FACTORS ASSOCIATED WITH ADULT ASTHMA RELATED EMERGENCY ROOM DISCHARGES IN NORTH CENTRAL TEXAS IN 2010 - 2014

by

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Onward!

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Abstract

Factors Associated With Adult Asthma Related Emergency Room Discharges In North Central Texas in 2010 – 2014

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Asthma is a common chronic disease of the airways characterized by recurrent reversible airway obstruction. More than 25 million Americans have asthma. In this study, factors associated with adult asthma related emergency room discharges in North Central Texas during the period 2010 – 2014 were investigated. This study involved a total of 78,444 cases of adult asthma hospital discharges obtained from the Dallas-Fort-Worth-Hospital Council Foundation, socioeconomic indicators from the U.S. Bureau of Census databases, and air pollution and meteorological data obtained from the Texas Commission on Environmental Quality (TCEQ).

A number of important relationships underpinning asthma hospital visits in NCT were identified. The NCT asthma discharge data exhibited a clear gender switch, demonstrated by the larger percentage of female asthma patients in all age groups; they also confirmed the reduced impact of asthma post menopause. The factors explored in relation to environmental correlates of asthma belonged to two categories: air pollution and socioeconomic status. Relationships between common outdoor air pollutants and asthma discharges was studied via the utilization of Principal Component Analysis (PCA), Hierarchical Agglomerative Clustering Analysis (HACA), Pearson correlation, and hot spot and cluster and outlier analyses. No strong and statistically significant correlation between outdoor air pollution and asthma discharges could be confirmed. Air pollution was concluded to not be a driver of emergency room visits for asthma. The association between socioeconomic status and asthma was revealed via multiple statistical analyses, namely Pearson correlation, hot spot and cluster and outlier analyses, and the construction of a socioeconomic deprivation index (SDI). Each analysis confirmed the statistically significant association between asthma discharge and socioeconomic status. The construction of SDI further suggested social standing disparities at the Census tract and county level of asthma patients.

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Chapter 1

INTRODUCTION

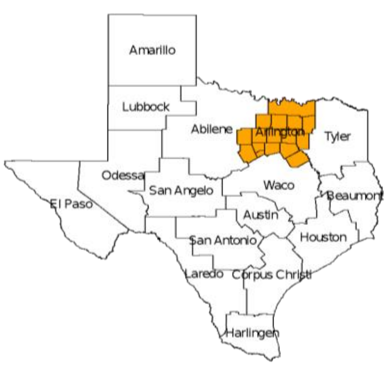
1.1. Study Area

Texas, located in the west-south-central region of the United States, is the second most populous state in the United States (Gorai et al., 2015). As of July 2018, Texas has a population estimate of 28,701,845 (QuickFacts). Covering a massive 696,241 square kilometres, Texas ranks 2nd by area, only after Alaska (Gorai et al., 2015). The North Central Texas study area has a climate that is subtropical with characteristic cool winters and hot summers (Texas). Average annual precipitation also varies considerably, ranging from less than 10 inches to more than 50 inches (Texas). The variability in the state's climate is determined by three main geographic features. The Gulf of Mexico, located toward the southeast of the state, provides the state with a great deal of moisture (Texas). The Rocky Mountains, lying in the North West of Texas, block moist Pacific air and directs air masses southwardly during the winter months (Texas). The flatness characteristic of the North American continent permits the ease in north-south movement of the continental air masses (Texas). These factors largely contribute to the state's east-west precipitation variation and escalates Texas's vulnerability in allowing various extreme weather events such as heat waves, tornadoes, droughts, and hurricanes to occur frequently (Texas).

North Central Texas (NCT), has been designated as Region 4 (of 24 separate regions) in Texas (North Central Texas Council of Governments). Demarcated in January 1966, the NCT covers an area of 12,321 square miles and has a population estimate of 7,594,879, as of January 2018, as shown in Table 1-1 (North Central Texas Council of Governments; Texas Demographic Center). This makes NCT the most populous region in the state of Texas, indicated in Table 1-1 (Texas

Demographic Center). NCT comprises 16 counties: Dallas, Denton, Hood, Hunt, Collin, Johnson, Palo Pinto, Parker, Navarro, Rockwall, Tarrant, Somervell, Wise, Kaufman, Ellis, and Erath, as illustrated in Figure 1-1 (c) (North Central Texas Council of Governments).

(a)



(b)

(c)

Figure 1-1: Study area

(a) USA's State Boundary

(b) 24 Regions in Texas

(c) 16 Countries in the North Central Texas

Texas Demographic Center Population Estimates Program July 1, 2017 and January 1, 2018 Estimates of the Total Population of Councils of Governments and 2010-2017 and 2010-2018 Population Change for All Councils of Governments in Texas

Council of Governments	Revised 2010 Census Count	July 1, 2017 Population Estimate	January 1, 2018 Population Estimate	Numerical Change 2010-17	Numerical Change 2010-18	Percent Change 2010-17	Percent Change 2010-18
Alamo Area	2,249,718	2,584,579	2,608,094	334,861	358,376	14.9	15.9
Ark-Tex	281,947	289,778	289,834	7,831	7,887	2.8	2.8
Brazos Valley	319,447	354,605	356,493	35,158	37,046	11.0	11.6
Capital Area	1,830,003	2,235,029	2,280,566	405,026	450,563	22.1	24.6
Central Texas	449,641	487,175	489,049	37,534	39,408	8.3	8.8
Coastal Bend	571,280	596,270	596,982	24,990	25,702	4.4	4.5
Concho Valley	154,192	159,827	158,891	5,635	4,699	3.7	3.0
Deep East Texas	378,477	387,556	387,492	9,079	9,015	2.4	2.4
East Texas	829,749	870,280	873,300	40,531	43,551	4.9	5.2
Golden Crescent	188,626	198,347	198,671	9,721	10,045	5.2	5.3
Heart of Texas	349,273	370,696	372,422	21,423	23,149	6.1	6.6
Houston-Galveston	6,087,133	7,033,951	7,088,057	946,818	1,000,924	15.6	16.4
Lower Rio Grande Valley	1,203,127	1,307,120	1,308,607	103,993	105,480	8.6	8.8
Middle Rio Grande	167,010	175,451	177,178	8,441	10,168	5.1	6.1
Nortex	222,860	222,572	222,575	-288	-285	-0.1	-0.1
North Central Texas	6,539,950	7,515,233	7,594,879	975,283	1,054,929	14.9	16.1
Panhandle	427,927	438,275	436,449	10,348	8,522	2.4	2.0
Permian Basin	417,679	478,058	479,011	60,379	61,332	14.5	14.7
Rio Grande	825,913	870,697	871,735	44,784	45,822	5.4	5.5
South East Texas	388,745	395,346	398,055	6,601	9,310	1.7	2.4
South Plains	411,659	434,180	434,565	22,521	22,906	5.5	5.6
South Texas	330,590	362,001	363,594	31,411	33,004	9.5	10.0
Texoma	193,229	204,749	206,364	11,520	13,135	6.0	6.8
West Central Texas	327,390	332,821	332,733	5,431	5,343	1.7	1.6
State of Texas	25,145,565	28,304,596	28,525,596	3,159,031	3,380,031	12.6	13.4

Source: Texas Demographic Center, Population Estimates and Projections Program

Table 1-1: Texas regions' population estimate (Texas Demographic Center)

Table 1-2 records the population estimates as of 2018 for all 16 counties in the NCT, based on the data obtained from the U.S. Census Bureau. Dallas county was the most populous county in the NCT, with an estimated population of 2,637,772. The county with the smallest population was Somervell, with 9016 residents. Somervell, Palo Pinto, Erath, and Navarro are rural counties while the rest of the counties are designated urbanized areas, based on the classification of the U.S. Census Bureau (Urban and Rural). According to this classification, an urbanized area has at least 50,000 or more people while a rural area encompasses all population, territory, and housing not counted as part of an urban area (Urban and Rural).

County	Total	Male	Female
Dallas	2637772	1301788	1335984
Tarrant	2084931	1020097	1064834
Collin	1005146	494802	510344
Denton	859064	422725	436339
Ellis	179436	88513	90923
Johnson	171361	85449	85912
Parker	138371	68872	69499
Kaufman	128622	63360	65262
Rockwall	100657	49740	50917
Hunt	96493	47593	48900
Wise	68305	34159	34146
Hood	60537	29601	30936
Navarro	49565	24313	25252
Erath	42446	20784	21662
Palo Pinto	28875	14235	14640
Somervell	9016	4442	4574

Table 1-2: NCT population estimate as of 2018, U.S. Census Bureau

All 16 counties in the NCT belong to the Health Service Region 3, administered by the Texas Department of State Health Services (Texas Department of State Health Services Public Health Regions 2 & 3). Region 3 consists of 19 counties, with 16 NCT counties and Cooke, Grayson, and Fannin, as indicated in Figure 1-2.

Figure 1-2: Texas Department of State Health Services' Region 2 and 3

(Adapted from Region 2-3 Map)

Out of all the 16 counties in the NCT, 11 counties belong to the Dallas-Fort Worth-Arlington metropolitan statistical area (Table 1-3), as delineated by the United States Office of

Management and Budget, applying to U.S. Census Bureau data (Metropolitan and Micropolitan). For any region to be assigned a metropolitan statistical area, it has to meet two standards: there is a core area comprising a considerable population centre; the neighbouring counties or county equivalents have a high level of social and economic integration with that population nucleus (Metropolitan and Micropolitan).

Metropolitan Statistical Area	County
Dallas-Fort Worth-Arlington, TX	Collin County
Dallas-Fort Worth-Arlington, TX	Dallas County
Dallas-Fort Worth-Arlington, TX	Denton County
Dallas-Fort Worth-Arlington, TX	Ellis County
Dallas-Fort Worth-Arlington, TX	Hunt County
Dallas-Fort Worth-Arlington, TX	Kaufman County
Dallas-Fort Worth-Arlington, TX	Rockwall County
Dallas-Fort Worth-Arlington, TX	Johnson County
Dallas-Fort Worth-Arlington, TX	Parker County
Dallas-Fort Worth-Arlington, TX	Tarrant County
Dallas-Fort Worth-Arlington, TX	Wise County

Table 1-3: Dallas-Fort Worth-Arlington Metropolitan Statistical Area

The Dallas-Fort Worth-Arlington (DFA) metropolitan area had the largest growth in the United States, according to the U.S. Census Bureau Population Estimates in 2018 (United States Census

Bureau). Figure 1-3 displays the metropolitan statistical areas with the higest cumulative total population change from 2010 to 2014 and the DFA was the one with the highest growth, followed by Houston-The Woodlands-Sugar Land (HWS) and Phoenix-Mesa-Scottsdale (PMS) metropolitan statistical areas. The total population change of DFA during this period was larger than the sum of the last two metropolitan statistical areas in the list and was more than 1.5 times as much as the total population change of the PMS metropolitan statistical area (Figure 1-3).

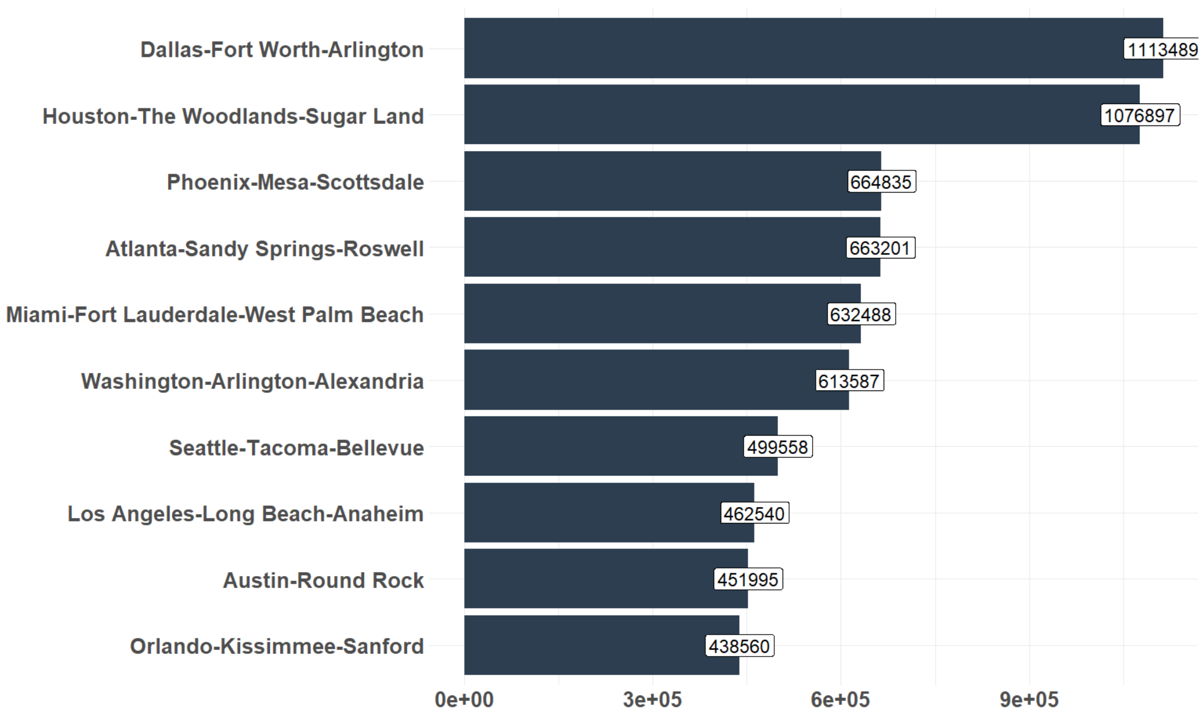


Figure 1-3: Metropolitan statistical area with the highest cumulative total population change from April, 2010 to July 1, 2018, U.S. Census Bureau

In addition, Tarrant, Dallas, Denton, and Collin were in the 10 counties with the highest numeric population change from July 1, 2016 to July 1, 2017, as shown in Figure 1-4 (Texas Keeps Getting Bigger).

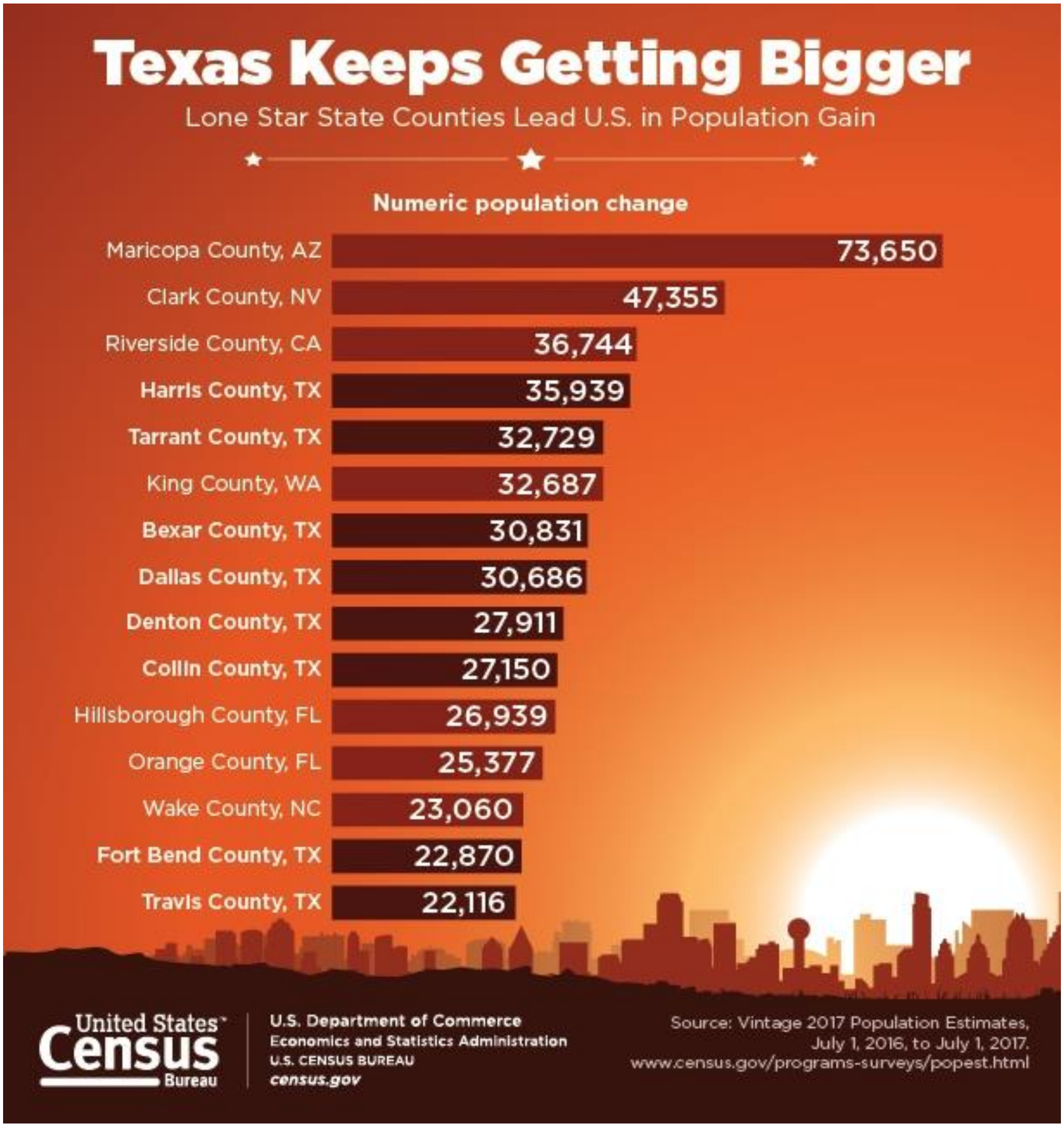


Figure 1-4: Counties with the highest numeric population change from July 1, 2016 to July 1, 2017 (Adapted from the U.S. Census Bureau)

More than 50% of the increase in population in DFA came from immigration, as denoted in Figure 1-5 and Table 1-4. Eight out of these 10 metropolitan statistical areas, except for Washington-Arlington-Alexandria and Los Angeles-Long Beach-Anaheim, depended more heavily on immigration than on natural increase for population growth . DFA is the sixth highest metropolitan statistical area when it comes to population increase by immigration (Table 1-4).

