAMC
Lowcountry Alliance for Model Communities

SCHOOL OF PUBLIC HEALTH

Appendix E: Eligibility Questionnaire Telephone Script

Environmental Health Disparities, Community Resilience, and Disease Risk in South Carolina

Eligibility Phone Script for Focus Groups:

Read (Introduction): Hello, my name is Kristen Naney and I am conducting a research study with the University of Maryland, College Park called "Environmental Health Disparities, Community Resilience, and Disease Risk in South Carolina."

Read (Purpose): The purpose of this research study is to use key informant interviews to understand how residents of North Charleston, South Carolina (SC) view environmental factors in their communities that may influence health outcomes and their ability to overcome any hardships or stress in their communities. You will also be given a chance to rate the priority level that should be given to each environmental indicator based on how it impacts health in your community, and will be able to provide feedback on what should be added or removed from the list. Using your feedback, we will be able to create a community informed environmental stressors index that better represents the burden of negative exposures to environmental hazards and the resources that are available to offset some of the hazards across communities in SC.

Read (Consent): To determine whether you can participate in this research study, I will first need to ask you a few basic questions. Please note that any information that I collect from you in this questionnaire will be kept confidential in a secure location and destroyed 5 years after the study period ends. If you are not able to participate in this study based on your responses, all of your information will be destroyed immediately. The screening questionnaire should take less than 8 minutes of your time. If you have no further questions, we can now begin.

- [If yes] Proceed to question #1
- [If no] Ask if they would like to receive a call back to complete the screening questionnaire and collect their contact information below; ***OR*** read the termination statement to end the call.

Note: Whether conducting the screening process over the phone or in person while recruiting in the field, a study team member should always read the questions to the potential study participant.

1. Are you at least 18 years of age or older?
   a) Yes
   b) No

[If yes] How old are you (optional, proceed to question #2)?

____

[If no, don't know, or no answer] Read the ineligibility and termination statement to end the call.

2. Are you African-American?

a) Yes
b) No

[If yes] Proceed to question #3.

[If no, don't know, or no answer] Read the ineligibility and termination statement to end the call.

3. Do you currently live in North Charleston, South Carolina?

a) Yes
b) No

[If yes] What is your current address (optional, proceed to question #4)?

[If no, don't know, or no answer] Read the ineligibility and termination statement to end the call.

4. Have you been living in North Charleston, South Carolina for at least one year?

a) Yes
b) No

[If yes] What North Charleston community are you a part of (optional, proceed to question #5)?

[If no, don't know, or no answer] Read the ineligibility and termination statement to end the call.

5. Have you ever been told by a doctor, nurse, or other health professional that you have any medical conditions (optional)?

a) Yes
b) No

[If yes] What are they (optional, proceed to question #6)?

[If no, don't know, or no answer] Proceed to question #6?

6. Do you currently have health insurance (optional)?

a) Yes
b) No

[If yes] Proceed to question #7.

[If no, don't know, or no answer] Proceed to question #7.

7. Are you currently employed (optional)?

a) Yes
b) No

[If yes] Proceed to question #8?

[If no, don't know, or no answer] Proceed to question #8.

8. What is the highest level of education that you have completed (optional)?

a) < High School Education
b) High School Graduate
c) GED or Equivalent
d) Some College
e) Associate's Degree
f) Bachelor's Degree
g) Master's Degree
h) Professional or Doctoral Degree

[If don't know or no answer] Proceed to question #9.

9. What is your median household income (optional)?

a) Less than $9,999
b) $10,000 - $19,999
c) $20,000 - $29,999
d) $30,000 - $39,999
e) $40,000 - $49,999
f) $50,000 - $59,999
g) $60,000 - $69,999
h) $70,000 - $79,999
i) $80,000 - $89,999
j) $90,000 - $99,999
k) $100,000 and above

[If don't now or no answer] Proceed to question #10.

10. Have you ever participated in a Low-country Alliance for Model Communities (LAMC) or Charleston Research to Action Board (CCRAB) community meeting or activity (optional)?

a) Yes
b) No

[If yes] What are they?

____

Read the eligibility and termination statement to end call.

Note: Based on the responses above, the potential participant will be informed on whether they are eligible for the study. If the participant answers "Yes" to questions 1 - 4, they are eligible to participate in the study. In contrast, if the participant answers "No" to any of the required questions (1 - 4) then they are not eligible to participate in the study. If the individual is eligible for the study, we will schedule a date and time for them to participate in 1 of 4 focus group sessions.

Read (Eligible): Read if all answers for questions 1 - 4 are "Yes": Based on your responses, you are eligible to participate in the study. I would now like to collect your contact information so that we can schedule a date and time for you to attend a focus group session. I will also send you a reminder message about your focus group session the day before it is scheduled.

Name:

____

Email:

____

Phone Number:

____

- Which do you prefer as your primary method of contact?

  ____

Note: Skip to "Termination" section.

Read (Ineligible): Read if any answers for questions 1 - 4 are "No": Based on your responses, you are not eligible to participate in the study.

Note: Skip to "Termination" section

Read (Termination): I would like to thank you on behalf of the University of Maryland, College Park for answering these questions. If you have any further questions about this study, you may contact me by phone (617-637-5929) or email (kburwell@umd.edu). If you have any questions about your rights as a survey participant, you may call the University of Maryland's Institutional Review Board at 301-405-0678. Thank you again for your time and enjoy the rest of your day.

- -

For Internal Use Only

Key Informant Interview Date:

Key Informant Interview Time:

Key Informant Interview Location:

Appendix F: Key Informant Interview Preliminary Codebook

Preliminary Codebook (Key Informant Interviews):

Pre-survey Questions:

1. What are some things that may contribute to ill health such as diabetes, high blood pressure, cancer, stroke, asthma, and heart disease to name a few?

- Unhealthy diet
- Physical inactivity
- Genetics
- Stress
- Smoking
- Alcohol consumption
- Environmental exposures

2. What is something negative in your environment, if anything, that may cause you to develop ill health? (Your environment includes where you live, work, and/or play.)

- Lack of green space or places to exercise
- Low access to health services
- Living near environmental hazards (i.e. heavily trafficked roadways, toxic release inventory facilities, superfund sites, brownfields, leaking underground storage tanks)
- Low access to grocery stores
- Air pollution exposure
- Crime
- Lead paint exposure
- High density of unhealthy food outlets
- High density of alcohol outlets

3. When considering some of the negative things that may exist or have occurred in your environment, what has allowed you to withstand hardships, adapt to stress, or in other words be resilient? (Your environment includes where you live, work, and/or play.)

- Faith
- Social networks (i.e. community, friends, family)
- Civic infrastructure (i.e. having an established CBO and becoming more aware of my rights, environmental issues that may contribute to poor health, etc..)

4. What is something positive in your environment, if anything, that may lower your risk of developing ill health? (Your environment includes where you live, work, and/or play.)

- Community centers

- Having places to worship
- Having close social networks

5. What is something that you need in your environment, if anything, to improve your ability to withstand hardships, adapt to stress, or in other words be resilient? (Your environment includes where you live, work, and/or play.)

- Having more access to green space or places to exercise
- Having grocery stores that sell healthy foods
- Access to health care services
- Better education
- Improved business environment
- Employment opportunities

Post-survey Questions:

6. What do you believe should be added to the list of environmental indicators, if anything, and why?

- Nothing should be added
- Water quality indicator
- Soil quality indicator

7. What do you believe should be removed from the list of environmental indicators, if anything, and why?

- Linguistically isolated – we do not have many non-English speakers in our community
- Non-white (minority) population – the amount of non-whites in an area should not affect the health of my community
- Non-white (minority) population – the amount of non-whites in an area should not affect the health of my community

Appendix G: Cumulative Stressors Index Survey

Instructions: Please read each indicator and definition carefully. Mark the box with an "x" that best represents the level of priority that should be given to each indicator based on how it may improve health in your community.

#	Indicators	Definitions	Not at all a Priority (1)	Low Priority (2)	Medium Priority (3)	High Priority (4)	Extremely High Priority (5)
1	Access to exercise facilities	Having fitness facilities nearby to use for exercise.					
2	Access to green space	Having a park or some open outdoor space nearby to exercise.					
3	Access to public transportation	Having public transportation in the area such as buses, railroads, streetcars, taxicabs, and ferryboats that may be used to travel across communities.					
4	Brownfields	The expansion, redevelopment or reuse of a property within an area that may contain toxic substances.					
5	Density of alcohol outlets	The number of places that sell alcohol in the area.					

6	Diesel particulate matter (PM) concentrations	The amount of diesel pollution in the air released from trucks, buses, trains, ships, and heavy-duty equipment.					
7	Educational attainment	The amount of persons aged 25 and older who graduated from high school in the area.					
8	Food swamps	The number of healthy food outlets (supermarket) is less than the number of unhealthy food outlets (convenience stores, fast-food restaurants, some carryout restaurants) in the area.					
9	Health insurance coverage status	The number of people without health insurance in the area.					
10	Health professional shortage areas (mental health)	A shortage of mental health care providers in the area.					
11	Health professional shortage	A shortage of primary health care providers					

	areas (primary care)	in the area.					
12	Lead paint (% pre-1960s housing)	The amount of older homes that still have lead paint in the area.					
13	Leaking underground storage tanks (LUSTs)	Leaking tanks or leaking underground piping in the area.					
14	Linguistically isolated	The amount of households in the area where no one aged 14 or older speaks English very well or does not speak English only.					
15	Long-term unemploy-ment	The number of persons aged 16 and older who have been out of work for at least 6 months and are eligible for employment in the area.					
16	Low income (% poverty)	The amount of the population who lives below the poverty level in the area.					
17	Non-white (minority) population	The amount of the people who is non-white in the area.					

18	Ozone (O_3) concentrations	The average amount of ozone released in the air from cars, trucks, buses, oil refineries, factories, and consumer products (paints, cleaners, and solvents).					
19	Particulate matter 2.5 ($PM_{2.5}$) concentrations	The average amount of particulate matter pollution released in the air from cars, power plants, wood burning, and coal and oil related activities.					
20	Residential segregation	The amount of racial segregation in the area.					
21	Superfund sites	Abandoned hazardous waste sites in the area that may still contain toxic substances.					
22	Toxic release inventory (TRI) facilities	Industries that release toxic substances in the area.					
23	Traffic density	The amount of traffic in the area.					

24	Toxic releases from facilities	The amount of toxic substances released into the air from industries in the area.					
25	Violent crime	The amount of non-negligent manslaughter, forcible rape, robbery, and aggravated assault offenses in the area.					
26	Vulnerable populations (children <10 and elderly >65)	The amount of the population who are less than 10 years age and older than 65 years of age in the area.					

Appendix H: Key Informant Interview Protocol

Environmental Health Disparities, Community Resilience, and Disease Risk in South Carolina

Note: This study protocol will only be used the PI and research assistant.

Focus Groups Itinerary:
Location: LAMC Office, 2125 Dorchester Rd., North Charleston, SC 29405
Date: 4-30-16
Time: Appointment times vary from 8:00 am – 5:00 pm.

