A Tale of Two Community Engaged Research Studies: Addressing Environmental Health Disparities in Washington State

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A dissertation

submitted in partial fulfillment of the

requirements for the degree of

Doctor of Philosophy

University of Washington

2020

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Program Authorized to Offer Degree:

Environmental and Occupational Health Sciences

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Abstract

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The goal for environmental justice is for everyone to have a healthy environment in which to live, learn, work, play, and worship. Community-academic partnerships have been effective in addressing environmental health disparities in various settings. This dissertation examined two different community engaged research projects that focus on understanding the environmental risk and burden for communities in WA. The first, the Washington Environmental Health Disparities Map project, describes a newly formed community-academic-government partnership. We documented the community engaged process of creating the Washington Environmental Health Disparities Map and its application. We displayed nineteen indicators of environmental threat and vulnerability for communities of Washington State in a publicly available platform. We found that census tracts with a higher proportion of people of color and higher proportion of people living below 185% federal poverty levels were disproportionately burdened by cumulative impacts of

environmental risks. Age-related susceptibility (children under five) was also found to be related to a greater burden of cumulative environmental risks and individual indicators. The second study used a set of semi-structured interview questions to evaluate the Home Air in Agriculture Pediatric Intervention study in the Lower Yakima Valley, Washington. This study was conducted within a mature community-academic partnership. We examined implementation of the intervention trial and the partnership's influence on the outcomes of the project. Results showed prioritization of community issues, responsiveness to community feedback, integration of community strengths and resources, and high levels of trust led to a highly functional partnership. The community-academic partnership led to community empowerment and enhanced community capacity to improve pediatric asthma health outcomes. Together, these studies demonstrate how academics can effectively address environmental health concerns with communities, for communities. Incorporating community into the research process is essential to correcting the disproportionate burdens of environmental hazards on marginalized and underserved communities.

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LIST OF ACRONYMS

ACS	American Community Survey
CalEPA	California Environmental Protection Agency
CEnR	Community Engaged Research
CDC	US Centers for Disease Control and Prevention
CNT	Center for Neighborhood Technology
DEOHS	University of Washington Department of Environmental and Occupational Health Sciences
DOH	Washington State Department of Health
ECY	Washington State Department of Ecology
EJ	Environmental Justice
EHD	Environmental Health Disparities
HAPI	Home Air in Agriculture Pediatric Intervention Trial
IBL	Information by Location tool on the Washington Tracking Network
NIEHS	National Institute of Environmental Health Sciences
NPL	National Priorities List
NTN	CDC National Tracking Network
NCEC/Radio KDNA	Northwest Communities Education Center/ Radio KDNA
NEJAC	National Environmental Justice Advisory Council
OFM	Washington State Office of Financial Management
PM	Particulate Matter

POC	People of Color
PSCAA	Puget Sound Clean Air Agency
RMP	Risk Management Plan
RSEI	Risk-Screening Environmental Indicators
TRI	Toxic Release Inventory
TSDF	Hazardous Waste Treatment Storage and Disposal Facilities
US EPA	US Environmental Protection Agency
UW	University of Washington
WTN	Washington Tracking Network (Washington State Department of Health)
YVFWC	Yakima Valley Farm Workers Clinic

ACKNOWLEDGEMENTS

I am grateful for Catherine Karr, Edmund Seto, and Stephanie Farquhar who provided me with support and mentorship. I thank Cynthia Pearson for serving as the Graduate School Representative.

I would like to thank the members of the HAPI team including Elizabeth Torres, Carmen Mireles, Adriana Perez, Isabel Reyes-Paz, Ryan Babadi, Karen Jansen, Jen Krenz, Pablo Palmandez, Anne Riederer, Maria Tchong-French, and Lisa Younglove for all their work and dedication on the HAPI project. I would also like to thank the members of the Environmental Justice Mapping Work Group including Deric Gruen, Debolina Banerjee, Tina Echeverria, Lauren Freelander, Michael Schmeltz, Erik Saganić, Millie Piazza, Vanessa Galaviz, and Michael Yost for their dedication on the project. The DEOHS communication team including Jolayne Houtz and Veronica Brace ensured that the communication plan for the Washington Environmental Health Disparities Map was successful.

This dissertation would not have been possible without my community partners, especially Elizabeth Torres, Carmen Mireles, Adriana Perez, Isabel Reyes-Paz, Deric Gruen, Debolina Banerjee, and the Front and Centered team.

I would like to thank my husband, the Min and Maga families, friends (especially Iyah Chen, Meagan Jackson, Kate McConnell, Noreene Shibata, Orly Stampfer, Fwjchim Thaoxaochay, and Lauren Weisenfluh) for their love and support.

DEDICATION

To James.

Chapter 1. INTRODUCTION

1.1 ENVIRONMENTAL JUSTICE

The goal for environmental justice (EJ) is for everyone to have a healthy environment in which to live, learn, play, work, and worship. Two categories of EJ have been addressed most frequently: procedural and distributive justice [1]. The EJ movement has focused on the importance of community involvement in environmental research and policy making to reduce environmental burdens for all people.

Federal mandates are one of many avenues to reduce environmental health disparities in communities. US EPA operates under the definition of EJ as "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" [2]. Since its establishment, the National Environmental Justice Advisory Council (NEJAC) has presented recommendations and guidance towards more equitable processes in environmental decision-making. In 1994, President Clinton signed Executive Order 12898, "Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations" to require federal agencies to identify unequal distribution of environmental burdens and to ensure meaningful engagement with communities [1]. Efforts in some states such as California have complemented efforts at the federal level.

Despite advances in recognizing and identifying EJ issues, the US has struggled to achieve EJ due to the complexities of race and poverty entrenched within civil rights and social justice movements [3]. Disproportionate burdens of environmental risks have been historically placed on marginalized and underserved communities due to policies and practices that discriminate based on race or socioeconomic class [4]. History of racial segregation and income inequality have exacerbated many of these burdens [5]. For example, in the early 1980s, a governor of North Carolina chose Warren County as a site to dump polychlorinated biphenyl (PCB) contaminated soil due to the county's high proportion of black residents and low-income families. The 1982 General Accounting Office study and the Toxic Wastes and Race in the United States report by the United Church of Christ found hazardous waste sites and landfills to be disproportionately located closer to communities of color across the nation [6, 7]. Numerous studies have since been conducted and have found distributive inequities continue to affect historically marginalized or underserved communities [4, 8, 9].

In EJ, understanding the similarities and differences in urban and rural communities are critical as "…urban and rural spaces are inextricably linked and bound up by intricate and highly uneven and unequal processes" [10]. Urban communities face high environmental risk related to urbanization such as traffic related air pollution or noise pollution, while rural communities may face different sources of environmental risks such as pesticide exposure or drinking water contamination [11]. To further complicate rural EJ issues, access to healthcare services and resources can be more limited than urban areas [12, 13].

A collaborative community engaged research (CEnR) framework may serve as an effective strategy in EJ research for both urban and rural communities [14-17]. CEnR in environmental health is grounded in community-academic partnerships to identify these disparities and explore solutions with the affected communities [18, 19]. CEnR promotes EJ procedurally by sharing power with community, enhancing community capacity, and cocreating knowledge [20-22]. In addition, CEnR enhances relevance of research, strengthens scientific rigor, and widens the reach of the overall study results [23].

Despite the clear importance of inclusive community engagement practices and equitable partnerships [24-27], there are challenges in implementing CEnR studies through successful community-academic partnerships. For new partnerships, the process of establishing trust and positive group dynamics may hinder progress in the project [28]. Community members are often uncompensated for the time spent to establish the partnership, which is often outside the scope of grant or project funding [29, 30]. In addition, community organizations and academic institutions often have differing priorities that could potentially create conflicts in designing or implementing a research project [29, 31, 32].

Future CEnR in Washington State may benefit from descriptions of the processes and elements involved in successful projects. Recent research activities in Washington State provide opportunities to critically examine the role of CEnR study in promoting EJ through community-academic partnerships. This dissertation comprises two different CEnR projects that focus on understanding the environmental risk and burden for communities in WA. Although both studies involve community-academic partnerships to solve environmental health and justice issues, they are sufficiently different such that this dissertation does not evaluate them against one another. Instead, the dissertation describes the lessons learned from each study. The first study is the development of a Washington statewide EJ map to identify distributive injustices through partnership and community involvement in research. The project is based on a newly formed community-academic-government partnership. This partnership engaged various groups with diverse environmental concerns and issues across the state. In contrast, the second study focuses on an intervention trial that grew out of a longstanding community-academic partnership in rural Washington. This case study is focused on a specific environmental health issue: air quality and asthma health in the rural Lower Yakima Valley. Together, these studies provide unique examples of how academics can work towards a solution with communities, for communities.

1.2 WASHINGTON ENVIRONMENTAL HEALTH DISPARITIES MAP

The Washington Environmental Health Disparities Map was created to identify distributive injustices of environmental risks and hazards in Washington State. Different from a more traditional research process led by an academic institution, this project was initiated by a coalition of community organizations. Community organizations, University of Washington (UW), and multiple government agencies launched a work group without any prior experience of working together. This project also did not have dedicated funding. Therefore, this project provides useful lessons from a newly formed community-academic-government partnership by describing the role of community in EJ mapping, use of quantitative data to identify environmental health disparities, and analysis of the EJ mapping tool to identify the disproportionate environmental burdens. This part of the dissertation examines the Washington EJ Mapping project to address the following aims:

Aim 1: Develop the Washington Environmental Health Disparities Map, a cumulative environmental impact assessment tool, describe the community-driven process and lessons learned, and characterize the relationships between data integrated in the tool.

Aim 2: Evaluate the environmental justice landscape of Washington State using indicators of environmental risk and vulnerability in the Washington Environmental Health Disparities Map, a cumulative impact assessment tool. Use an inequality index to quantitatively assess the level of equality in environmental risk and hazard based on race, poverty, and age.

1.3 Home Air in Agriculture Pediatric Intervention Trial

The HAPI trial is a CEnR study focused on indoor air quality and asthma health in the rural Lower Yakima Valley of Washington [33-35]. Formally proposed and funded through the National Institute of Environmental Health Sciences (NIEHS), the HAPI study was developed within a longstanding partnership between community organizations and UW.

Meaningful participation from the community in research is critical and requires the partnership to address ongoing challenges and sustain the relationship among partners [30, 32, 36, 37]. Partnership evaluations can provide useful insight into how a partnership process affects the success of the project. While many urban partnerships have employed extensive evaluations of the partnership process, this has yet to be extensively examined in rural partnerships. Therefore, an evaluation of the HAPI study gives useful insight on this mature partnership's process and influence of the CEnR project outcomes. This part of the dissertation examines the HAPI study to address the following objective:

Aim 3: Evaluate a longstanding community-academic partnership process in implementing a CEnR project and its influence on the outcomes of a CEnR project, the HAPI study, based in rural Washington.

Chapter 2. THE WASHINGTON STATE ENVIRONMENTAL HEALTH DISPARITIES MAP: DEVELOPMENT OF A COMMUNITY-RESPONSIVE CUMULATIVE IMPACTS ASSESSMENT TOOL

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2.1 ABSTRACT

Communities across Washington State have expressed the need for neighborhood-level information on the cumulative impact of environmental hazards and social conditions to illuminate disparities and address environmental justice issues. Many existing mapping tools have not explicitly integrated community voice and lived experience as an integral part of their development. The goals of this project were to create a new community–academic–government partnership to collect and summarize community concerns and to develop a publicly available mapping tool that ranks relative environmental health disparities for populations across Washington State. Using a community-driven framework, we developed the Washington Environmental Health Disparities Map, a cumulative environmental health impacts assessment tool. Nineteen regularly updated environmental and population indicators were integrated into the geospatial tool that allows for comparisons of the cumulative impacts between census tracts. This interactive map provides critical information for the public, agencies, policymakers, and community-based organizations to make informed decisions. The unique community–academic–government partnership and the community-driven framework can be used as a template for other environmental and social justice mapping endeavors.

2.2 INTRODUCTION

Institutional environmental justice (EJ) initiatives have focused on promoting environmental equity and social justice through the meaningful involvement of impacted communities and equitable distribution of the environmental burdens [1]. These efforts are framed as a response to procedural and distributive injustices that have contributed to disparities in exposures to environmental hazards and threaten the health and well-being of communities of color and low-income populations in the United States. Specifically, procedural justice addresses the historical imbalances in privilege, power, and representation that effectively exclude these populations from influencing the multitude of environmental decisions that impact communities [1, 18, 27, 38]. Distributive justice addresses the inequitable distribution of environmental burdens across communities [1, 38]. In Washington State, there is a need to identify communities where health disparities are likely to occur because of environmental injustices.

Identifying communities with high pollution burden and who are vulnerable to pollution's effects is important for advancing environmental justice. Understanding the unequal distribution of environmental hazards or risks is important for developing solutions to environmental health disparities. Cumulative environmental impact assessment tools can help quantify the so-called "double jeopardy" issue—the combined and interactive exposure to environmental hazards and socioeconomic stressors that contribute to environmental health disparities [39, 40]. This additional consideration of population vulnerability is typically not fully appreciated within a traditional risk assessment methodology. Methods for cumulative impact assessment are emerging [40-42], often implemented in the form of screening tools to help identify the likelihood of the occurrence of environmental health disparities [43].

Existing tools, such as the US Environmental Protection Agency's (EPA) Environmental Justice Screening and Mapping Tool (EJSCREEN, EPA, Washington, DC, USA) and the California Office of Environmental Health Hazard Assessment's (OEHHA, Sacramento, CA, USA) California Communities Environmental Health Screening Tool (CalEnviroScreen, Sacramento, CA, USA), have developed methodologies to identify communities disproportionately impacted by pollution burden while integrating population characteristics data to account for intrinsic and extrinsic vulnerabilities. Fundamental differences exist between the

EJSCREEN and CalEnviroScreen frameworks. The EJSCREEN assesses excess environmental risk of exposure to environmental hazards and burden on communities by comparing populations in census blocks to other census blocks across the nation. It also provides multiple indices based on individual environmental risk factors rather than creating a single composite score that integrates multiple risk factors. In contrast, CalEnviroScreen assesses the cumulative environmental impacts of various risks to communities at the census tract level in California.

These mapping tools are fundamental to environmental justice, as they illuminate the disparities in environmental health conditions across populations. However, strategies to promote distributive justice need more inclusive and systematic ways to actively engage impacted communities for environmental decisions. In California, before the creation of CalEnviroScreen, the OEHHA convened a research team and science advisory board to develop new methods for cumulative impact assessment and precautionary approaches. The CalEnviroScreen, as a tool for systematically quantifying EJ cumulative impacts, was the result of policy implemented by people of color from disadvantaged communities who worked with EJ leaders to write bills which were passed that mandated the integration of EJ into policy and the development of CalEnviroScreen. While there was community and EJ leadership advocating for greater consideration of EJ and tools, the methodology for CalEnviroScreen was developed from an agency-driven, top-down approach, and it is unclear what role community residents and organizations played in the selection of environmental risks and how they would be combined to quantify cumulative risk. The development of tools, like CalEnviroScreen in California and EJSCREEN at the national level, have implications for procedural justice (i.e., how communities with EJ considerations are identified, and who gets a seat at the table when working on EJ policy issues) and distributive justice (i.e., determining which communities are prioritized for corrective/restorative actions, and which communities bear environmental burdens). Only a few articles have been published studying the relationship between existing tools to known disparities related to socioeconomic status, race/ethnic groups, and health outcomes [44-46].

Recent work has demonstrated that a community-driven framework may be used to develop EJ tools [47]. University of Maryland researchers, stakeholders, and residents representing various EJ issues in Prince George's County in the state of Maryland (MD), worked collaboratively to build the MD EJSCREEN, based on the USEPA's EJSCREEN framework [47]. The MD EJSCREEN integrates national, statewide, and regional specific indicators to represent the cumulative environmental impact of risk for the state of Maryland through community feedback and engagement early in the project [47]. However, the authors limited the outreach and engagement efforts to a specific county of Maryland, Prince George's County. Although Prince George's County represented a racially diverse population affected by environmental injustices, the authors did not state efforts to engage more communities outside of this county [47].

Independently, over a two-year period, a work group in Washington State collaborated to develop a new cumulative impacts mapping tool which was based on a community-engaged process. This work built upon the lessons and expertise of preceding mapping projects with the intent to create the first cumulative impact of environmental hazards and resulting disparities across the state.

The goals of the Washington Environmental Health Disparities Map project were to create a community–academic–government partnership to develop an EJ map and to create a map that ranks relative environmental health disparities of communities in Washington State using a community-driven framework. The goal of this paper was to summarize our process, the methodological framework for integrating environmental and population indicators into cumulative impact rankings, environmental justice findings for the state based on the first version of the mapping tool, and the policy implications of the tool.

2.3 Materials and Methods

In early 2017, the Washington EJ Mapping Work Group was initiated by Front and Centered, an EJ coalition of organizations rooted in communities of color, in partnership with Puget Sound Sage, University of Washington Department of Environmental and Occupational Health Sciences (DEOHS), the Washington State Department of Health (DOH) Washington Tracking Network (WTN) program, the state Department of Ecology (ECY), and the Puget Sound Clean Air Agency (PSCAA), a regional air quality management agency.

Front and Centered coordinated the work group meetings, led community engagement efforts, provided feedback for the project, and monitored progress of the project. The DEOHS took the lead in the technical aspects of the project, conducted the literature review, developed models for datasets, and conducted sensitivity analysis for the map. The DOH WTN staff provided input on the methodology and data used for the tool in addition to staff time and resources required to integrate the map into their mapping platform. The ECY staff provided insight for the environmental data for Washington State and the potential application of other Washington State-specific data for the project. The PSCAA staff offered technical expertise for air quality data in addition to sharing experience mapping community vulnerability at a regional level in Washington State.

Monthly meetings were held between January 2017 and February 2019 to discuss the expectations of each partner, review the timeline and progress on the project, provide feedback on the content, and report back mapping-related activities to the rest of the work group. The goal of the Washington EJ Mapping Work Group was to oversee the development of the Washington

Environmental Health Disparities Map through the community–academic–government partnership.

2.3.1 *Community Listening Sessions*

In mid-2017, Front and Centered issued a request for proposals (RFPs) from community-based organizations across the state to host listening sessions. Eleven different community organizations hosted a series of community listening sessions to discuss the environmental health risk factors communities have faced [48]. Two questions were asked: (1) What kinds of pollution, if any, are impacting your life or work and that of your family and community? (2) What factors best show if your community is healthy or doing well compared to other communities?

Front and Centered developed a facilitator's guide and accompanying materials, including a sign-in sheet with zip codes, a note-taking template, and a summary template for facilitators. Community leaders from host organizations facilitated the sessions, took individual notes, and summarized each of their meetings.

Eleven two-hour community listening sessions were hosted between July and November 2017 with over 170 participants (Figure 2.1). The primary audience for engagement were communities across Washington who were identified through literature as disproportionately vulnerable to cumulative environmental burdens, particularly communities of color, households with lower incomes, immigrants and refugees, and linguistically isolated groups.

The common themes identified in these listening sessions were used to inform the work group on indicator selection. Detailed results from the listening session are presented in a dedicated report [49].

Figure 2.1. Location of listening sessions held between July and November 2017.

2.3.2 *EJ Mapping Symposium*

In February 2018, over fifty participants from research, government, and community-based organizations convened for a daylong work session to discuss potential indicators for the tool, methods for determining and illustrating the severity of environmental health disparities and the impact of climate change on environmental factors in communities across the state. A portion of the symposium included breakout sessions with participants discussing four key areas: population characteristics, environmental effects and exposures, climate impacts, and application of policy in practice. The discussion groups then came together to share summaries from each group discussion and propose new potential indicators of environmental health disparities, such as wealth inequality, concerns (such as accounting for undocumented and indigenous people), and the need for actionable data and information at the community level.

2.3.3 *Literature Review and Indicator Selection*

The DEOHS conducted a literature review for the potential data sources that could inform indicators identified through the series of community listening sessions and the EJ mapping symposium. Data sources were reviewed for statewide availability, reliability of the data source, and quality of data at the census tract level. At this time, other existing EJ mapping tools were reviewed for their methodology and inclusion of specific indicators.

From April to July 2018, the work group reviewed the secondary data and literature, and reached consensus for selection of specific indicators and methodology to create indicators if needed, and the cumulative impact framework to model, score, and rank environmental risks in Washington State.

2.3.4 *Draft Map Development*

The DOH integrated the selected indicators and methodology into the Washington Tracking Network, a platform featuring publicly accessible data on more than 300 measures of environmental risks and public health. Based on feedback from the work group, the DEOHS developed a draft technical report specifying the methodology for each indicator [49]. Two different sensitivity analyses were conducted: Spearman's correlation coefficients and principal component analysis. Principal component analysis (PCA) was conducted using the "prcomp" function in R (Version 3.6.0, The R Foundation for Statistical Computing, Vienna, Austria) and Rstudio (Version 1.2.1335, Boston, MA, USA).

Once a draft map was created, the work group members hosted a webinar in September 2018 to share the findings in the draft report. Organizations that hosted the listening sessions, staff from government agencies such as OEHHA and ECY, stakeholders from partner organizations, and academic researchers in related fields were invited to the webinar. More than 90 people attended the webinar or listened to the webinar recording. The work group was able to gather participant feedback on ways to frame the environmental risks and environmental health disparities captured in the final map and interpret its findings.

2.3.5 *Communication Planning*

A subgroup consisting of communication experts in the work group met biweekly from October 2018 to January 2019. The subgroup outlined the communication goals in order to effectively and collaboratively launch the inaugural map. The subgroup also created a shared document to solicit feedback from one another and negotiate the description of the tool, roles of each, and background information on the project. The communication plan also included consistent terminology to be used by all partners and how to frame environmental risk, health impacts, and burden related to the mapping tool. At this time, work group partners named the tool "Washington Environmental Health Disparities Map."

2.3.6 *Launch of Washington Environmental Health Disparities Map*

The work group partners worked together to release a press advisory to formally launch the tool in January 2019. In addition, Front and Centered hosted a Statewide Environmental Justice Summit to release the Washington Environmental Health Disparities Map to more than 200 community members and organizers.

2.4 Results

2.4.1 *The Model*

A review of the literature and methods for EJSCREEN and CalEnviroScreen suggested that the CalEnviroScreen model was better aligned with the goals of the work group. The CalEnviroScreen model focused on producing cumulative impact scoring across a variety of environmental hazards and population characteristics for communities in the state as opposed to evaluating risk based on individual hazards as provided in the EJSCREEN model. Therefore, similar to CalEnviroScreen, the inaugural version of the Washington Environmental Health Disparities Map was based on a model that integrates measures of environmental exposures, adverse environmental effects, sensitivities, and sociodemographic vulnerabilities together to create a single composite score [50]. The approach was based on scientific support—from existing research, risk assessment principles, and established risk scoring system—that vulnerability at an individual or community level modifies environmental risk for communities [51].