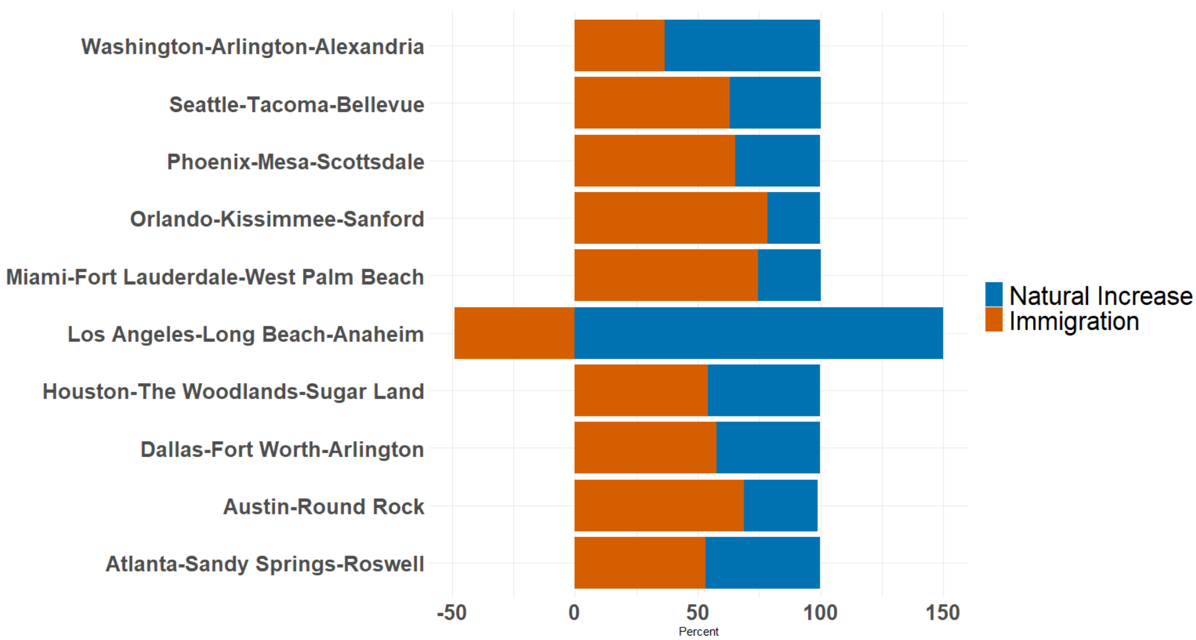


Figure 1-5: Percentage of factors contributing to cumlative total population change from April, 2010 to July 1, 2018 of top 10 metropolitan statistical areas, U.S. Census Bureau

Metropolitan Statistical Area	Natural Increase (%)	Immigration (%)
Orlando-Kissimmee-Sanford	21.31	78.44
Miami-Fort Lauderdale-West Palm Beach	25.31	74.69
Austin-Round Rock	30.12	68.79
Phoenix-Mesa-Scottsdale	34.26	65.45
Seattle-Tacoma-Bellevue	36.77	63.22
Dallas-Fort Worth-Arlington	42.18	57.63
Houston-The Woodlands-Sugar Land	45.53	54.24
Atlanta-Sandy Springs-Roswell	46.81	53.07
Washington-Arlington-Alexandria	62.94	36.70
Los Angeles-Long Beach-Anaheim	150.02	-49.02

Table 1-4: Percentage of factors contributing to cumlative total population change from April, 2010 to July 1, 2018 of top 10 metropolitan statistical areas

1.2. Asthma

Asthma, a clinical pulmonary chronic disease characterized by sporadic wheezing, hyperresponsiveness and reversible obstruction in the airways, affects individuals of all ages (Gorai et al., 2014; Johnston and Holgate, 2002). Originated from the Greek word "shortness of breath," asthma was initially referred to as a variety of clinical conditions of the lung and heart (Holgate, 2011). This broader definition of asthma was subsequently restricted in the mid-nineteenth century when Dr. Henry Hyde Salter described asthma as a disease caused by airflow obstruction in his publication "On Asthma and its Treatment" (as cited in Holgate, 2011).

Currently, there is no cure for asthma and the exact causes of this major respiratory disease is unknown (Wu, 2014). Typically, for the majority of people with asthma, symptom reduction involves avoidance of the triggers of asthma (Wu, 2014). The common asthma triggers are believed to be airway irritants (i.e. air pollutants), respiratory infections, allergens, stress factors, and even exercise (as cited in Akinbami et al., 2011). Aside from such environmental triggers, unmodifiable elements such as genes, gender, age, and socioeconomic factors are correspondingly known to be drivers of asthma (Turner, 2012). The asthma burden disproportionately affects populations within certain geographic areas, of specific socioeconomic status, and possessing defined demographic properties (Wu, 2014).

As of 2008, there were approximately 300 million people from all ages and all ethnic backgrounds in the world having asthma and recent decades have witnessed a steady rise in asthma prevalence in both adults and children (Bahadori et al., 2009). The Global Initiative for Asthma (GINA) credits such increase to the adoption of modern style of living and urbanization (Masoli et al., 2004). With the predicted rise in urbanization from 45% to 59% by 2025, it is projected that compared to 2009, there will be approximately 100 more million people with asthma (Masoli et al., 2004). Moreover, annually, there are 250,000 deaths due to this chronic condition (as cited in Gorai et al., 2014).

As one of the most widespread respiratory conditions, asthma affects roughly 1/3 of children and 1/10 of adults in the Western countries (Jackson, 2011). Among children, regardless of age, asthma is a dominant cause of hospitalization; specifically, among children 1 – 9 years of age, coupled with infections, asthma accounts for approximately 30% to 50% of all hospitalizations (Chung et al., 2015).

In addition to causing morbidity burden, asthma incurs a hefty medical cost, estimated at over $1 billion in 2005 (Wang et al., 2005). A detailed investigation of direct and indirect asthma-related costs was reported by Bahadori et al. (2009). The authors revealed that in spite of the readily available preventive therapies, asthma-related costs were continuously on the rise (Bahadori et al., 2009). In this systematic review of sixty-eight studies, medications and hospitalization were concluded to be the most significant direct costs, while school and work absenteeism was responsible for most of the indirect costs (Bahadori et al., 2009). Not only did asthma-related costs steadily increase, they were one of the highest compared to many other chronic diseases (Bahadori et al., 2009). In the U.S, in 2007, there was an alarming 1.75 million asthma-related emergency room visits and in 2008, there were 14.2 million work days and 10.5 million school days missed due to asthma (Akinbami et al., 2011). Furthermore, a major indirect cost concept used by GINA was the disability-adjusted life years (DALYs), as quoted in Masoli et al. (2004). As of 2004, worldwide asthma-related DALYs lost was 15 million cases per year, which was similar to that of schizophrenia, diabetes, or cirrhosis of liver (Masoli et al., 2004). GINA also reported there was one asthma-related death for every 250 deaths worldwide (Masoli et al., 2004). What was concerning was a great number of those deaths were preventable, had it not been for the slowness in obtaining treatment and substandard level of care in many instances (Masoli et al., 2004).

1.3. Asthma Surveillance System

Asthma data at both the national and state level is collected via multiple surveillance systems administered by the Centers for Disease Control and Prevention (CDC) (Asthma Surveillance Data). The asthma surveilance system is part of the effort established by the CDC’s National Asthma Control Program (NACP) which was founded in 1999 (CDC's National Asthma Control

Program). The states and territories funded by the NACP during the period 2009 – 2014 are shown in Figure 1-6 (Successes of the National Asthma Control Program, 2009-2014).

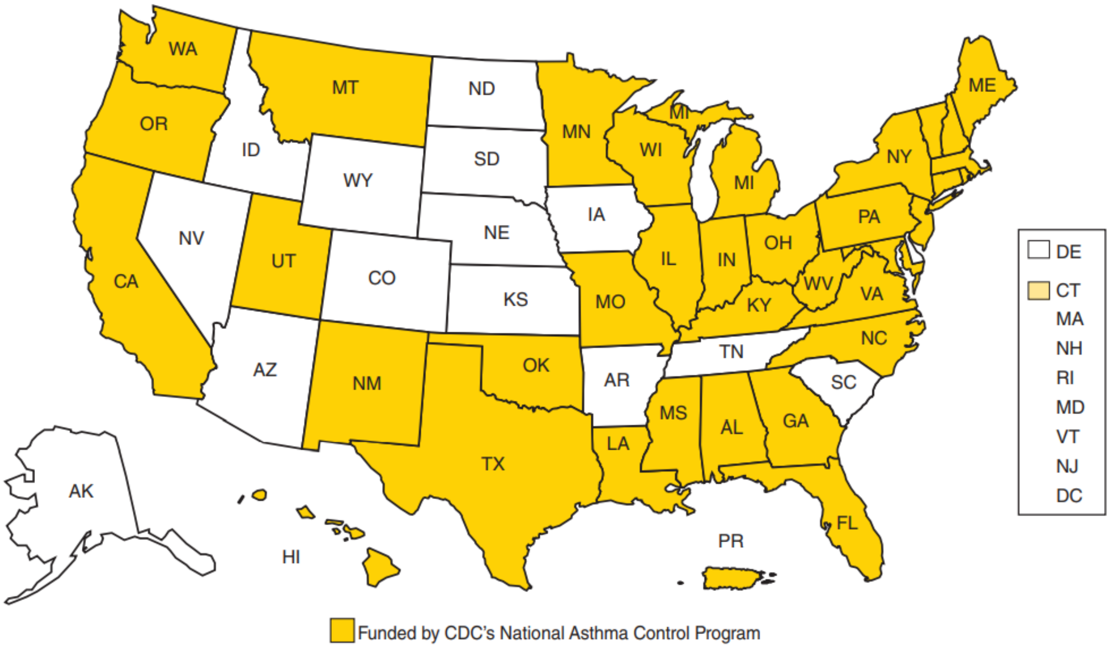


Figure 1-6: States and territores funded by NACP, 2010 – 2014 (adapted from the CDC)

NACP's overarching stated goal was to provide asthma management tools for asthma patients via the national asthma surveillance system and through the funding provided to the U.S. states and territories (Breathing easier). Without a proper and effective asthma management system, asthma can cause more hospitalization, emergency department visits, and mortality, among many other things (Breathing easier).

At the national level, the asthma surveillance data on emergency room visits, hospitalizations, education on self-management, asthma-related deaths, etc. is collecded from the Vital Statistics System and the National Center for Health Statistics (NCHS) surveys (Asthma Surveillance

Data). At the state level, asthma data is amassed via the implementation of the state-based BRFSS Asthma Call-back Survey (ACBS) and the Behavioral Risk Factor Surveillance System (BRFSS) (Asthma Surveillance Data).

Out of all the asthma-related data recorded by the asthma surveillance system, asthma prevalence, widely used in a multitude of publications, denotes the severity of the burden of asthma. Asthma prevalence is the percentage estimate of U.S. population with asthma; more specifically, it describes the percentage of the U.S. population who had asthma when the survey was carried out and had had an asthma diagnosis (Asthma Prevalence and Health Care Resource Utilization Estimates, United States, 2001-2017).

Even though the asthma prevalence concept is widely used in many asthma studies, it is essential to note that the true asthma prevalence is a challenge to determine due to the lack of a widely accepted single diagnostic criterion, a variety of asthma classification methods, and various symptom interpretations across regions (Masoli et al., 2004). Nevertheless, it is a perfectly acceptable notion to be used.

1.4. Asthma Prevalence in the U.S.

In the U.S., adult asthma prevalence has reached the highest level, distinctly demonstrated by an increase of 33% from 2000 to 2009 (Zhang et al., 2013). In 2009, 19.5 million people in the U.S., accounting for 8.4% of U.S. adults, reported having asthma, a significant gain of 4.8 million persons from 2000 (Zhang et al., 2013). The adult asthma prevalence during 2001-2017 increased from 6.9% in 2001 to 7.7% in 2017, a major 11.6 % increase (Figure 1-7).

Interestingly, childhood asthma prevalence showed a moderate decrease from 8.7% in 2001 to 8.4% in 2017 (Figure 1-7). The corresponding total asthma prevalence from 2001 to 2017 had mostly and consistently increased from 7.4% in 2001 to 7.9 % in 2017 (Figure 1-7). Figure 1-7 illustrates the total, adult, and children asthma prevalence from 2001 to 2017 (Asthma Prevalence).

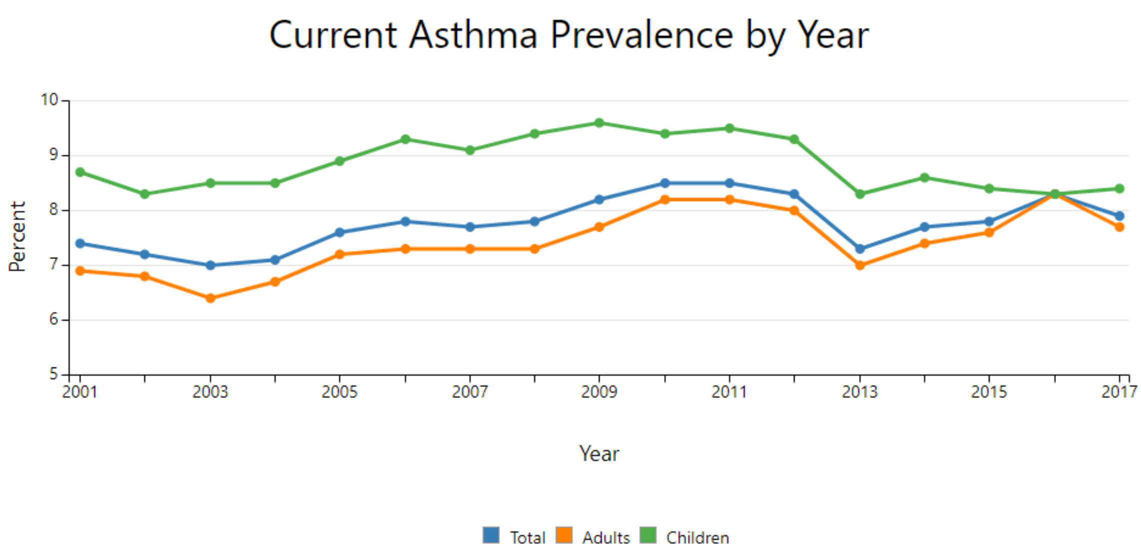


Figure 1-7: Asthma prevalence (Adapted from the CDC)

Prior to this period, the study by Akinbami et al. (2011) reported a steady upsurge in asthma prevalence from 1980 to 2009 with an annual hike of 1.2% from 2001 to 2009 (Figure 1-8). It is also alarming to note that as of 2009, the asthma attack prevalence, defined as the population percentage with more than one asthma attack the prior year, was at a high rate of 4.2%, meaning that 52% of those with asthma for that year had attacks or were prone to severe outcomes (i.e. hospitalization or ER visits) (Akinbami et al., 2011). For clinical asthma prevalence, the U.S. is among the few countries with an asthma prevalence of more than 10% of the population (Figure

1-9) (Masoli et al., 2004). Also of concern is the asthma mortality rate. Although the U.S. is not the country with the highest mortality rate, the U.S. rate is significant. As reported in Masoli et al. (2004), there were approximately 5.1 – 10.0 fatalities in the 5- to 34- year age group out of 100,000 asthmatics (Figure 1-10).