Supplies:
1. Sign-in sheet
2. Audio recorders (2)
3. $25 VISA gift cards
4. Food
5. Incentive sign-out sheet
6. Original consent forms
7. Summary consent forms
8. Ink pens
9. Cumulative stressors survey
10. Computers (2)
11. Participant contact information
12. Drinks
13. Key informant interview questions

Protocol:
Key informant interview participants will arrive at the Lowcountry Alliance for Model Communities (LAMC) office during their appointment time and will immediately sign in. Each study participant will be assigned a unique identification number that will be written on his or her documents and used throughout the entirety of the interview. Two interviews will be conducted simultaneously with the PI and research assistant in separate areas of the LAMC office. The interviews will begin approximately five minutes after each participant arrives and light refreshments will be provided.

Introduction Script (Read):
Good morning (afternoon or evening) and thank you for coming today. I will now read a summarized version of the consent form and ask that you sign the original consent form if you are still interested in being a part of the study. You will also receive a copy of the consent form to take home with you at the end of the interview.

Hand out the original consent form, read the summarized version, and have participants sign and initial the original consent form.

(Read) The interview will be recorded so please speak clearly and do not use names. I also ask that you turn off or silence your cell phone during the interview. There are no right or wrong answers so please speak freely and limit your answers to no more than 3-4 minutes. If there are no further questions, I will now read the interview questions.

Turn on the recorder. State the participant's unique ID number before you ask the first question.

Key Informant Interviews (Read):

<u>Pre-survey questions</u>

1. What are some things that may contribute to ill health such as diabetes, high blood pressure, cancer, stroke, asthma, and heart disease to name a few?
2. What is something negative in your environment, if anything, that may cause you to develop ill health? (Your environment includes where you live, work, and/or play.)
3. When considering some of the negative things that may exist or have occurred in your environment, what has allowed you to withstand hardships, adapt to the stress, or in other words be resilient? (Your environment includes where you live, work, and/or play.)
4. What is something positive in your environment, if anything, that may lower your risk of developing ill health? (Your environment includes where you live, work, and/or play.)
5. What is something that you need in your environment, if anything, to improve your ability to withstand hardships, adapt to stress, or in other words be resilient? (Your environment includes where you live, work, and/or play.)

(Read) We will now transition to the environmental stressors survey. I will give you 10 - 15 minutes to read through the list of environmental indicators on your own and rate your level of priority for each item based on how it may improve health in your community. When you have completed the survey, I will ask you two final questions.

Stop the recorder and pass out the environmental stressors survey.

(Read) *"Example for indicator 1: Think about your community. If there are not many fitness facilities nearby for you to exercise to improve your health, this may be a higher priority item. If there are fitness facilities nearby to exercise, this may be marked as lower priority item in improving health in your community."*

Start recording again after the survey is complete. State the participant's unique ID number before you begin.

<u>Post-survey questions</u>

6. What do you believe should be added to the list of environmental indicators, if anything, and why?
7. What do you believe should be removed from the list of environmental indicators, if anything, and why?

Closing Remarks (Read):
That concludes our interview. I would like to thank you for your participation and I will keep you informed of all study outcomes once they have been summarized. The information that you provide will allow us to better measure the combined impacts of stress and prioritize resources to improve health in SC communities.

Stop the recorder.

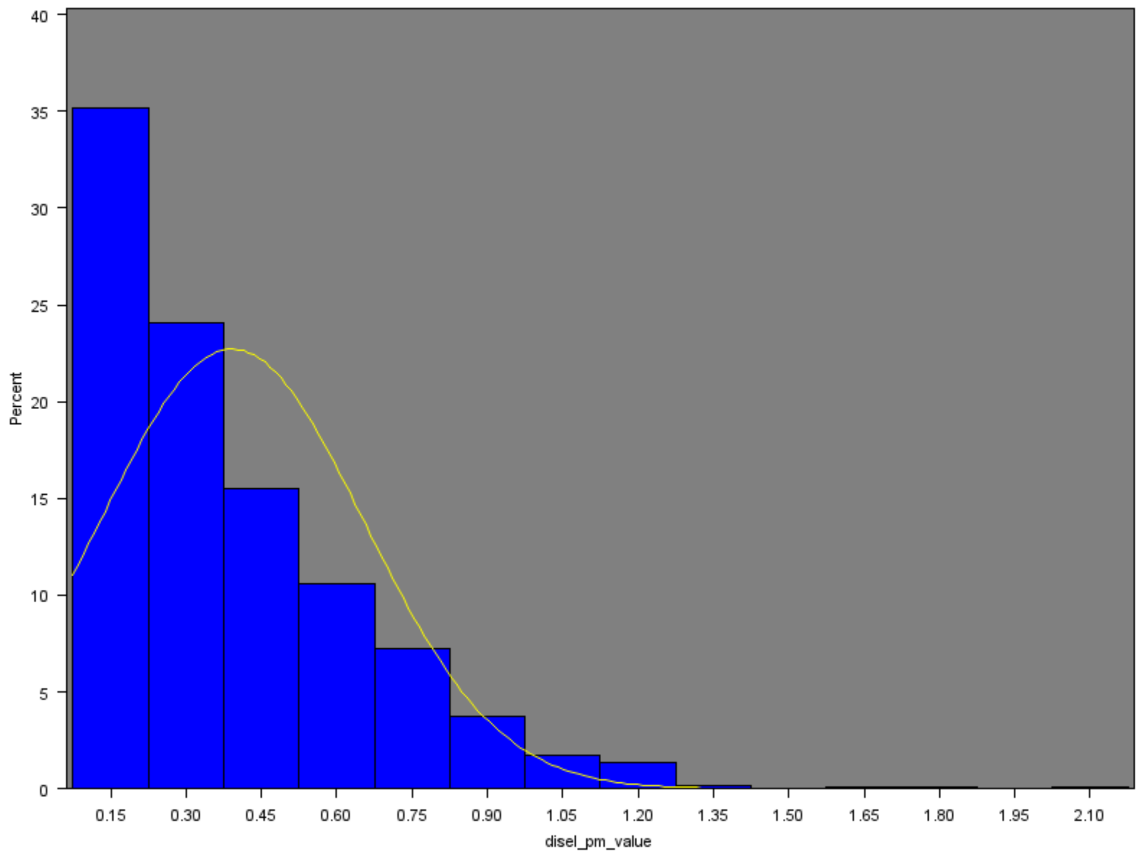
[Hand out the $25 VISA gift card incentives and have the participants sign their name beside their printed name on the attendance sheet.]

Appendix I: CSRI Variable Details

Environmental Stressors

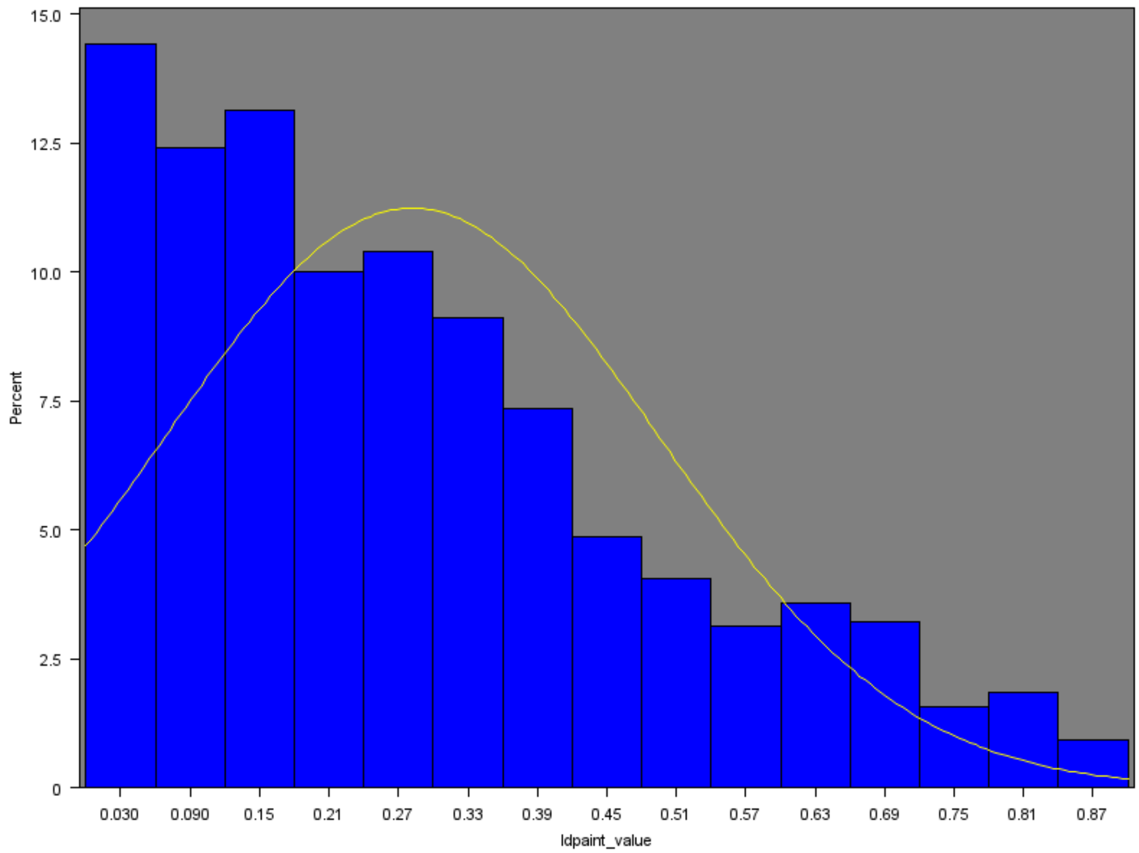
Environmental Exposures:

Figure 9. Histogram for Diesel PM Indicator



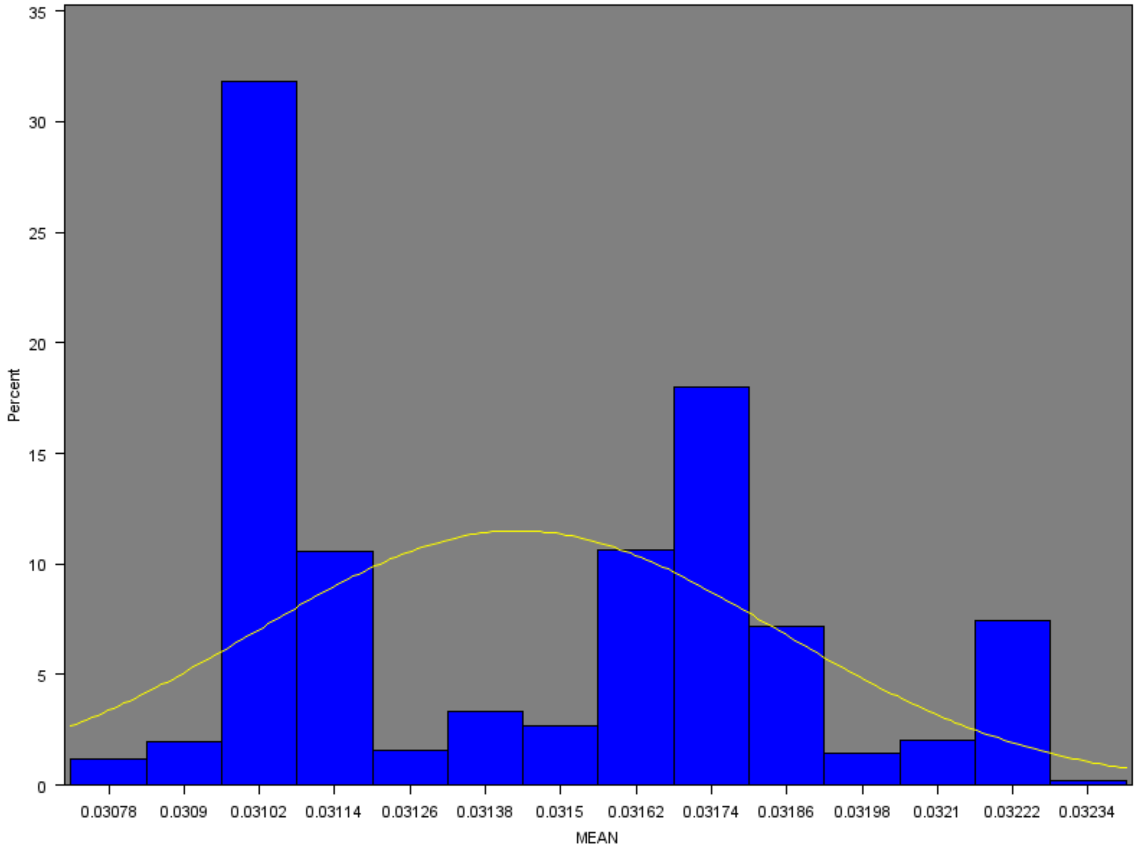
Methods: Diesel PM concentrations (micrograms/meters cubed [μg/m^3]) from the NATA database were linked with 2010 US Census at the census tract level. Percentiles were calculated based on the statewide distribution of diesel particulates.

Figure 10. Histogram for Lead Paint (% Pre-1960s Housing)



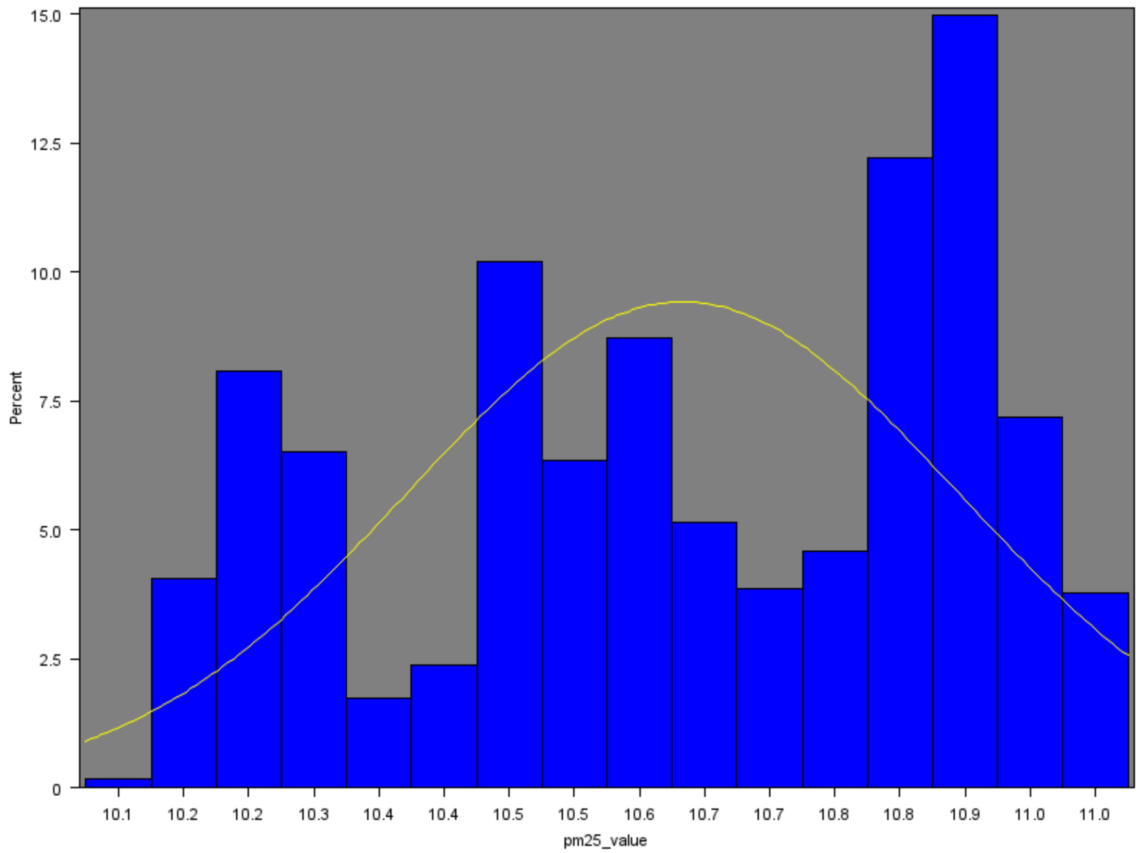
Methods: Data for pre-1960s housing and housing units were downloaded from ACS (2011-2015). The number of homes built pre-1960 were divided the number of housing units within the census tract to calculate the percentage of pre-1960s homes. Percentiles were calculated for percent pre-1960s housing to represent the distribution of lead paint.

Figure 11. Histogram for Ozone Concentrations



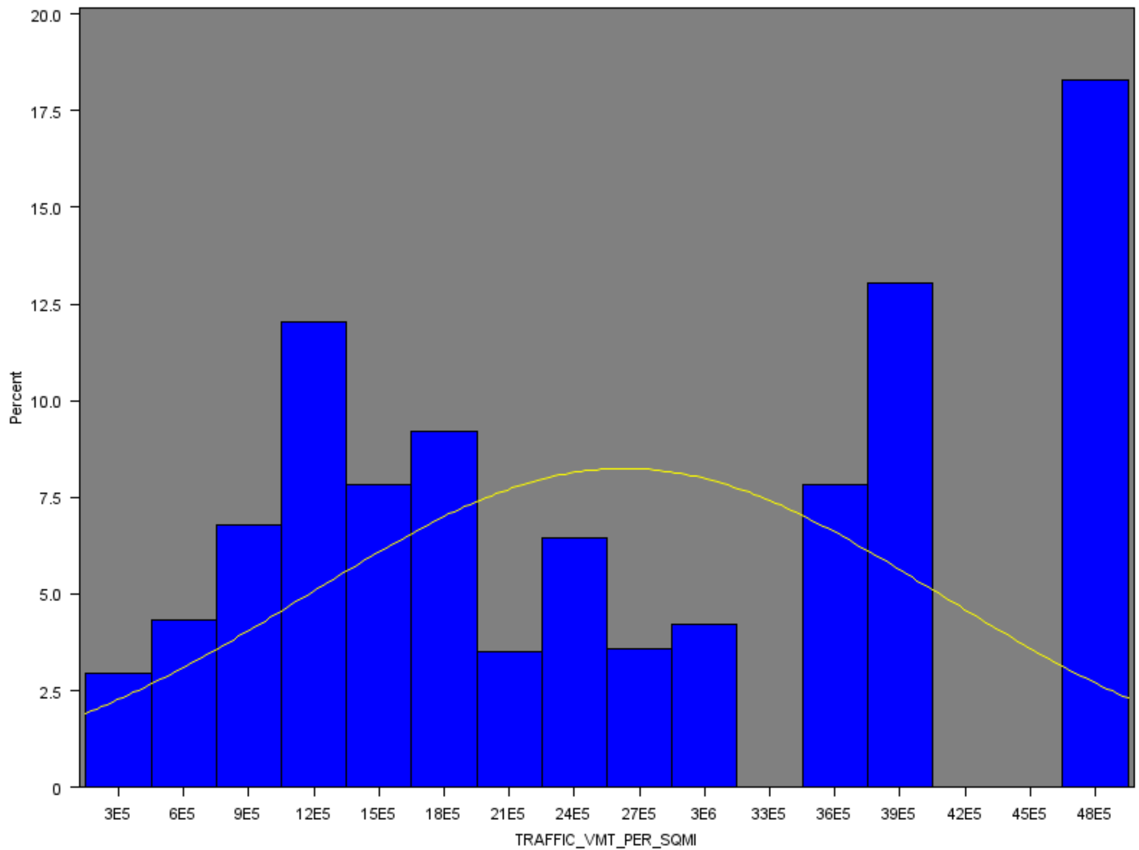
Methods: Eight-hour mean ozone concentration (parts per million [ppm]) data was obtained from air pollution monitoring stations across the state from SCDHEC. We calculated mean 8-hour mean ozone concentrations for each monitoring station for 2010. We performed ordinary kriging in ArcMap 10.5 to obtain predicted mean 8-hour mean ozone concentrations at unmeasured locations and calculated the corresponding percentiles.

Figure 12. Histogram for $PM_{2.5}$ Concentrations



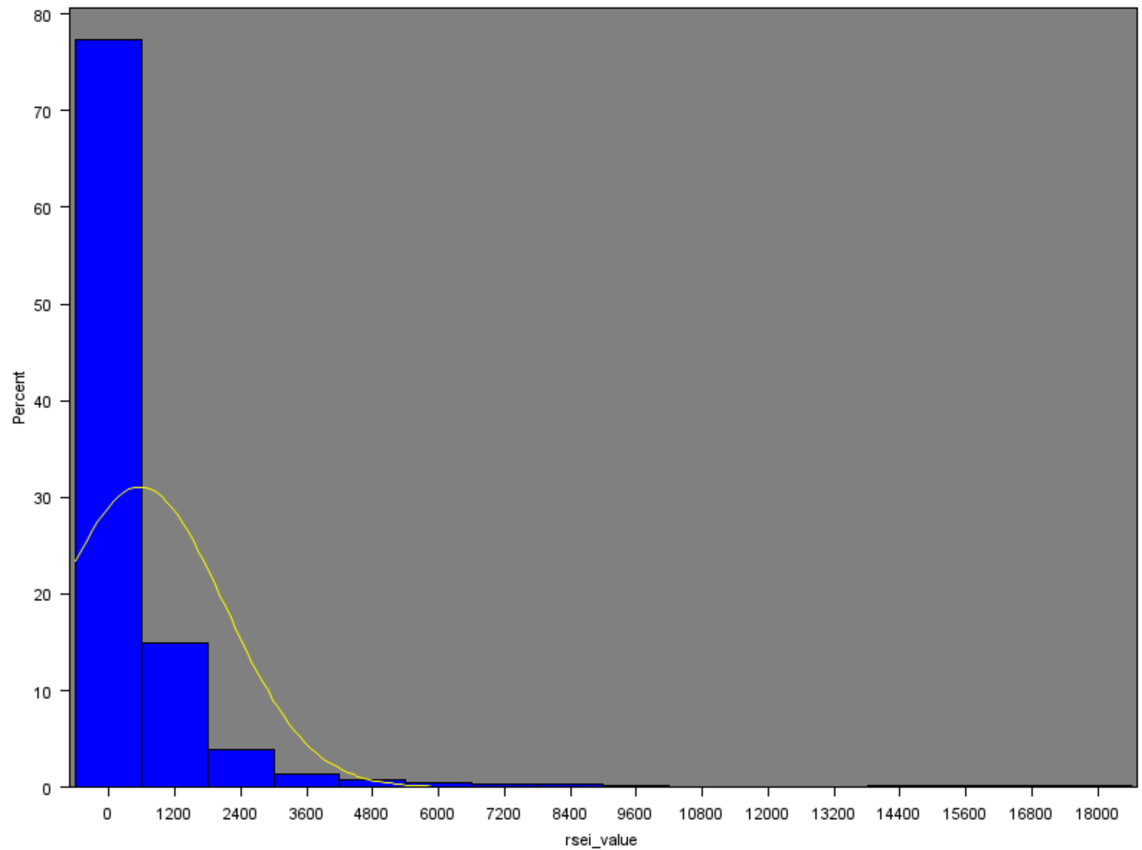
Methods: Twenty-four hour mean $PM_{2.5}$ concentration (μg/m^3) data was obtained from air pollution monitoring stations across the state from SCDHEC. We calculated mean 24-hour mean $PM_{2.5}$ concentrations for each monitoring station for 2010. We performed ordinary kriging to obtain predicted mean 24-hour mean $PM_{2.5}$ concentrations at unmeasured locations and calculated the corresponding percentiles.