The equation (2.1) used in this model was based on the established risk scoring:

$$\text{Risk} = \text{Threat} \times \text{Vulnerability [50, 51]} \tag{2.1}$$

The equation (2.2-2.3) were modified for our model accordingly:

$$\text{Disparities Rank} = \text{Environmental Exposures and Effects} \times \text{Sensitive Populations and Socioeconomic Factors} \tag{2.2}$$

$$\text{Final Score} = \text{Pollution Burden Score} \times \text{Population Characteristics Score} \tag{2.3}$$

The Pollution Burden score summarized the environmental risk factors and hazards in communities. It was calculated by modeling the pollution burden from the levels of certain pollutants that populations come into contact with and are exposed to directly. Threat also captured indicators that account for the damage to environmental quality, which can increase environmental risk factors for nearby communities.

The Population Characteristics score was represented by various biological and non-biological characteristics at a community level. Characteristics captured in this category were proxy metrics for population characteristics that represent vulnerability to environmental risk and may affect the susceptibility or resilience to pollution burden, including educational attainment and poverty. These characteristics modified the environmental risk.

2.4.2 *The Indicators*

The indicators in the map were assigned to one of the four categories: (a) Environmental Exposures (measurement of pollutants), (b) Environmental Effects (adverse environmental quality that may pose a risk to nearby communities), (c) Sensitive Populations (biological/intrinsic vulnerability in a community), and (d) Socioeconomic Factors (extrinsic vulnerabilities that modify resilience to environmental hazards). Data sources included US EPA, US Census Bureau, DOH, and ECY.

For each indicator, individual census tracts were assigned a decile score, based on rank order of the raw values. The Environmental Exposures and Environmental Effects category were combined into the Pollution Burden score (maximum score of 10), based on the Equation (2.4):

$$\begin{aligned}\text{Pollution Burden score} \\ &= \big(\text{Average percentile score of Environmental Exposures indicators} \\ &+ 0.5 \times \text{Average percentile score of Environmental Effects indicators}\big) \div 2\end{aligned} \tag{2.4}$$

Note that the percentile score for Environmental Effects Indicators is half weighted because of uncertainties in the extent to which proximity to hazardous sites and pollutant sources reflects exposures to individuals in the community. This follows a similar methodology used by CalEnviroScreen. The Sensitive Populations and Socioeconomic Factors categories were combined into the Population Characteristics score (maximum score of 10), based on the Equation (2.5):

$$\begin{aligned}\text{Population Characteristics score} \\ &= (\text{Average percentile score of Sensitive Populations indicators} \\ &+ \text{Average percentile score of Population Characterstics indicators}) \div 2\end{aligned} \tag{2.5}$$

When displaying the final disparities rank, a decile ranking of 1–10 is subsequently used in the resulting map.

The indicators for each category are shown in Table 2.1.

Table 2.1. List of 19 indicators for the Washington Environmental Health Disparities Map, version 1.0.

Category	Indicators	Indicator description	Data Source
Environmental exposure	Diesel emissions	Combined gridded emissions, reallocated to census tracts using area-weighted spatial interpolation	Washington State Department of Ecology Comprehensive Emissions Inventory (2014)
Environmental exposure	Ozone	Three-year mean concentration of daily maximum 8 hour rolling averaged ozone	AIRPACT (2009–2011) [52]
Environmental exposure	$PM_{2.5}$	Three-year mean concentration of annual $PM_{2.5}$	AIRPACT (2009–2011)
Environmental exposure	Toxic releases from facilities	Toxicity-weighted concentrations of chemical releases to air from facility emissions and off-site incineration	Risk Screening Environmental Indicators (RSEI) (2014–2016)
Environmental exposure	Traffic density	Percentage of population exposed to busy roadways within each census tract	Washington State Office of Financial Management and Washington State Department of Transportation (2017)
Environmental effects	Lead risk and exposure	Total number of houses and proportion of houses by year of construction	ACS 5-year estimates (2012–2016)
Environmental effects	Proximity to hazardous waste generators and facilities	Count of all commercial Hazardous waste Treatment, Storage and Disposal Facilities (TSDF) facilities within 5 km, divided by distance, presented as population weighted averages of blocks in each census tract	EJSCREEN (2017)
Environmental effects	Proximity to Superfund sites	Count of sites proposed and listed on the National Priorities List (NPL)	EJSCREEN (2017)
Environmental effects	Proximity to facilities with highly toxic substances	Count of RMP facilities within 5 km, divided by distance, presented as population-weighted averages of blocks in each census tract	EJSCREEN (2017)
Environmental effects	Wastewater discharge	Toxicity-weighted concentration in stream reach segments within 500 meters of a block centroid, divided by distance in meters, presented as the population-weighted average of blocks in each census tract	EJSCREEN (2017)
Sensitive Populations	Cardiovascular disease	Mortality rate from cardiovascular diseases for 2012–2016 per 100,000 population	Washington State Department of Health Center for Health Statistics (2012–2016)
Sensitive Populations	Low birth weight infants	Number of live born singleton (one baby) infants born at term (at or above 37 completed weeks of gestation) with a birth weight of less than 2500 grams (about 5.5 lbs.)	Washington State Department of Health Center for Health Statistics (2012–2016)
Socioeconomic Factors	Low educational attainment	Percent of population over age 25 with less than a high school education	ACS 5-year estimates (2012–2016)

Socioeconomic Factors	Housing burden	Modeled percent of income spent on housing for a four-person household making the median household income	ACS 5-year estimates (2012–2016)
Socioeconomic Factors	Linguistic isolation	Percent of limited English-speaking households	ACS 5-year estimates (2012–2016)
Socioeconomic Factors	Poverty	Percent of the population living below 185 percent of the federal poverty level	ACS 5-year estimates (2012-2016)
Socioeconomic Factors	Race (people of color)	Sum of all race/ethnicity categories except White/Non-Hispanics, including Black, American Indian/Alaskan Native, Asian, Native Hawaiian other Pacific Islander, and two or more races	Washington State Office of Financial Management (2015)
Socioeconomic Factors	Transportation expense	Transportation costs based on percentage of income for the regional moderate household	Center for Neighborhood Technology (CNT) (2014–2015)
Socioeconomic Factors	Unemployment	Percent of the population over the age of 16 that is unemployed and eligible for the labor force	ACS 5-year estimates (2012–2016)

2.4.3 *Spearman's Correlation between Indicators*

In an effort to reduce duplicative indicators, Spearman's correlation was used to determine the relationship among each indicator values included in the map (shown in Table 2.2).

Within the environmental exposure category, only diesel emission and $PM_{2.5}$ were moderately correlated ($\rho = 0.51$). Proximity to Hazardous waste Treatment, Storage and Disposal Facilities (TSDF) facilities were moderately correlated with toxic releases from facilities and proximity to Superfund/NPL sites ($\rho = 0.52$ for both). Poverty (185% below federal poverty level) was highly correlated with education ($\rho = 0.70$) and moderately correlated with housing burden ($\rho = 0.57$). Linguistic isolation was highly correlated with race/ethnicity ($\rho = 0.81$). Transportation expense was negatively correlated with diesel emission ($\rho = -0.78$).

Based on the correlation coefficients, only linguistic isolation and race/ethnicity were found to be highly correlated indicators. Since each of these two indicators capture different vulnerabilities, both indicators were selected to remain in the final Washington Environmental Health Disparities Map (e.g., linguistic isolation captures those that may experience difficulty accessing environmental information in non-English material while race/ethnicity indicator captures minority populations).

Table 2.2. Spearman's correlation coefficient for the 19 indicators and the composite scores. Indicators that are moderately (coefficient between −0.8 and −0.5 or between +0.5 and +0.8) or highly correlated (coefficient below −0.8 or above 0.8) are shown in gray highlights.

	Exposure	Ozone	PM 2.5	Diesel Emission	Toxic Release	Traffic	Environmental Effects	Lead Risk	Superfund Sites	Hazardous Waste	Risk Management Plan	Wastewater Discharge	Sensitive Population	Cardiovascular Disease	Low Birth Weight	Socioeconomic Factor	Low Educational Attainment	Linguistic Isolation	Poverty	Unemployment	Housing Burden	Race/Ethnicity	Transportation Expense
Environmental Exposure	1																						
Ozone	−0.11	1																					
PM2.5	0.64	−0.16	1																				
Diesel Emission	0.74	−0.40	0.51	1																			
Toxic Release	0.54	−0.38	0.21	0.36	1																		
Traffic	0.69	−0.21	0.23	0.49	0.14	1																	
Environmental Effects	0.56	−0.16	0.58	0.46	0.44	0.19	1																
Lead Risk	0.16	−0.11	0.22	0.23	0.12	0.01	0.51	1															
Superfund Sites	0.52	0.04	0.39	0.37	0.38	0.21	0.67	0.16	1														
Hazardous Waste	0.51	−0.11	0.36	0.31	0.52	0.21	0.6	0.02	0.52	1													
Risk Management Plan	0.29	−0.12	0.48	0.31	0.14	0.04	0.67	0.27	0.22	0.25	1												
Wastewater Discharge	0.19	−0.18	0.29	0.16	0.16	0.09	0.51	0.13	0.14	−0.02	0.31	1											
Sensitive Population	0.15	0.06	0.22	0.08	0.01	0.07	0.20	0.20	0.16	0.08	0.10	0.06	1										
Cardiovascular Disease	0.08	0.11	0.17	−0.02	−0.10	0.05	0.09	0.10	0.05	0.06	0.05	0.04	0.67	1									
Low Birth Weight	0.13	−0.02	0.13	0.11	0.1	0.03	0.19	0.15	0.20	0.05	0.09	0.09	0.69	0.08	1								
Socioeconomic Factors	0.17	−0.03	0.33	0.12	−0.05	0.13	0.24	0.22	0.1	0.09	0.27	0.06	0.38	0.38	0.14	1							
Low Educational Attainment	0.08	0.02	0.29	−0.03	−0.07	0.06	0.17	0.22	−0.02	0.06	0.24	0.04	0.4	0.41	0.13	0.82							
Linguistic Isolation	0.33	−0.27	0.4	0.36	0.17	0.24	0.24	0.05	0.12	0.25	0.29	0.04	0.12	0.11	0.05	0.63	0.49						
Poverty	0.09	0.11	0.21	0.01	−0.14	0.08	0.23	0.34	0.11	−0.04	0.21	0.09	0.39	0.36	0.17	0.82	0.7	0.32					
Unemployment	0.03	0.11	0.08	0	−0.11	0	0.04	0.08	0.03	0	0.03	−0.02	0.18	0.19	0.06	0.5	0.33	0.12	0.39				
Housing Burden	0.34	−0.14	0.27	0.41	0.09	0.27	0.27	0.18	0.25	0.17	0.13	0.11	0.28	0.25	0.14	0.6	0.34	0.31	0.57	0.25			
Race/Ethnicity	0.4	−0.34	0.47	0.43	0.26	0.25	0.34	0.09	0.24	0.37	0.31	0.04	0.19	0.15	0.12	0.61	0.43	0.81	0.32	0.15	0.37		
Transportation Expense	−0.60	0.46	−0.38	−0.78	−0.47	−0.40	−0.34	−0.13	−0.33	−0.38	−0.10	−0.11	−0.04	0.05	−0.09	−0.04	0.1	−0.32	0.05	0.05	−0.45	−0.47	
Final Ranking	0.71	−0.02	0.65	0.52	0.3	0.43	0.65	0.33	0.51	0.45	0.45	0.25	0.63	0.45	0.43	0.62	0.51	0.49	0.51	0.26	0.53	0.56	−0.37

Spearman's correlation coefficient based on IBL ranking.

2.4.4 *Washington Environmental Health Disparities Map, Version 1.0*

The underlying indicators (including descriptions of data sources, data methods, and links to download data) and cumulative risk results are accessible as a free, publicly available online mapping tool developed and maintained by DOH WTN [53]. The tool supports interactive zooming and panning, searching for specific locations, selection, and viewing of individual indicators and categories and overall risk. Based on the final score (Equation 2.3), the Washington Environmental Health Disparities Map depicts the final environmental health disparities (EHD) ranking from 1 to 10, with 10 indicating the highest cumulative impact due to the environmental risks and vulnerabilities. These rankings reflect the risk each census tract faces from pollution and vulnerabilities relative to other census tracts in Washington. A screenshot of the resulting map on the website is shown in Figure 2.2.

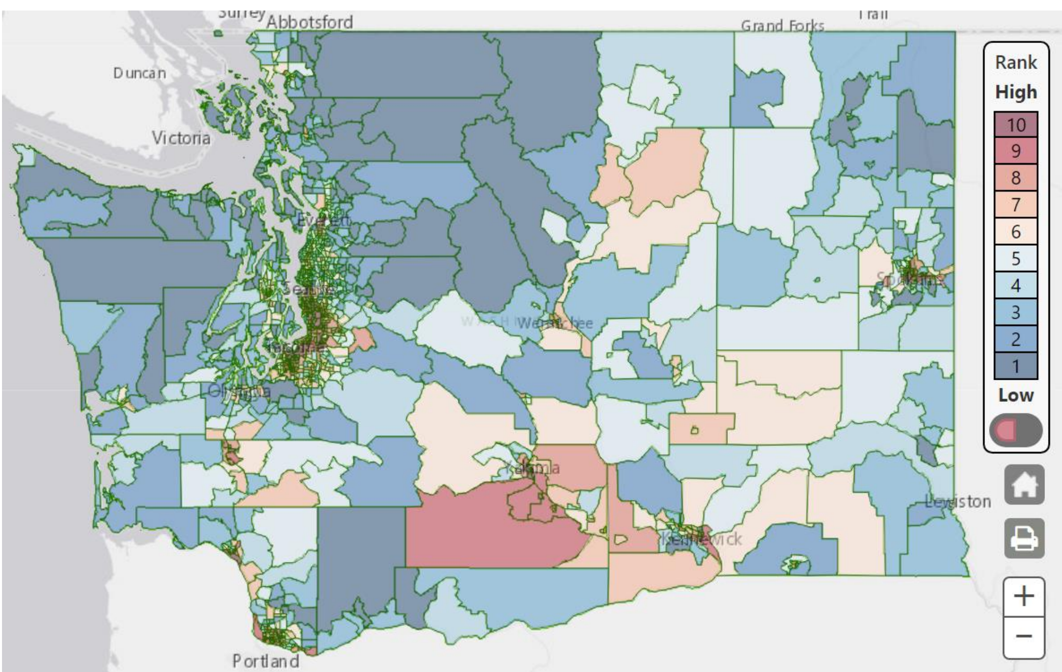


Figure 2.2. Screenshot of the final environmental health disparities (EHDs) ranking of the Washington Environmental Health Disparities Map version 1.0.

2.4.5 *Principal Component Analysis (PCA)*

We used PCA to understand the groups of indicators that influence the final ranking. Rank order of the raw values for each indicator was used in order to account for unit variability among indicators. Based on the results of the preliminary PCA analyses, low birth weight and cardiovascular disease data were excluded due to the fact that both factors did not have a strong weight in any of the main principal components. After examining the scree plot, five principal components were selected accounting for 66.26% of the variance. The components corresponded approximately to (1) pollution related to urbanized areas, (2) socioeconomic factors, (3) traffic-related pollution, (4) hazardous waste, and (5) peri-urban related pollution, with each accounting for 28.71%, 14.43%, 8.41%, 7.77%, and 6.95% of the variance, respectively (Figure 2.3).

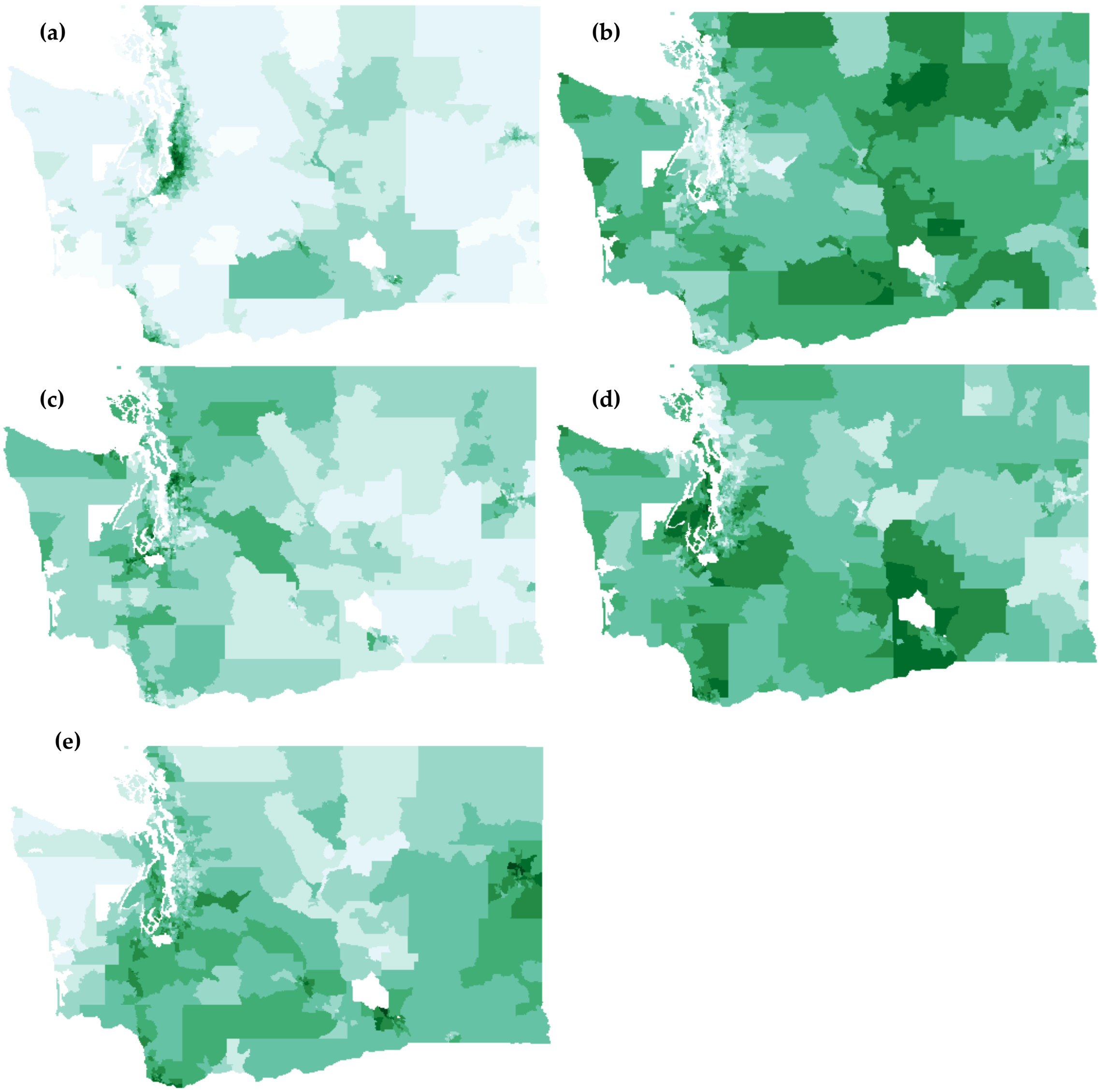
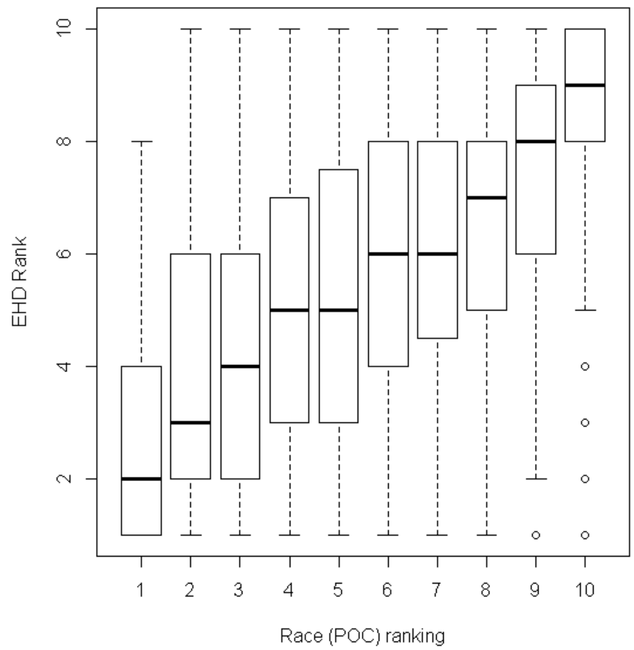


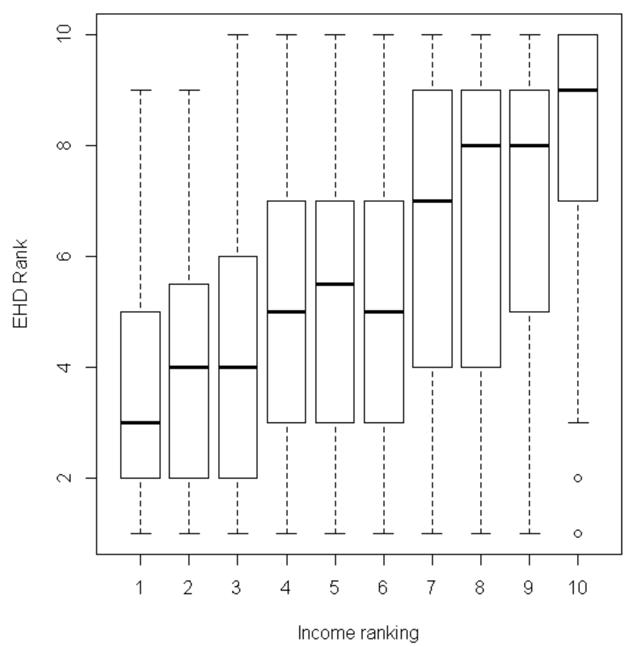
Figure 2.3. Map of components from the PCA: (a) urbanized areas (diesel emissions, $PM_{2.5}$, people of color, linguistic isolation); (b) socioeconomic factor (poverty, low educational attainment); (c) traffic-related pollution (traffic density); (d) hazardous waste (proximity to hazardous waste, toxic releases from facilities); (e) Peri-urban/Superfund-related pollution (ozone, proximity to Superfund sites).

2.4.6 *Race and Income*

The final EHD ranking, based on race and income, shows that census tracts with a higher proportion of people of color and a population living below 185 percent of the federal poverty level are more likely to experience higher environmental health disparities (Figure 2.4).