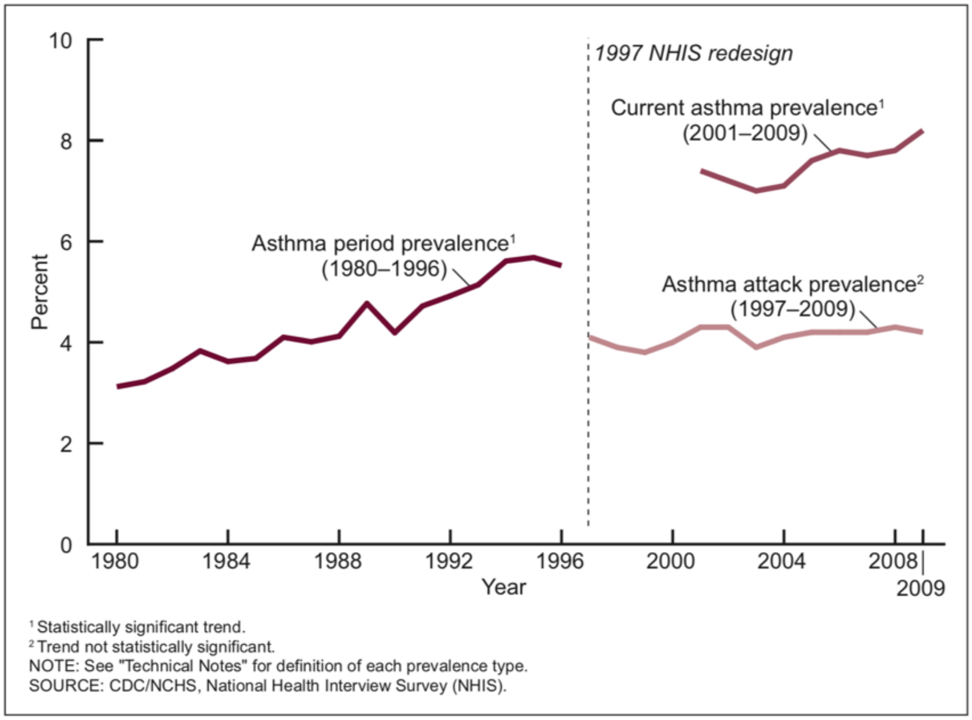


Figure 1. Asthma period prevalence, asthma attack prevalence, and current asthma prevalence for all ages: United States, 1980–2009

Figure 1-8: Asthma prevalence for all ages during 1980 – 2009 (Akinbami et al., 2011)

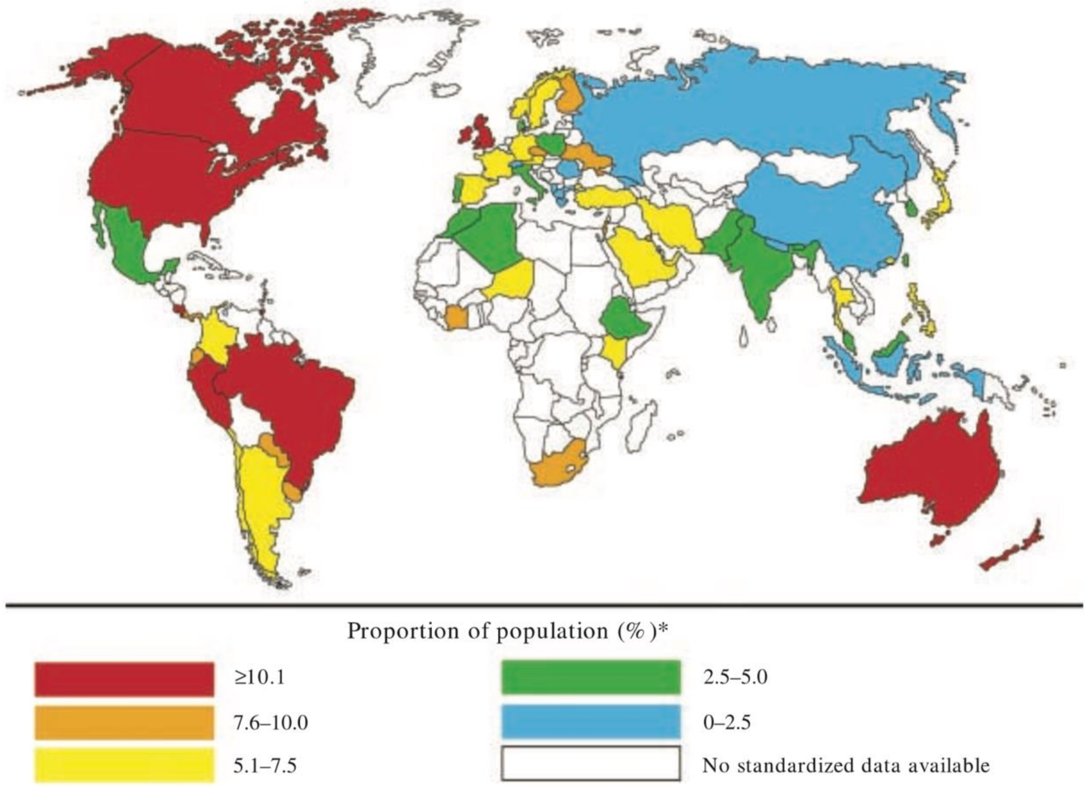


Figure 1-9: Asthma Prevalence (Adapted from Masoli et al., 2004)

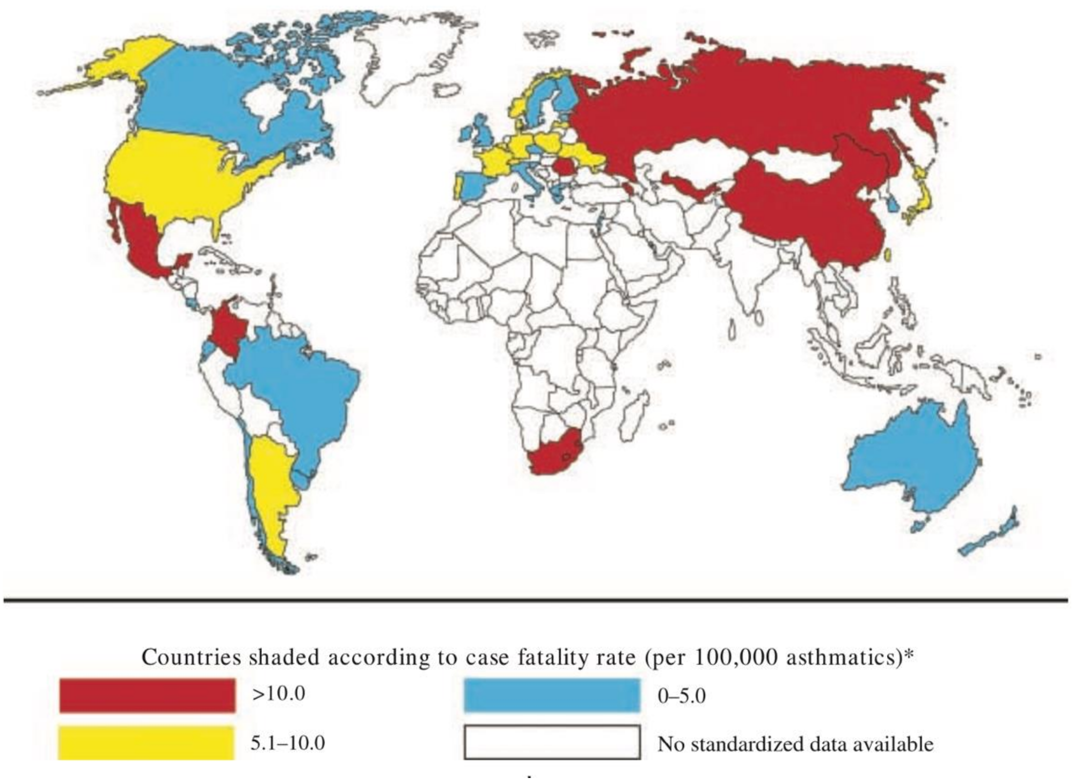


Figure 1-10: Asthma fatality rates in 5- to 34-year age group

(Masoli et al., 2004)

Asthma prevalence in the U.S. also affects people of different races and ethnicities disproportionately, as shown in Figure 1-11 (Successes of the National Asthma Control Program, 2009-2014). Race is defined as the self-identification of a person with one social group or more while ethnicity denotes if a person has a Hispanic origin or not (Race & Ethnicity) . The Black population appears to be more affected by asthma compared to the White population. All three major groups (White, Black, and Hispanic) witnessed an increase in asthma prevalence, with the difference between the beginning and the end of the period being the largest among the Black population.

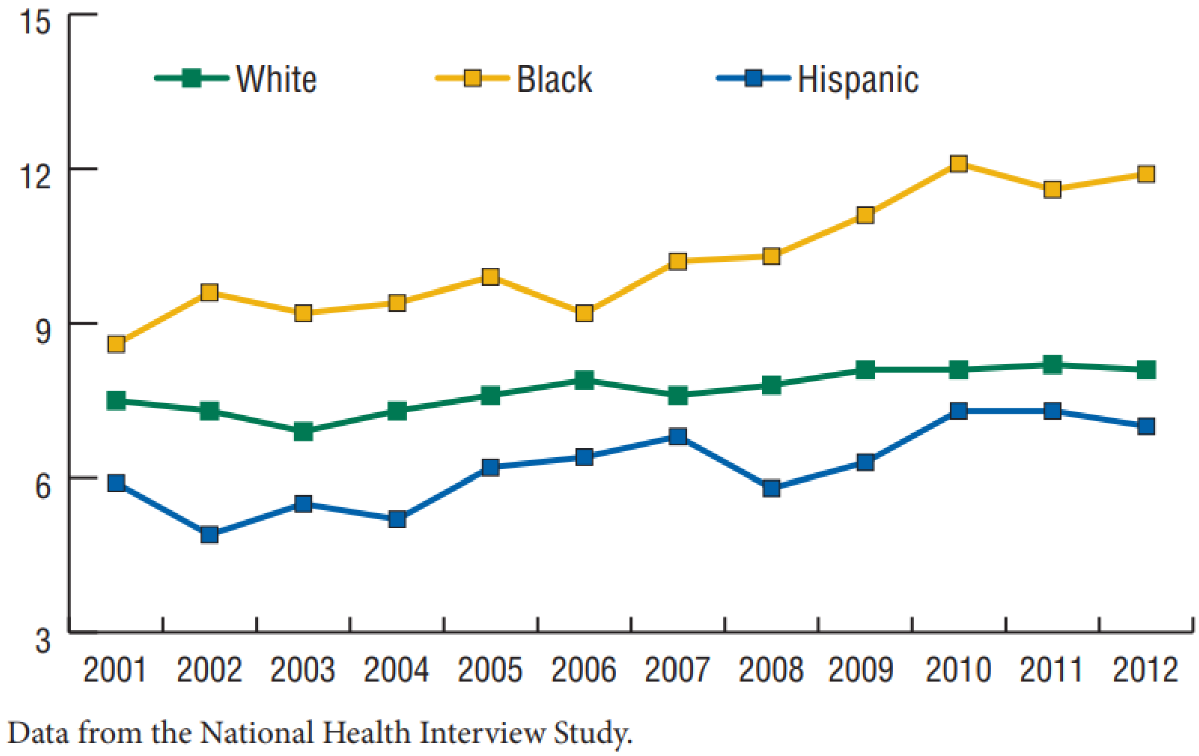


Figure 1-11: Asthma prevalence by race and ethnicity, all ages, 2001-1012

(Adapted from the CDC)

In short, the insignificant shrinkage of childhood asthma prevalence, the substantial upsurge of adult asthma prevalence, the moderate change in asthma fatality cases, and the upward trend in asthma prevalence across various races and ethnicities during the past decades suggest a lack of significant progress in asthma management and in the burden of asthma throughout the U.S.

1.5. Asthma Prevalence in Texas

1.5.1. Overview

As of 2013, more than 617,000 children and 1.4 million adults in Texas had asthma, which translated into roughly 9.1% of children and 7.3% of adults state-wide (Wu, 2014). Texas's adult and childhood asthma prevalence as of 2013 were higher than the corresponding U.S. numbers, which were at 8.3% and 7.0% (Asthma Prevalence). According to various findings, asthma prevalence tends to be higher among children than adults (Akinbami et al., 2011; Akinbami et al., 2012; Asthma Prevalence); therefore, a vast amount of available literature has focused on childhood asthma. Adult asthma prevalence, despite not being as high as children asthma prevalence, is considerable.

Similar to the U.S., Texas has experienced a disproportionate effect of adult asthma in certain populations (Wu, 2014). More specifically, Texas adult asthma prevalence has been the highest among blacks, females, tobacco users, low income households, obese individuals, and persons having medical insurance (Wu, 2014). The frequency of adult asthma trended upward from 2000 - 2016, as shown in Figure 1-12 (Data obtained from Behavioral Risk Factor Surveillance System (BRFSS) Prevalence Data). Compared to the U.S. average at 7.7%, asthma occurrence for all adults in Texas was approximately 7% (Akinbami et al., 2011). Overall, the adult asthma prevalence in Texas has exhibited a continuing pattern of elevated adult asthma prevalence (Figure 1-11).

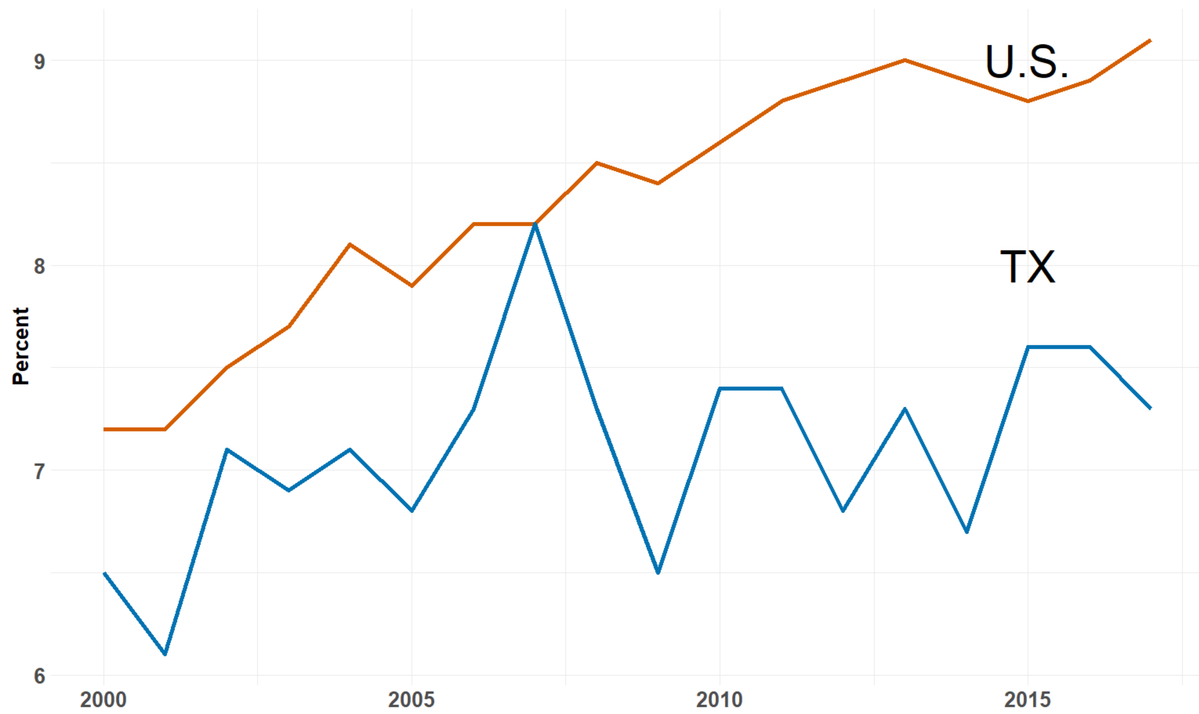


Figure 1-12: Adult asthma prevalence in Texas and the U.S., 2000 – 2016, BRFSS

The adult asthma prevalence exhibited an upward trend at both the national and state level. However, the current asthma prevalence is significantly higher in the U.S. compared to that in Texas. From 2015 onward, while the adult asthma prevalence in Texas has stayed contant, such prevalence continued to increase throughout the U.S.

1.5.2. Asthma Prevalence, Period 2010 – 2014

NCT is the study region, and 2010 – 2014 is the study period. Comparisons on adult asthma prevalence between Texas and the U.S. regarding various demographic and social status factors in this period are detailed from Figure 1-13 to Figure 1-18. These figures provide an essential background for a further examination into the NCT asthma disparities as detailed in the next chapters.

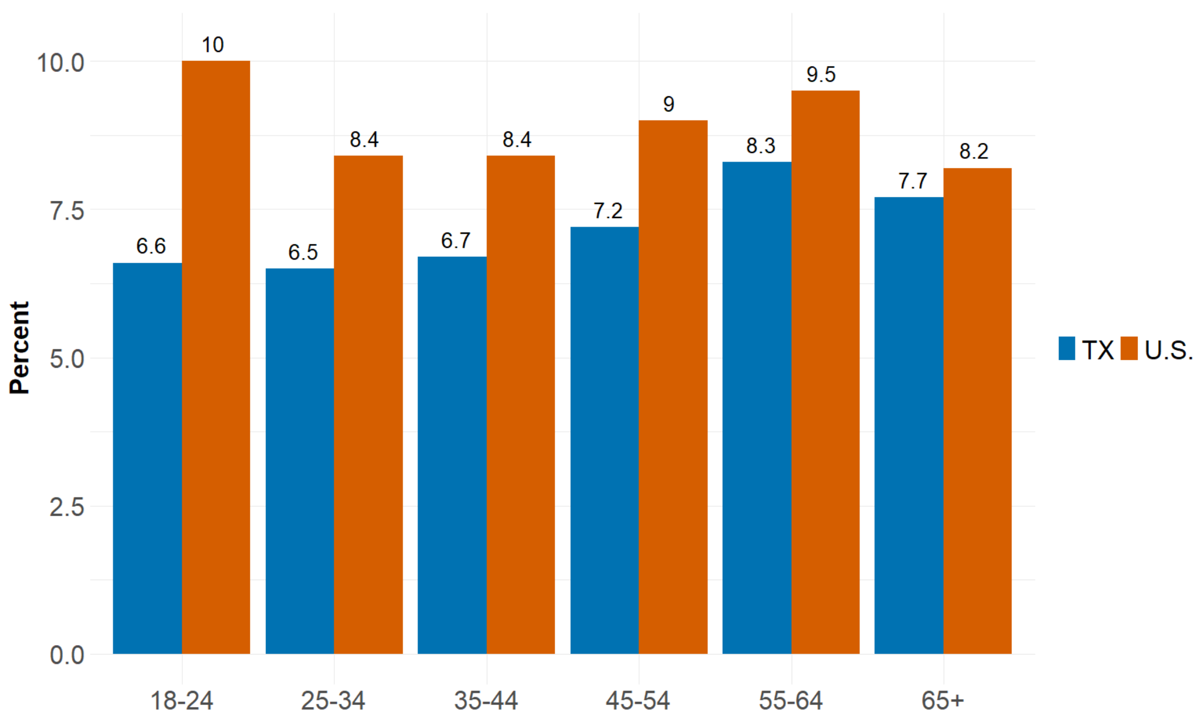


Figure 1-13: Adult asthma prevalence by age, BRFSS, 2010-2014

The adult asthma prevalence exhibited little variation among all age groups in Texas with the exception of the peak group: adults aged 55-64 years. In each age group, the asthma prevalence was smaller compared to its corresponding national figure. Throughout the U.S., the adult asthma prevalence was the highest among adults aged 18-24 years.