Figure 13. Histogram for Traffic Density



<u>Methods:</u> Annual vehicle miles traveled (VMT) data for 2010 was obtained from the SCDOT at the county level. The VMT data was based on the road segment length and its respective average annual daily traffic (AADT); therefore, we used the following equation to calculate traffic density: (traffic density = county VMT / area of county). The area of each county was calculated using ArcMap 10.5. Traffic density values for each county were applied to all census tracts within the county and percentiles were calculated respectively.

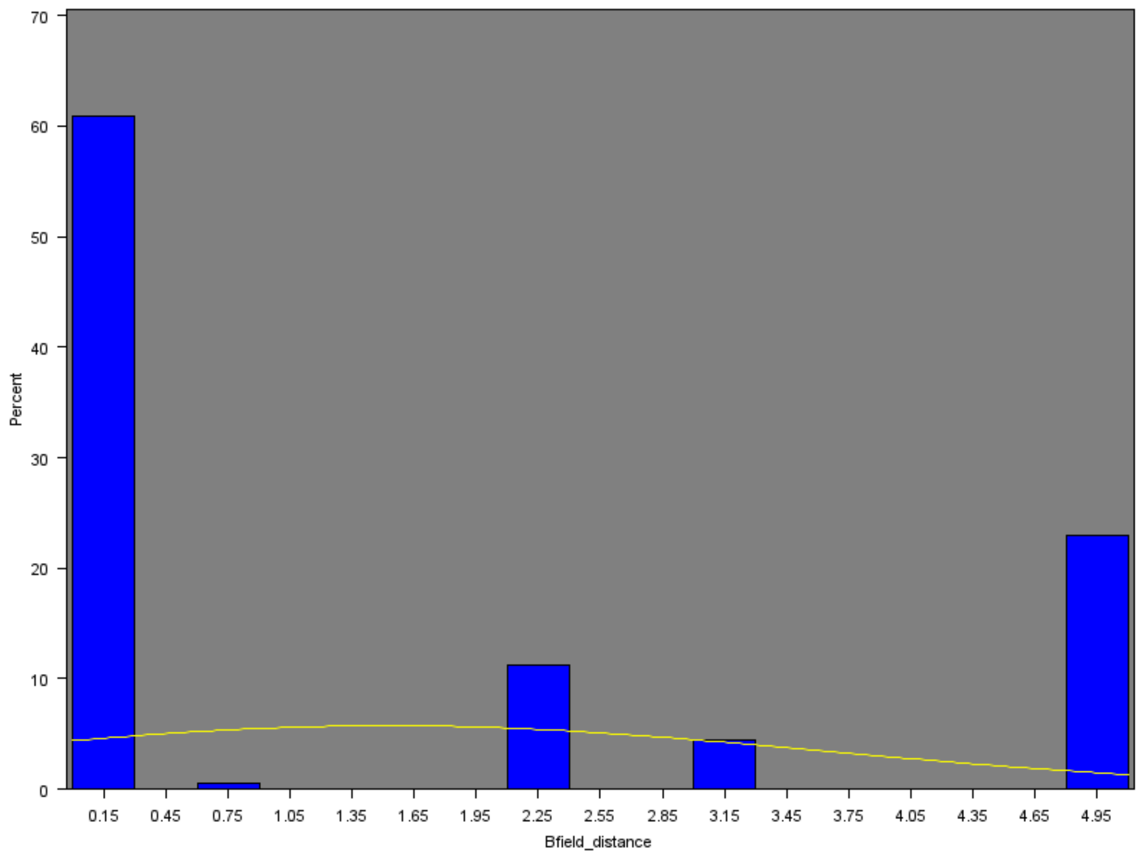
Figure 14. Histogram for Toxic Releases from Facilities



Methods: Geometric microdata for modeled air releases was downloaded from the EPA's RSEI tool and toxicity-weighted concentrations were converted to census blocks using area-based conversion. To obtain census tract level estimates of toxic releases, we calculated the land-area weighted average of the block level values for each census tract. Percentiles were calculated for each census tract.

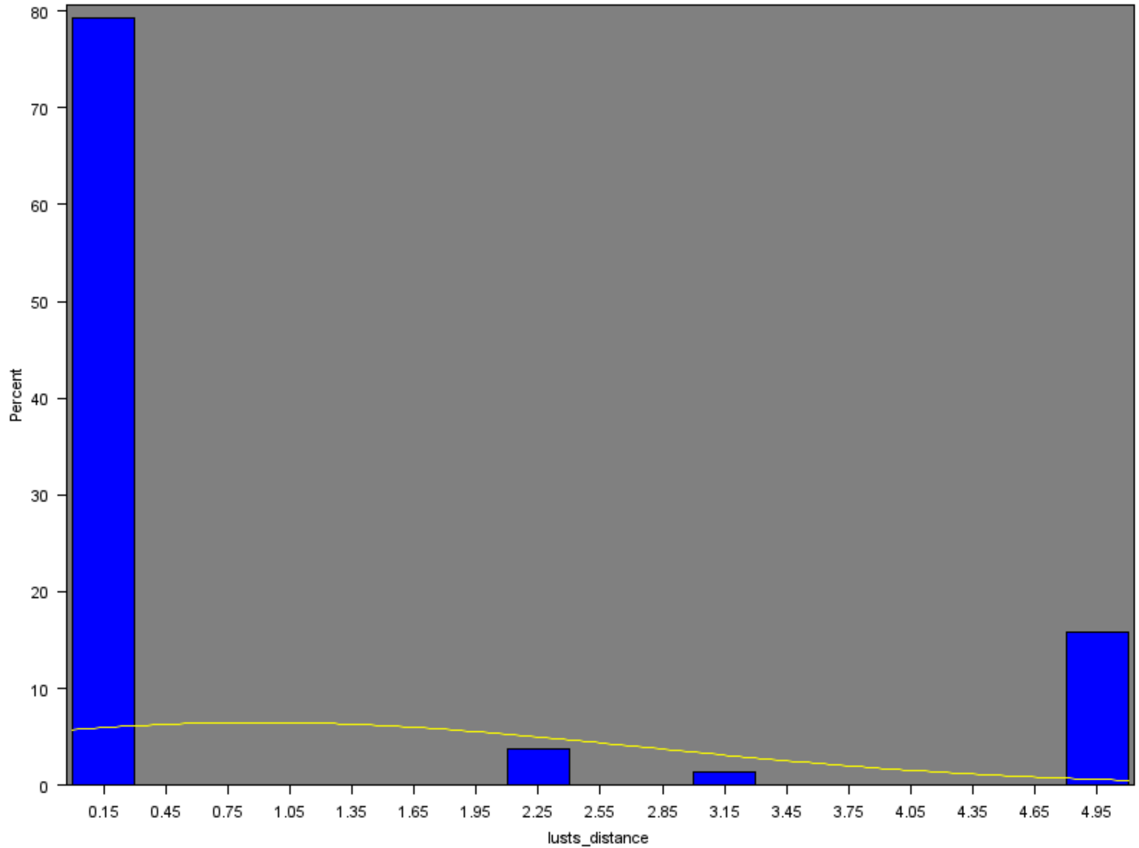
Environmental Hazards

Figure 15. Histogram for Brownfields



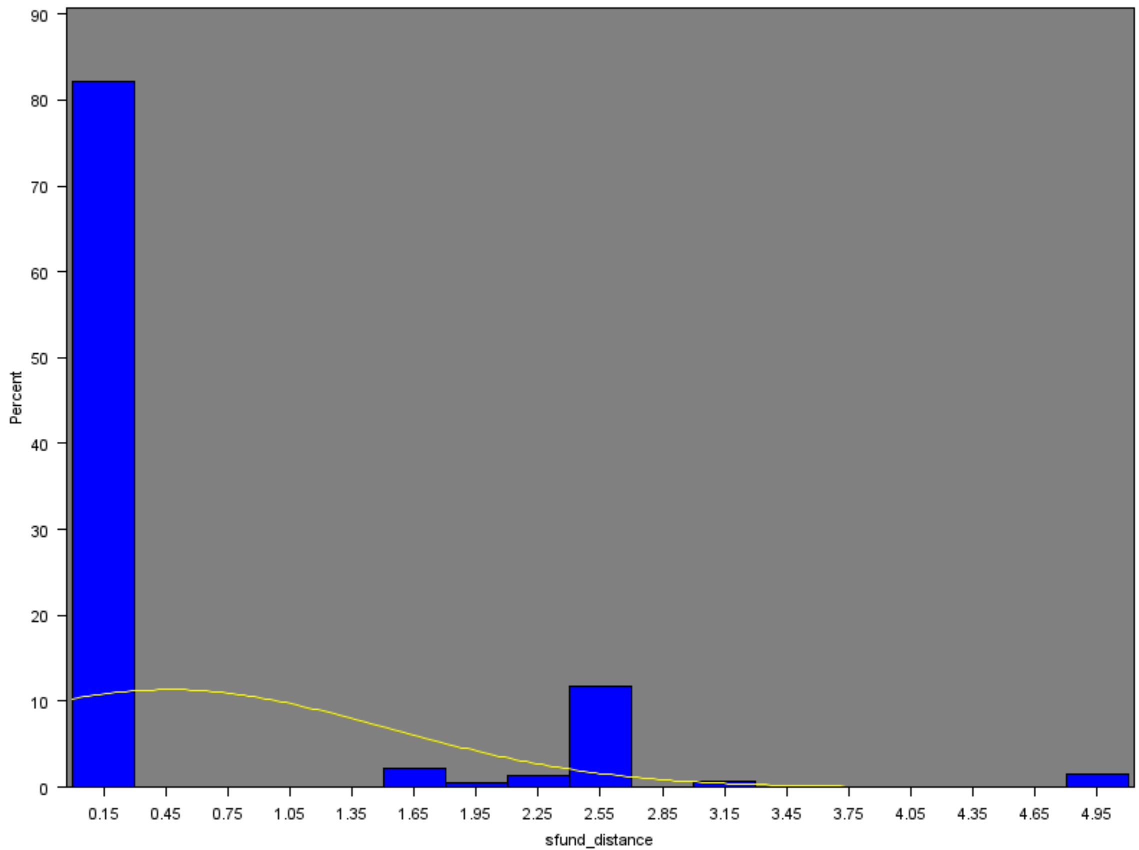
Methods: Addresses and geographic coordinates were downloaded for Brownfields using NETROnline. Brownfield addresses were geocoded in ArcMap 10.5 and buffer zones were created around each site at distances of 0.5, 1, and 5 kilometers (km). We used the union procedure in ArcMap 10.5 to join the buffer layer to the census tract map layer. The corresponding attribute table was imported into SAS Enterprise Guide version 7.1 and mean distances were calculated for census tracts sharing buffer zones. Percentiles were then calculated for the buffer zones.