(a)

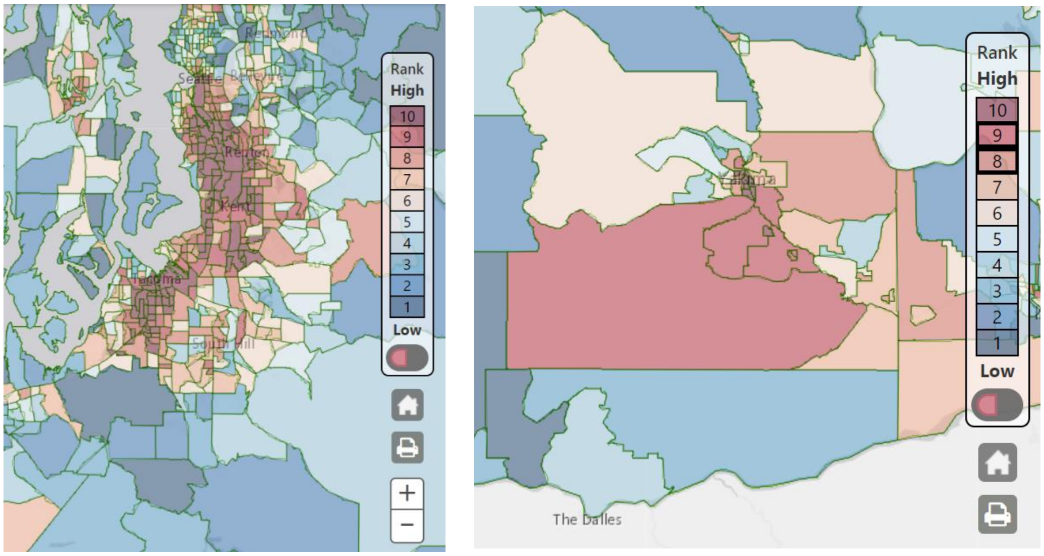


(b)

Figure 2.4. Distribution of the final EHD ranking: (a) by race/people of color (POC) indicator ranking and (b) income/poverty indicator ranking. The bar shows the median ranking for each group. The box shows the interquartile range.

2.4.7 *Communities Highly Impacted by Environmental Health Disparities (80th Percentile)*

Approximately eight clusters were identified for areas ranked "9" or "10" or the top 20 percent (80th percentile) of highly impacted communities in both western and eastern Washington. These included urban areas such as South Seattle, Kent, Tacoma, Vancouver, and Spokane and rural areas such as Centralia, Longview, Yakima Valley, and the Tri-Cities. Environmental risk factors driving the final score to a "9" or a "10" varied depending on the region. For example, a cluster of census tracts in urbanized areas of South Seattle, Kent, and Tacoma were ranked in the top 20 percent (Figure 2.5a). Environmental health disparities in these tracts were influenced by diesel emission, traffic density, toxic release from facilities, proximity to Superfund/NPL sites, and housing burden that ranked "9" or "10" for these individual indicators. Rural census tracts in Yakima Valley were also ranked in the top 20 percent due to the indicators such as $PM_{2.5}$, wastewater discharge, poor educational attainment, and transportation expense (Figure 2.5b). Both of these areas were similarly and highly impacted by linguistic isolation, people of color, poverty, and cardiovascular disease.



(a) (b)

Figure 2.5. Screenshot of the final EHD ranking: (a) South Seattle, Kent, and Tacoma area; (b) the Yakima Valley region.

2.5 Discussion

To our knowledge, this is one of the first community-driven frameworks for mapping statewide environmental justice issues. The community–academic–government partnership for this project was relatively new, formed in an ad-hoc manner through initiation from Front and Centered. The project was made possible by leveraging existing resources within the partnering organizations, presenting potential challenges for a new, multifaceted partnership. However, explicit efforts were made to integrate procedural justice throughout the project. Negotiating and establishing goals of the project at the partnership formation became a solid foundation for the work group to succeed in this project. In addition, listening to the experiences of different communities at the early stages of the project, and being responsive to community input and direction were also critical for the project's success.

2.5.1 *Findings*

The Washington Environmental Health Disparities Map identifies communities most heavily impacted by the environmental risks and vulnerabilities. Results from the PCA demonstrate opportunities for more targeted priorities for different regions of the state. For example, Figure 2.3a shows diesel emissions may be most relevant for urbanized area, especially in communities of color. In contrast, Figure 2.3b indicates areas that are suffering from low socioeconomic status that may benefit from strategic public health programming.

The final EHD ranking also suggests that people of color and poverty are likely to experience higher pollution and increased vulnerabilities to pollution's effects [54, 55]. The Washington Environmental Health Disparities Map framework captures race and income as two key populations that are affected more by environmental health risks [8, 56].

2.5.2 *Data and Methodological Needs*

By working in partnership with state agencies with access to both public health and environmental monitoring data, we were able to identify data of high quality that are maintained and routinely updated. This was a strong requirement for our inclusion of specific indicators to help promote the sustainability of the tool and the ability to assess changing environmental health disparities as community conditions change over time. At the same time, this project identified data gaps and methodological needs that warrant more attention. For example, quantifying the prevalence of asthma or cardiovascular disease in each census tract can help identify communities that are more sensitive to pollution [57-60]. However, Washington State does not currently maintain an easy-to-access database to measure prevalence of these chronic conditions. Proxy measures such as emergency department utilization rates are under development but not yet available.

As another example, drinking water contaminants are difficult to model and measure. The participants in the community listening sessions emphasized the importance of safe, clean drinking water. While public water systems are required to report annual water quality data, private wells are not. This poses a challenge when modeling drinking water contaminants for Washington State, as approximately 15% of Washington residents (over 1 million people) rely on private wells for drinking water [61].

Many of the indicators in this map rely on national data sources. While nationwide data provide insight into environmental health burdens at the national level, these data may not capture the nuances that state-specific data would. Therefore, more research is required to model the state-specific data, such as a community's proximity to state-specific cleanup sites in addition to the NPL sites. In addition, more effort to collect regional and statewide data sustainably is critical to improve maps such as the Washington Environmental Health Disparities Map.

The cumulative environmental risk framework we used is critical in mapping environmental health disparities. This map intentionally does not model resilience or asset-based indicators contributing to environmental health. This map also does not model the overall burden on communities nor does it reflect the actual number of individuals affected by environmental burden. Further, the map does not model the positive or negative likelihood of an individual health outcome. However, the authors acknowledge the importance of a parallel asset-based map, as emphasized by communities during the listening sessions.

2.5.3 *Potential Uses in Policy and Practice*

A statewide mapping tool showing the cumulative impact of environmental risk can strengthen the ability of government agencies and policy makers to more systematically identify and quantify drivers of disparities in the pursuit of environmental justice [18]. Additionally, the Washington

Environmental Health Disparities Map can be used to assist in resource allocation and decision-making. This can be done through identifying and designating highly impacted communities to receive a proportion or the entirety of a resource, through scaling a resource investment proportional to the risk level, or through other strategies that direct investment. By focusing on highly impacted census tracts identified by the Washington Environmental Health Disparities Map, the state can direct investments, programs, and other resources to ensure environmental and public health equity. As an example, recently passed legislation, Washington Senate Bill (SB) 5116 (2019)—the state's Clean Energy Policy—requires equitable distribution of energy and non-energy benefits and reduction of burdens to vulnerable populations and highly impacted communities through the use of cumulative impacts analysis [62].

Another potential use of the Washington Environmental Health Disparities Map is to improve public health through strategic and meaningful community engagement in census tracts with high cumulative impacts. Communities burdened with environmental health disparities may receive less attention from governmental agencies [63]. These communities may also face additional barriers to participation such as insufficient or sometimes exclusionary outreach and information dissemination by public entities, lack of resources and time to attend, language barriers, literacy differences, and health issues [64, 65]. There is scientific evidence that community engagement reduces health disparities due to the presence of factors such as improved knowledge and self-efficiency [65, 66]. Additional benefits from increased community engagement include reciprocal knowledge translation, improved community-stakeholder relationships, and improvements in the Washington Environmental Health Disparities Map as new concerns are identified and data sources are developed to respond to those concerns.

Policies should also recognize tribal areas as highly impacted areas for environmental health disparities. Several tribal members and representatives from Native American organizations were engaged in the community listening sessions, and actively provided feedback through participation in the symposium, webinar, and emails. Washington State is home to 29 federally recognized Native American tribes and several out-of-state tribes with treaty or traditional territory within the state and is home to numerous tribal communities throughout the state. Policies and actions intended to address cumulative environmental impacts across the state should be developed in consultation with the affected tribal governments and communities.

2.5.4 *Limitations*

This map was developed based on a specific model of relative pollution burden and vulnerabilities. Models have inherent uncertainty associated in the methodology of the tool. There is no single way to accurately capture the level of uncertainty associated with the cumulative impacts of all communities. However, this map represents a widely accepted science-based approach to quantify the cumulative environmental risks.

2.5.5 *Future Research Directions*

The work group intends to update the map as statewide data for additional indicators become available. Partners in the work group plan to explore additional indicators such as asthma, noise pollution, proximity to state-specific clean-up sites, and quality of surface water. Other potential indicators require more development, such as drinking water quality, the effects of inequality and the effects of the built environment. Additional analysis is being conducted to make decisions on health outcomes that may be affiliated with the environmental risk factors.

The 2017 listening sessions included eleven communities and did not fully cover all geographic regions or communities within Washington State. As a result, the work group plans to continue to include input from more communities in the future to address this limitation.

2.6 CONCLUSIONS

Understanding the cumulative impacts from the complex interaction between pollution and vulnerability can allow informed decision-making to improve public health and the environment. Using the cumulative impacts assessment approach, we developed the Washington Environmental Health Disparities Map. The Washington Environmental Health Disparities Map allows for cumulative impact comparison among census tracts and provides the public agencies, policymakers, and community-based organizations critical information on disparities with which they can make informed decisions. In addition, the community-driven framework for building the map can be used as a template for other EJ mapping efforts to capture the voices of community in the map.

Author Contributions: Conceptualization, E.M., D.G. and E.Y.W.S.; Formal analysis, E.M. and E.Y.W.S.; Methodology, E.M., D.G., D.B., T.E., L.F., M.S., E.S., M.P., V.G., M.Y. and E.Y.W.S.; Validation, E.M., T.E. and L.F.; Writing—original draft, E.M.; Writing—review and editing, E.M., D.G., D.B., T.E., L.F., M.S., E.S., M.P., V.G., M.Y. and E.Y.W.S.

Funding: The community listening sessions were funded through The Russell Family Foundation, the Rose Foundation, and the Seattle Foundation. Esther Min's participation in listening sessions were possible through donations from Ms. Crystal Dou. The EJ mapping symposium was supported by DEOHS, PSCAA, and Front and Centered. UW NIEHS EDGE Center (5P30 ES007033-23) supported part of Edmund Seto's time.

Acknowledgments: We acknowledge the contributions of the people statewide who participated in the community listening sessions that directly shaped the development of the Washington Environmental Health Disparities Map.

Conflicts of Interest: The authors declare no conflict of interest.

Chapter 3. QUANTIFYING THE DISTRIBUTION OF ENVIRONMENTAL HEALTH DISPARITIES IN WASHINGTON STATE WITH THE CUMULATIVE ENVIRONMENTAL INEQUALITY INDEX

3.1 ABSTRACT

Assessing cumulative environmental risks and hazards through geospatial mapping has been used to identify communities most impacted by the distributive burdens of pollution. Quantitative environmental justice analysis of map data may improve understanding of environmental inequities. The goal of this paper was to evaluate the distribution of pollution burden across census tracts in Washington state using an inequality index (II). Using the Washington Environmental Health Disparities Map, a cumulative impact assessment tool, we quantified the level of disproportionate burden on populations such as communities of color, communities with higher levels of poverty, and communities with greater proportion of children under five using a cumulative environmental risk index and ten individual environmental indicators. We conducted additional analyses of rural and urban census tracts separately to assess the level of disparities. Census tracts with a higher proportion of people of color and those with people living below 185% federal poverty levels were found to be disproportionately burdened by cumulative impacts of environmental risks (($II = -0.175$, and $II = -0.167$, respectively, $p < 0.001$). Individual indicators such as $PM_{2.5}$ concentration levels and proximity to facilities with highly toxic substances were also found to disproportionately burden communities of color and low-income communities significantly. Similar patterns were found when stratified by urban and rural census tracts. Age-related susceptibility (children under five) was also found to be related to a greater burden of

cumulative environmental risks ($II = -0.076$, $p < 0.001$) and individual indicators. These findings can be applied in policy and regulatory actions to correct the distributive environmental disparities observed in rural and urban communities.

3.2 INTRODUCTION

Cumulative impact assessment accounts for a multitude of environmental risks and hazards along with biological susceptibility of individuals and extrinsic vulnerabilities in communities such as socioeconomic status. Cumulative environmental impact analyses have been informative in identifying and quantifying environmental justice issues of communities across the United States [42, 44, 67, 68]. Assessing the distribution of environmental risk and exposure identifies subpopulations that are burdened disproportionately.

Geographic information system (GIS) tools using the cumulative impact framework have gained popularity in recent years [69]. These mapping tools such as US EPA EJSCREEN, CalEPA CalEnviroScreen, and Washington Environmental Health Disparities Map have provided a visual way to communicate spatial distribution of environmental health disparities at regional, statewide, and national levels [47, 50, 70, 71]. These tools often overlay various spatial indicators, which may include concentrations of different environmental pollutants, presence, or proximity to hazardous sites, as well as population sociodemographic factors known to condition or modify the relationships between environmental exposure and health effects. Moreover, the development of some of the aforementioned examples of mapping tools have involved a participatory process, in which affected communities have driven the creation of the tool, and the prioritization and inclusion of indicators that best reflect the lived experiences of environmental justice communities. These maps have been incorporated in policies to address environmental health disparities by procedurally incorporating affected communities into the decision-making process (CA Senate Bill 535 2012; WA Senate Bill 5116 2019)

The main quantitative policy application of EJ mapping has been in identifying *highly impacted communities* (or similar terms) – particular regions on the map that when the various indicators are overlaid, ranked and scored, emerge as more affected by pollutants than others communities within the region. For example, a census tract's score on CalEPA's CalEnviroScreen map is used to determine if it falls within the top 25 percent of tracts within California that are disproportionately burdened by, and vulnerable to, multiple sources of pollution. If so, that tract is identified as a *disadvantaged community* – a policy term under CA SB 535 that specifically targets the community for investment of proceeds from the State's cap-and-trade program and other opportunities.

However, the use of formal inequality analysis methods to better quantify and characterize factors responsible for environmental (in)equity has been limited [44]. In recent years, an inequality index (II) used to measure income tax progressivity in economics has been applied to assess environmental inequality [68, 72, 73]. Formal inequality analysis with EJ mapping tools may help to better inform the environmental justice landscape, identify subpopulations that are disproportionately burdened, and suggest improvements to specific environmental indicators to best correct for environmental inequities in affected communities.

The goal of this paper was to evaluate the environmental justice landscape of Washington state using indicators of environmental risk and vulnerability in the Washington Environmental Health Disparities Map, a cumulative impact assessment tool. We used an II based on the cumulative share of environmental risk to quantitatively assess the level of equality in environmental risk and hazard based on race, poverty, and age.

3.3 Methods

3.3.1 *Data on Environmental Risks and Exposures*

Launched in 2019, the Washington Environmental Health Disparities Map was created through a community-academic-government partnership. The details of the map are reported in a previous publication [71]. Data used in this study was downloaded from Washington State Department of Health (DOH) Washington Tracking Network (WTN) for the topic "Washington Environmental Health Disparities" version 1.0. The Washington Environmental Health Disparities Map version 1.0 combined nineteen environmental and population indicators. The indicators in the map were assigned to one of the four categories: a) Environmental Exposures (measurement of pollutants), b) Environmental Effects (adverse environmental quality that may pose a risk to nearby communities), c) Sensitive Populations (biological/intrinsic vulnerability in a community), and d) Socioeconomic Factors (extrinsic vulnerabilities that modify resilience to environmental hazards). Table 3.3 describes each of the indicators used in the Washington Environmental Health Disparities Map and its data source.

Table 3.3. List of 19 indicators with abbreviated names in parentheses for the Washington Environmental Health Disparities Map, version 1.0.

Category	Indicators	Indicator description	Data source
Environmental exposure	Diesel emissions	Combined gridded emissions, reallocated to census tracts using area-weighted spatial interpolation	Washington State Department of Ecology Comprehensive Emissions Inventory (2014)
	Ozone	Three-year mean concentration of daily maximum 8-hour rolling averaged ozone	AIRPACT (2009-2011) [52]
	$PM_{2.5}$	Three-year mean concentration of annual $PM_{2.5}$	AIRPACT (2009-2011)
	Toxic releases from facilities in air	Toxicity-weighted concentrations of chemical releases to air from facility emissions and off-site incineration	Risk Screening Environmental Indicators (RSEI) (2014-2016)
	Traffic density	Percentage of population exposed to busy roadways within each census tract	Washington State Office of Financial Management and Washington State

			Department of Transportation (2017)
Environmental effects	Lead risk and exposure (Lead)	Total number of houses and proportion of houses by year of construction	American Community Survey (ACS) 5-year estimates (2012-2016)
	Proximity to hazardous waste generators and facilities (TSDF)	Count of all commercial Hazardous Waste Treatment, Storage and Disposal Facilities (TSDF) facilities within 5 km, divided by distance, presented as population weighted averages of blocks in each census tract	EJSCREEN (2017)
	Proximity to Superfund sites (NPL)	Count of sites proposed and listed on the National Priorities List (NPL)	EJSCREEN (2017)
	Proximity to facilities with highly toxic substances (RMP)	Count of RMP facilities within 5 km, divided by distance, presented as population-weighted averages of blocks in each census tract	EJSCREEN (2017)
	Wastewater discharge (WDIS)	Toxicity-weighted concentration in stream reach segments within 500 meters of a block centroid, divided by distance in meters, presented as the population-weighted average of blocks in each census tract	EJSCREEN (2017)
Sensitive Populations	Cardiovascular disease	Mortality rate from cardiovascular diseases for 2012–2016 per 100,000 population	Washington State Department of Health Center for Health Statistics (2012-2016)
	Low birth weight infants	Number of live born singleton (one baby) infants born at term (at or above 37 completed weeks of gestation) with a birth weight of less than 2,500 grams (about 5.5 lbs.)	Washington State Department of Health Center for Health Statistics (2012-2016)
Socioeconomic Factors	Low educational attainment	Percent of population over age 25 with less than a high school education	ACS 5-year estimates (2012-2016)
	Housing burden	Modeled percent of income spent on housing for a four-person household making the median household income	ACS 5-year estimates (2012-2016)
	Linguistic isolation	Percent of limited English-speaking households	ACS 5-year estimates (2012-2016)
	Poverty	Percent of the population living below 185 percent of the federal poverty level	ACS 5-year estimates (2012-2016)
	Race (People of color)	Sum of all race/ethnicity categories except White/Non-Hispanics, including Black, American Indian/Alaskan Native, Asian, Native Hawaiian-other Pacific Islander and two or more races	Washington State Office of Financial Management (2015)
	Transportation expense	Transportation costs based on percentage of income for the regional moderate household	Center for Neighborhood Technology (CNT) (2014-2015)
	Unemployment	Percent of the population over the age of 16 that is unemployed and eligible for the labor force	ACS 5-year estimates (2012-2016)

For each indicator, individual census tracts were assigned a percentile score, based on rank-order of the raw values. The percentile score of the indicators were averaged to create an average percentile score for each category. The final environmental health disparities score was calculated based on the following formula and placed into deciles as the final environmental health disparities ranking.

$$Final\ EH\ disparities\ score = \frac{\text{Avg percentile score of Environmental Exposures indicators} + 0.5 \times \text{Avg percentile score of Environmental Effects indicators}}{2} \times \frac{\text{Avg percentile score of Sensitive Populations indicators} + \text{Avg percentile score of Population Characterstics indicators}}{2} \quad (3.1)$$

When displaying the different categories and indicators, a relative ranking was used to display each indicator and category as a decile, 1 being the least impacted and 10 being the most impacted.

3.3.2 *Vulnerability Related to Environmental Risks and Exposures*

To visualize the relationship between specific factors and the overall environmental health disparities ranking, cumulative share figures were created. The cumulative share of the population ordered by measures of vulnerability or susceptibility to environmental health disparities was plotted on the x-axis. The cumulative share of the environmental risk and hazard (final environmental disparities ranking, environmental exposure category, environmental effects category, and ten of its individual indicators) were plotted on the y-axis.

Measures of susceptibility or vulnerability include proportion of people of color, people living in poverty, and age. Estimates for people of color were obtained through the Washington State Office of Financial Management 2015 estimates to calculate the proportion of people of color for each census tract (the sum of all race/ethnicity categories including Black, American Indian/Alaskan Native, Asian, Native Hawaiian-other Pacific Islander and two or more races). Estimates for people living in poverty as percent of the population living below 185 percent of the federal poverty level (FPL) and children (percent of population under the age of five) were obtained from the American Community Survey (ACS) 2012-2016 5-year estimates.

Additional analysis was conducted for race and income levels based on the Rural-Urban Commuting Area (RUCA) categories, developed by the Federal Office of Rural Health and Policy (FORHP). The specific RUCA codes designated as rural or urban census tract (Appendix A) are specified in DOH's guidelines for using RUCA for community health assessment [74].

We used an II, originally called the Concentration Index by Kakwani et al., 1997, to evaluate the distribution of cumulative environmental health disparities, environmental risks, and exposures. While II is related to the well-known Gini Index, the II ranks census tracts by the measure of vulnerability such as income rather than by outcome. The II was visualized by plotting the cumulative proportion of the population ranked by various vulnerability levels. The II was calculated by twice the area between the plotted curve and the 45 degree diagonal line, known as the line of equality, as shown in equation 3.2 [44, 68, 72].

$$Inequality\ Index = 1 - 2\int_0^1 L(s)ds \qquad (3.2)$$

The II, ranging from -1 to 1, represents the level of inequality. When the inequality curve coincides with the line of equality (45-degree line), the II is equal to zero, implying equal distribution or burden of environmental risk or hazard. A positive II implies census tracts that are more privileged experience a higher burden of the environmental risks. A negative II means census tracts less privileged or disadvantaged bear a disproportionate burden of the environmental risks.

We calculated the II based on grouped level data as described in previous literature (equation 3.3) [72]. Based on the rank-order method of standardization, we tested the null hypothesis as C=0 for each environmental indicator using equations 3.3-3.6 where μ_t is the env/health score of census tract *t*, f_t is the proportion of the total population that is contributed by the tract, and R_t is the relative rank of the tract, computed as the cumulative proportion of the population up to the midpoint of each tract [68, 72].

$$II = \frac{2}{\mu}\sum_{t=1}^{T} f_t \mu_t R_t - 1 \quad (3.3)$$

$$var(II) = \frac{1}{n}\left[\sum_{t=1}^{T} f_t\, a_t^2 - (1 + II)^2\right] \quad (3.4)$$

$$q_t = \frac{1}{\mu}\sum_{k=1}^{t}(\mu_k f_k) \quad (3.5)$$

$$a_t = \frac{\mu_t}{\mu}(2R_t - 1 - II) + 2 - q_{t-1} - q_t \quad (3.6)$$

There were two assumptions of the model. The first was that environmental equality transfers the burden from the more vulnerable to the less vulnerable, regardless of the health status. Second, variance was estimated assuming asymptotic normal distribution. With the relatively large number of census tracts, we used normal distribution as an approximation of the t-distribution when doing hypothesis testing (Appendix B).

All statistical analyses were conducted in R and RStudio (version 3.6.0; RStudio Team).