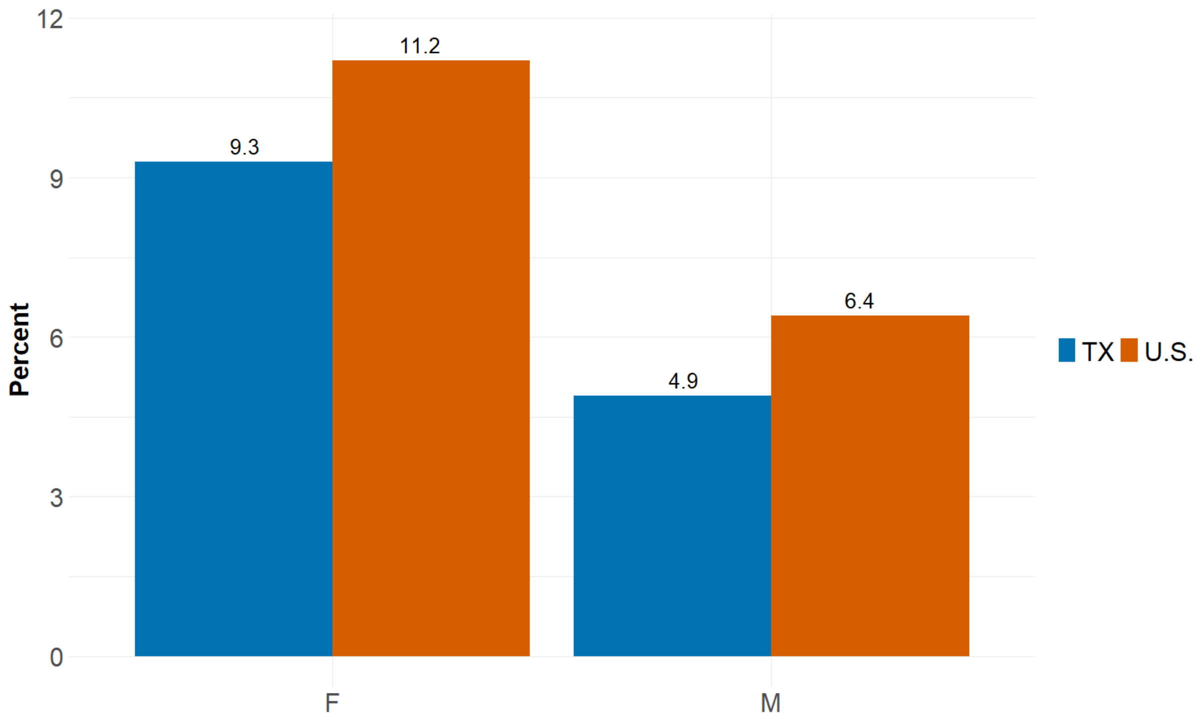


Figure 1-14: Adult asthma prevalence by sex, BRFSS, 2010-2014

Throughout the U.S. the adult asthma prevalence was 6.4 for males and 11.2 for females. A similar pattern was observed in Texas, with the corresponding figure being 4.9 and 9.3. It is important to note that at both the national and state level, the prevalence of adult female asthma was almost twice as much that of adult male asthma.

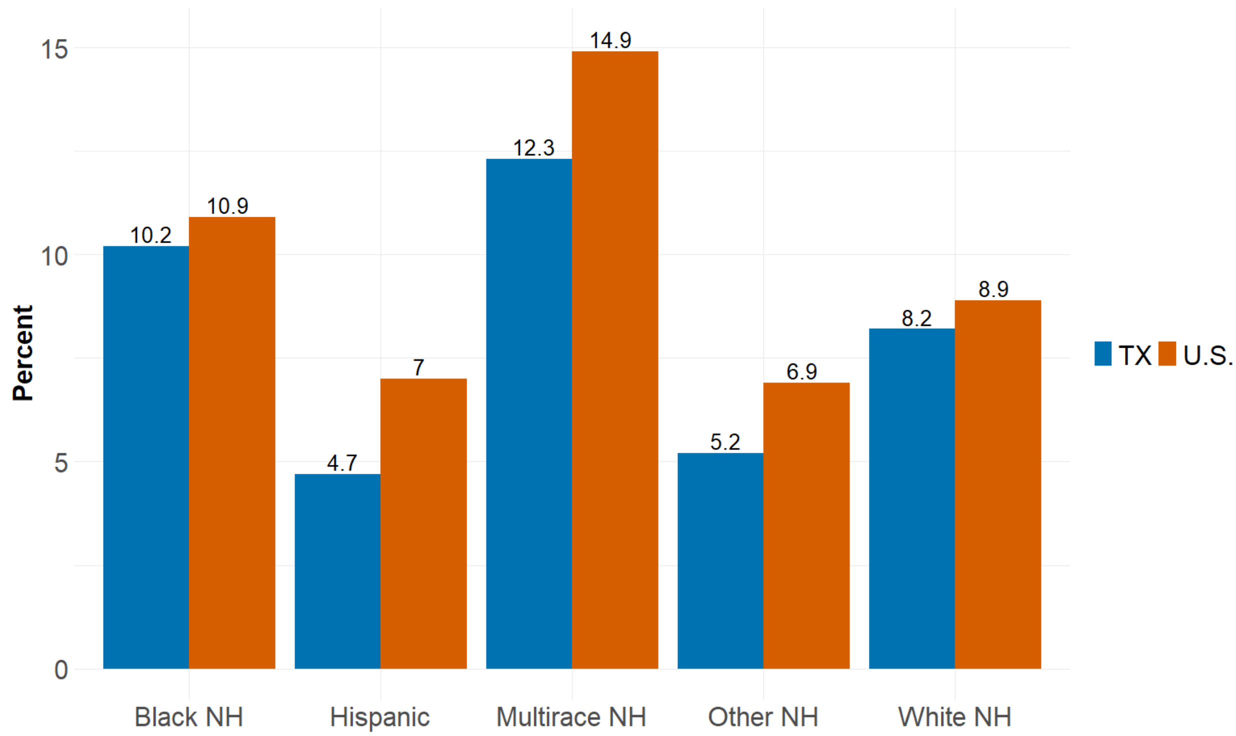


Figure 1-15: Adult asthma prevalence by Race/Ethnicity, BRFSS, 2010 – 2014

For race and ethnicity, the adult asthma prevalence was the lowest among the Hispanic group in both Texas and the U.S.. Among the non-Hispanic groups, the adult asthma prevalence was the highest among the multi-race non-Hispanic, followed by the Black non-Hispanic. The same proportional pattern was observed in TX and throughout the U.S. As in the case from the previous figures, the adult asthma prevalence in Texas was not as high as that of the U.S., across all race/ethinicity categories.

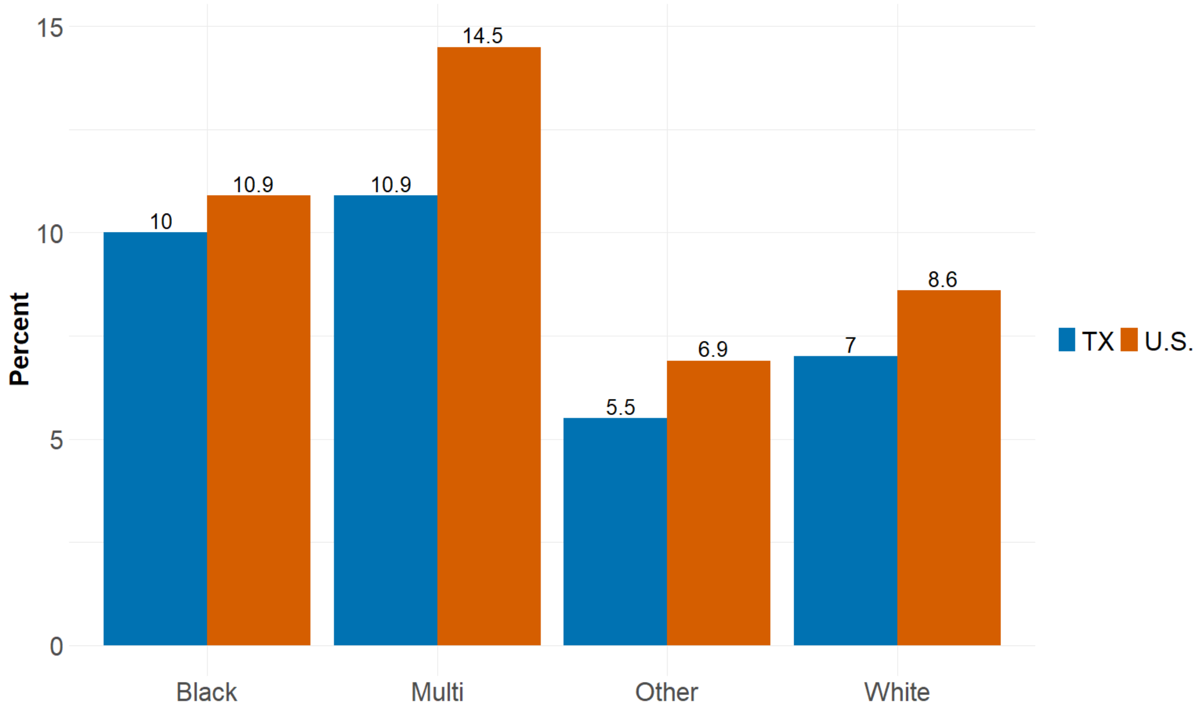


Figure 1-16: Adult current asthma prevalence by race, BRFSS, 2010 – 2014

When ethnicity is not taken into account, it is clear that multi-race and Black were still the two groups with the highest adult asthma prevalence, at both state and national level. The difference between Black population and White population was more substantial at both levels compared to the difference when both race and ethnicity were considered.

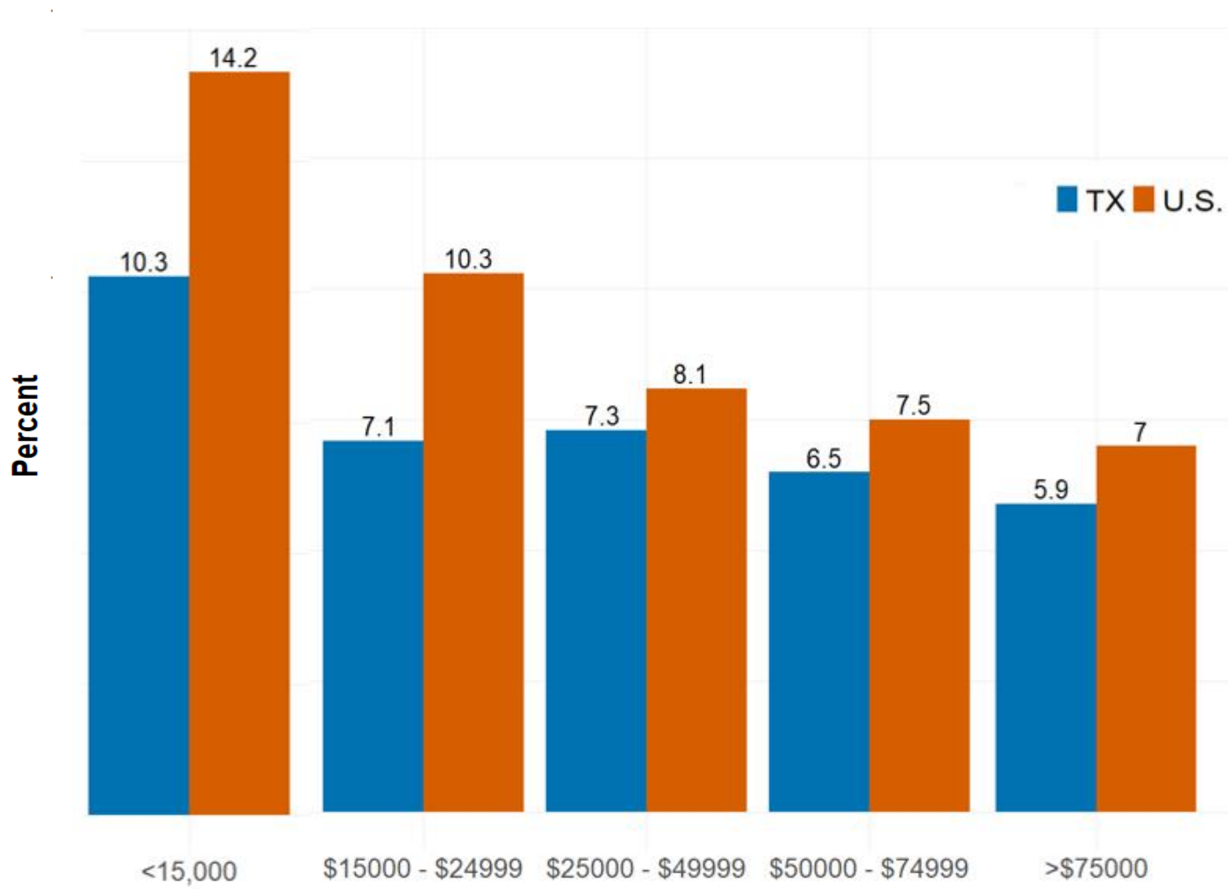


Figure 1-17: Adult current asthma prevalence by income group, BRFSS, 2010 – 2014

The disparity of adult asthma prevalence among different income groups was marked in Texas and the U.S. There was a stark difference between the lowest earners (annual income $15000 or less) and the highest earners (annual income $75000 or more) with the former exhibiting the highest prevalence and the latter having the lowest rate, regardless of level. The income disparity became less with increasing income group.

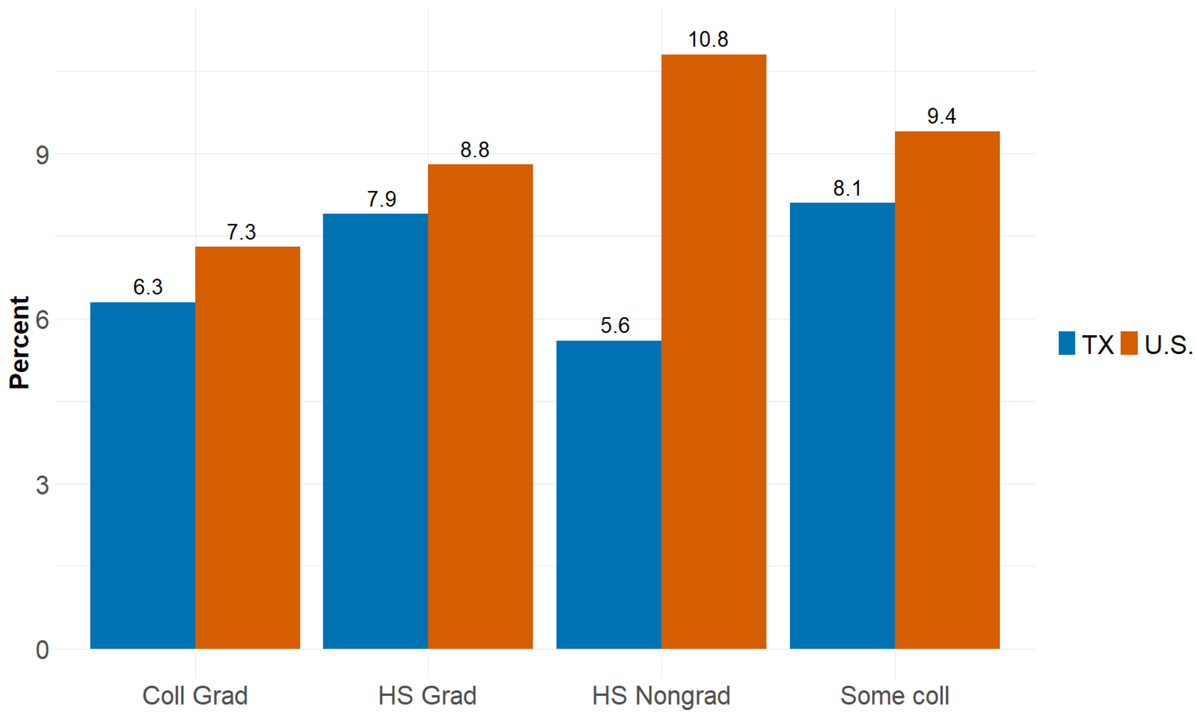


Figure 1-18: Adult asthma prevalence by education, BRFSS, 2010 – 2014

The adult asthma prevalence's disparity for different education levels was substantial. At the national level, the prevalence was highest among the people with asthma who had not graduated from high school and lowest among college graduates. However, at the state level, the prevalence was lowest among people with asthma with no high school diploma and the prevalence was highest in people with asthma with some college education. Unlike previous factors, the disparity of the state prevalence was different from that of the national prevalence.