Figure 16. Histogram for Leaking Underground Storage Tanks



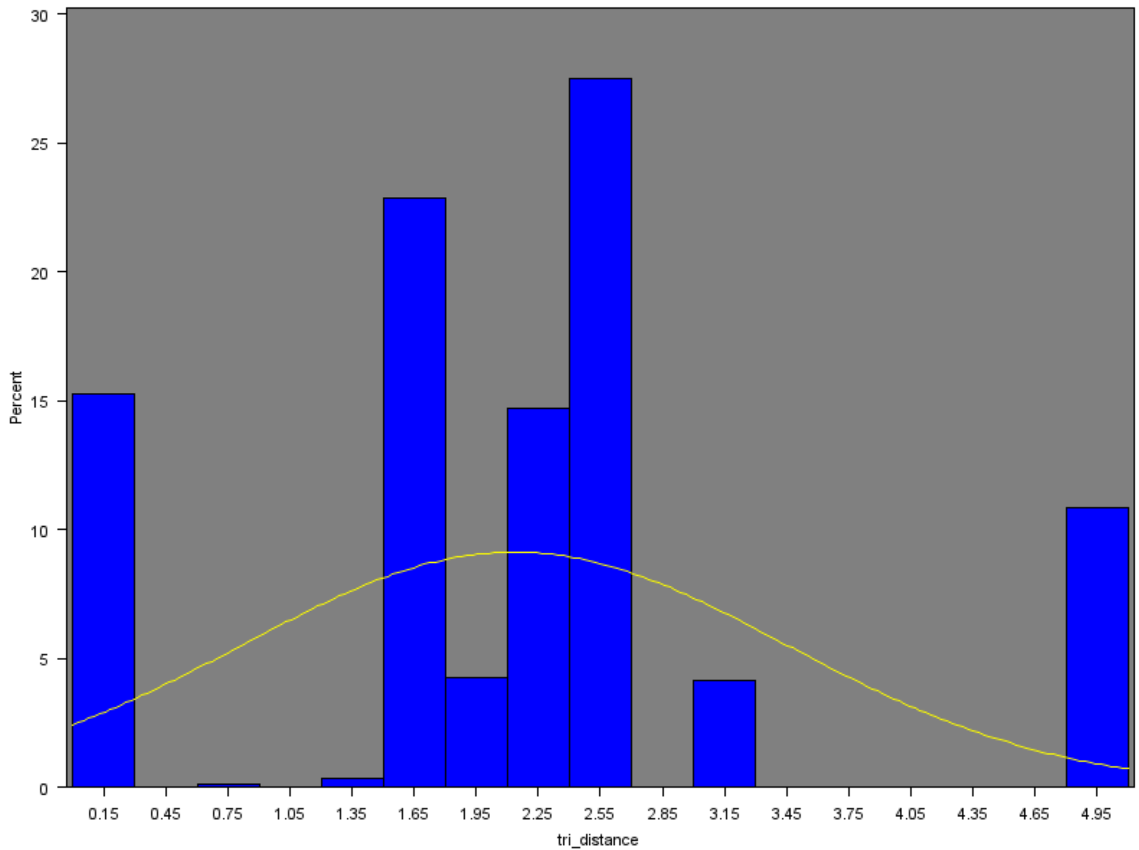
Methods: Addresses and geographic coordinates were downloaded for LUSTs using NETROnline. LUST addresses were geocoded in ArcMap 10.5 and buffer zones were created around each site at distances of 0.5, 1, and 5 kilometers (km). We used the union procedure in ArcMap 10.5 to join the buffer layer to the census tract map layer. The corresponding attribute table was imported into SAS Enterprise Guide version 7.1 and mean distances were calculated for census tracts sharing buffer zones. Percentiles were then calculated for the buffer zones.

Figure 17. Histogram for Superfund Sites



Methods: Addresses and geographic coordinates for Superfund sites were downloaded using TOXMAP. Superfund site addresses were geocoded in ArcMap 10.5 and buffer zones were created around each site at distances of 0.5, 1, and 5 kilometers (km). We used the union procedure in ArcMap 10.5 to join the buffer layer to the census tract map layer. The corresponding attribute table was imported into SAS Enterprise Guide version 7.1 and mean distances were calculated for census tracts sharing buffer zones. Percentiles were then calculated for the buffer zones.

Figure 18. Histogram for Toxic Release Inventory (TRI) Facilities

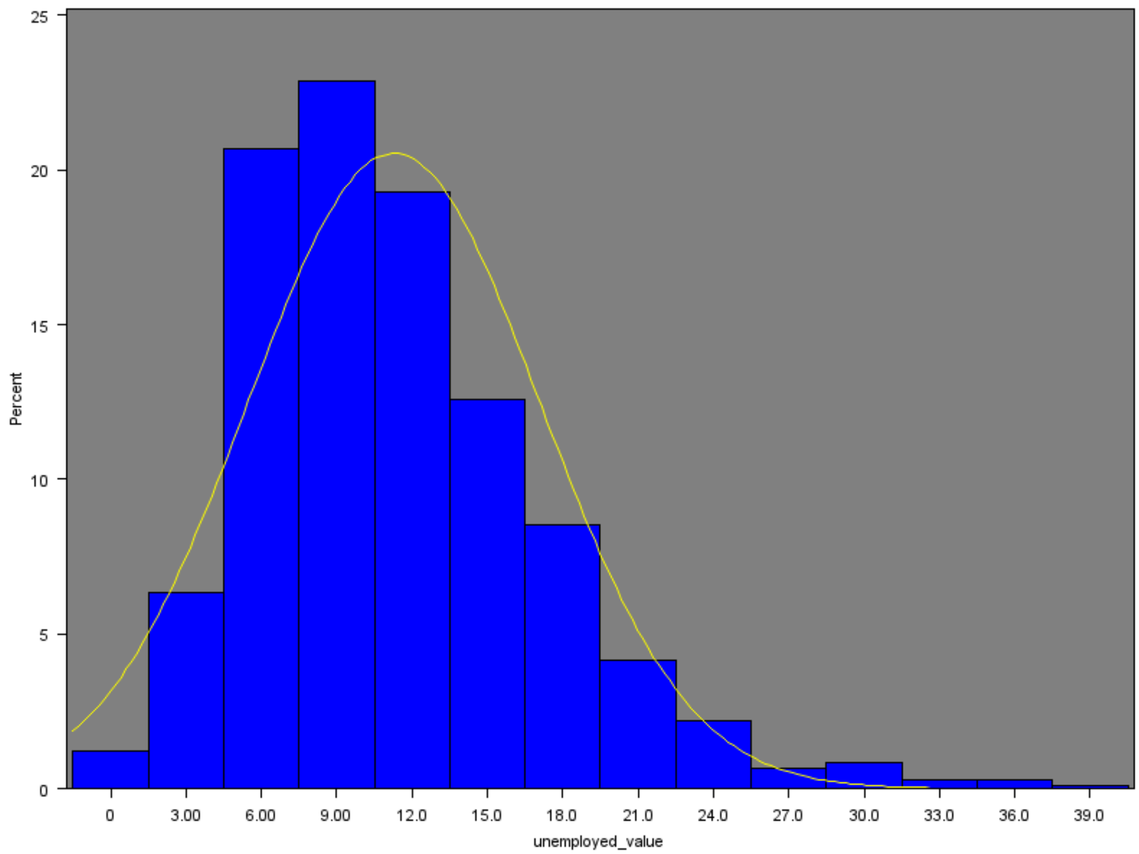


Methods: Addresses and geographic coordinates were downloaded for TRI facilities using TOXMAP. TRI facility addresses were geocoded in ArcMap 10.5 and buffer zones were created around each site at distances of 0.5, 1, and 5 kilometers (km). We used the union procedure in ArcMap 10.5 to join the buffer layer to the census tract map layer. The corresponding attribute table was imported into SAS Enterprise Guide version 7.1 and mean distances were calculated for census tracts sharing buffer zones. Percentiles were then calculated for the buffer zones.