3.4 Results

3.4.1 *Descriptive Analysis*

Of 1458 census tracts, 13 census tracts were excluded due to no recorded population in the ACS 2012-2016 5-year estimate. The total sample size of 1445 census tracts were included in the analyses presented. Table 3.4 presents demographic composition of the total population, children under five, people living 185% below federal poverty level, and groups by race and ethnicity. Table 3.5 presents descriptive statistics for the cumulative measures, individual indicators, and demographic data for all census tracts combined and categorized as urban and rural census tracts.

Among the 7 million people living in Washington State, approximately 87.5% of the population (over 6.1 million people) live in urban census tracts while approximately 12.5% live in rural census tracts. While the proportion of non-Hispanic Whites are relatively similar between rural and urban census tracts, there is a greater proportion of Hispanic or Latino descent and

American Indian Alaska Natives that reside within rural census tracts compared to urban census tracts.

Based on the ACS 2012-2016 5-year estimates, approximately 29.6% of people living in Washington were people of color (approximately 2.1 million individuals). The mean proportion of people of color in a census tract was 29.7%.

Over 1.85 million individuals or approximately 26.2% of Washingtonians lived below 185% of the FPL. In rural census tracts, approximately 35.8% of the population lived below the 185% FPL in contrast to 24.8% of urban populations living below the 185% FPL. The mean proportion of people living below 185% of FPL for each census tract was 27.4%.

Approximately 6.3% of Washington's population were children under the age of five. The mean proportion of children under the age of five for each census tract was 6.2%.

Table 3.4. Demographics composition of Washington State total population, children under the age of five, people living 185% below federal poverty level, and groups by race and ethnicity based on ACS 2012-2016 5-year estimates.

	All Census Tracts	**% of population**	**Urban Census Tracts**	**% of population**	**Rural Census Tracts**	**% of population**
			Race			
Total	**7,073,146**	**100**	**6,187,478**	**100**	**885,668**	**100**
White	5,470,566	77.3	4,728,430	76.4	742,136	83.8
Black or African American	256,990	3.6	247,928	4.0	9,062	1.0
American Indian Alaska Native	94,026	1.3	67,959	1.1	26,067	2.9
Asian	552,032	7.8	534,393	8.6	17,639	2.0
Native Hawaiian Pacific Islander	44,870	0.6	43,228	0.7	1,642	0.2
Some other race (one race)	276,959	3.9	220,393	3.6	56,566	6.4
Two or more race	377,703	5.3	345,147	5.6	32,556	3.7
			Ethnicity			
Hispanic or Latino	854,275	12.1	679,114	11.0	175,161	19.8
			Vulnerability			
185% below federal poverty level	1,854,527	26.2	1,537,353	24.8	317,174	35.8

Children under the age of five	447,143	6.3	391,843	6.3	55,300	6.2

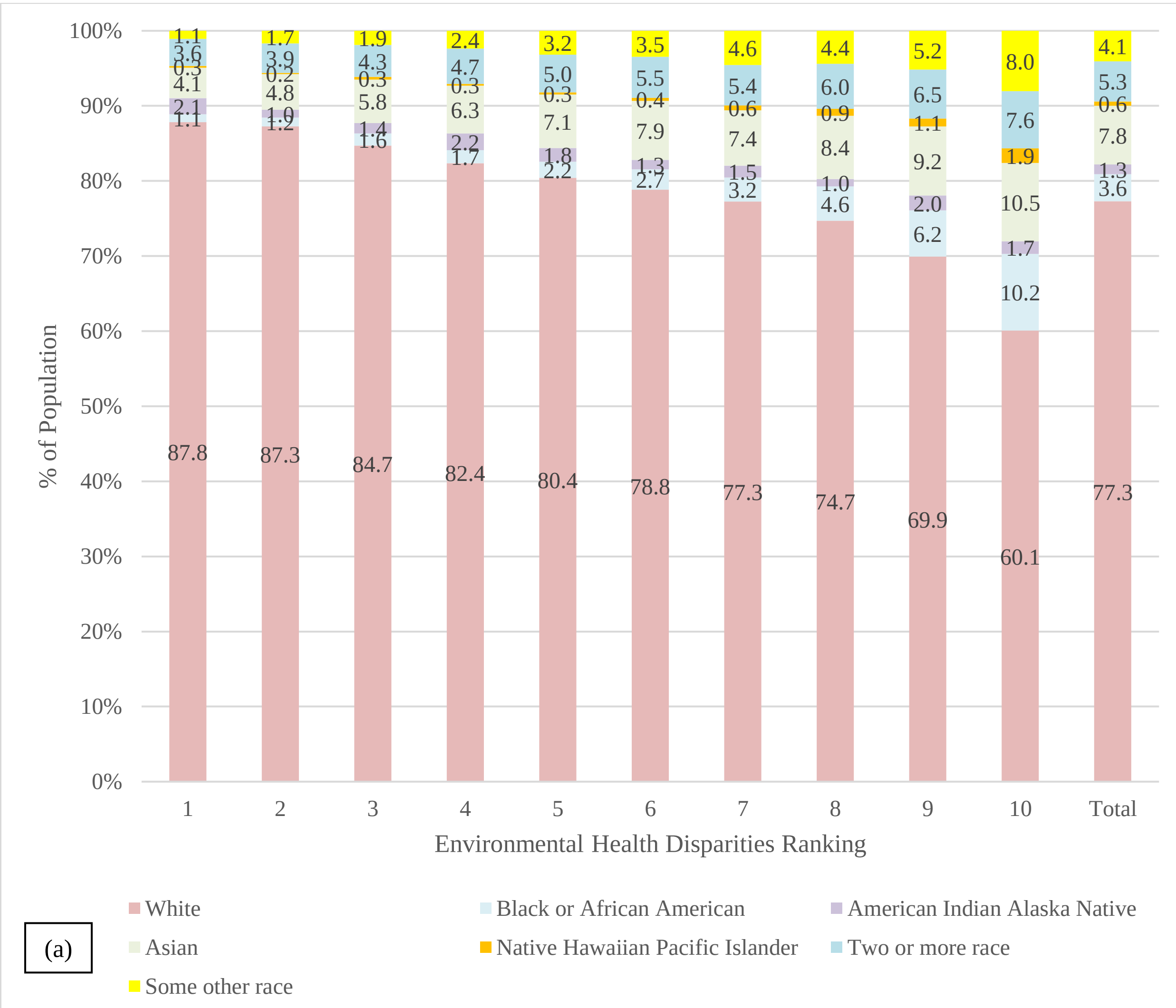
The average cumulative rankings for exposures category ranking, and environmental effects ranking, and the cumulative environmental health disparities ranking were higher in urban census tracts compared to rural census tracts (Table 3.5). Within each indicator, there was large variability in the raw values, especially for toxic release into air, traffic density, and average proximity to wastewater discharge. For raw values of individual indicators, lead risk in housing and wastewater discharge had higher mean values in rural census tracts compared to urban areas.

Table 3.5. Descriptive statistics for the cumulative rankings, raw values of individual indicators, and demographic vulnerability measures for all census tracts, urban, and rural census tracts.

	All Census Tracts					Urban Census Tracts					Rural Census Tracts				
	Mean	Median	Min	Max	SD	Mean	Median	Min	Max	SD	Mean	Median	Min	Max	SD
Cumulative Rankings															
Final EHD (index)	5.6	6.0	1.0	10.0	2.9	5.8	6.0	1.0	10.0	2.9	4.0	4.0	1.0	10.0	2.4
Exposures (index)	5.5	6.0	1.0	10.0	2.9	6.0	6.0	1.0	10.0	2.7	2.4	2.0	1.0	9.0	1.9
Environmental Effects (index)	5.5	5.0	1.0	10.0	2.9	5.8	6.0	1.0	10.0	2.8	3.4	3.0	1.0	9.0	2.2
Individual Indicators															
Diesel emission (annual Tons/km^2)	9.3	5.7	0.0	95.2	12.3	10.4	6.9	0.0	95.2	12.7	2.3	0.6	0.0	46.8	6.7
Ozone concentration (ppb)	53.0	52.7	44.2	62.9	3.5	53.1	52.9	44.2	62.9	3.4	52.4	52.1	44.2	59.6	3.5
$PM_{2.5}$ concentration (µg/m^3)	5.8	5.8	2.7	8.0	1.0	5.9	6.0	3.2	8.0	0.9	4.9	5.1	2.7	7.8	1.1
Toxic release into air (RSEI hazard-weighted concentrations)	6191.5	323.1	0.0	$1.86\text{x}10^5$	16873.4	7125.7	1429.7	0.0	$1.86\text{x}10^5$	$1.80\text{x}10^4$	666.4	20.6	0.0	24941.0	2688.4
Traffic density (% of population)	5059.0	4904.0	5.0	14157.0	1929.6	5177.6	5030.5	5.0	14157.0	1848.9	4358.1	3925.0	110.0	13922.0	2230.5
Lead risk (number and proportion of houses)	34.6	34.8	0.3	80.0	14.1	34.3	34.5	0.3	80.0	14.6	36.6	35.5	13.4	58.8	10.4
Average TSDF (population-weighted averages)	0.1	0.0	0.0	0.9	0.1	0.1	0.1	0.0	0.9	0.1	0.0	0.0	0.0	0.1	0.0
Average NPL (population-weighted averages)	0.2	0.1	0.0	2.3	0.3	0.2	0.1	0.0	2.3	0.3	0.1	0.0	0.0	1.7	0.2
Average RMP (population-weighted averages)	0.6	0.3	0.0	6.4	0.7	0.6	0.3	0.0	6.4	0.8	0.4	0.2	0.0	4.3	0.6
Average WDIS (population-weighted averages)	$8.91\text{x}10^4$	62.1	0.0	$2.30\text{x}10^7$	$1.05\text{ x}10^6$	87385.9	70.5	0.0	$2.30\text{ x}10^7$	$1.11\text{x}10^6$	99110.2	45.6	0.0	$4.13\text{x}10^6$	$5.20\text{x}10^5$
Vulnerability Measures															
POC (%)	29.7	24.6	4.4	96.0	18.3	30.1	25.7	6.1	93.9	17.2	27.3	17.7	4.4	96.0	23.3
Poverty (% of people below 185% FPL)	27.4	25.0	0.0	92.6	15.0	25.8	23.3	0.0	82.5	14.6	36.8	35.7	10.9	92.6	13.5
Children under the age of five (%)	6.2	5.9	0.0	34.8	2.7	6.2	6.0	0.0	34.8	2.7	6.0	5.5	0.0	17.4	2.7

EHD: Environmental Health Disparities; RSEI: Risk Screening Environmental Indicators; TSDF: Hazardous Waste Treatment Storage and Disposal Facilities; NPL: National Priorities List; RMP: Facilities with Risk Management Plans; WDIS: Wastewater Discharge; POC: people of color; FPL: federal poverty level;

We found uneven distribution of the cumulative environmental health disparities across different racial and ethnic groups. Figure 3.1 displays the racial and ethnic composition by each environmental health disparities decile.



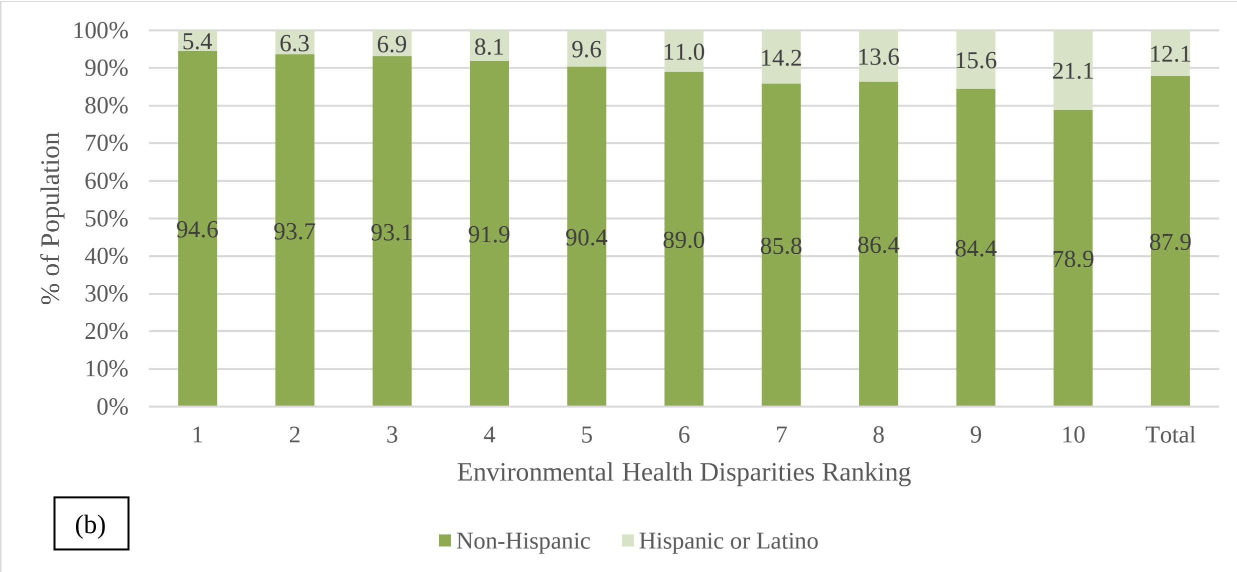
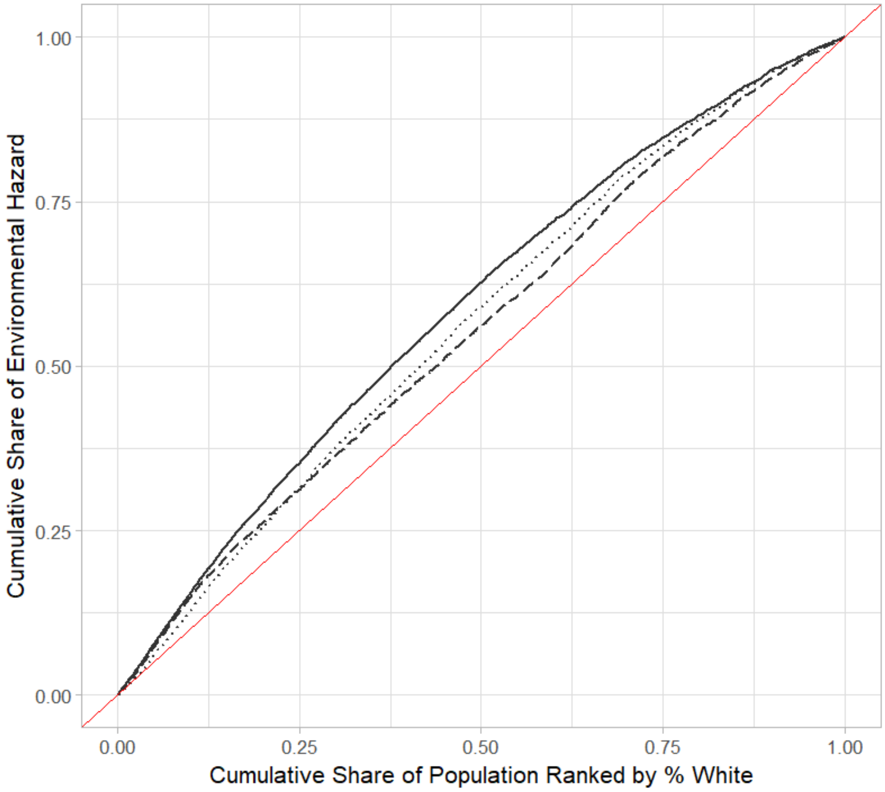


Figure 3.1. Percent (a) racial composition and (b) Hispanic or Latino by environmental health disparities ranking

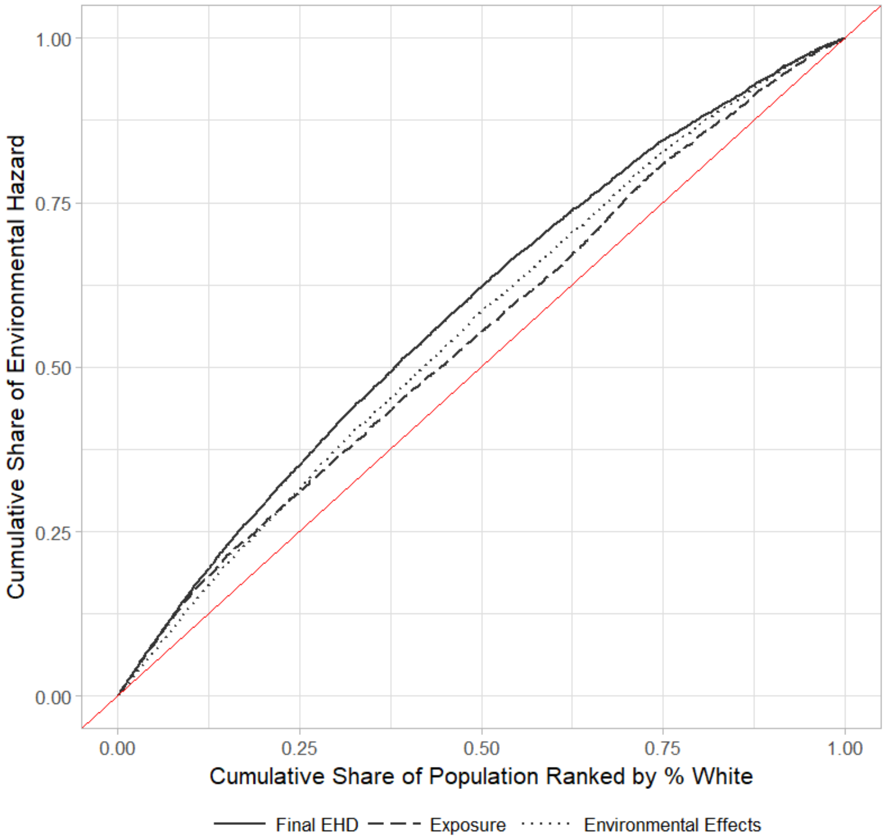
3.4.2 *Inequality Indices*

Inequality curves in Figures 3.2 - 3.4 illustrate the distribution of cumulative environmental indicators with many of the curves lies above the 45-degree line implying inequality where the burden of the indicator disproportionately affects less advantaged groups. Inequality curves for individual indicators can be found in Appendix C.

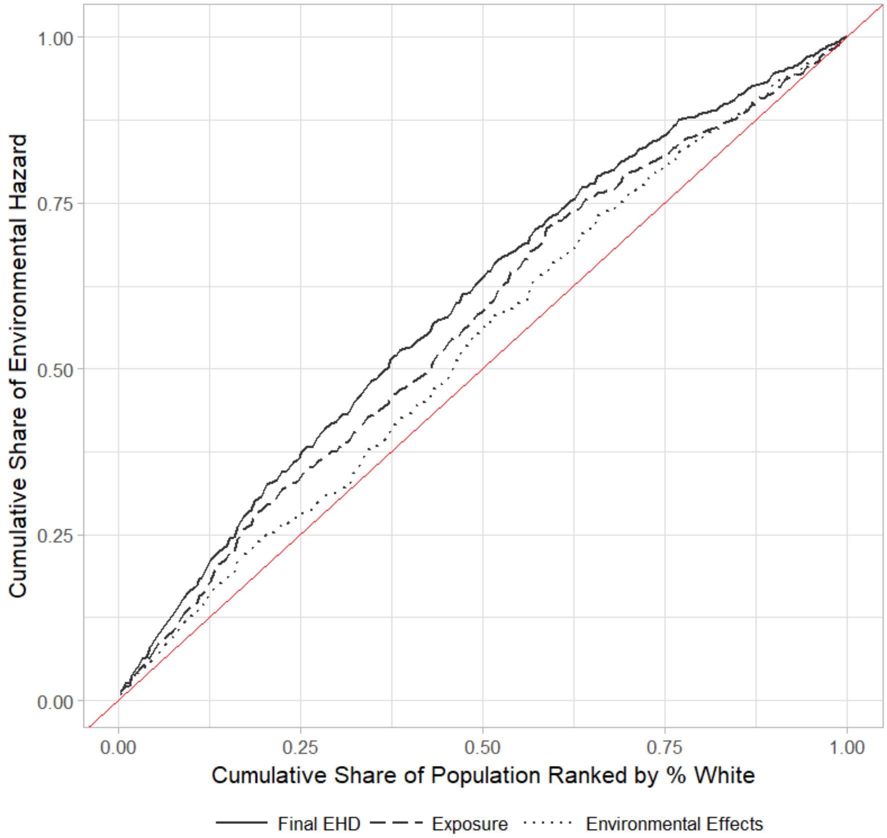
The distribution of pollution burden by proportion of people of color and people living below 185% FPL are shown in Figures 3.2 – 3.3 for all, urban, and rural census tracts. The distribution of environmental hazard for age-related susceptibility for children under the age of five for all census tracts in Washington state is shown in Figure 3.4. Table 3.6-3.8 summarize the t-tests of environmental inequality using the II.