CHAPTER 2

ASTHMA IN NORTH CENTRAL TEXAS

2.1. Introduction

In the previous chapter, the data suggested a slight downward trend in adult asthma prevalence in Texas and a mostly consistent upward trend in the U.S. At first glance, this may seem like good news as it proves that the effort to manage and control adult asthma in Texas has yielded positive result. However, such an outcome is tempered by the obvious disparities across various population groups, especially with respect to the ones with lower social standings (Newcomb and Li, 2019). For instance, the average asthma prevalence among adults in 2010-2014 was especially high with Blacks at 10%, compared to Whites at 7%. Asthma prevalence was also higher for asthmatic individuals with lower income levels, with the highest asthma prevalence among individuals making the least amount of money. Not only is the disparity shown in asthma prevalence, it is also confirmed when asthma hospitalization was considered. For example, the asthma hospitalization rates were higher in Blacks compared to Whites; Newcomb and Li (2019) reported that the hospitalization rates were 13.9 per 10,000 for Blacks and 7.6 per 10,000 for Whites. Various factors could contribute to or be associated with the asthma disparities, such as environmental and/or socioeconomic factors, which have been extensively and well documented in the literature (Johnson and Holgate, 2002; Koenig, 1999; Moore et al., 2008; Chen et al., 2006; Gupta et al., 2018; Basagaña et al., 2004).

Various studies have been conducted to investigate the association between asthma and a multitude of factors state-wide or at specific regions in Texas. For example, Goodman et al.

(2017) conducted a time series analysis to assess the correlation between ozone and asthma hospital admissions in Texas; Grineski et al. (2011) investigated the health effects of low wind and dust towards asthma hospital admission in El Paso, Texas; Zora et al. (2013) studied the associations between pediatric asthma control and air pollution in El Paso, Texas; Pilat et al. (2012) attempted to elucidate the effect of vegetation and tree cover on childhood asthma incident in various Metropolitan Statistical Areas of Texas; Sun and Sundell (2013) reported the connection between childhood asthma and dampness as well as housing characteristics in Northeast Texas; Newcomb and Li (2019) predicted adult asthma admissions in North Texas based mostly on socioeconomic factors. Among these studies, only Newcomb and Li (2019) specifically reported asthma data from the North Central Texas region. In Newcomb and Li (2019), certain attributes associated with underprivileged patients were used to predict asthma exacerbations. This approach, while comprehensive, left other aspects of the asthma problem in the NCT, such as air pollution and asthma patients' population profile, not investigated. This prompts a need for a wide ranging and multi-faceted approach in developing a thorough grasp of the adult asthma profile and various factors associated with it in the NCT.

This chapter provides a comprehensive exploratory data analysis of the NCT adult asthma discharges; the next two chapters explore the association between the NCT adult asthma discharges and air pollution as well as socioeconomic factors.

2.2. NCT Asthma Discharge Overview

The adult asthma hospital discharge data was obtained from the DFW Hospital Council Foundation. This project was thoroughly reviewed and approved by the Texas Health Resources Institutional Review Board (Newcomb and Li, 2019). The original dataset consisted of 87538 cases of adult asthma discharges during the period 2010 – 2014 from 66 hospitals in the 8 counties in the NCT (Newcomb and Li, 2019). Various parameters such as patients' age, gender, admission diagnosis, discharge diagnosis, and patient's addresses were in the dataset. Upon further investigation, the original dataset was scaled down to include only patients whose zip codes suggested their residence in the NCT.

According to the Centers for Disease Control and Prevention (CDC), there are two systems of morbidity classifications: the International Classification of Disease (ICD) published by the World Health Organization (WHO) and the International Classification of Diseases, Tenth Revision, Clinical Modification (ICD-10-CM), published by the United States (ICD-9-CM to ICD-10-CM Conversion). Prior to ICD-10, the morbidity classification published by the United States was the International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM) (International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM)). This system of classification designates procedures and codes concerning hospital use in the United States (International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM)).

The ICD-10-CM codes classify asthma by severity with four classifications: mild intermittent, mild persistent, moderate persistent, and severe persistent while the ICD-9-CM stratifies asthma by intrinsic and extrinsic group (ICD-9-CM to ICD-10-CM Conversion). Table 2-1 and table 2-3 shows the asthma classification for ICD-10-CM and ICD-9-CM, respectively (ICD-9-CM to ICD-10-CM Conversion). Table 2-2, adapted from Malamed (2015), specifies the symptoms of each classification in ICD-10-CM. ICD-10-CM diagnose codes (Table 2-1) stratify asthma by severity with six categories: four on severity (mild intermittent / J45-20 – J45.22, mild persistent asthma/ J45.30 – J45.32, moderate persistent asthma/ J45.40 – J45.42, and severe persistent asthma/ J45.50 – J45.52) and two on unspecified asthma or other variants (other and unspecified/ J45.90-J45.909, other asthma (J45.99 – J45.998). On the other hand, the ICD-9-CM codes classify asthma based on the causative factors with extrinsic being allergic asthma and intrinsic being nonallergic and nonatopic asthma (Malamed, 2015). Extrinsic asthma affects approximately 50% of asthma patients and it tends to occur more in younger adults and children; intrinsic asthma, conversely, occurs more frequently in adults older than 35 years of age (Malamed, 2015). ICD-9-10-CM codes classify asthma into five groups (Table 2-3): extrinsic asthma/ 493.00 – 493.02, intrinsic asthma (493.10 – 493.12), obstructive asthma (493.20 – 493.22), other forms of asthma (493.81 – 493.82), and asthma, unspecified (493.90 – 493.92).

The transition from ICD-9-CM codes to ICD-10-CM codes took place on October 1, 2015 and it was advised by the CDC that analysis on asthma emergency department visits and asthma hospitalization for data prior to 2015 would still follow the ICD-9-CM standard, as there was a great deal of difference between the two system (ICD-9-CM to ICD-10-CM Conversion).

The study period, 2010 – 2014, was prior to the year the transition took place; therefore, the ICD-9-CM system was utilized. As asthma is the focus of the study and the ICD-9-CM codes for asthma range from 493.0 to 493.99, only cases with such diagnosis codes were extracted and cases with non-asthma discharge status were excluded. As a result, the evaluated dataset consisted of 78444 cases. Out of these 78444 asthma discharge cases, 35220 patients lived in Dallas, 24910 lived in Tarrant, 5767 lived in Denton, 5402 lived in Collin, and the rest lived in the remaining 12 counties. It is important to keep in mind that approximately 90.1 percent of patients resided in the four most populous counties in the NCT, namely Dallas, Tarrant, Denton, and Collin.

ICD-10 Code	Principal Diagnosis
J45.2	**Mild intermittent asthma**
J45.20	Mild intermittent asthma, uncomplicated
J45.21	Mild intermit., acute exacerbation
J45.22	Mild intermit. asthma, status asthmaticus
J45.3	**Mild persistent asthma**
J45.30	Mild persistent asthma, uncomplicated
J45.31	Mild persistent asthma, (acute) exacerbation
J45.32	Mild persistent asthma, status asthmaticus
J45.4	**Moderate persistent asthma**
J45.40	Moderate persistent asthma, uncomplicated
J45.41	Mod. persistent asthma, (acute) exacerbation
J45.42	Mod. persistent asthma, status asthmaticus
J45.5	**Severe persistent asthma**
J45.50	Severe persistent asthma, uncomplicated
J45.51	Severe persistent asthma, (acute) exacerbation
J45.52	Severe persistent asthma, status asthmaticus
J45.9	**Other and unspecified asthma**
J45.90	Unspecified asthma
J45.901	Unspecified asthma, (acute) exacerbation
J45.902	Unspecified asthma, status asthmaticus
J45.909	Unspecified asthma, uncomplicated
J45.99	**Other asthma**
J45.990	Exercise-induced bronchospasm
J45.991	Cough variant asthma
J45.998	Other asthma

Table 2-1: Asthma ICD-10 code

Classification	Symptoms	Nighttime symptoms	Lung function
Mild intermittent	Symptoms ≤2 times a week Asymptomatic and normal PEF between exacerbations Exacerbations brief (from a few hours to a few days); intensity may vary	≤2 times a month	FEV_1 or PEF 80% predicted
Mild persistent	Symptoms >2 times a week but ≤ once per day Exacerbations may affect activity	>2 times a month	FEV_1 or PEF ≥80% predicted PEF variability, 20–30%
Moderate persistent	Daily symptoms Daily use of inhaled short-acting β_2-agonist Exacerbations affect activity Exacerbations ≥2 times a week; may last days	>1 time a week	FEV_1 or PEF >60% ≤80% predicted PEF variability >30%
Severe persistent	Continual symptoms Limited physical activity Frequent exacerbations	Frequent	FEV_1 or PEF ≤60% predicted PEF variability >30%

FEV_1, forced expiratory volume in 1 second; PEF, peak expiratory flow.
Modified from National Heart, Lung, and Blood Institute: *Expert Panel report 2. Guidelines for the diagnosis and management of asthma,* Baltimore, MD. U.S. Department of Health and Human Services, Public Health Service, National Institutes of Health, National Heart, Lung, and Blood Institute, 1997. NIH publication no. 4051.

Table 2-2: ICD-10 Classification with symptoms (adapted from Malamed, 2015)

ICD-9 Code	Principal Diagnosis
493.0	**Extrinsic asthma**
493.00	Extrinsic asthma, unspecified
493.01	Extrinsic asthma, status asthmaticus
493.02	Extrinsic asthma, (acute) exacerbation
493.1	**Intrinsic asthma**
493.10	Intrinsic asthma, unspecified
493.11	Intrinsic asthma, status asthmaticus
493.12	Intrinsic asthma, (acute) exacerbation
493.20	**Obstructive asthma**
493.20	Obstructive asthma, unspecified
493.21	Obstructive asthma, status asthmaticus
493.22	Obstructive asthma, (acute) exacerbation
493.8	**Other forms of asthma**
493.81	Exercise-induced bronchospasm`
493.82	Cough variant asthma
493.9	**Asthma, unspecified**
493.90	Asthma, unspecified type, unspecified
493.91	Asthma, unspecified, status asthmaticus
493.92	Asthma, unspecified, (acute) exacerbation

Table 2-3: Asthma ICD-9 code

2.3. NCT Asthma Discharge Variation

Figures 2-1 to 2-5 display the distribution of discharge cases by county, by age group and gender, by race, by ethnicity, and by health care utilization, respectively.

2.3.1. Variation by County

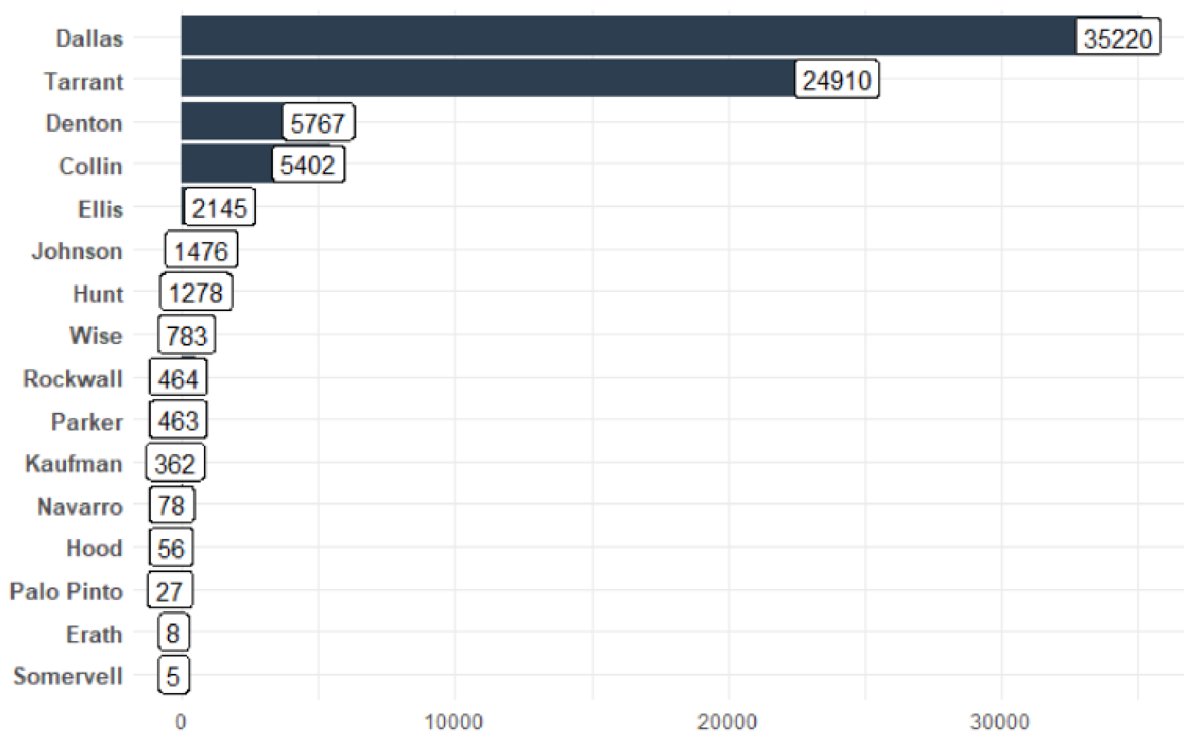


Figure 2-1: Asthma hospital discharge by county in NCT, 2010-2014

As expected, almost 50% of the adult asthma discharges were from the most populous county – Dallas. The top four counties with the highest number of asthma discharges corresponded to the four most populous counties: Dallas, Tarrant, Denton, and Collin.

2.3.2. Variation by Age Group and Gender

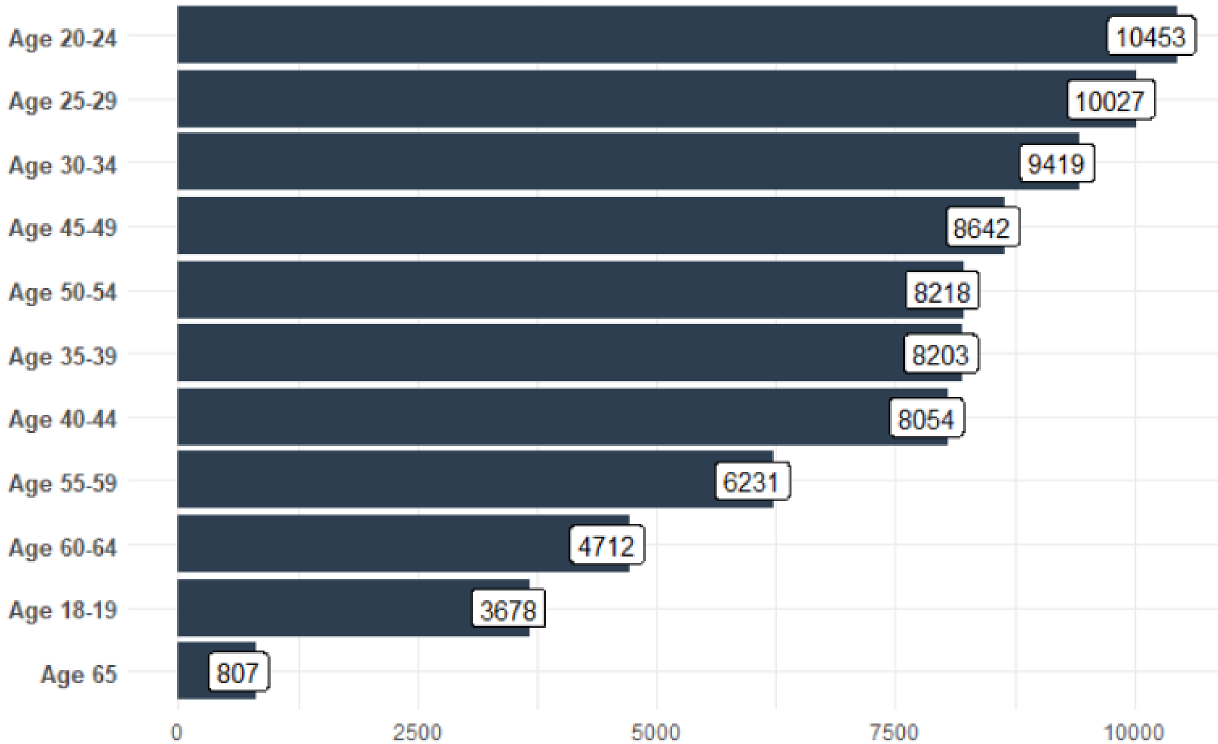


Figure 2-2: Asthma hospital discharges by age group in NCT, 2010-2014

As this specific dataset contained only adult hospital discharge cases, the patients' age ranged from 18 to 65; the age group distribution is indicated in Figure 2-2. The two age groups with the largest number of asthma patients comprised patients who were younger than 30 years and older than 20 years of age.

Figure 2-3, Figure 2-4, and Figure 2-5 show the population pyramid of the asthma discharge in NCT, the population pyramid of NCT, and the population in the period 2010 – 2014 (Figure 2-3 and Figure 2-4) and year 2015 (Figure 2-5). The asthma discharges were obtained from the asthma data set while the NCT population was the averaged population obtained from the U.S. Bureau of Census.