Resiliency Buffers

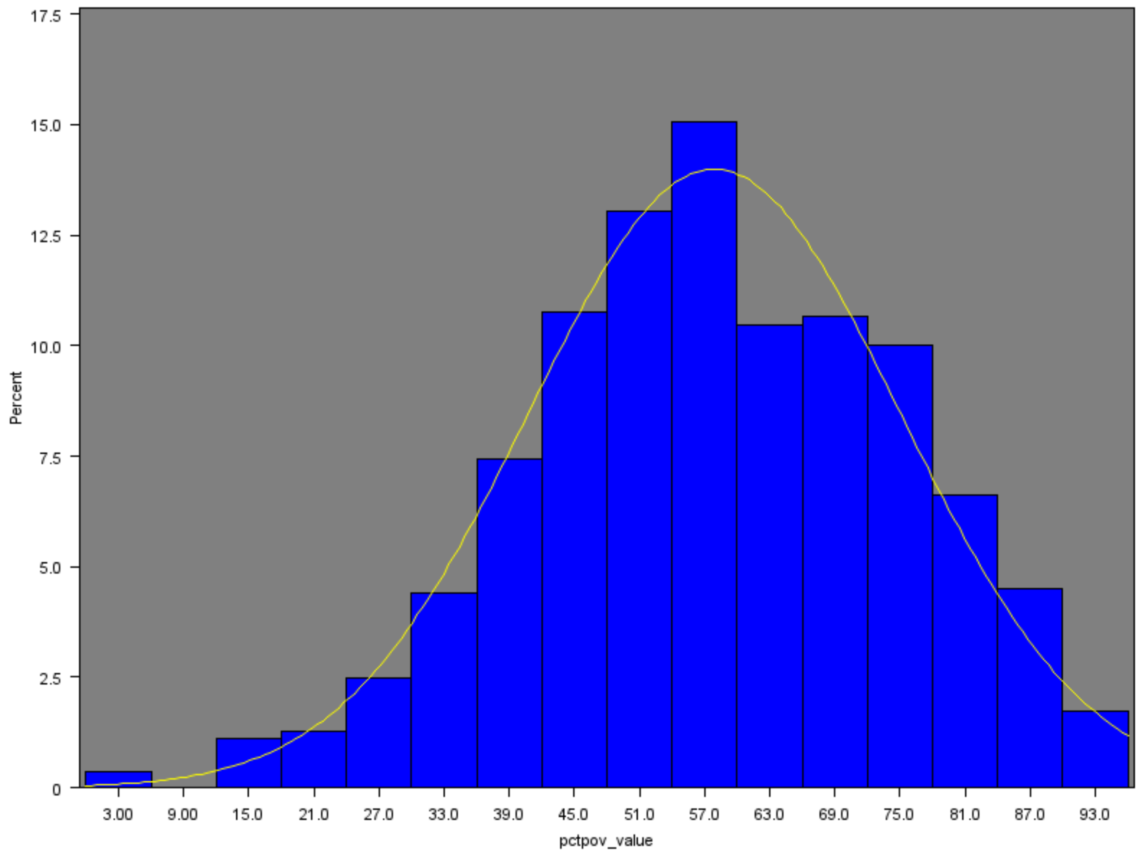
Pathogenic Factors

Figure 19. Histogram for Unemployment



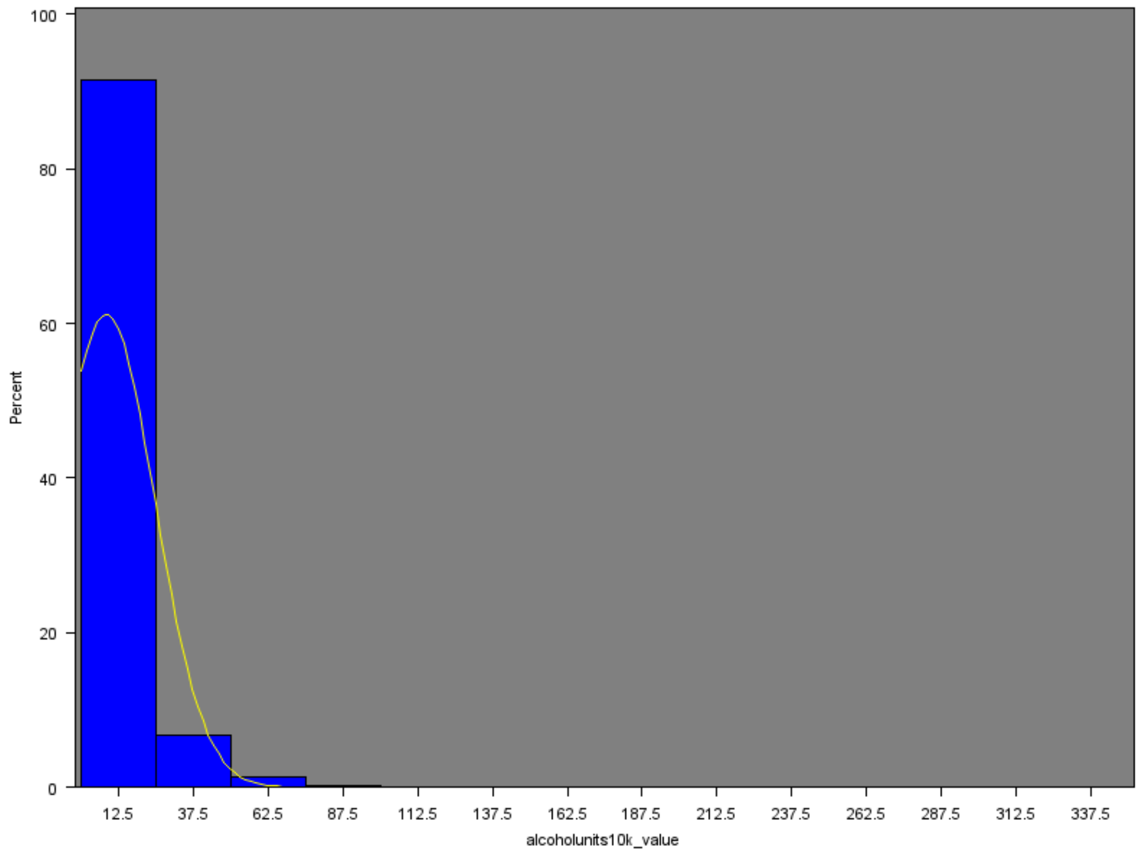
Methods: Unemployment data was downloaded from ACS (2011-2015) and population-weighted averages were calculated to determine the percent of persons ≥16 years of age who were unemployed over the past 12 months at the census tract level. Unemployment counts were divided by the total population ≥16 years of age to obtain percent unemployment values and percentiles were calculated based on the percentages.

Figure 20. Histogram for Low-Income (% Poverty)



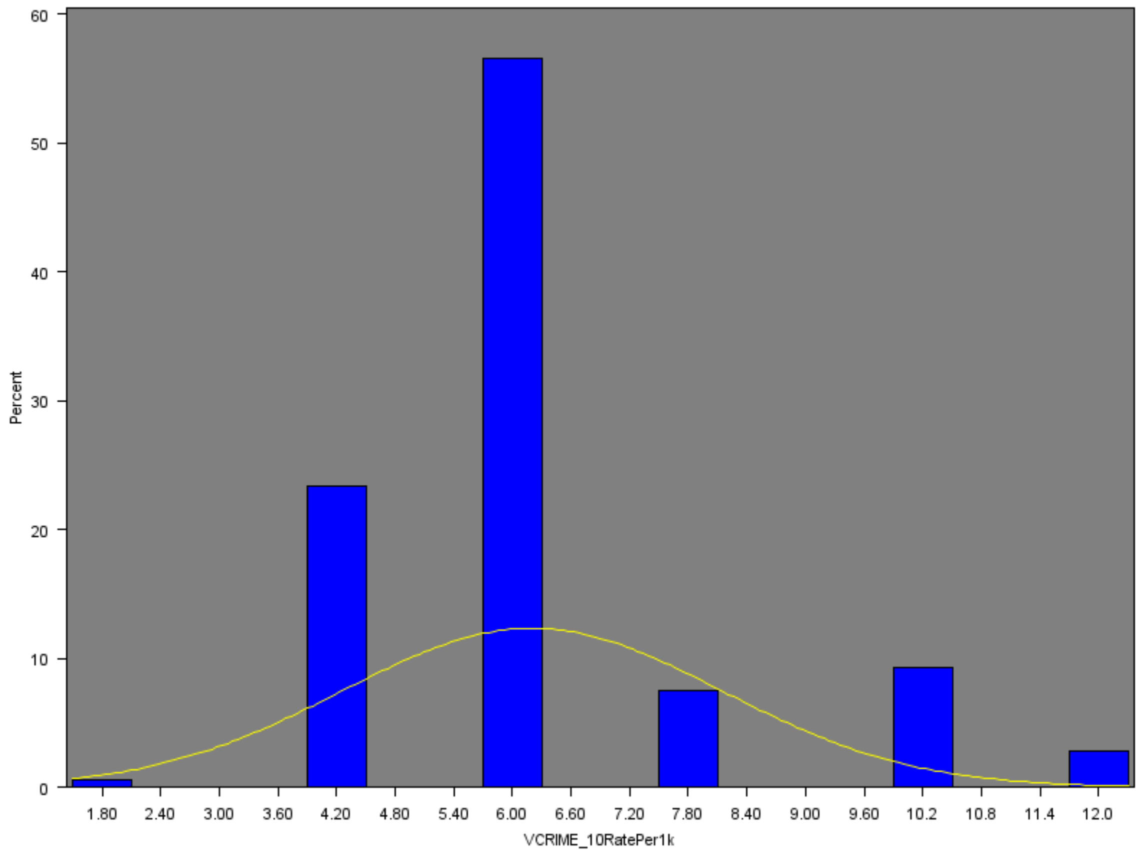
Methods: Poverty data were downloaded from ACS (2011-2015) at the census tract level. We divided the number of persons below the poverty level by the total population in each census tract to determine the percentage of poverty in each census tract. Corresponding percentiles were also calculated.

Figure 21. Histogram for Access to Alcohol Outlets



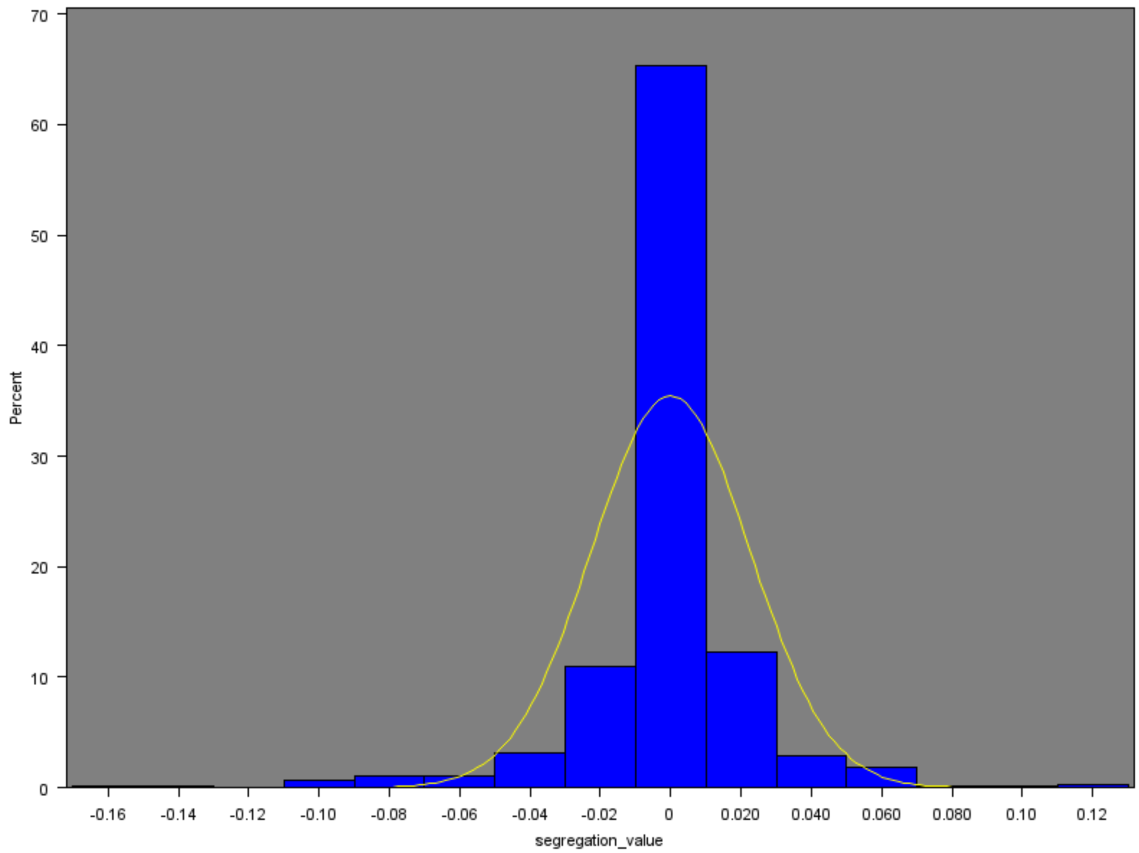
Methods: Addresses of alcohol outlets (single and branch locations) were obtained from the Hoover's Company Information database (2014-2016) using the North American Industry Classification System (NAICS) code 445310. The addresses were geocoded using the US Census Geocoder Tool to identify the census tract for each alcohol outlet. We measured the density of alcohol outlets by calculating the number of alcohol outlets per 10,000 adults (>21) in each census tract. Percentiles were then calculated for the number of alcohol outlet per 10,000 adults >21.