(a) All census tracts

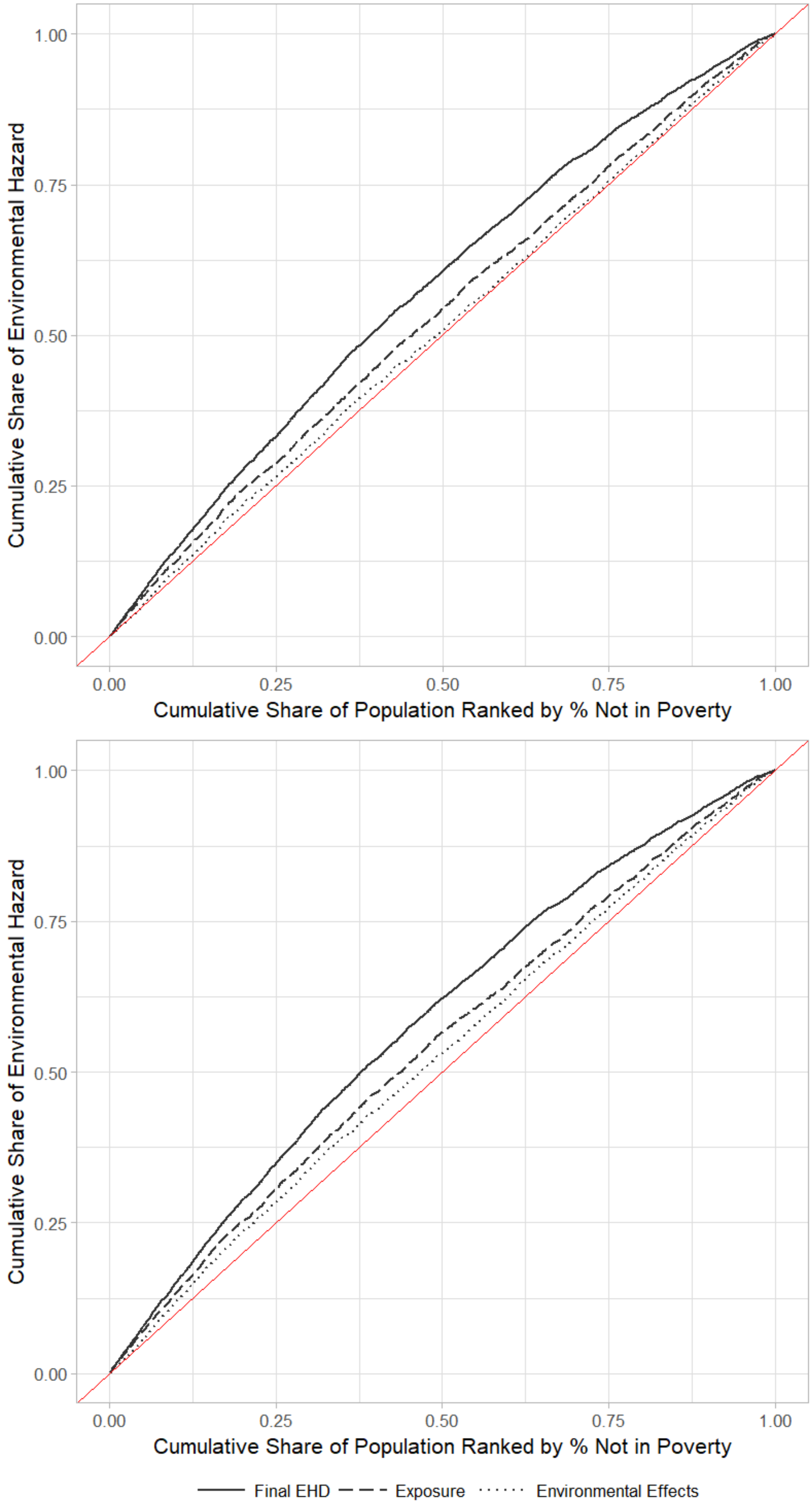


(b) Urban census tracts



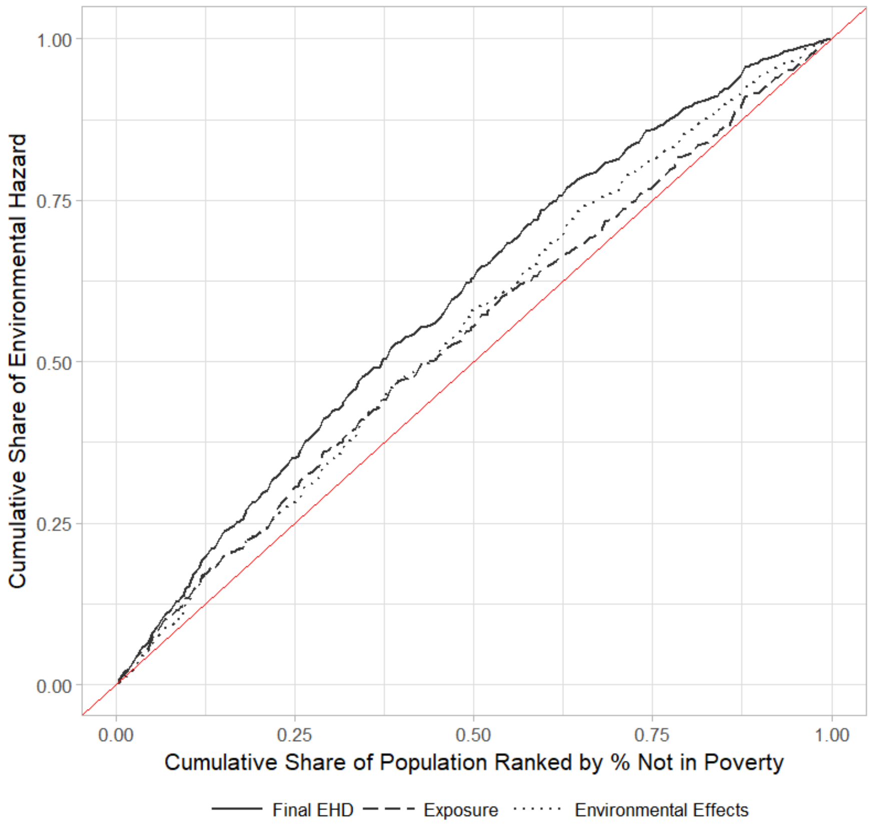
(c)
Rural census
tracts

Figure 3.2. Inequality curves for race: (a) all census tracts, (b) urban census tracts, and (c) rural census tracts. The diagonal line (red) indicates the equality line.



(a) All census tracts

(b) Urban census tracts



(c) Rural census tracts

Figure 3.3. Inequality curves for poverty: (a) all census tracts, (b) urban census tracts, and (c) rural census tracts. The diagonal line (red) indicates the equality line.

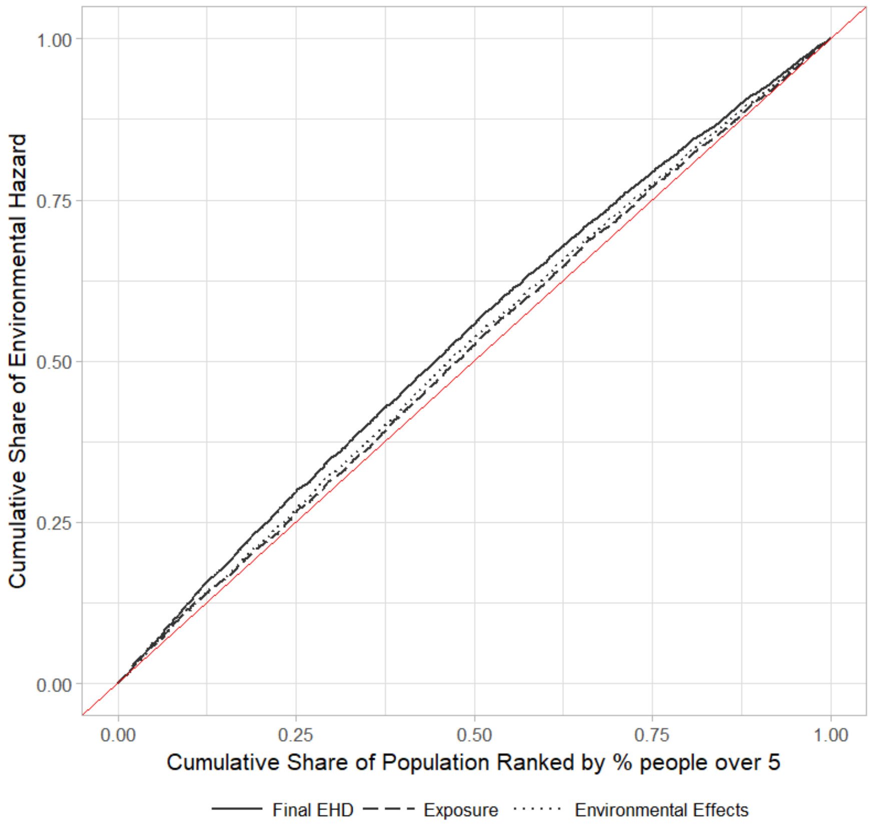


Figure 3.4. Inequality curves for age related susceptibility (children under the age of five) for all census tracts. The diagonal line (red) indicates the equality line.

The inequality curves above the 45-degree line suggested people of color experienced disproportionate burdens of cumulative environmental health disparities, exposure, and environmental effects rankings and most individual indicators (Figure 3.2). The t-tests of inequality corroborated the extent of the disproportionate burdens observed (Table 3.6).

For all census tracts in Washington state (Figure 3.2a), IIs suggested that the cumulative environmental health disparities ($II = -0.175$, $p < 0.001$), exposures ($II = -0.127$, $p < 0.001$), and environmental effects ($II = -0.105$, $p < 0.001$) were all regressively distributed towards people of color. For individual indicators, census tracts with a greater proportion of people of color had a greater burden of pollution for all indicators, except for ozone and wastewater discharge ($p < 0.001$). For urban census tracts (Figure 3.2b), cumulative environmental health disparities (II =

−0.170, $p < 0.001$), exposures (II = −0.120, $p < 0.001$), and environmental effects (II = −0.095, $p < 0.001$) and individual measures of exposures and environmental effects except for ozone levels were regressively distributed with respect to communities of color ($p < 0.05$). For rural census tracts (Figure 3.2c), all cumulative indices, $PM_{2.5}$, ozone levels, lead risk, proximity to NPL, RMP, and TSDF sites disproportionately burdened census tracts with greater proportion of people of color ($p < 0.01$). For ozone indicators, census tracts with a higher proportion of Whites experienced a greater burden in the statewide analysis (II = 0.088, $p < 0.001$) and in urban census tracts (II = 0.114, $p < 0.001$). In rural census tracts, those with greater proportion of Whites were statistically significantly burdened based on the toxic release into air indicator (II = 0.052, p < 001).

Table 3.6. Inequality index and 95% confidence interval for cumulative rankings and individual indicators based on % people of color.

		Indicator	Inequality Index	95% Confidence Interval		p value
All Washington census tracts	Composite score	Final EHD	-0.175	-0.188	-0.163	< 0.001
		Exposure	-0.127	-0.141	-0.113	< 0.001
		Environmental Effects	-0.105	-0.120	-0.090	< 0.001
	Exposure	$PM_{2.5}$	-0.141	-0.155	-0.127	< 0.001
		Diesel	-0.137	-0.151	-0.122	< 0.001
		Ozone	0.088	0.073	0.103	< 0.001
		Toxic release	-0.086	-0.105	-0.067	< 0.001
		Traffic	-0.119	-0.141	-0.096	< 0.001
	Environmental Effects	Lead	-0.032	-0.048	-0.017	< 0.001
		NPL	-0.071	-0.086	-0.056	< 0.001
		RMP	-0.095	-0.110	-0.080	< 0.001
		TSDF	-0.119	-0.136	-0.103	< 0.001
		WDIS	-0.016	-0.033	0.001	
Urban census tracts	Composite score	Final EHD	-0.170	-0.183	-0.157	< 0.001
		Exposure	-0.120	-0.133	-0.107	< 0.001
		Environmental Effects	-0.095	-0.110	-0.080	< 0.001
	Exposure	$PM_{2.5}$	-0.128	-0.142	-0.114	< 0.001
		Diesel	-0.132	-0.145	-0.118	< 0.001

		Ozone	0.114	0.099	0.129	< 0.001
		Toxic release	-0.102	-0.122	-0.081	< 0.001
		Traffic	-0.122	-0.145	-0.100	< 0.001
	Environmental Effects	Lead	-0.032	-0.050	-0.015	< 0.001
		NPL	-0.060	-0.074	-0.046	< 0.001
		RMP	-0.082	-0.098	-0.067	< 0.001
		TSDF	-0.108	-0.124	-0.092	< 0.001
		WDIS	-0.019	-0.037	0.000	< 0.05
Rural census tracts	Composite score	Final EHD	-0.187	-0.222	-0.153	< 0.001
		Exposure	-0.070	-0.109	-0.031	< 0.001
		Environmental Effects	-0.127	-0.173	-0.082	< 0.001
	Exposure	PM$_{2.5}$	-0.181	-0.233	-0.130	< 0.001
		Diesel	-0.044	-0.093	0.005	
		Ozone	-0.055	-0.094	-0.016	< 0.01
		Toxic release	0.052	0.013	0.091	< 0.01
		Traffic	0.069	-0.006	0.144	
	Environmental Effects	Lead	-0.048	-0.078	-0.017	< 0.01
		NPL	-0.094	-0.141	-0.047	< 0.001
		RMP	-0.153	-0.205	-0.102	< 0.001
		TSDF	-0.093	-0.157	-0.030	< 0.01
		WDIS	-0.009	-0.053	0.034	

EHD: Environmental Health Disparities; RSEI: Risk Screening Environmental Indicators; TSDF: Hazardous Waste Treatment Storage and Disposal Facilities; NPL: National Priorities List; RMP: Facilities with Risk Management Plans; WDIS: Wastewater Discharge;

With respect to poverty (Table 3.7), cumulative environmental health disparities (II = −0.148, p < 0.001), exposures (II = −0.018, p < 0.5), and environmental effects (II = −0.063, p < 0.001) were also regressively distributed towards census tracts with greater proportion of people living in poverty (Figure 3.3a). For individual indicators, census tracts with economic disadvantage had a disproportionate burden to all indicators except for diesel emission and toxic release into air (p < 0.05). For the toxic release into air indicator, census tracts with greater proportion of people living above 185% FPL experienced statistically significant burdens (II = 0.064, p < 0.001). For urban census tracts (Figure 3.3b), census tracts with greater economic disadvantage experienced greater burden to all cumulative and individual measures excluding toxic release into air (p < 0.05). For rural census tracts (Figure 3.3c), results showed significant burden of the cumulative indices, $PM_{2.5}$, ozone levels, lead risk, and proximity to RMP sites on those that are economically disadvantaged ($p < 0.01$).

Census tracts with higher proportions of children under the age of five experienced disproportionate burden of all three cumulative measures of environmental health disparities (II $= -0.076$, $p < 0.001$), exposure category (II $= -0.041$, $p < 0.001$) and environmental effects category (II $= -0.029$, $p < 0.01$) and individual indicators except toxic release in air, lead risk, and wastewater discharge (Table 3.8).

Table 3.7. Inequality index and 95% confidence interval for cumulative rankings and individual indicators, based on % people living in poverty (185% below federal poverty level).

		Indicator	Inequality Index	95% Confidence Interval		p value
All Washington census tracts	Composite score	Final EHD	-0.148	-0.160	-0.135	< 0.001
		Exposure	-0.018	-0.032	-0.003	< 0.05
		Environmental Effects	-0.063	-0.078	-0.048	< 0.001
	Exposure	$PM_{2.5}$	-0.062	-0.077	-0.048	< 0.001
		Diesel	-0.001	-0.015	0.013	
		Ozone	-0.023	-0.039	-0.008	< 0.01
		Toxic release	0.064	0.044	0.084	< 0.001
		Traffic	-0.030	-0.054	-0.007	< 0.05
	Environmental Effects	Lead	-0.096	-0.112	-0.079	< 0.001
		NPL	-0.023	-0.038	-0.007	< 0.01
		RMP	-0.064	-0.078	-0.049	< 0.001
		TSDF	0.017	0.000	0.033	< 0.05
		WDIS	-0.030	-0.045	-0.014	< 0.001
Urban census tracts	Composite score	Final EHD	-0.167	-0.180	-0.154	< 0.001
		Exposure	-0.049	-0.062	-0.036	< 0.001
		Environmental Effects	-0.087	-0.102	-0.072	< 0.001
	Exposure	$PM_{2.5}$	-0.081	-0.095	-0.067	< 0.001
		Diesel	-0.036	-0.049	-0.024	< 0.001
		Ozone	-0.021	-0.038	-0.004	< 0.05

		Toxic release	0.059	0.037	0.081	< 0.001
		Traffic	-0.067	-0.091	-0.044	< 0.001
	Environmental Effects	Lead	-0.094	-0.113	-0.076	< 0.001
		NPL	-0.054	-0.068	-0.040	< 0.001
		RMP	-0.076	-0.090	-0.061	< 0.001
		TSDF	-0.020	-0.036	-0.005	< 0.05
		WDIS	-0.032	-0.049	-0.015	< 0.001
Rural census tracts	Composite score	Final EHD	-0.184	-0.222	-0.146	< 0.001
		Exposure	-0.095	-0.141	-0.048	< 0.001
		Environmental Effects	-0.071	-0.118	-0.024	< 0.01
	Exposure	$PM_{2.5}$	-0.173	-0.220	-0.127	< 0.001
		Diesel	-0.012	-0.071	0.047	
		Ozone	-0.086	-0.128	-0.044	< 0.001
		Toxic release	0.023	-0.020	0.065	
		Traffic	0.042	-0.037	0.121	
	Environmental Effects	Lead	-0.093	-0.124	-0.062	< 0.001
		NPL	0.019	-0.037	0.075	
		RMP	-0.080	-0.133	-0.028	< 0.01
		TSDF	0.019	-0.053	0.091	
		WDIS	-0.012	-0.059	0.035	

EHD: Environmental Health Disparities; RSEI: Risk Screening Environmental Indicators; TSDF: Hazardous Waste Treatment Storage and Disposal Facilities; NPL: National Priorities List; RMP: Facilities with Risk Management Plans; WDIS: Wastewater Discharge;

Table 3.8. Inequality index and 95% confidence interval for cumulative rankings and individual indicators for children under the age of five.

	Indicator	Inequality Index	95% CI		p value
Composite score	Final EHD	-0.076	-0.090	-0.062	< 0.001
	Exposure	-0.041	-0.056	-0.027	< 0.001
	Environmental Effects	-0.029	-0.044	-0.014	< 0.001
Exposure	$PM_{2.5}$	-0.052	-0.066	-0.037	< 0.001
	Diesel	-0.022	-0.036	-0.008	< 0.01
	Ozone	-0.032	-0.046	-0.017	< 0.001
	Toxic release	0.025	0.004	0.045	< 0.05
	Traffic	-0.036	-0.059	-0.012	< 0.01
Environmental Effects	Lead	0.005	-0.011	0.022	
	NPL	-0.022	-0.037	-0.006	< 0.01
	RMP	-0.045	-0.060	-0.030	< 0.001
	TSDF	-0.029	-0.046	-0.013	< 0.001
	WDIS	0.001	-0.015	0.018	

EHD: Environmental Health Disparities; RSEI: Risk Screening Environmental Indicators; TSDF: Hazardous Waste Treatment Storage and Disposal Facilities; NPL: National Priorities List; RMP: Facilities with Risk Management Plans; WDIS: Wastewater Discharge;

3.5 Discussion

This study evaluated the environmental justice landscape of Washington State by quantitatively analyzing the Washington Environmental Health Disparities Map using the IIs and inequality curves. Statewide findings identified census tracts with a higher proportion of people of color and people living in poverty as subpopulations with disproportionate burden of environmental risks and hazards. Although the degree of inequality varied for specific indicators, similar disparities were found when stratified by rural and urban census tracts. Finally, census tracts with a higher proportion of children under the age of five were found to experience a disproportionate burden of environmental risks and exposures.

The disproportionate burden of the cumulative environmental risks and hazards on communities of color and low-income communities in our studies corroborates similar analyses in California and Michigan. Using CalEnviroScreen data, studies found people of color and people living in poverty experienced disproportionate burden to cumulative environmental risks and specific pollution burdens such as pesticide use, diesel emission, and solid waste sites [44]. Another study found people of color, specifically Latinos, were more likely to experience greater pollution burden and live in lower levels of socioeconomic status [45]. An analysis in Michigan found communities with more people of color, higher poverty levels, more renters, and lower levels of educational attainment experienced a disproportionate burden of air pollution and associated health risks [67].

Disparities in the proximity to environmental hazards and single pollutants in this study were similar to those found in other regions across the US. Particularly, disproportionate burden of air pollution on minority populations and lower income populations has persisted over decades [7, 9]. A study in Florida found households of color, especially African American households, lived in closer proximity to TRI sites, Superfund sites and hazardous waste sites [75]. In California, TRI sites were disproportionately located in Latino communities [76]. For census tracts in the US, a different study found disparities on $PM_{2.5}$ exposure based on racial status, age, income, educational attainment and poverty [77]. In urbanized counties within California, disproportionate burden of diesel emission and $PM_{2.5}$ levels were placed on communities of color [78]. In Seattle, minorities and communities with higher levels of poverty were not only in closer proximity to TRI sites, but also struggling with issues of gentrification [79]. In urban US cities, Hispanic or Latino and African Americans, specifically those with lower income levels, were disproportionately impacted by pollution estimated through EPA's RSEI model [80]. In Charleston, South Carolina, investigators found a disproportionate number of TRI sites next to communities living in poverty with higher levels of unemployment and lower levels of educational attainment [81].

Our study provides unique insight on environmental burdens in rural Washington, demonstrating statistically significant burdens of pollution including ozone $PM_{2.5}$ and RMP sites on communities of color and people living in poverty within rural census tracts. While other studies in urban communities have yielded similar findings [78-81], few studies have evaluated exclusively rural areas [82, 83]. Additional consideration for urban and rural differences in environmental risks such as pesticide usage (not included as an indicator in current version of the Washington map) and unique environmental characteristics of each should be accounted for in future EJ mapping projects and statewide EJ policies.

Vulnerabilities and susceptibilities that further compound the issues of pollution burden were found to be important in this study. Our findings indicated disproportionate burden on young children who are already more susceptible to pollutants due to biological and developmental vulnerabilities. In a nationwide study, people under the age of 19 were disproportionately burdened with $PM_{2.5}$ [77]. In Michigan, census tracts with larger proportions of children under the age of five experienced greater burden to air pollution [67]. Although lead has been shown to have detrimental effects on children [84], our findings did not find a statistically significant burden of lead on census tracts with a greater proportion of children under five. In future frameworks to evaluate cumulative environmental impacts, age related susceptibility should be considered as an indicator of vulnerability.

Our findings demonstrated the usefulness of measuring environmental equity using cumulative environmental impact maps using the II. The widely used Gini index and its related Lorenz curve provides insight on distributional inequality of environmental outcomes. In contrast with the Gini index, the II provides a statistical method to measure unequal distribution of environmental risks and hazards caused by socioeconomic factors. Therefore, the II can likely be expanded by tracking improvements of environmental justice conditions over time [85].

As demographic data and environmental conditions evolve, these analyses can be repeated to monitor the change in environmental burdens among vulnerable populations. If policies, regulatory actions, or community action ultimately result in distributive justice, the distributional burden of environmental risks and hazards should shift over time. Environmental justice policies can also be developed to address the disproportionate burdens on subpopulations that are identified through these maps [18, 86]. For example, the Washington Governor's Interagency Council on Health Disparities created an interagency EJ task force in 2019. The task force will recommend agency guidelines for establishing standards for EJ in state agencies and guidance about how to use the Washington Environmental Health Disparities Map to identify highly impacted communities. Moving forward, the task force will also recommend ways to engage communities that are highly impacted by environmental justice issues and measurable goals for reducing these identified environmental health disparities.

There are a few limitations to this study. We did not conduct our statistical analysis of inequality index based on specific race and ethnic groups, rather we focused our analysis on people of color as a single group. This was because of the large variability in proportion of minority groups throughout the state. In addition, the nature of our analysis approach relied on rank-ordering of census tracts within Washington State, and did not account for actual regulatory limits or guidelines to exposure levels. Our analysis on environmental burden was also limited to the indicators in the Washington Environmental Health Disparities Map version 1.0. There may be benefits to integrating other environmental data or methods used for the EJ analysis, in addition to the II analyses conducted in this study.

Despite these limitations, our study has several strengths. To our knowledge, this is the first study that evaluates cumulative environmental impacts based on both exposures and sociodemographic conditions on a statewide level in Washington. We also found the extent of the disproportionate burden remains true when stratified by rural and urban census tracts, demonstrating the need to consider urbanicity and rurality in future EJ analyses.

3.6 CONCLUSION

This study demonstrated a statistically significant amount of disproportionate burden of cumulative environmental risks and hazards on people of color, those below federal poverty levels, and children under the age of five in Washington State. We found much higher burdens among historically marginalized communities and children who are more susceptible to environmental risks and hazards. Findings from this study are important to consider in an environmental justice strategy to correct these distributive injustices towards environmental equity.