At first glance, the population pyramid of asthma discharge is different from the other two pyramids and the population pyramid of NCT is similar to that of the U.S. There are a larger percentage of younger people and there are a larger percentage of females in the older groups. The population pyramid of adult asthma discharge indicates a larger number of female patients compared to male patients across all age groups. In male asthma discharge group, age 20-24 is the group with the largest number of asthma patients and the number of asthma discharge gets progressively smaller as the age groups gets older. However, in the female asthma discharge group, the number of asthma discharge stays relatively constant until age 50-54 and then only gets progressively smaller for the older age group. The proportion of asthma discharge and the female/male ratio of asthma discharge normalized by NCT population are shown in Figure 2-6 and Figure 2-7. It is clear that from age 35 upward, the percentage of female asthma discharges is twice as much as the percentage of male asthma discharges. This observation has similarly been made in various studies: Baibergenova et al. (2006) asserted that the majority of adult asthma emergency department visits (62%) were women; Leynaert et al. (2012) concluded that for adults aged 35 and above, asthma was 20% more common in women. Numerous studies have confirmed a gender reversal at puberty with a higher prevalence of childhood asthma in boys and a higher percentage of adult asthma females (De Marco et al., 2000; Chen et al., 2003; Zein and

Erzurum, 2015). Explanations for such difference between two sexes have been offered, including: changes in sex hormones, the level of immunoglobulin E (IgE are the antibodies that characterize the immune response in allergy and asthma), and the bronchial airway size (as cited in Baibergenova et al., 2005)

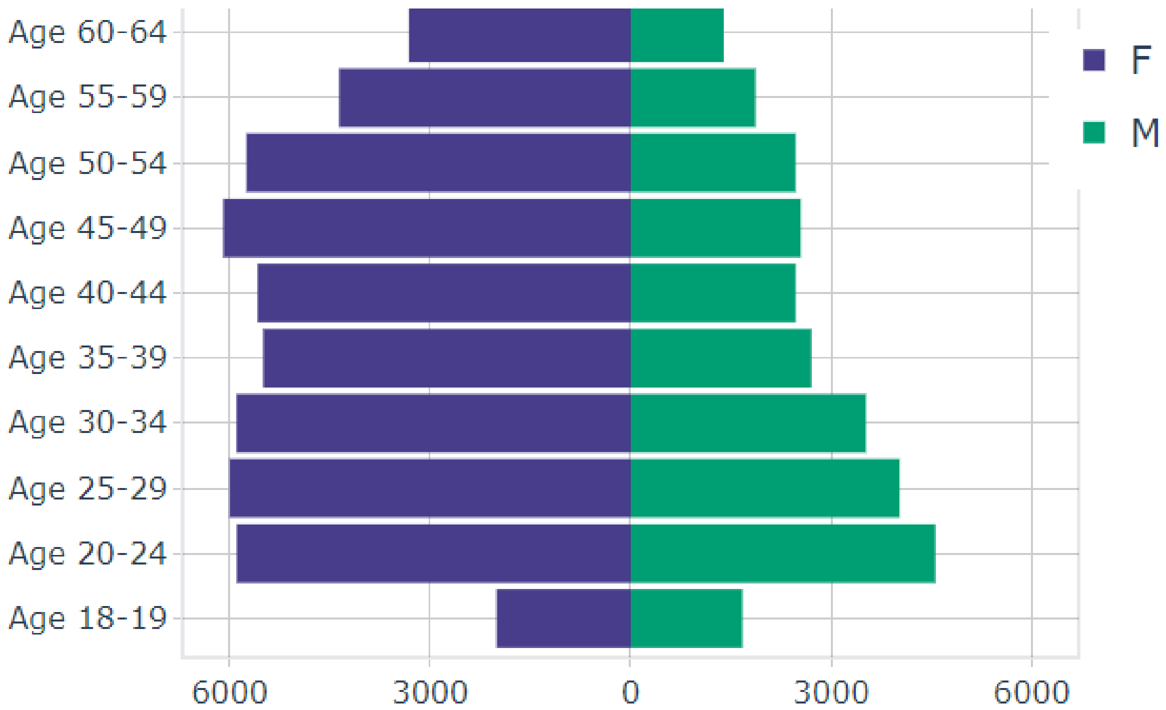


Figure 2-3: Population pyramid of asthma discharge in NCT, 2010 – 2014

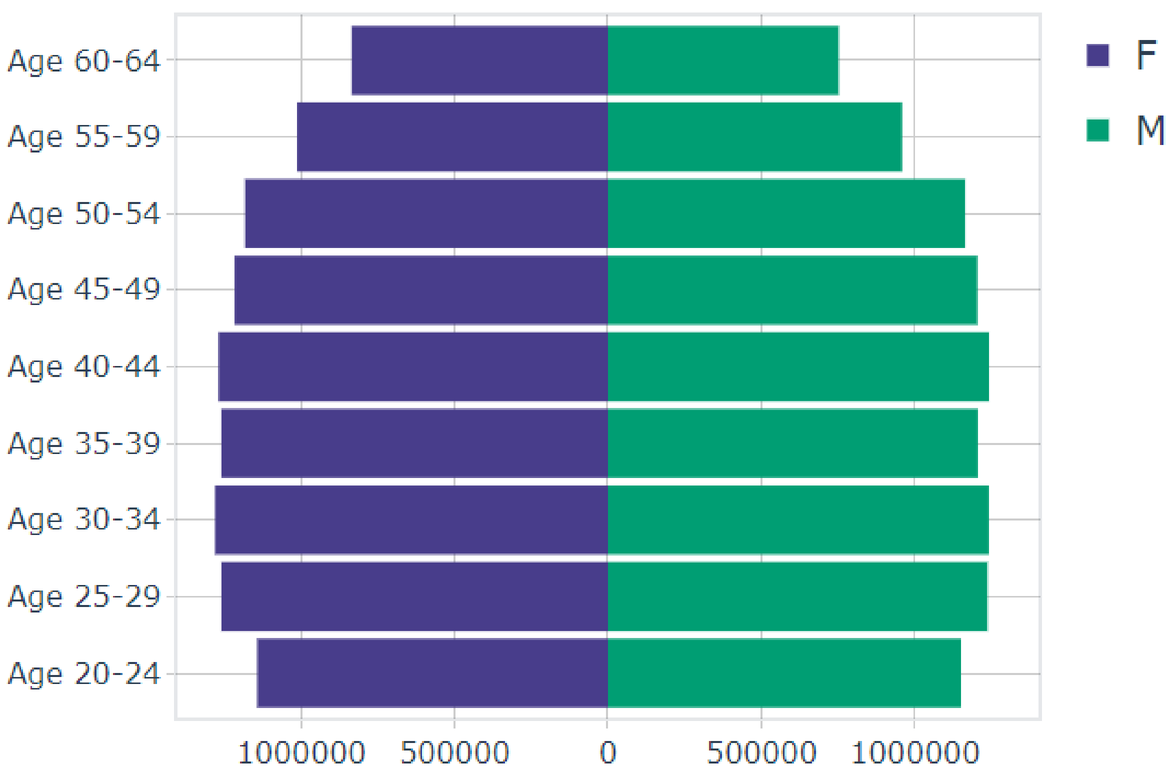


Figure 2-4: Population pyramid of NCT, 2010 – 2014

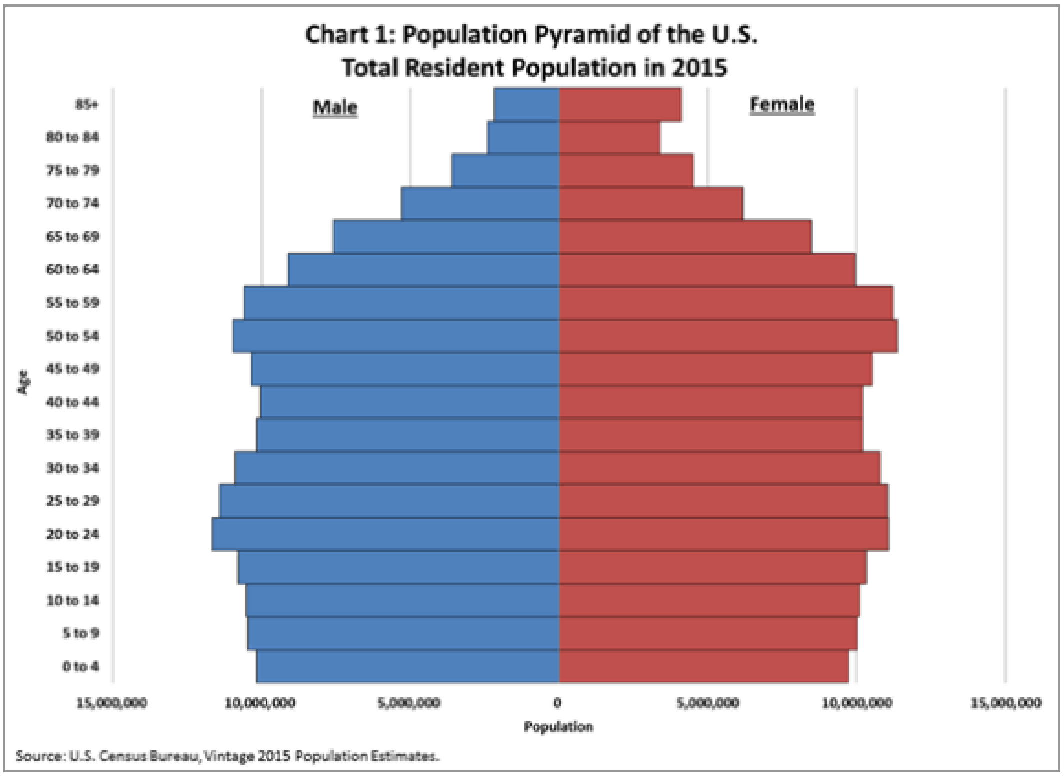


Figure 2-5: Population Pyramid of the U.S. (Adapted from the U.S. Census Bureau)

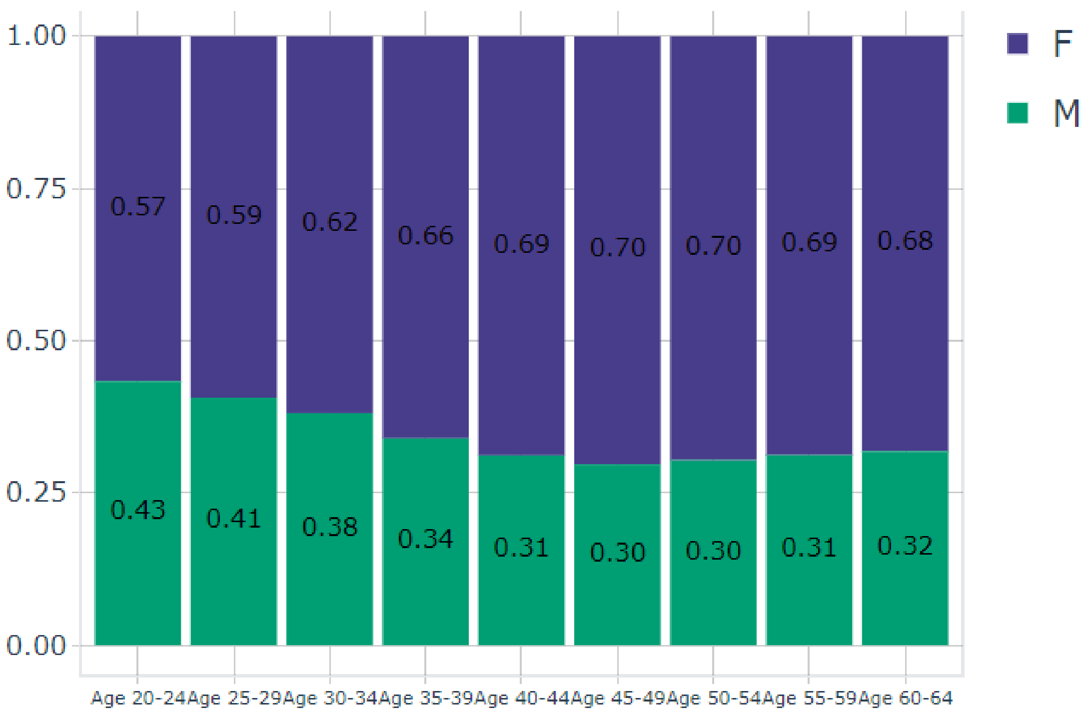


Figure 2-6: Percentage of asthma discharge by gender normalized to 100%

in NCT,
2010 – 2014

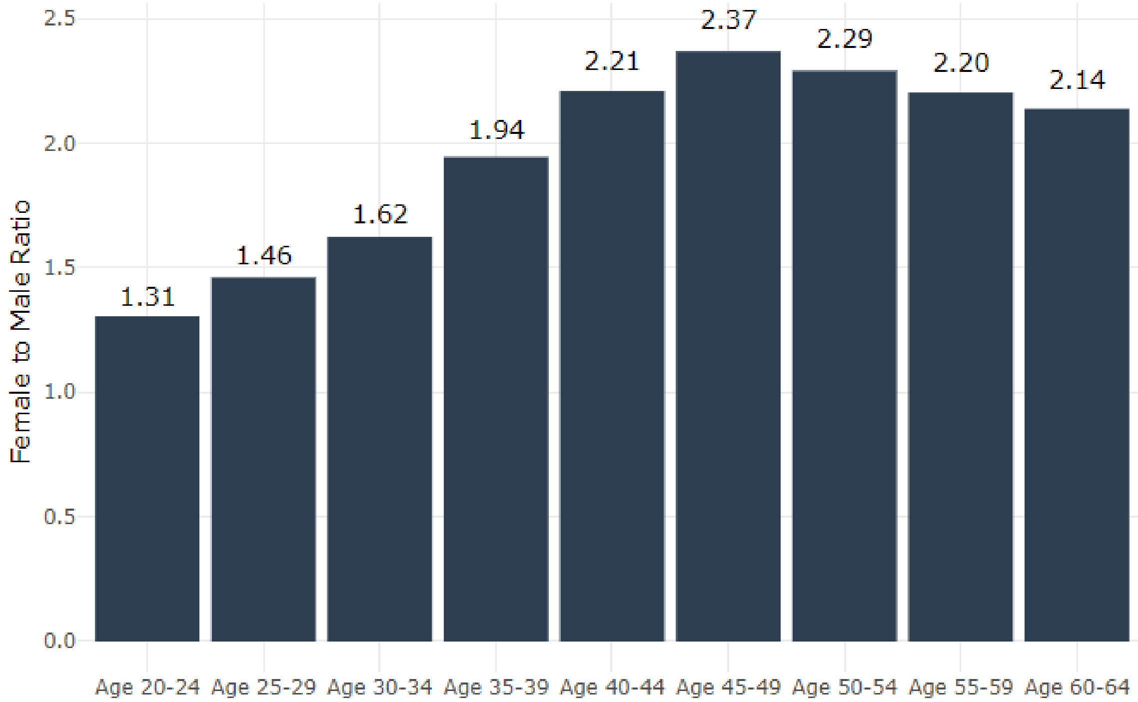


Figure 2-7: Female/Male ratio of asthma discharge by age group normalized to NCT population, 2010 – 2014