Figure 22. Histogram for Violent Crime



Methods: Violent crime data (i.e. non-negligent manslaughter, forcible rape, robbery, and aggravated assault offenses) was obtained from the SC Law Enforcement Division (SLED) at the county level for 2010. We divided county level violent crime counts by the respective county population and multiplied by 1,000 to create a crime rate. We assigned the number of crimes per 1,000 persons to all census tracts within a county and calculated the percentiles.

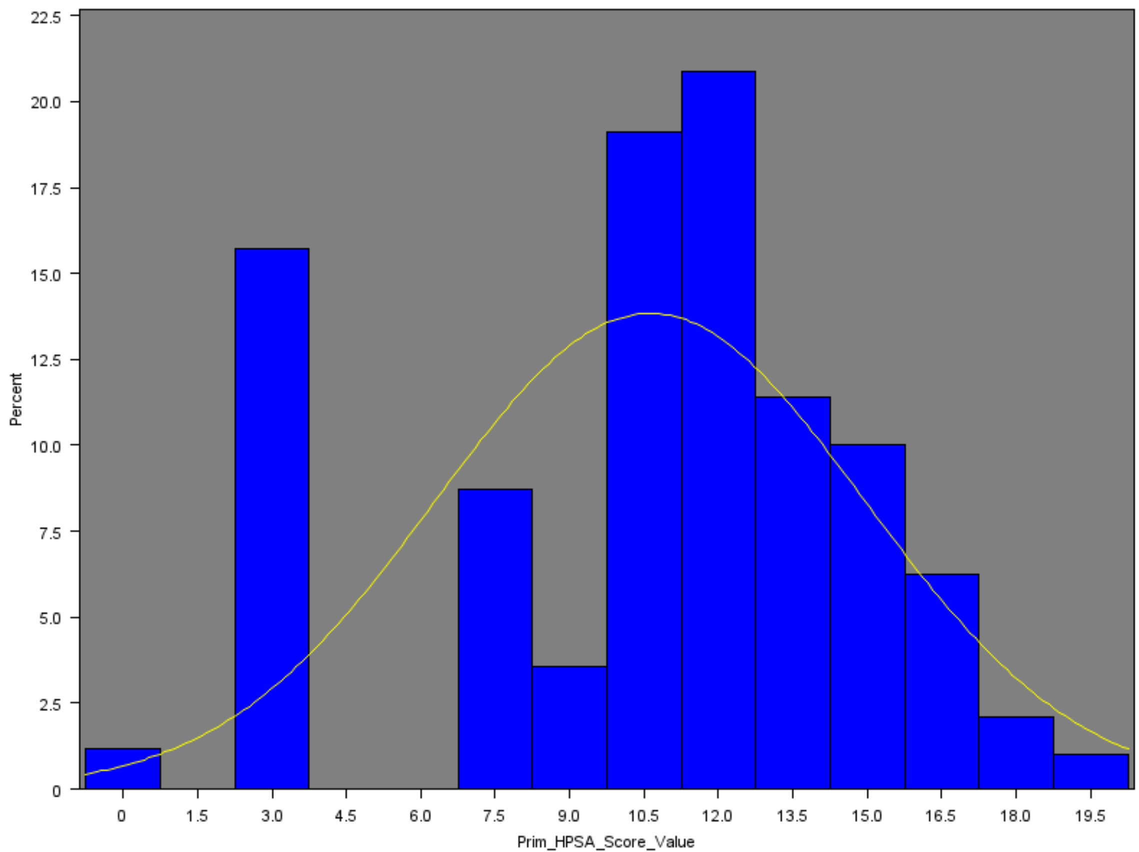
Figure 23. Histogram for Segregation



Methods: The Dissimilarity Index was calculated using data from ACS (2011-2015): $D = \sum_{i=1}^{n} [t_i|p_i - P|/2TP(1-P)]$, where t_i and p_i are the total population and proportion of non-white populations in sub area ι respectively, and T and P represent the total population and non-white proportion within the total area. Percentiles were calculated for residential segregation.

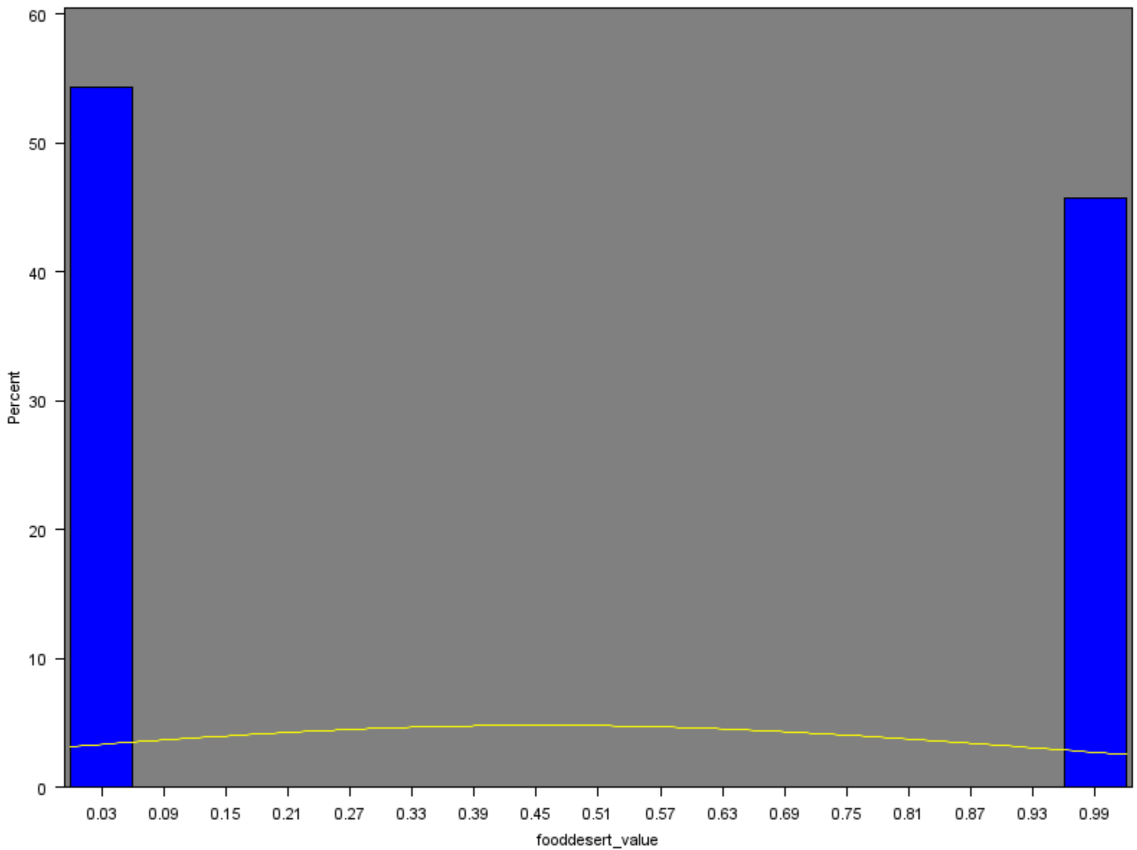
Salutogenic Factors

Figure 24. Histogram for Access to Primary Healthcare



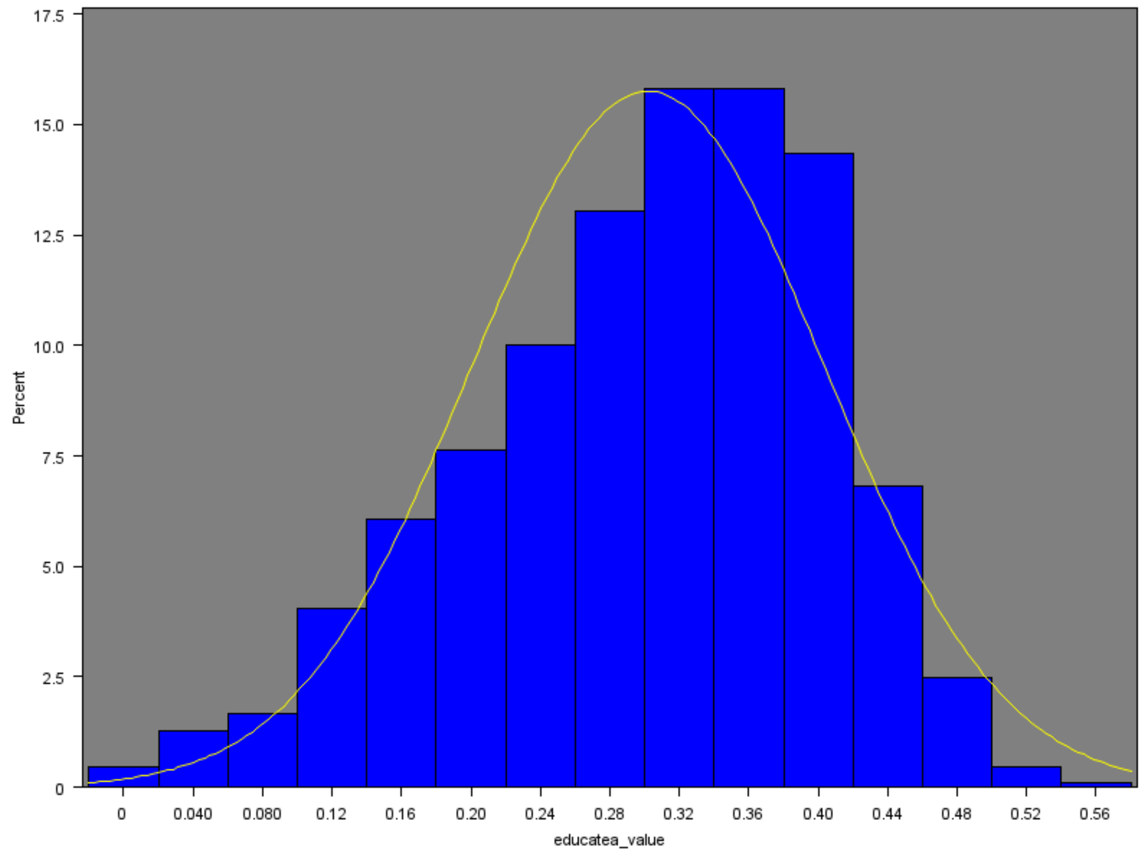
Methods: Primary care HPSA data was downloaded from HRSA at the county level from 2002-2015. We calculated mean HPSA scores for each county based on the HPSA score created by the NHSC to determine priorities for assignment of clinicians. Mean HPSA scores for SC counties were assigned to all census tracts within each county. Original HPSA scores ranged from 1-26, where higher scores were indicative of higher priority areas. Percentiles were then calculated for mean HPSA scores.