Chapter 4. THE HOME AIR IN AGRICULTURE PEDIATRIC INTERVENTION TRIAL: APPLICATION OF AUTHENTIC COMMUNITY ENGAGED RESEARCH PRACTICE IN RURAL WASHINGTON

4.1 ABSTRACT

This paper assesses a longstanding community-academic partnership in rural Washington and its application of community engaged research practice in implementing the Home Air in Agriculture Pediatric Intervention Trial (HAPI). We used a set of semi-structured interview questions to assess the partnership process and its influence on the project outcomes. All thirteen members (eight academic partner research staff and five community partner research staff) of the study team participated in this evaluation. Prioritization of community issues, responsiveness to community feedback, integration of community strengths and resources, and high levels of trust led to a highly functional partnership. The partnership enhanced capacity in the community through increased staffing and programmatic resources and empowered individuals and partner organizations. Ultimately, the partnership led to community empowerment and improved awareness to improve pediatric asthma health outcomes in the community. The research model used by this partnership can be applied to other partnerships in similar contexts.

4.2 INTRODUCTION

Community-academic research partnerships can promote environmental justice by collaboratively identifying solutions to reduce environmental health hazards [66, 87]. Longstanding community-academic partnerships have been particularly effective in historically marginalized settings by sharing common values that enhance capacity and strengthen cohesion in the community [88-90].

When best practices of authentic community engagement are followed within the partnership, community engaged research (CEnR) projects offer meaningful approaches to tackle environmental justice priorities in the community [25]. While academic and community partners both benefit from a thoughtfully executed CEnR project, the approach may add an additional burden to the community and academics compared to a "traditional" study [16, 91]. In CEnR studies, community partners have to constantly balance opportunity costs for participating in research activities and competing demands on other organizational priorities [29-31]. In addition, community organizations and academic institutions have differing organizational cultures that could potentially create conflicts in designing or implementing a research project [29, 31, 32]. To minimize these burdens, meaningful participation from the community is important when designing and implementing a research project and requires the partnership to address ongoing challenges in a timely manner [30, 32, 36, 37].

Partnership evaluations examine contextual features of the partnership, its effectiveness in working together, and its collaborative accomplishments [29, 92-95]. These evaluations can identify elements of authentic community engagement practiced in the partnership and demonstrate benefits of participation for all partners [94-97]. In addition, self-evaluation of a CEnR project encourages team cohesion and community empowerment by identifying achievements and areas for improvement for the collective group [17, 29, 97, 98]. Many community-academic partnerships have been evaluated in urban partnerships and several evaluation models of the partnership process or the outcomes of a CEnR project exist [15, 22, 94, 95, 99, 100].

However, existing evaluation models have often employed extensive qualitative evaluations and lengthy questionnaires that burden community partners [21, 94, 101-107]. In addition, the relationship between a mature partnership's process and CEnR project outcomes has yet to be extensively examined in rural partnerships [108, 109]. Rural communities navigate some unique features including complicated political environments where one or few major economic drivers in community are also linked to environmental impacts (e.g. agricultural industry) [110, 111]. In addition, distance to clinics and health related services and distance between academic partners, largely in urban centers and their partnering communities can pose challenges for rural partnerships and require strategies specific to these challenges [111-115].

This paper evaluates an 18-year community-academic partnership in rural Washington to assess its process in implementing a CEnR project and its influence on the project outcomes for the Home Air in Agriculture Pediatric Intervention Trial (HAPI).

4.3 Methods

4.3.1 *Partnership Background and Research Design*

We used a case study approach. This empirical approach was chosen as a method to rigorously assess the partnership in-depth within the context of the lower Yakima Valley community in Washington [116].

The Yakima Valley is a rural region in central eastern Washington known for its productive agricultural industry with a large Latino immigrant workforce. The region is home to a longstanding CEnR partnership, El Proyecto Bienestar (EPB), translated as the Well-Being Project. EPB comprises local community entities and the Seattle-based University of Washington's (UW) Pacific Northwest Agricultural Safety & Health Center (PNASH) [117]. The current community partners include Northwest Communities Education Center (NCEC) / Radio KDNA – a public Spanish language radio station and Yakima Valley Farm Workers Clinic

(YVFWC) – a set of federally qualified community health centers; EPB also established a community advisory board (CAB) for discussion of community concerns, needs, and research directions.

Since 2002, UW has worked with the CAB to identify research priorities, which have included air quality and pediatric asthma. EPB partners conducted their first study of children with asthma from 2009-2015. After the study identified adverse impacts of ambient air pollutants on the children's lung function and symptoms [34, 35, 118], EPB partners emphasized the group's interest in solution-driven research.

In response, the UW reviewed the evidence base to identify strategies most likely to succeed in delivering better asthma outcomes and proposed the use of High Efficiency Particulate Air (HEPA) indoor cleaners. Launched in 2014, the HAPI study is a randomized trial to test the effectiveness of the YVFWC asthma education program alone versus combined with provision of portable HEPA cleaners to improve indoor air quality and pediatric asthma health outcomes. Details of the HAPI study design are described elsewhere [119].

To evaluate the effectiveness of the EPB partnership and how the partnership process influenced the HAPI study outcomes, the following research questions were developed. 1) How did the partnership influence the achievement of study objectives and the research methodology and design? 2) What elements of authentic community engagement were practiced in this project? 3) How did project participation affect the partners and the partner organizations? 4) How did partnership in the HAPI study affect community empowerment?

4.3.2 *Evaluation Framework and Data Analysis*

The framework for this evaluation is presented in Figure 4.1, drawing on previous work from Brown et al., 2012, Schulz, Israel & Lantz, 2003, and National Institute of Environmental Health Sciences Partnerships for Environmental Public Health Evaluation Metrics Manual [17, 94, 120].

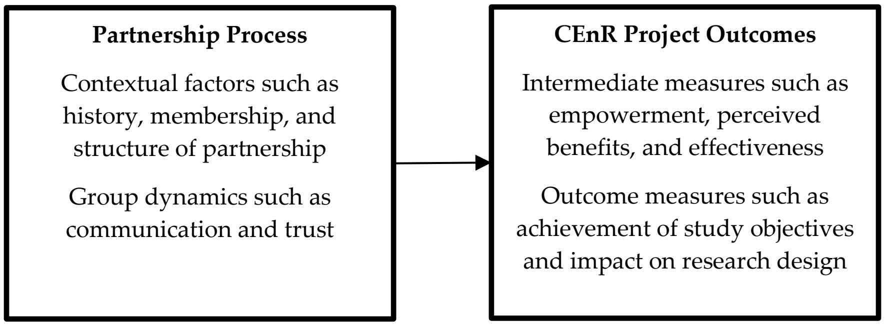


Figure 4.1. Framework for evaluating partnership and outcome of a CEnR study, adapted from Brown et al., 2012, Schulz, Israel & Lantz, 2003, and National Institute of Environmental Health Sciences Partnerships for Environmental Public Health Evaluation Metrics Manual.

Within this framework, we developed a set of eleven semi-structured interview questions using a combination of open ended and 5-point Likert scale questions (1- strongly disagree to 5-strongly agree) questions (Table 4.9). Co-investigators reviewed the corresponding interview guide. The interview guide was pilot tested in both English and Spanish prior to the start of interviews (Appendix D). The partnership evaluation was approved by the University of Washington Institutional Review Board (IRB).

Table 4.9. Interview questions and related constructs.

Construct	Interview question
Impact on research design	Do you think this partnership enhanced or made better some aspects of the project such as recruiting and keeping participants in the projects? How do you think the partnership influenced how and what we measured in the study? If you could repeat this study, what would you do differently? What would you keep the same?

Impact on study objectives and outcomes	What did you hope this project would accomplish? Has the project failed to meet, met, or exceeded your expectations? Why do you say that?
Authentic community engagement	How would you rate the level of collaboration on this project among partners? (5 being the highest amount of collaboration and 1 being the lowest amount of collaboration) Tell me why you gave that rating.
Authentic community engagement	How would you rate communication between team members at the start of the project? What about now? (5 being the highest amount of effective communication and 1 being the lowest amount of effective communication).
Authentic community engagement	How would you rate trust in this project? (5 being the highest amount of trust, 1 being the lowest)? Tell me why you gave that rating. What is an example of what trust looks/looked like in this partnership or project?
Perceived benefits and effectiveness	How effective was the partnership in getting the work done?
Impact of partnership	What was the impact of the partnership on [you or your organization]'s ability to address pediatric asthma?
Community empowerment	How has the partnership affected the community's ability to take action, create change, and exercise power? Examples?
	Is there anything else you would like to mention?

The interviews were conducted within four months after data collection activity concluded for the HAPI study. All thirteen members (eight academic partner research staff and five community partner research staff) of the study team participated in the interview. All interviews were conducted in person, audio-recorded, and transcribed. The interviews were conducted by an internal evaluator (author EM). For one partner who preferred to be interviewed in Spanish, author EM conducted the interview with translation by a bilingual external evaluator. The bilingual external evaluator transcribed and translated the transcript for further analysis. The semi-structured interviews ranged from 22 to 60 minutes, with an average of 30 minutes per interview.

We created a codebook *a priori* based on the framework in Figure 1. We used constant comparison approach to refine themes, triangulation of Likert scale questions with qualitative questions, and consultation with co-investigators to maintain rigorous coding methodology [121-

123]. A primary coder (author EM) coded each transcript three times. We used In Vivo coding during the first cycle of coding, then the codebook during the second round. Emergent codes from the first two cycles were added to the codebook and reviewed prior to the final round of coding. After each coding cycle, author SF reviewed the codes and quotes. After coding was completed, emergent themes were identified through content analysis. Atlas.ti 7 was used to aggregate codes for each identified theme. For quantitative data, descriptive data analysis was conducted in Microsoft Excel to compare means between community and academic partners.

4.4 RESULTS

Common themes to each research question are identified below. Responses discussing the partnership's impact on individual, organizational and community empowerment (questions 3 and 4) are summarized together.

4.4.1 *Partnership Influence on Study Objectives and Study Design*

The longstanding nature of working together established a strong foundation in this project. A community partner described the significance of the CEnR approach. *"I think it has something to do with the fact that we were already working together through the previous grant …It's a model where we all sat at the table together and we all had the same levels of responsibilities and we all have the same level of saying within the project…And even though some people will change and move on, I think the model stayed there."* This allowed the different partners to work together effectively from the outset to identify study objectives for the HAPI study.

The team's commitment to community-identified priorities was reflected in the study design. When designing the HAPI project, the community advisory board and community partners emphasized the importance of a solution-oriented research project. In response, the UW team focused on scientifically plausible intervention study designs. Community partners felt the proposed intervention to use portable air cleaners was practical and leveraged their deep experience in delivering asthma education in the community. A community partner articulated, "*When we started talking about the intervention … I was just hoping for our community to learn more about what they can do immediately … I think my hope was to bring more practical solutions into the community, especially the participants with asthma. So, I think we have accomplished that. We were able to bring practical solutions and solutions that can be done now, instead of waiting until a policy has changed or things [have] changed at a different level*."

The diversity in the partnership influenced the study design in several ways. In the grant proposal, roles and responsibilities of the study team were developed based on organizational partner strengths and opportunities in the community, goals identified together, and lessons learned in the previous asthma study. The UW was responsible for overseeing the scientific integrity through development of procedures for quality control and assurance, standard operating procedures, equipment selection and maintenance, and field staff training. The YVFWC asthma program team leveraged their trusted relationship with the project participants. The YVFWC team served as the point of contact for participants and was responsible for recruiting participants, scheduling, and conducting asthma health assessments. The NCEC/ Radio KDNA team conducted field-based environmental sampling in participants' homes during study visits and sampling equipment management. An academic partner stated, "*…when you look at any partner's role in this, if you took that out, it would fall apart. It was a fairly equal contribution in a way when you look at the components …the endeavor to understand indoor environments of the homes…Our partners at KDNA really held that up in the biggest way. And our ability to enroll and engage families and keep them engaged and teach kids about asthma and see how their asthma was doing* *was really held up by the Farm Workers Clinic. And UW, the whole scientific integrity and oversight and training…It just felt like there were really big components being supported and carried out and owned in a lot of ways by the different partners so I think that seems truly collaborative.*"

4.4.2 *Authentic Community Engagement in Partnership*

Multiple elements of authentic community engagement were practiced in this partnership including trust, communication, and collaboration through equitable decision-making and power sharing.

4.4.2.1 Trust

Academic partners and community partners both rated levels of trust highly, giving an average score of 4.4 and 4.6 out of 5, respectively, when asked to rate trust within this project. A community partner summarized the high level of trust in the partnership. "[It] *takes … our team to work together and be mature enough to develop that type of relationship. So… we have set up a high expectation of trust within our group. And it has worked."*

When asked for an example of what trust looked like, trust was described as the scenario where mistakes or issues can be discussed and resolved without feeling judgement. A community partner described this level of openness and receptivity within the partnership. *"I feel confident enough to say 'hey, this is not working, can we talk about it?' …You know, when you get to a level where you can address or bring something to the table without feeling like I'm going to be criticized."* An academic partner described similar levels of trust as *"I can speak freely and you can give me back what you think or what your opinion is to help me out."*

Partners identified two drivers of trust in this partnership: time and personal relationships. More specifically, the high level of trust was formed by developing deeper relationships among partners over time. One community partner described how time helped deepen trust. "*At the beginning, I did not feel comfortable talking or saying or asking ... I kind of waited a little while to get to know people and then I was able to relate more with everyone.*" People participated in social gatherings unrelated to the project in both the study community and the city where the academic institution is based to continue relationships among partners. By fostering these relationships, the partnership navigated through issues that came up during the project because the partners "*[understood] things about each other's lives… [and were able to] relate to each other on a social level."* An academic partner felt that this deepened level of understanding *"builds trust in each other in being able to say this is working for me and this isn't working for me."*

In addition to a high level of trust and personal relationships, many academic partners referenced trust in the context of data quality and data collection. For these partners, adhering to protocol, quality of data, and the QA/QC protocol influenced the perception of trust. For example, an academic partner stated, *"If 100% trust means there is no need to QA/QC things and no follow up questions, that would be a 5. But since it is a complicated project, there is this built-in need to make sure things go smoothly."*

4.4.2.2 Communication

Partners were asked to compare communication between team members at the start of the project four years ago or when they started the project to communication at the time of this interview. Regarding the start of the project, academic and community partners gave an average score of 3.3 and 4.0 out of 5.0 respectively. When asked how effective communication was at the time of the interview, both noted an improvement in communication over time, giving an average score of 4.0 and 4.8 out of 5, respectively.

Both community and academic partners discussed the importance of bidirectional and continuous communication throughout the project. Partners also discussed challenges in communication such as geographical distance (3.5-hour drive) and a mountain pass between UW and the study community, multiple partner organizations with differing priorities, and the large number of individuals working on the project. After launching the project, the HAPI team invested a considerable amount of time fine-tuning the study team communication protocols based on feedback from the community partners. For example, some partners preferred to communicate via email while others preferred to talk on the phone or send text messages for short correspondences. The team started a shared online calendar to keep track of project activities, monthly all-team phone meetings, yearly all team in-person meetings, and ad hoc meetings for various topics such as exposure science, outreach, and dissemination. Phone meetings helped bridge the geographical gap between the two teams while the shared calendar provided an additional medium for improved schedule management of meetings, conferences, study visits, clinic visits, etc. A community partner discussed the importance of having constant dialogue within the partnership through these channels of communication. The partner noted, "*having weekly meetings, meetings constantly, and asking something was new, if something was wrong…[was very helpful]…even though everything was fine [or] nothing changed from the last time the team had a meeting…[The team] wanted to have a meeting to see if someone wanted to share something, so everyone was up-to-date.*"

4.4.2.3 Collaboration through decision-making and power sharing

The project was a result of collaboration between all organizations and included equitable decision-making and power sharing throughout the partnership. Academic partners rated level of collaboration as 4.3 out of 5 while community partners gave an average of 4.8 out of 5. Partners felt that the shared decision-making process was necessary to successfully collaborate in this HAPI project. Each partner organization was treated as equal partners in this project. Sharing decision-making power led to conversations that strengthened the study design and became more effective as a partnership. An academic partner described, "*I feel that we listened to them, and they listened to us. They learned what we needed to accomplish our … study goals. But then we also listened to them of what was realistic and what we, you know, so we weren't putting in unrealistic goals of this is what we want to do, so I felt that they also told us, 'hey, this is what is reasonable. This is what will be beneficial to keep your participants*.'"

When decisions needed to be made, the project team consulted one another through scheduled or impromptu meetings. As one academic staff stated, "*project staff in UW would never do something without the green light and review of the community and of the field staff*." For example, the outreach team consisting of both academic and community staff met biweekly to strategize around how to disseminate study results. The community partners emphasized the need for practical solutions as a key focus of the dissemination efforts. Together, the outreach team decided on various ways to disseminate study results to the community such as health fairs and radionovelas. These suggestions were included in the outreach and dissemination plan.

Equitable decision-making was also reflected in the study design. The YVFWC asthma program staff wanted to examine delivering some of the education in clinics versus home visits exclusively. This approach was thought to potentially enhance the YVFWC asthma program's efficiency and lower costs in a future model. The agreed upon final study design included the four standard asthma education modules with the first visit conducted in clinic coinciding with the participant's initial study health assessment.

Another example of collaboration was reflected in how the project team interacted with participants and how the agreed upon design resulted in increased retention rates and acceptance of the intervention. A community partner discussed how YVFWC and Radio KDNA brought to the partnership years of recognition and rapport with community members. "*[The community] trusts the Farm Workers Clinic because they are the medical provider [in the community]. They also trust Radio KDNA."* To deepen this connection with the community, the YVFWC staff wanted to serve as the primary contact point with the participants rather than having the academic team interact directly. All visits were scheduled by the YVFWC staff and only YVFWC and NCEC/Radio KDNA staff conducted home visits. The community partner described how this ultimately resulted in better retention in the study. "*When we were getting into [the participant's] homes, it wasn't just anybody getting into their homes. It was employees of [the Yakima Valley] Farm Workers Clinic and Radio KDNA…Because of the trust of the community they have for the organizations, we were able to maintain that level of participation*.'" An academic partner discussed how this shared decision-making opportunity strengthened the study. *"If we're calling from the university, they may not care as much but if you're calling from the clinic and they know [the community health worker], they would be more willing and more responsive."*

4.4.3 *Impact of Partnership on Individuals, Partner Organizations, and Community Empowerment*

Both community and academic partners discussed empowerment of individuals as an immediate impact of the partnership. One example of individual level of empowerment was equipping families with knowledge through the asthma program and providing tangible solutions such as HEPA cleaners, asthma medicine boxes, and green cleaning kits that can improve indoor air quality and reduce asthma symptoms. An academic partner stated, "*The study has…introduced or* *refreshed the study participants on some asthma control strategies… I think that is intrinsically empowering*." A community partner echoed the importance of integrating asthma education as part of the study design for both control and intervention groups as one way to increase knowledge and agency of the participants. *"I think it gave the participants [an opportunity] to learn about [indoor asthma triggers] that are in the home that aren't necessary to have for someone who has asthma and find different alternatives. For example, we provided the green cleaning kit and talked to them about how certain chemicals can be more toxic and using more [less chemically abrasive cleaning] products …[and] how to use their medications, whether they're using them appropriately, and explaining the importance of using those medications as prescribed by their doctor."* A different community partner gave another example of individual empowerment—increase knowledge for themselves. *"I did not know many things about what affects asthma in children. I did not know about the cleaning products. And while we were doing the work I was also learning."* This partner described using opportunities to share knowledge and increase awareness around pediatric asthma and indoor air quality with friends and family.

At the organizational level, the partnership empowered each organization to improve asthma outcomes in the community by building more capacity. The partnership increased programmatic capacity at partner organizations, offered training that targeted specific skill-building, and supported outreach activities. For YVFWC, this project supported a full-time asthma educator and a part-time asthma program coordinator. In addition, the study design widened the reach of the existing asthma program by increasing the number of home visits with the asthma educators over the course of the year. A community partner discussed how the HAPI project benefited the asthma program and its patients. "*For the asthma program we [typically] do three visits… But for HAPI…we followed that family for a whole year [over six visits] … Sometimes [the clinic] sees* *patients, let's say in the summer and they are fine. Everything is fine, nothing is wrong. Now, winter hits and I'm [typically] not seeing them [as part of the regular asthma education program] ... but that's when they get sick the most because they get more flare-ups in the winter. So ... seeing the [HAPI] participants year-round helps to see those seasonal triggers."*

For NCEC/Radio KDNA, the partners discussed increased technical and professional skills, capacity, and resources (such as indirect costs to help the organization operate) as benefits from participation. The HAPI project supported a full-time research coordinator and part time technician at NCEC/Radio KDNA. The research coordinator also facilitated meetings for the EPB CAB. In addition, NCEC/Radio KDNA staff expanded their technical capacity for data collection and air sampling and continued building more trust in the community. The radio station increased their capacity to educate the community on asthma and air quality issues in the Yakima Valley through outreach and dissemination opportunities such as airing information spots or radionovelas.

At the community level, the partnership's commitment to community priorities ultimately increased community empowerment through raising awareness and deepening trust within the community. For example, the HAPI team routinely shared the study progress and preliminary results with the CAB and sought feedback regarding how to best talk about the study with the community. A community partner discussed how outside of the CAB meetings, CAB members have brought up the issues of pediatric asthma and indoor air quality in their own networks and have been raising awareness in the greater community. A community partner described, "*I think it's the community that is more aware…[and] we're going to create more and more awareness…[E]specially our participant's families, they are more aware of things that they can do to prevent asthma, especially in their immediate circles. That's something that is important within our organization and our community…through our CAB meeting… And so now, I feel like* *we're able to raise our voices and say … there is this issue, can we do something about that? It may not be [on a] legislative level, but it will be on a community level of awareness and knowing exactly what is going on with their health and the issues that we have on air quality."*

4.5 Discussion

The purpose of this evaluation was to understand how the longstanding partnership process between an academic institution, community clinics, and a community center/public radio station strengthened outcomes of the HAPI study in rural Washington. Meaningful community participation improved HAPI project outcomes through a practical intervention choice and robust study design. Positive group dynamics also increased the perception of the HAPI team's effectiveness through the culture of power sharing and equitable decision-making. Ultimately, the process enhanced staff and programmatic capacity in YVFWC and Radio KDNA, increased technical and professional skills of partners, raised more awareness of pediatric asthma and indoor air quality, and deepened trust in the community.