2.3.3. Variation by Race and Ethnicity

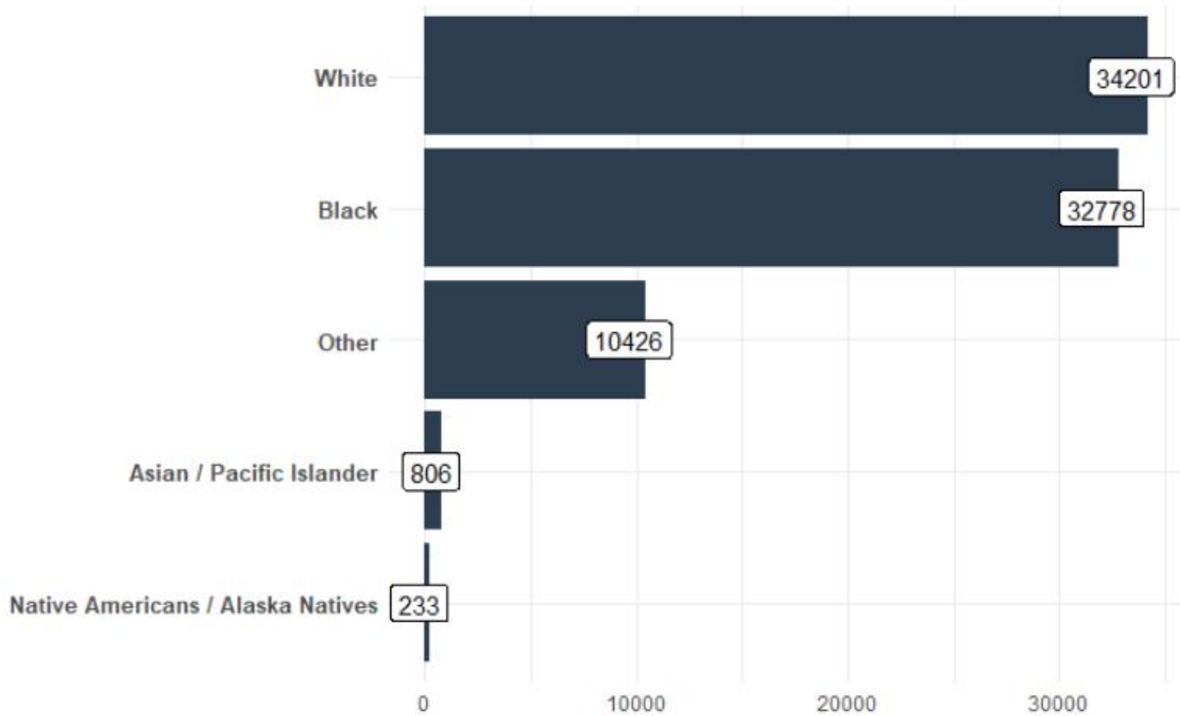


Figure 2-8: Asthma hospital discharges by race in NCT, 2010-2014

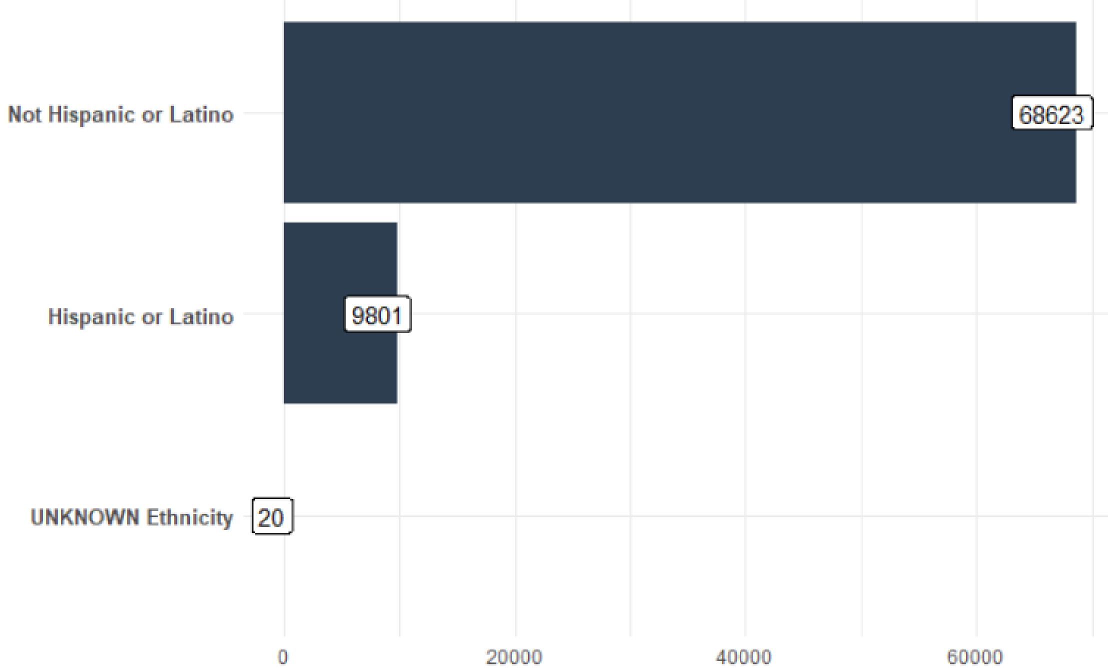


Figure 2-9: Asthma hospital discharges by ethnicity in NCT, 2010-2014

Figure 2-8 and figure 2-9 show the asthma discharge distribution by race and ethnicity. There was approximately an equal number of White and Black asthma discharges. Asian/Pacific Islander and Native Americans/ Alaska Natives constituted an extremely small percentage of adult asthma discharges. Approximately 12% of discharges were Hispanic or Latino.

For a more comprehensive understanding of the difference, or lack thereof, of various race/ethnic groups in relation to asthma discharge, multiple population pyramids were constructed, as shown in Figures 2-10 to 2-12. The two groups Asian/Pacific Islanders and Native Americans/Alaska Natives were excluded due to the small value of asthma discharges.

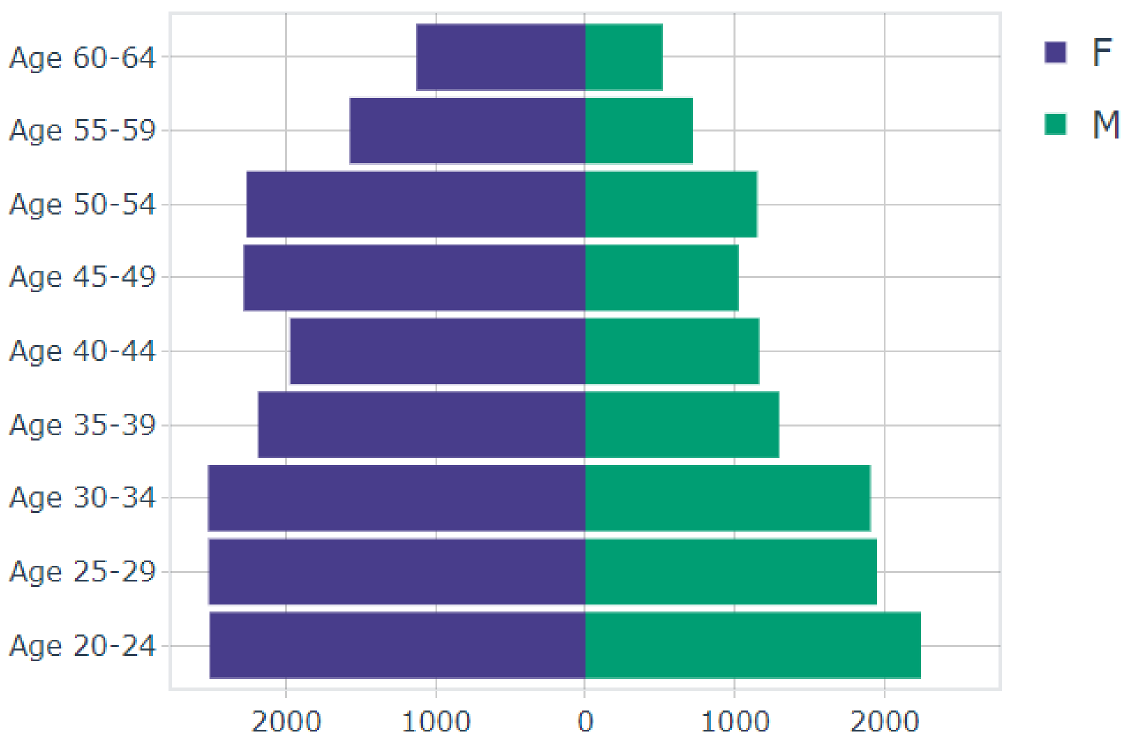


Figure 2-10: Population pyramid of Black asthma discharge in NCT (2010 – 2014)

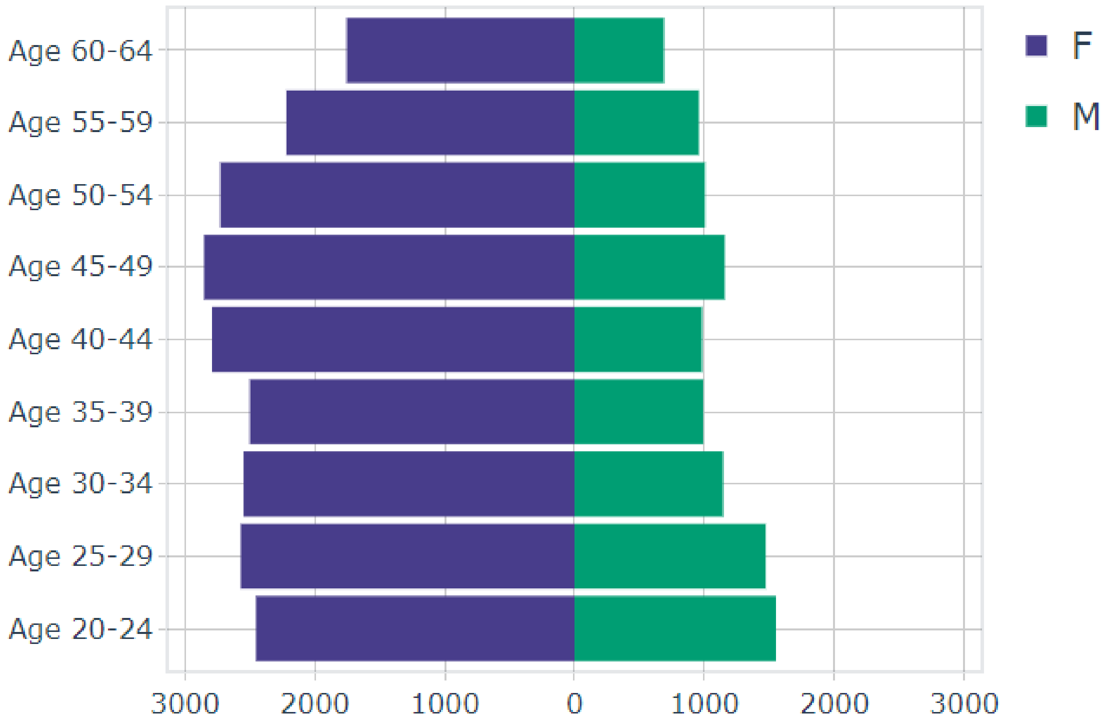


Figure 2-11: Population pyramid of White asthma discharge in NCT (2010 – 2014)

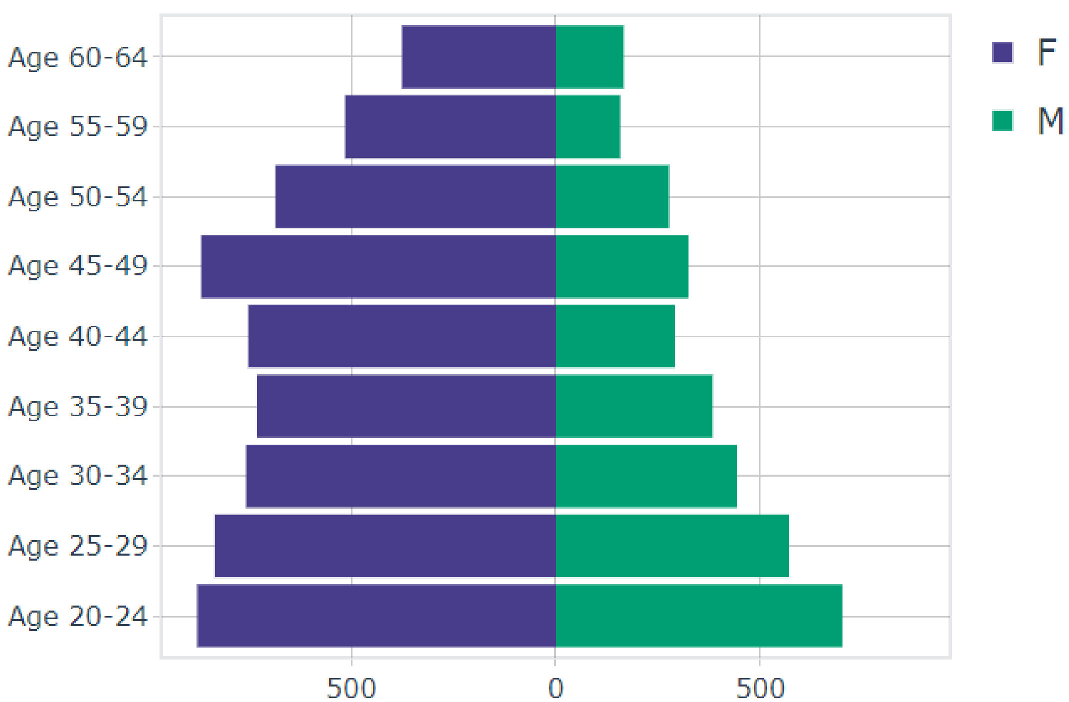


Figure 2-12: Population pyramid of Hispanic asthma discharge in NCT (2010 – 2014)

In general, the age and gender pattern of the population pyramid of Black, White, and Hispanic asthma discharges was similar to that of the NCT asthma discharge for all races. However, there appeared to be a higher percentage of Black and Hispanic asthma discharge in younger age groups in relation to the other age groups; this pattern was not observed in White asthma discharges. Noteworthy, was the asthma discharge for women started decreasing after the age 45-49, across all population pyramids. This appears to support the theory that asthma generally improves post menopause (Zein and Erzurum, 2015). More specifically, Zein et al. (2015) stated that the risk of severe asthma ceased to continue in women after 45 years of age. According to the North American Menopause Society, the average age for women in North America to likely experience natural menopause is 51 (The North American Menopause Society). This corresponds with the decrease in asthma discharges, as noted earlier.

2.3.4. Variation by Healthcare Utilization

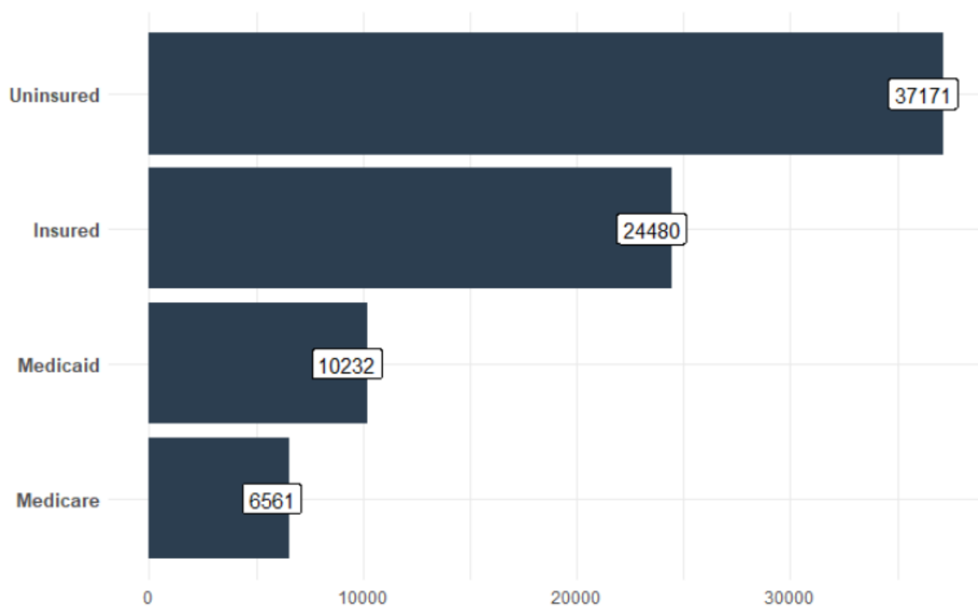


Figure 2-13: Asthma hospital discharges by health care utilization in NCT, 2010-2014

Approximately 50% of asthma hospital discharges were uninsured; 30% were insured; the rest used either Medicaid or Medicare. Medicare is an insurance program that primarily serves people over 65 years of age while Medicaid is an assistance program serving the low-income population (What is the difference between Medicare and Medicaid?). With Medicaid, patients pay little to none for their medical expenses (What is the difference between Medicare and Medicaid?). In Texas, in order to qualify for Medicaid, a person's financial situation must be characterized as low or very low income; the income requirement is shown in Table 2-4 (Texas Medicaid). Together, the uninsured and the Medicaid group constituted 60% of the health care utilization, suggesting the undeserved status of this asthma population.

Household Size*	Maximum Income Level (Per Year)
1	$24,731
2	$33,482
3	$42,234
4	$50,985
5	$59,737
6	$68,489
7	$77,240
8	$85,992

Table 2-4: Income requirement for Medicaid in Texas (adapted from Texas Medicaid)

2.4. NCT Asthma Discharge Seasonality

The asthma discharge by year and asthma discharge by month are shown in Figure 2-14 and Figure 2-15. There appeared to be a clear seasonal pattern with a peak in number of discharges around April and January and a minimum in July, regardless of the year. This pattern mostly corresponds with the U.S.'s seasonal asthma hospitalization, which exhibited a minimum in summer and a peak in late fall (as cited in Thomas and Whitman, 1999). From summer to late fall, the asthma discharge in NCT steadily increased; however, the peak was clearly in January, a winter month. This can be explained by an increase in respiratory tract infection, as suggested in numerous studies (Teichtahl et al., 1997; Beasley et al., 1988). Interestingly, mountain cedar (*Juniperus ashei*), which grows naturally in Texas produces a potent allergenic pollen. Mountain cedar (MC) pollen counts peak in January (see e.g., Andrews et al.., 2013). "Cedar Fever," as the allergic response to MC pollen is referred to colloquially, was described by Black (1929) almost a century ago. MC pollen can travel long distances (Levetin, 1998), and a strong allergic response may be mounted by susceptible individuals (Ramirez, 1984). The peak in April could potentially be attributed to the Spring allergy season in the NCT. Further studies would be needed to confirm such suggestion.