Figure 25. Histogram for Access to Grocery Stores



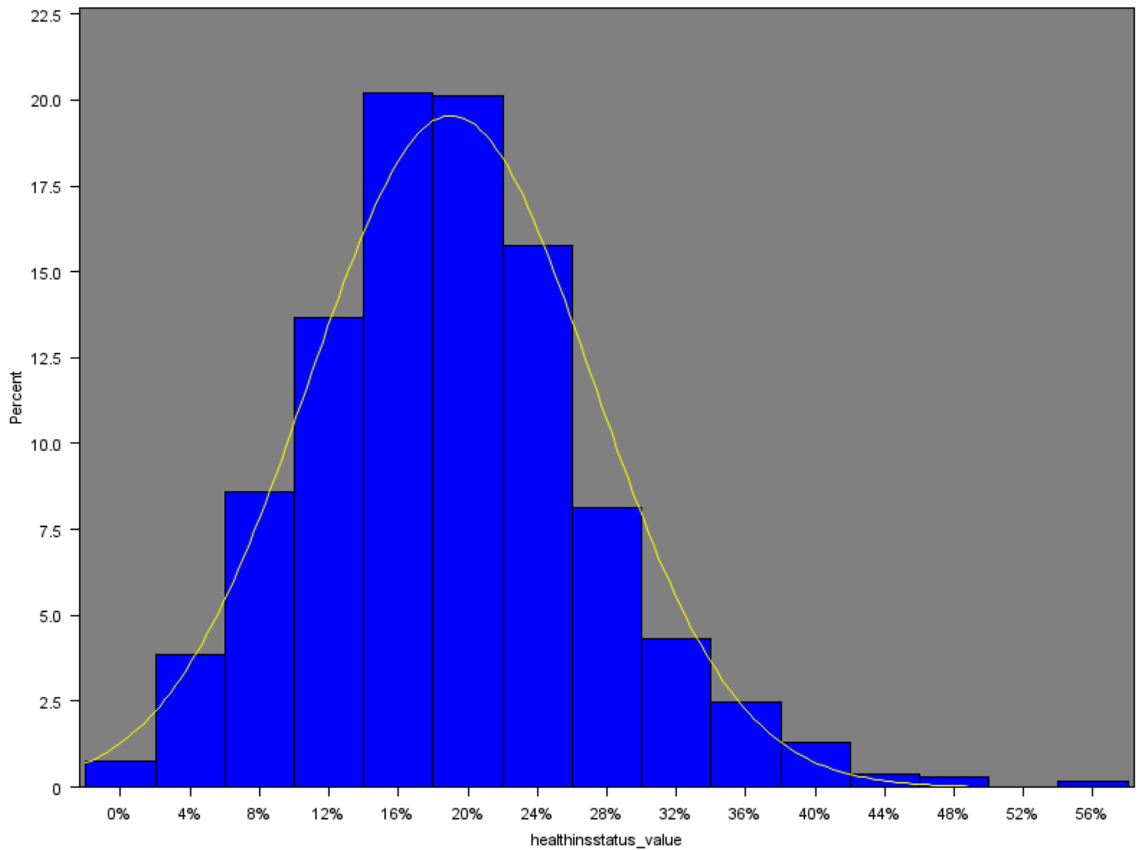
<u>Methods:</u> Grocery store data was downloaded from the United States Department of Agriculture (USDA) Food Access Research Atlas for 2010. Specifically, census tracts were designated as low access if at least 500 people or 33% of the population live farther than 1 mile (urban) or 10 miles (rural) from the nearest supermarket. Percentiles could not be calculated for this variable since the results were binary (low access tract and high access tract).

Figure 26. Histogram for Educational Attainment



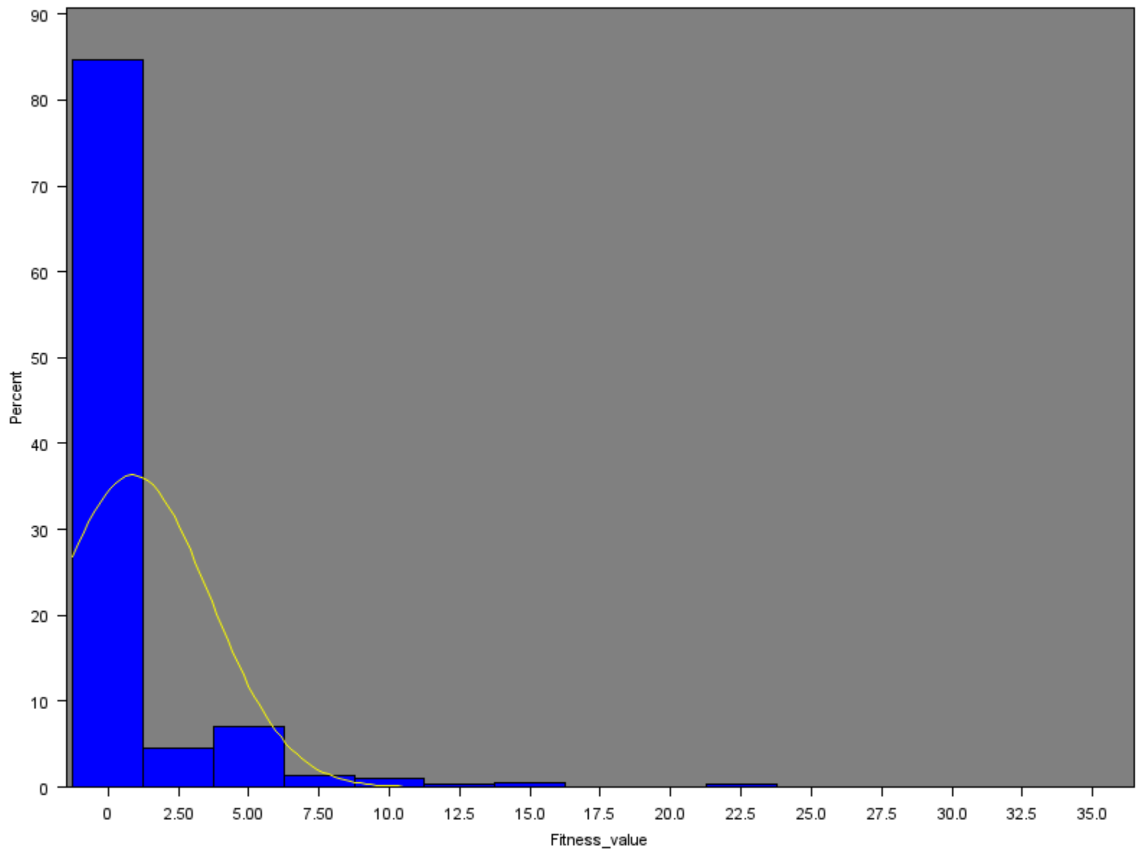
Methods: Educational attainment data was downloaded from ACS (2011-2015) at the census tract level. We performed the following equation to derive percent educational attainment for each census tract: [(persons aged 25 and older with a high school diploma / population aged 25 and older) x 100]. Percentiles were then calculated for percent educational attainment.

Figure 27. Histogram for Health Insurance Coverage



<u>Methods:</u> To assess health insurance coverage, we calculated the percentage of the population within a census tract who did not report having health insurance (private or government) for the previous calendar year based on data obtained from ACS (2011-2015). Specifically, we performed the following calculation for each census tract: [(uninsured population / total population) x 100] to obtain the percentage of uninsured persons at the tract level. Percentiles were then calculated for the percentage of the population with health insurance coverage.

Figure 28. Histogram for Access to Fitness Facilities



<u>Methods:</u> Addresses for fitness facilities (single and branch locations) were obtained from the Hoover's Company Information database from 2014-2016 using the North American Industry Classification System (NAICS) code 713940. We excluded the following SIC codes that represented non-traditional fitness activities: 79991202, 79991200, 79910103, 79990202, 79990600, 79990602, 79990603, and 79990703. The addresses were geocoded using the US Census Geocoder Tool and alcohol outlet density was calculated for each census tract using the following equation: [(number of alcohol outlets / census tract population) x 10,000]. Percentiles were then calculated for the fitness facilities per 10,000 people.

Appendix J: High Resiliency Community

	Environmental Stressors				Resiliency Buffers			
	Environmental Exposures (6)		Environmental Hazards (4)		Pathogenic Factors (5)		Salutogenic Factors (5)	
CSRI Components	Raw Score	Indicator Score	Raw Score	Indicator Score	Raw Score	Indicator Score	Raw Score	Indicator Score
	Ozone 0.031 ppm	0.25	Brownfields N/A	0	Poverty 64.8%	0.75	Education 38.0%	0.25
	$PM_{2.5}$ 10.4 $\mu g/m^3$	0.25	Superfund N/A	0	Unemployment 4.9%	0.25	Grocery Stores 0	0
	Diesel PM 0.14 $\mu g/m^3$	0.25	TRI Facilities N/A	0	Violent Crime 4/1,000 residents	0.25	Health Insurance 12.0%	0.25
	Lead Paint 10.0%	0.25	LUSTs N/A	0	Alcohol Outlet Density 0/10,000 residents ≥21 years of age	0.25	Fitness Facilities 0/10,000 residents	1.00
	Toxic Releases Mean RSEI Score 12.1	0.50			Residential Segregation 0.0	0.75	Primary Healthcare Mean HPSA score 10	0.50
	Traffic Density (1270000 VMT per sq mi)	0.25						
Subcategory Totals	(0.25 + 0.25 + 0.25 + 0.25 + 0.50 + 0.25) = 1.75		(0 + 0 + 0 + 0) = 0		(0.75 + 0.25 + 0.25 + 0.25 + 0.75) = 2.25		(0.25 + 0 + 0.25 + 1.00 + 0.50) = 2.00	
Category Totals (Range 0-10)	1.75 + 0 = 1.75				2.25 + 2.00 = 4.25			
CSRI Calculation (Potential Range 0-100)	**1.75 x 4.25 = 7.44**							

Appendix K: Low Resiliency Community

	Environmental Stressors				**Resiliency Buffers**			
	Environmental Exposures (6)		**Environmental Hazards (4)**		**Pathogenic Factors (5)**		**Salutogenic Factors (5)**	
CSRI Components	Raw Score	Indicator Score	Raw Score	Indicator Score	Raw Score	Indicator Score	Raw Score	Indicator Score
	Ozone 0.032 ppm	0.75	Brownfields 2.17 km	0.75	Poverty 26.7%	0.25	Education 30.0%	0.75
	$PM_{2.5}$ 10.9 $\mu g/m^3$	1.00	Superfund N/A	0	Unemployment 16.3%	1.00	Grocery Stores 1	1.00
	Diesel PM 0.66 $\mu g/m^3$	1.00	TRI Facilities 2.17 km	0.75	Violent Crime 6/1,000 residents	0.75	Health Insurance 42.0%	1.00
	Lead Paint 59.0%	1.00	LUSTs 2.17 km	0.75	Alcohol Outlet Density 12.8/10,000 residents ≥21 years of age	1.00	Fitness Facilities 0/10,000 residents	1.00
	Toxic Releases Mean RSEI Score 1207	1.00			Residential Segregation -0.0	0.50	Primary Healthcare Mean HPSA score 12	0.75
	Traffic Density (4830000 VMT per sq mi)	1.00						
Subcategory Totals	(0.75 + 1.00 + 1.00 + 1.00 + 1.00 + 1.00) = 5.75		(0.75 + 0 + 0.75 + 0.75) = 2.25		(0.25 + 1.00 + 0.75 + 1.00 + 0.50) = 3.50		(0.75 + 1.00 + 1.00 + 1.00 + 0.75) = 4.50	
Category Totals (Range 0-10)	5.75 + 2.25 = 8.00				3.50 + 4.50 = 8.00			
CSRI Calculation (Potential Range 0-100)	**8.00 x 8.00 = 64.0**							

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