This partnership's model can be used as a best practice guideline for meaningful community participation in research. The importance of meaningful community participation has been noted in other CEnR projects [21, 124, 125]. Studies have described challenges in balancing community participation and scientific rigor, and have emphasized the need for robust partnership processes that meaningfully incorporate community voice into all stages of research [98, 124, 126]. Similar to the HAPI study team, other rural partnerships have also demonstrated culturally appropriate interventions by working closely with community partners and CABs to prioritize research topics and design studies collaboratively [114, 115, 127]. The diversity of partner organizations, as seen in the HAPI team, allows community partners to be embedded into all stages of research as recruiters, health educators, data collectors, technicians, connectors between community members, and information disseminators [127]. As discussed in this evaluation, bringing in community skill sets such as YVFWC asthma educators, elevating existing resources such as Radio KDNA's role in the community, and integrating local knowledge of an immigrant, Latino farmworker community into the study design contributed to the success of the HAPI project.

This evaluation reiterates the importance of trust both within the partnership and the greater community [31, 112, 128]. History of mistrust between "outsider" academic institutions and historically marginalized or rural communities may create a challenge for partnerships to work effectively [98, 129]. Different organizational structures in community organizations versus academic institutions can also create points of conflict within a partnership [126]. Similar to other longstanding partnerships [28, 112, 125, 130, 131], as the partnership matured, the HAPI partners built common values and shared norms that overcame these challenges. For example, with a deepened level of trust, the HAPI team negotiated best modes for communicating formally and informally to resolve differences in communication styles without jeopardizing progress in the HAPI study. Although individual relationships varied, cohesion within the partnership strengthened and likely contributed to successfully accomplishing the research objectives, as seen in other partnership evaluations [28, 104, 128, 132]. In addition, study participants demonstrated improvements in indoor air quality and asthma health outcomes [133].

An important finding of this evaluation is the extent of capacity building and levels of empowerment achieved during the five years of the HAPI study implementation. Aligning HAPI study goals with EPB's overall priorities in the community led to an effective partnership in promoting community level action. Other highly functional and mature partnerships in both rural and urban communities have led to improvements in complex health outcomes and increased levels of empowerment in those communities [125, 131, 134-136]. Projects led by partnerships with an equitable decision-making process ultimately led to positive community level actions [29, 65, 130, 137]. Deliberate efforts on both academic and community partners towards maintaining such processes will remain fundamental to the success of the overall partnership [100, 112, 115].

Although this study demonstrated effective collaboration among partners, one finding to note is that community partners rated higher levels of communication and collaboration than academic partners. Differences in rating of communication and collaboration may be due to differing expectations of each partner. Since some academic partners associated data and trust closely, academic partners may have also connected collaboration closely with involvement in formal data analysis, which was undertaken solely by the academic partner. The power differential between academic and community partners may also have influenced the ratings [125], although this was most likely minimized through the years of relationship built between the primary evaluator and the HAPI team. This finding emphasizes the importance of continuous dialogue between partners to manage expectations and encourage positive group dynamics throughout the project.

As with other qualitative studies, this partnership may not be statistically representative of other partnerships or generalizable to all community-academic partnerships. In addition, this evaluation had a small sample size (n=13). However, we were able to interview all study team members of the partnership which provided the available diversity of perspectives around the partnership processes and project outcomes.

The processes used in this community-academic partnership to build on community skills and programs with deep trust and effective communication can be replicated in other settings. In addition, the semi-structured interview framework, a combination of Likert-scale questions and qualitative questions, presents a low-burden way to assess process and outcome evaluation of partnerships. Although results from the evaluation are specific to the context of this partnership, this model can be adapted to improve outcomes of CEnR studies in other rural partnerships.

4.6 CONCLUSIONS

This case study set to evaluate a mature community-academic partnership in rural Washington by using a concise but theoretically informed set of questions. The longstanding partnership implemented a successful CEnR project through meaningful participation from community partners, shared decision-making, trust building, and effective bidirectional communication. Community feedback and flexibility/adaptability in project implementation resulted in community empowerment and community capacity. The EPB community-academic partnership serves as a model for research to improve pediatric health outcomes and indoor air quality in a rural farmworker community.

Funding: This research was funded by NIEHS-sponsored Home Air in Agriculture Pediatric Intervention (HAPI) Trial, Grant #: NIEHS 5R01ES023510-04.

Acknowledgments: I would like to acknowledge all the partners who participated in this evaluation and the HAPI participants, YVFWC, NCEC/Radio KDNA for making this study possible. Partial support for this research came from a Eunice Kennedy Shriver National Institute of Child Health and Human Development research infrastructure grant, P2C HD042828, to the Center for Studies in Demography & Ecology at the University of Washington.

Chapter 5. CONCLUSIONS

This dissertation sought to describe two CEnR studies addressing environmental health disparities. Both studies addressed environmental justice through procedural and distributive equity. As both projects in this dissertation demonstrate, the role of community in research is essential to achieving environmental justice and equity [23, 138]. Diversity of partners in both projects and each partner's commitment towards environmental justice in communities contributed to the success of each partnership.

Chapter 2 described the development of the Washington Environmental Health Disparities Map. The goal of this chapter was to examine this newly formed community-academic-government partnership, summarize the process of developing the mapping tool, describe the methodological framework for integrating environmental and population indicators into cumulative impact rankings, summarize the environmental justice findings for the state based on the inaugural version of the mapping tool, and discuss policy implications. Authentic community engagement principles were applied to this community responsive and community driven research project, striving for procedural equity in the process.

Chapter 3 described an evaluation of the burden of cumulative environmental risks on race, poverty, and age-related susceptibility and identified distributive inequalities using the Washington Environmental Health Disparities Map. Findings indicated a significantly disproportionate burden of cumulative environmental risks and hazards on people of color, those below federal poverty levels, and children under the age of five in Washington State. These disparities remained when stratified by urban and rural census tracts.

Findings from Chapters 2 and 3 provide a model for newly formed community-academic-government partnerships to be effective in identifying environmental health disparities and developing EJ tools. Tools built in this community driven framework may provide public agencies, policymakers, and communities critical information on environmental health disparities with which they can make informed decisions.

Chapter 4 presented an evaluation of a mature community-academic partnership in the Lower Yakima Valley, Washington through the HAPI project. The longstanding partnership implemented a successful CEnR project through meaningful participation from community partners, shared decision-making, trust building, and bidirectional communication. Responding to community feedback and practicing flexibility in project implementation increased community empowerment and community capacity during the study. Using the HAPI study as a case study, this chapter demonstrates how a long-term community-academic partnerships, maintained beyond a single research project, can further benefit communities by continuing to amplify the power and voices of communities [137-139]. Findings from Chapter 4 serves as a model for longstanding partnership to improve health outcomes and environmental quality in other rural communities.

Lessons from this dissertation can collectively inform future CEnR studies and establishment of community-academic partnerships to advance EJ. Future studies should focus on community-driven solutions to reduce the environmental health disparities identified by the Washington Environmental Health Disparities Map and address ongoing priorities identified by mature community-academic partnerships. Additional studies should assess the impact of these partnerships in improving environmental health outcomes systemic change. For example, the HAPI study demonstrated that the HEPA cleaners can effectively improve pediatric asthma outcomes and indoor air quality in homes. Studies should evaluate how the results can be applied to state policies to help cover the cost of the HEPA cleaners. As another example, as Washington state agencies use the Washington Environmental Health Disparities Map and adopt policies and programs to reduce environmental health disparities, studies should evaluate how these ultimately improve environmental health outcomes for communities.

Increasing community resilience is critical when correcting the disproportionate burdens of environmental hazards on marginalized and underserved communities. Future studies should use community-driven methods similar to the Washington Environmental Health Disparities Mapping project to model resilience and develop asset-based indicators. With this approach, identifying resilience factors will be essential to increase resilience based on existing assets in communities over time. Establishing a baseline for measuring community resilience will be important to track improvements in community resilience.

Ultimately, as communities are faced with existing and new challenges such as COVID-19 and climate change, prioritizing community-driven solutions and increasing community resilience will be key to creating healthier environment with communities, for communities.

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APPENDIX A

Urban/Rural Codes

The following table presents the urban rural classification based on RUCA Rural-Urban Commuting Area (RUCA) codes.

Table A-1. Secondary RUCA codes based on urban and rural two-tier classification.

	Secondary RUCA Codes
Urban	1.0, 1.1, 2.0, 2.1, 3.0
Rural	4.0, 4.1, 4.2, 5.0, 5.1, 5.2, 6.0, 6.1, 7.0, 7.1, 7.2, 7.3, 7.4, 8.0, 8.1, 8.2, 8.3, 8.4, 9.0, 9.1, 9.2,10.0, 10.1, 10.2, 10.3, 10.4, 10.5, 10.6

APPENDIX B

Significance test for inequality index

The t value was calculated based on the following formula:

$$t = \frac{II}{\sqrt{var(\widehat{II})}}$$

degrees of freedom= $n - 1$

To calculate the 95% confidence interval, the following equation was used:

$$C \pm 1.96 \times \sqrt{var(II)}$$

APPENDIX C

Inequality curves

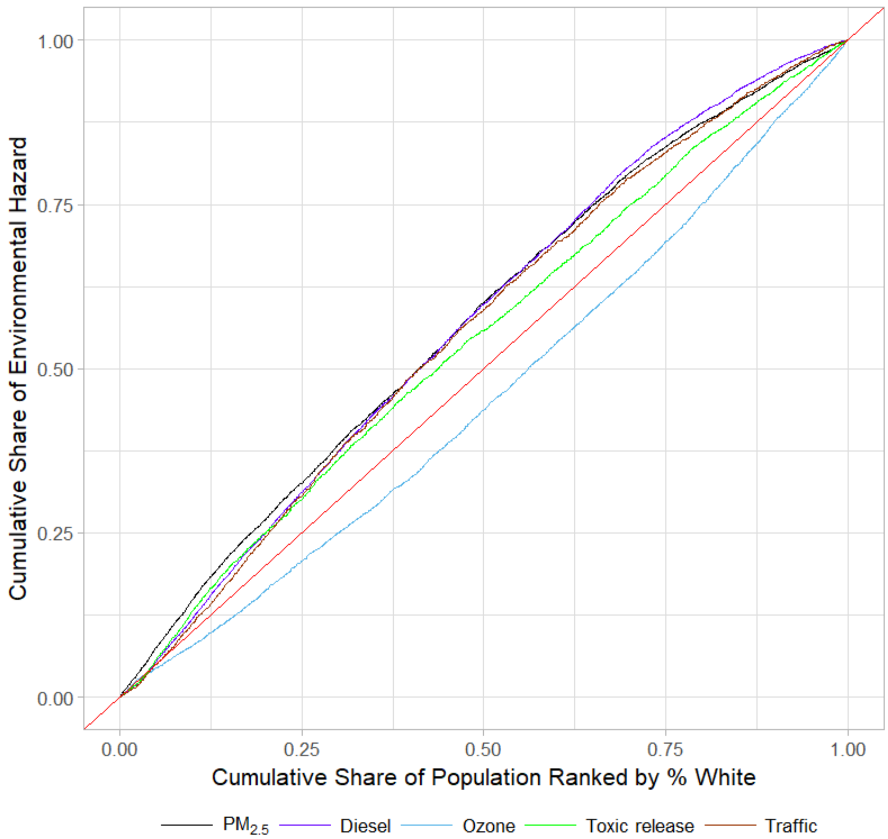

Figure C-1. Indicators for the Environmental Exposure category for all census tracts ranked by % White.

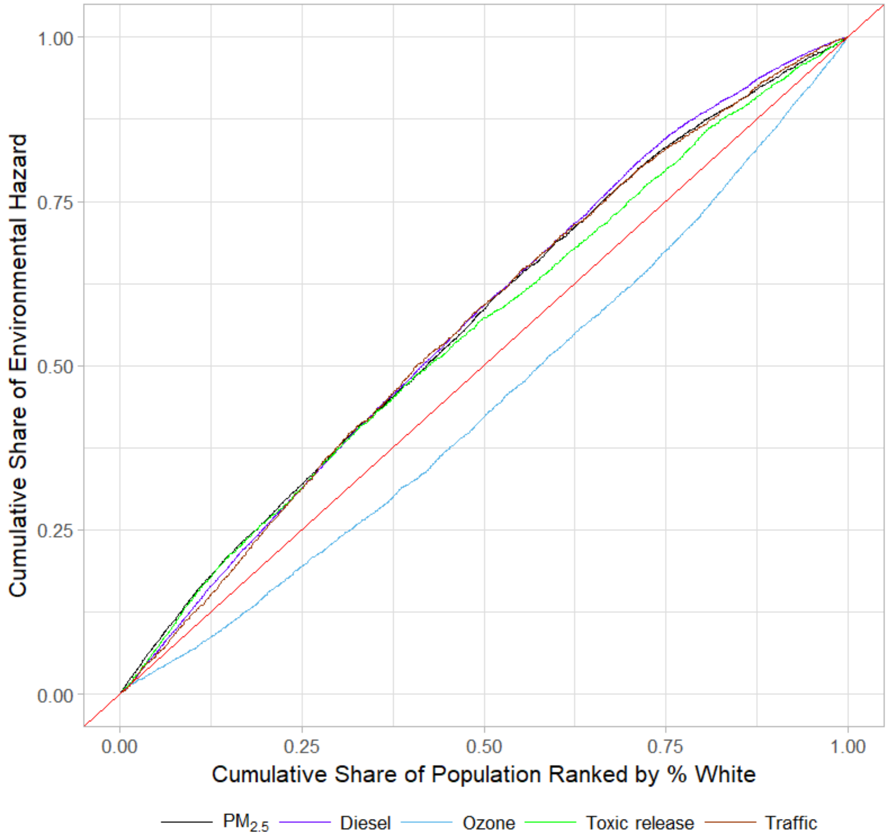

Figure C-2. Indicators for the Environmental Exposure category for urban census tracts ranked by % White.

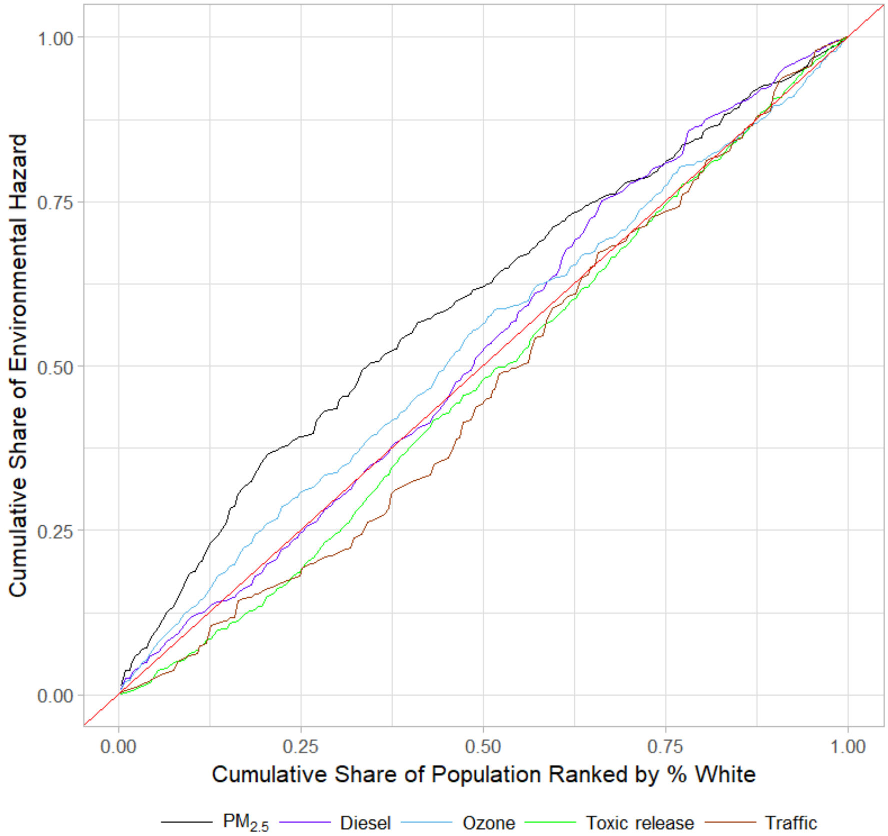

Figure C-3. Indicators for the Environmental Exposure category for rural census tracts ranked by % White.

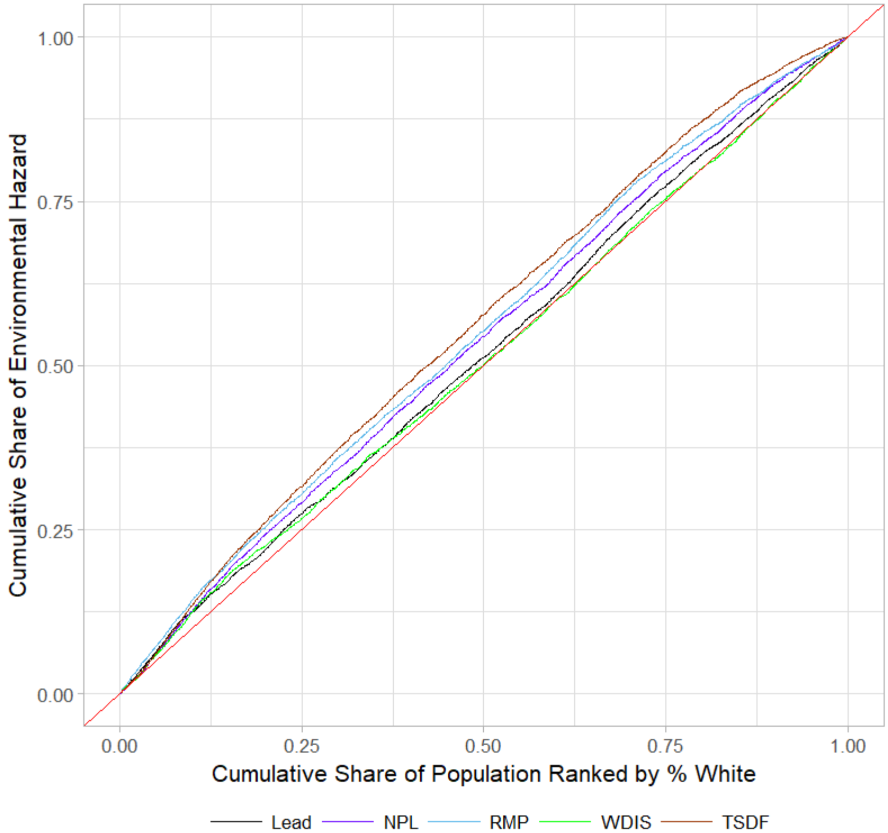

Figure C-4. Indicators for the Environmental Effects category for all census tracts ranked by % White.

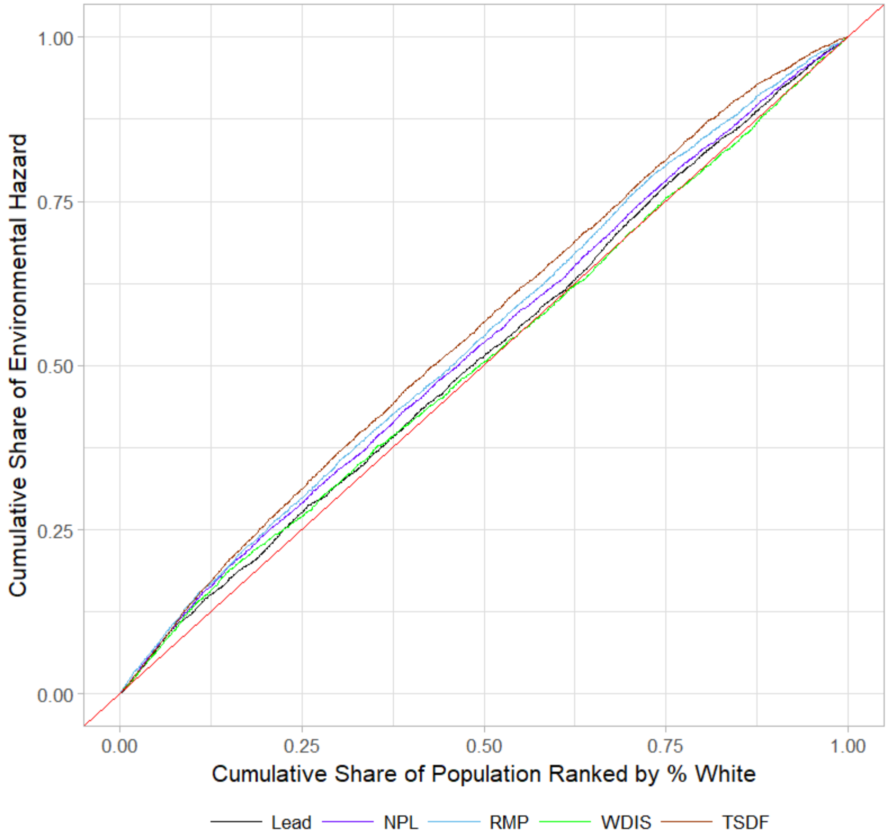

Figure C-5. Indicators for the Environmental Effects category for urban census tracts ranked by % White.

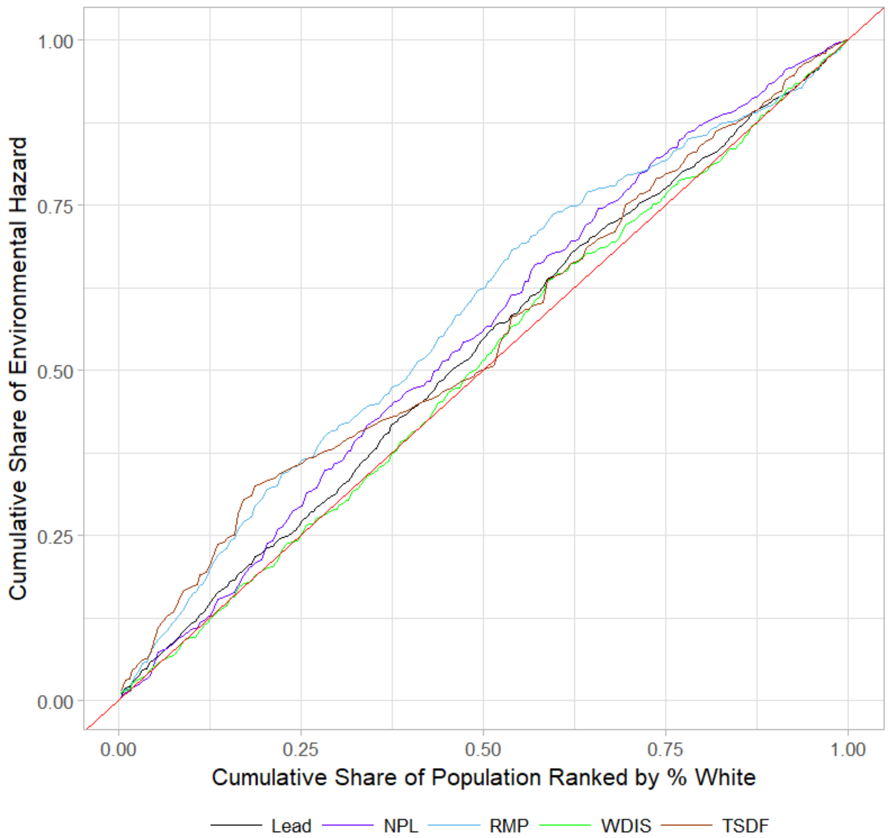

Figure C-6. Indicators for the Environmental Effects category for rural census tracts ranked by % White.

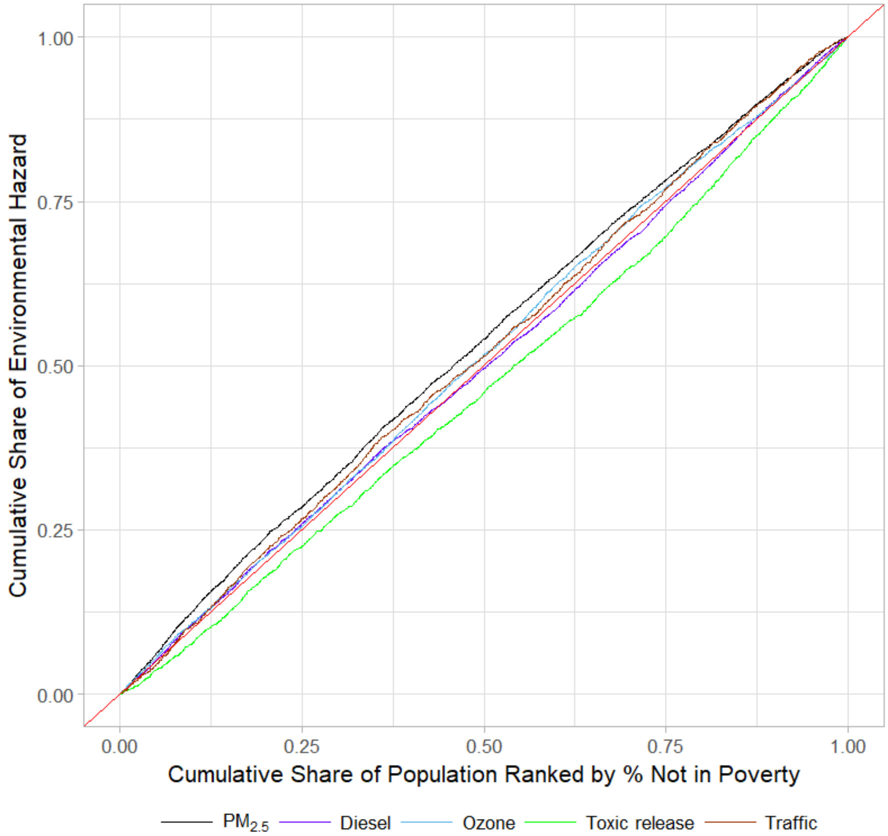

Figure C-7. Indicators for the Environmental Exposure category for all census tracts ranked by % not in poverty.

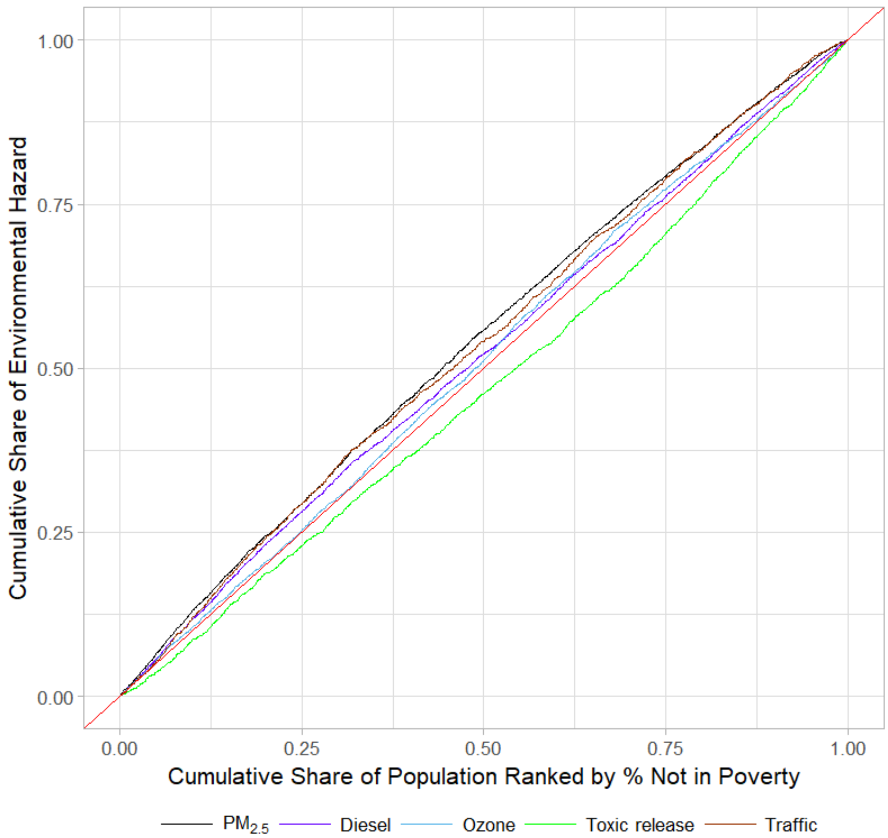

Figure C-8. Indicators for the Environmental Exposure category for urban census tracts ranked by % not in poverty.

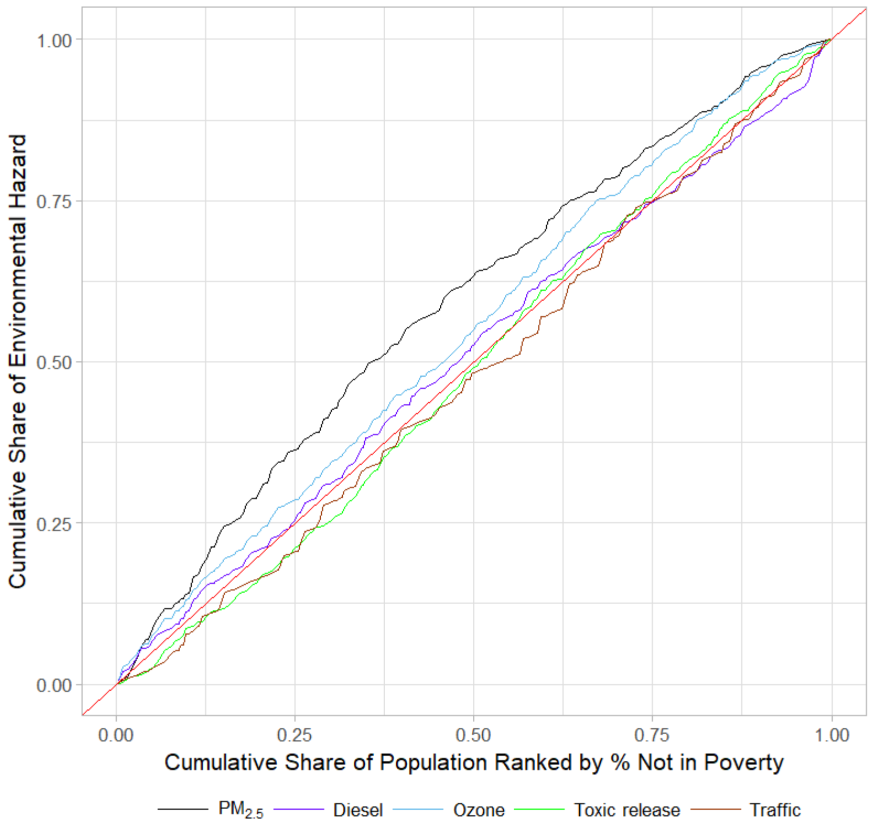

Figure C-9. Indicators for the Environmental Exposure category for rural census tracts ranked by % not in poverty.

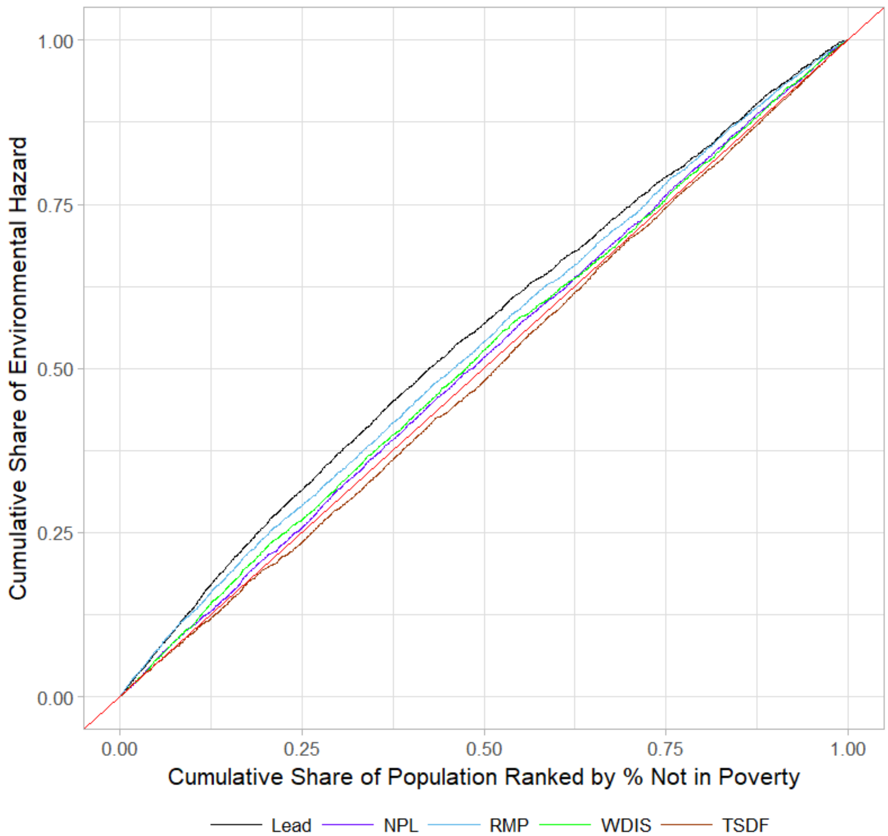

Figure C-10. Indicators for the Environmental Effects category for all census tracts ranked by % not in poverty.

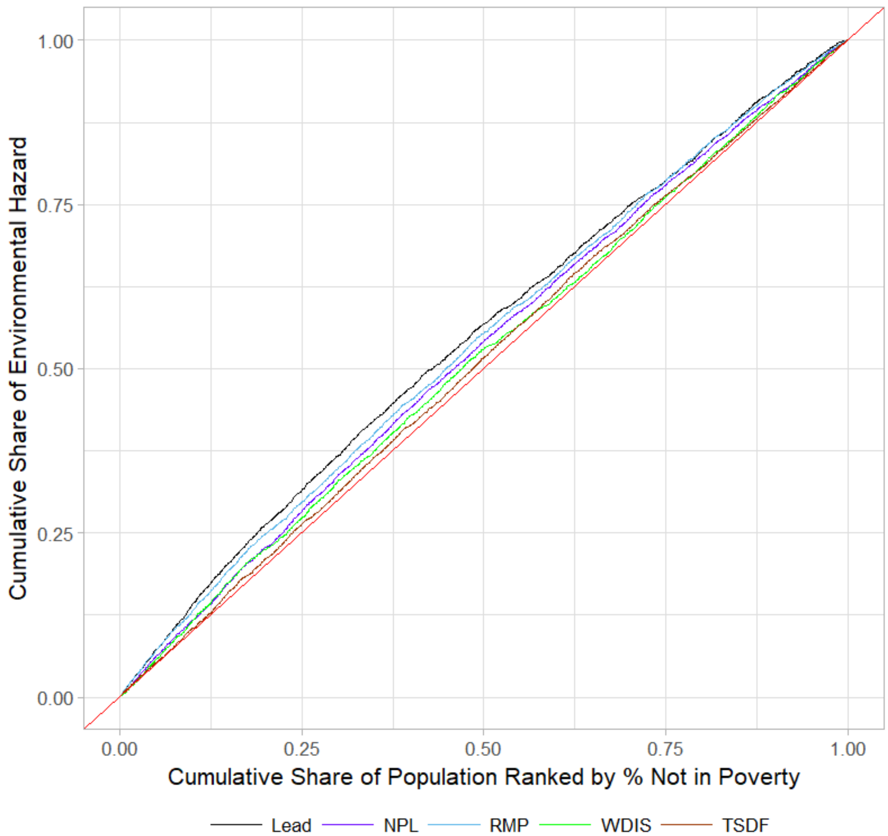

Figure C-11. Indicators for the Environmental Effects category for urban census tracts ranked by % not in poverty.

Figure C-12. Indicators for the Environmental Effects category for rural census tracts ranked by % people over the age of five.

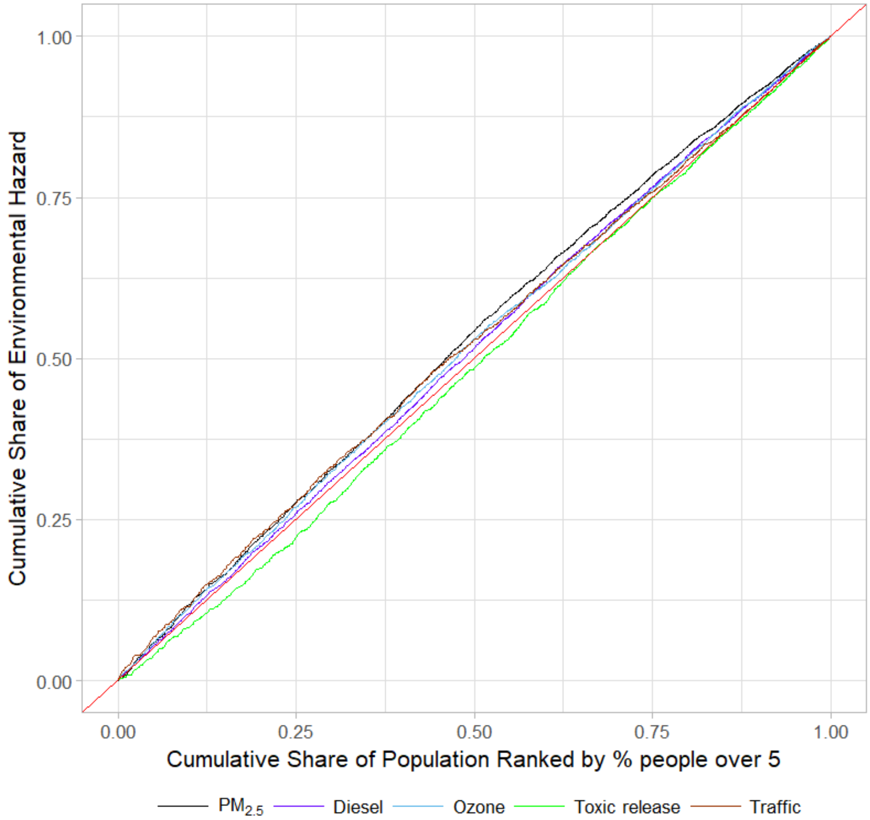

Figure C-13. Indicators for the Environmental Exposure category for all census tracts ranked by % people over the age of five.

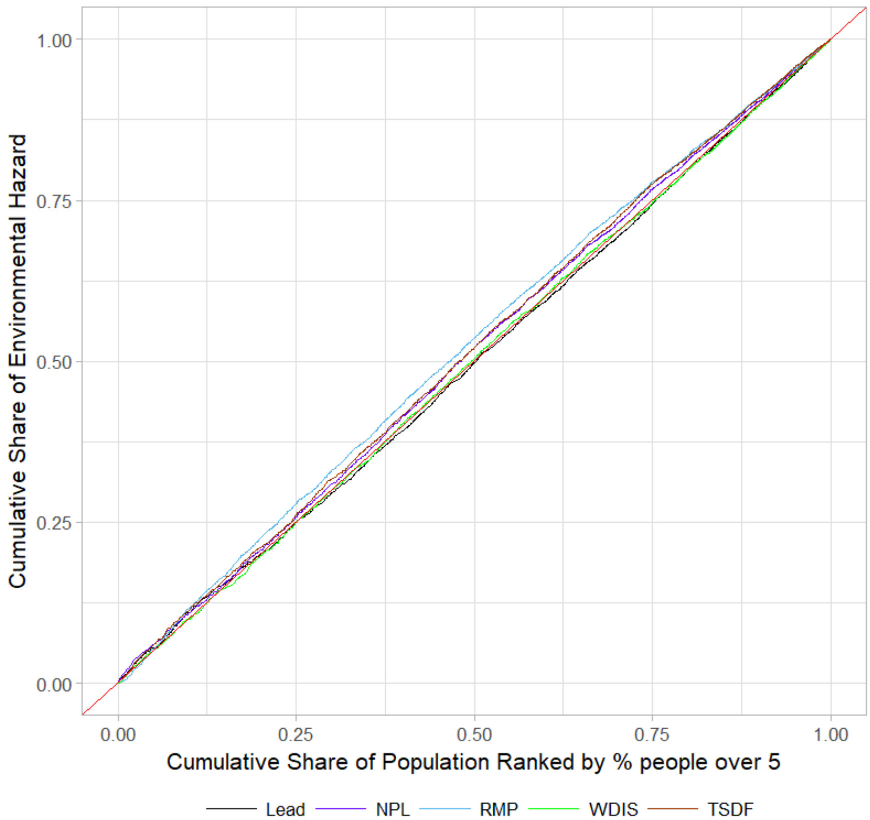

Figure C-14. Indicators for the Environmental Effects category for all census tracts ranked by % % people over the age of five.

APPENDIX D

Interview guide

The purpose of this interview is to get information about your thoughts and experiences about the HAPI partnership. We are hoping to interview all of our partners in the project, and will combine the responses for the analysis. Nothing you say will ever be identified with you personally. Your insight is important to learn about how this partnership worked together. If you have any questions about why I am asking something, feel free to ask. Any questions before we begin? Is it ok to audio-record this interview?

1. How effective was the partnership in getting the work done?
    a. Anything that helped the group get the work done? Hinder?
2. What was the impact of the partnership on [you or your organization]'s ability to address pediatric asthma?
    a. Capacity of you or your organization? Did you learn anything you found useful? What do you think your organization learned from this partnership?
3. How has the partnership affected the community's ability to take action, create change, and exercise power? Examples?
    a. What do you think could have affected the community's ability to take action?
4. How would you rate the level of collaboration on this project among partners? (5 being the highest amount of collaboration and 1 being the lowest amount of collaboration)
5. Tell me why you gave that rating. Walk me through why you gave that number. What were the best parts of working together? What was difficult/challenging?

Over the course of the project, the group made recommendations about how to communicate better as a team.

6. How would you rate communication between team members at the start of the project? What about now? (5 being the highest amount of effective communication and 1 being the lowest amount of effective communication)
    a. Tell me why you answered that way.

Trust is important in any partnership and relationship.

7. How would you rate trust in this project? (5 being the highest amount of trust, 1 being the lowest)? Tell me why you gave that rating. What is an example of what trust looks/looked like in this partnership or project?
    a. Can you walk me through why you gave that number? What does trust or distrust mean to you, and how would you describe trust in this project or partnership?
8. What did you hope this project would accomplish? Has the project failed to meet, met, or exceeded your expectations? Why do you say that?
9. Do you think this partnership enhanced or made better some aspects of the project – such as recruiting and keeping participants in the projects? How do you think the partnership influenced how and what we measured in the study?
10. If you could repeat this study, what would you do differently? What would you keep the same?
11. Is there anything else you would like to mention?

Thank you for your time.

Interview guide (Spanish)

El propósito de esta entrevista es obtener información sobre sus pensamientos y experiencias sobre la asociación HAPI. Esperamos entrevistar a todos nuestros socios/miembros de la asociación en el proyecto y combinaremos las respuestas para el análisis. Nada de lo que diga sera identificado con usted personalmente. Su conocimiento es importante para aprender cómo esta asociación trabajó en conjunto. Si tiene alguna pregunta sobre por qué estoy preguntando algo, no dude en preguntar. ¿Alguna pregunta antes de comenzar? ¿Está bien si grabamos la entrevista en audio?

1. ¿Qué tan efectiva fue la asociación (o el grupo) para hacer el trabajo?
   a. *Siguiente Pregunata (Indague/incite): ¿Hay algo que haya ayudado al grupo a realizar el trabajo? ¿Hay algo que haya impedido al grupo a realizar el trabajo?*
2. ¿Cuál fue el impacto de la asociación en usted o en la capacidad de Radio KDNA para abordar el asma pediátrica?
   a. *Siguiente Pregunata (Indague/incite): ¿Cuál fue la capacidad de usted o de su organización? ¿Aprendio algo que encontro útil? ¿Qué cree que aprendió su organización de esta asociación?*
3. ¿Cómo ha afectado la asociación a la capacidad de la comunidad para tomar medidas, crear cambios y ejercer poder? Me puede Ejemplos?
   a. *Siguiente Pregunata (Indague/incite): ¿Qué cree que podría haber afectado la capacidad de la comunidad para tomar medidas?*
4. ¿Cómo calificaría el nivel de colaboración entre los miembros de la asociación en este proyecto? (5 es la cantidad más alta de colaboración y 1 la cantidad más baja de colaboración)
5. ¿Me puede decir por qué dio esa calificación? *Siguiente Pregunata (Indague/incite): ¿Me puedo explicar por qué le dio ese número como calificación? ¿Cuáles fueron las mejores partes de trabajar juntos? ¿Cuáles partes de trabajar juntos fueron difícil?*

A lo largo del proyecto, el grupo hizo recomendaciones sobre cómo comunicarse mejor como equipo.

6. ¿Cómo calificaría la comunicación entre los miembros del equipo al inicio del proyecto? ¿Qué le parece ahora? (5 es la cantidad más alta de comunicación efectiva y 1 la cantidad más baja de comunicación efectiva)
   a. *Siguiente Pregunata (Indague/incite): ¿Me puede decir por qué respondió de esa manera?*

La confianza es importante en cualquier asociación y relación.

7. ¿Cómo calificaría la confianza en este proyecto? (5 siendo la cantidad más alta de confianza, 1 siendo la más baja)? ¿Me puede explicar por qué le dio esa calificación? ¿Cuál es un ejemplo de cómo se ve o se vio la confianza en esta asociación o proyecto?
   a. *Siguiente Pregunata (Indague/incite): ¿Puede explicarme por qué le dio esa calificación? ¿Qué significa para usted la confianza o la desconfianza, y cómo describiría la confianza en este proyecto o asociación?*
8. 8a. ¿Hay algo que usted esperaba que este proyecto lograría?

8b. ¿Usted cree que este proyecto no cumplió sus expectativas? ¿Usted cree que este proyecto sí cumplió sus expectativas? ¿Usted cree que este proyecto superó sus expectativas? ¿Me puede explicar por qué cree eso?

9. 9a. ¿Usted cree que esta asociación ha mejorado algunos aspectos del proyecto, como reclutar y mantener a los participantes en el proyecto?
   9b. ¿Cómo cree que la asociación influyó la forma en cómo medimos y lo que medimos en el estudio?
10. Si pudiera repetir este estudio, ¿qué haría de manera diferente? ¿Qué mantendría igual?
11. ¿Hay algo más que le gustaria mencionar?

Gracias por su tiempo.