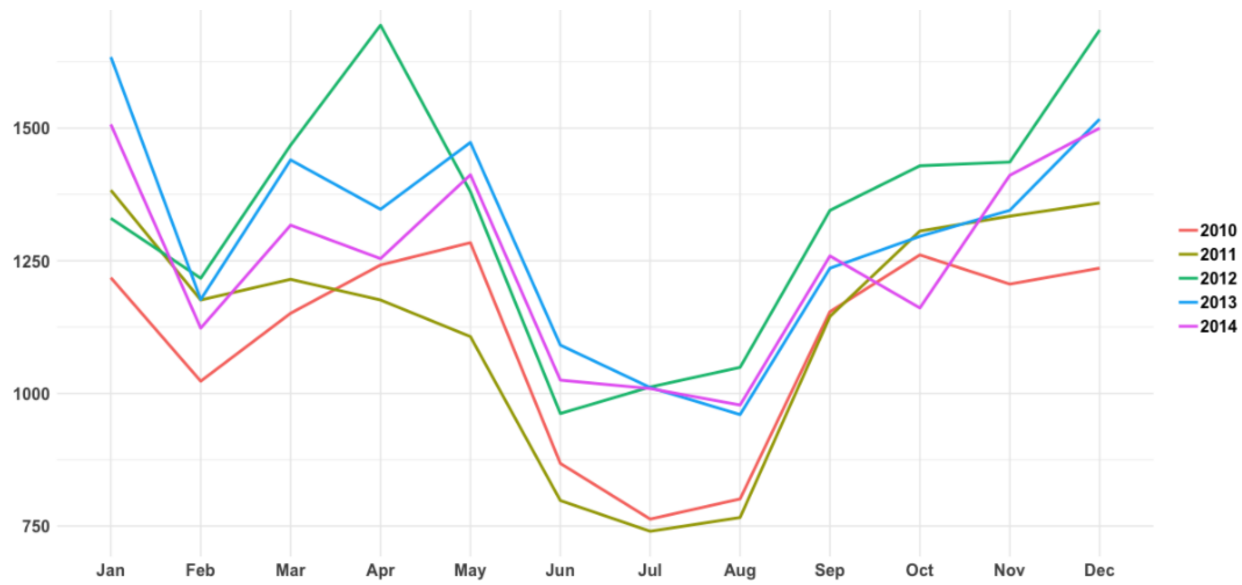


Figure 2-14: Asthma discharge in NCT by year, 2010 – 2014

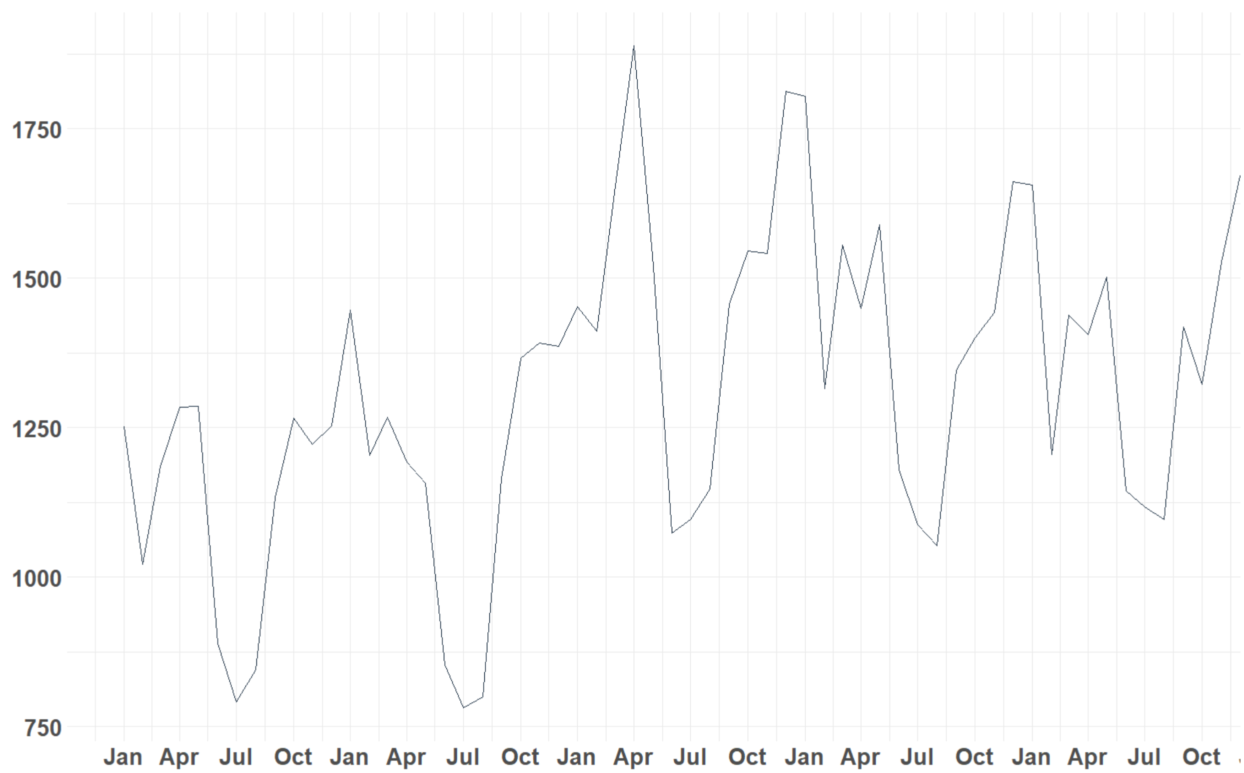


Figure 2-15: Asthma discharge in NCT by month, 2010 – 2014

2.5. Discussion

A comprehensive exploratory data analysis of the NCT emergency room adult asthma discharge records was carried out. Cases with ICD-9-CM asthma codes were retrieved from the original asthma database. Asthma discharge variability was clearly observed in multiple domains: county, age, sex, race and ethnicity, and healthcare utilization. The four most populous counties (Dallas, Tarrant, Denton, and Collin) exhibited the highest number of asthma discharges. This is not unsurprising; individuals with asthma will be located "where the people are." More asthma patients aged 20-30 visited hospitals than other age groups. The gender switch appeared to be supported. The gender switch theory suggested that there was a reversal of the severity and occurrence of asthma from male to female post puberty. This appeared to be the case in the NCT; there was a substantially larger percentage of adult female asthma patients compared to males across all age groups. This pattern was observed regardless of race and ethnicity. Moreover, the theory that asthma seemed to improve post menopause was also supported. Across all races and ethnic groups, the number of female asthma discharges started decreasing after age 49, which approximately corresponded to age 51 – the average age women in North America started to experience natural menopause. When it comes to health care utilization, the majority of patients were either uninsured or using an assistance program such as Medicaid. The seasonality of asthma discharges was clearly observed with a minimum in July and two peaks in January and April. This could be attributed to the combination of respiratory infections, cedar pollen exposure, and the spring allergy season.

CHAPTER 3

SPATIAL VARIATION BETWEEN COMMON AIR POLLUTANTS AND ADULT ASTHMA DISCHARGE CASES

3.1. Literature Review

As far as environmental factors are concerned, air pollution is believed to be among many aggressive factors that adversely affect respiratory health and can lead to an increase in mortality, as demonstrated and documented in many epidemiologic studies (Goodman, 2004; Levy et al., 2000; Pope et al., 2004; Schwartz, 2004). According to the 2010 Global Burden of Disease comparative risk assessment, a comprehensive study on the burden of disease attributable to independent risk factors, air pollution from solid fuels remained one of the top 3 leading risk factors associating with the global disease burden (Lim et al., 2012). As cited in Guarnieri and Balmes (2014), outdoor air pollution attributed to 3% of the yearly disability-adjusted life years lost.

According to Johnston and Holgate (2002), asthma is hypothesized to be caused by an enhanced exposure to aggressive factors (i.e. airborne outdoor pollutants, indoor allergens) or a decreased exposure to protective factors such as antioxidants and physical exercise. Among these factors, the heightened exposure to airborne outdoor pollutants has received special attention as asthma is known to be aggravated by inhaled agents (Koenig, 1999).

Numerous observational and experimental studies have convincingly established the association between asthma and common air pollutants (Koenig, 1999; Moore et al., 2008; Janset et al., 2005; Gent et al., 2003; Riedl and Diaz-Sanchez, 2005, Hollingsworth et al., 2007). For example, Li and Buglak (2015) and Koenig (1999) explain the influence on airway inflammation of PM_{10} and O_3; Norris et al. (1999) correlates CO concentrations with increased childhood emergency visits for asthma; WHO (1997), and Son, et al. (2013) confirm the sensitivity of individuals with asthma to the effects of NO_2. In general, in many studies, air pollutants are believed to induce and increase the release of inflammatory mediators from bronchial epithelial cells, leading to a greater susceptibility of asthmatics to the deleterious impacts of these pollutants (Bayram, et al., 2001).

It is important to note that the relationship between environmental exposure (exposure to outdoor air pollutants in this case specifically) and asthma is not convincingly a causal relationship, even though for many studies, the two are strongly and positively correlated (Turner, 2012).

Furthermore, while many environmental health studies have reported a positive correlation between air pollutants and asthma, many other studies also concluded that there was no such association to be established (Gorai et al., 2014). In fact, quantifying the possible association is a monumental task due to the lack of a gold standard in the literature, as concluded in Turner (2012). He also asserted that the true relationship between asthma and the environment will more than likely never be completely understood due to the imprecise and complex nature of all factors involved (Turner, 2012).

The conflicting nature of reporting suggests a possibly strong geographic variation and that diverse approaches concerning different associations need to be taken to fully elucidate this relationship. Local studies on the subject of geographic variation of such possible relationship are, therefore, essential in adding to the general body of knowledge of this complex respiratory disease.

3.2. Hypotheses

This chapter and the subsequent chapter are designed to clarify the relationship between asthma and two groups of asthma drivers: environmental factors and socioeconomic factors.

In this chapter, the focus is on understanding the possible association between asthma discharge rate (ADR) and various air pollutants and meteorological variables in the study region during the chosen period (2010 – 2014).

Here it is hypothesized that asthma events in NCT are triggered by environmental exposures (e.g., common ambient air pollutants) and environmental conditions (e.g., ambient temperature), and the triggering effect exhibits a seasonal variation. Given the geographic spread of the asthma data, these relationships are best understood from a spatial perspective. Therefore, the widely known spatial software Geographic Information System (GIS) was implemented in the analyses.

Due to the sheer volume of the data and its complexity, three major analyses were carried out in the process: an exploratory data analysis, a point correlation analysis, and a hot spot analysis. The exploratory data analysis is designed to find meaningful clusters of air pollutants and major meteorological variables by the application of multivariate analysis, more specifically Principal Component Analysis (PCA) and Hierarchical Agglomerative Cluster Analysis (HACA). In point correlation analysis, there are developed pairwise correlations of each concentration with the variable of interest, ADR. Pearson correlation coefficient for each pair is calculated to assess the strength of the association. In hot spot analysis, the focus is on identifying regions with high asthma clusters via the application of Getis-Ord Gi* statistic and Anselin Local Moran's I Statistic.

3.3. Methodology

3.3.1. Data Extraction and Analysis

3.3.1.1 Data Extraction

3.3.1.1.1 Air Pollution Data and Meteorological Data

Air pollution and meteorological data were obtained from the Texas Commission on Environmental Quality (TCEQ). Hourly concentrations of particulate matter less than 2.5 micrometers (PM 2.5), nitric oxide (NO) in parts per billion (ppb), nitrogen dioxide (NO_2) in ppb, ozone (O_3) in parts per million (ppm), outdoor temperature in degrees Fahrenheit, and wind speed in meters per second (m/s) were obtained from various Continuous Ambient Monitoring Sites (CAMS) across the North Texas region **(**Figure 3-1**)**. Figure 3-1 shows the locations of currently active air monitoring stations in Texas and Table 3-1 lists all the stations that were used as part of the study. A total of 20 stations were part of the first analysis while 19 (for ozone) or 13 (for other parameters) stations were utilized from the second analysis onward.

The CAMS system is part of Texas’s effort to manage air quality, in compliance with the Environmental Protection Agency (EPA)’s guidance (Managing Air Quality – Ambient Air Monitoring). According to the EPA, ambient air monitoring stations are a crucial part for an effective management system of air quality (Managing Air Quality – Ambient Air Monitoring). This system provides comprehensive and timely data to investigate data quality trend, inform the public, support air quality standards' implementations, and enhance the air quality research, inter alia (Managing Air Quality – Ambient Air Monitoring).

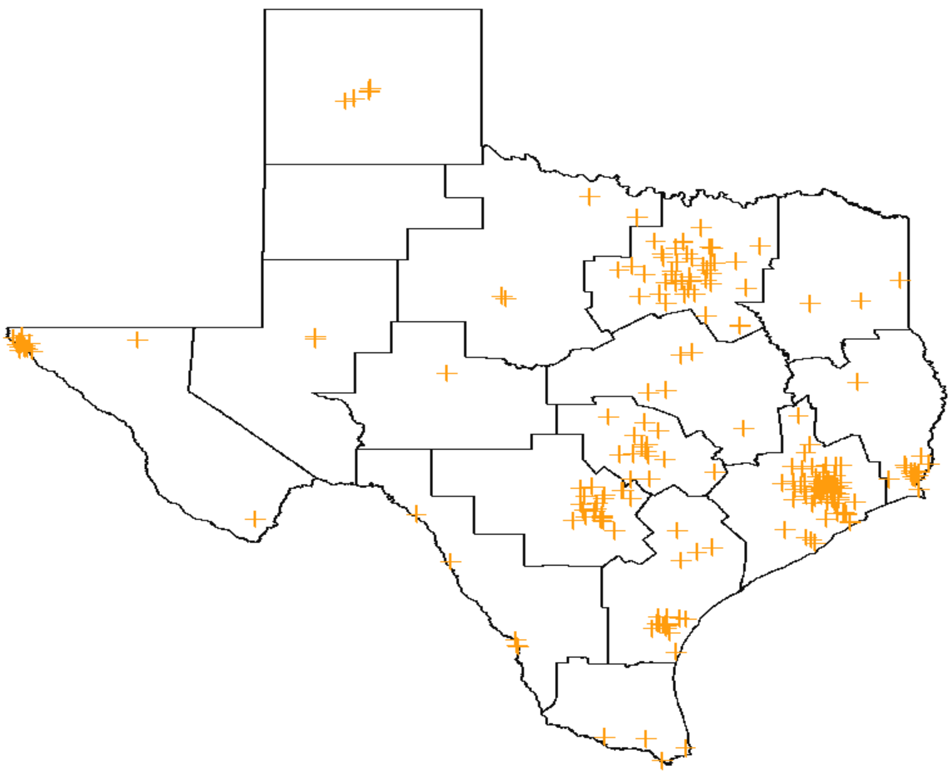


Figure 3-1: Locations of Air Monitoring Stations in Texas

Station ID	Station Name	County	Lat	Long
13	Ft. Worth	Tarrant	32.8058183	-97.3565675
17	Keller	Tarrant	32.9224736	-97.282088
31	Firsco	Collin	33.1324003	-96.7864188
52	Midlothian OFW	Ellis	32.4820829	-97.0268987
56	Denton Airport South	Denton	33.219069	-97.1962836
60	Dallas Hinton	Dallas	32.8200608	-96.8601165
61	Arlington Municipal Airport	Tarrant	32.6563574	-97.0885849
63	Dallas North #2	Dallas	32.9192056	-96.8084975
70	Grapevine Fairway	Tarrant	32.9842596	-97.0637211
71	Kaufman	Kaufman	32.5649684	-96.3176873
75	Eagle Mountain Lake	Tarrant	32.9878908	-97.4771754
76	Parker County	Parker	32.8687727	-97.9059308
77	Cleburne Airport	Johnson	32.3535945	-97.4367419
310	Haws Athletic Center	Tarrant	32.7591432	-97.3423337
312	Convention Center	Dallas	32.7742622	-96.7976859
402	Dallas Redbird Airport Executive	Dallas	32.6764506	-96.8720596
1006	Greenville	Hunt	33.1530882	-96.1155717
1032	Pilot Point	Denton	33.4106476	-96.9445903
1044	Italy	Ellis	32.1754166	-96.8701892
1051	Corsicana Airport	Navarro	32.0319335	-96.3991408

Table 3-1: Locations of Air Monitoring Stations in NCT Used in the Study

3.3.1.1.2 Adult Asthma Hospital Discharges

Adult asthma hospital discharge cases were extracted from the dataset provided by the Dallas Fort-Worth-Hospital Council Foundation (DFWHCF). The data was part of a project that was officially approved by the Texas Health Resources Institutional Review Board (Newcomb and Li, 2019). The processed data set yielded 78,444 cases with various asthma diagnoses based on the ICD-9 codes. The asthma patients' racial makeup covers a wide range of groups: White, Black, to Asian/ Pacific Islanders, Native Americans and Alaska Native. Most of the asthma patients were non-Hispanic or Latino. The age distribution ranges from 18 to 65 years of age, with 20-24 year-old-age group being the group with the largest number of patients.

3.3.1.1.3. Geographic Information System (GIS) Boundary Data

GIS boundary data in the form of shapefiles were obtained from the North Central Texas Council of Governments' Regional Data Site (Geographic Information System (GIS)). A shapefile is a common GIS file utilized for geometric location and attribute information storage (What is a shapefile?). Overall, in a shapefile, geographic features can be represented by different forms such as points, lines, or polygons (What is a shapefile?). For this project, shapefiles for the NCT at county and census tract level in the form of polygons were used.

3.3.1.2. Data Analysis

3.3.1.2.1. Principal Component Analysis and Hierarchical Agglomerative Clustering Analysis

As there are multiple air pollution variables and an extensive amount of data, it was important to conduct an exploratory data analysis to understand the nature of such variables, their possible interactions, and their spatial distribution. According to the EPA (2000), there are six possible interactions among air pollutants: masking, additive, antagonism, synergism, inhibition, and potentiation (as cited in Austin et al., 2013). Due to the voluminous nature of air pollution data, a high dimensionality data reduction is often employed to reduce the number of dimensions in a dataset. Various data reduction techniques as part of principle component methods and factor analysis methods were employed in many studies such as rotation factor analysis (Koutrakis and Spengler, 1987), positive matrix factorization (Paatero and Tapper, 1994), UNMIX (Kim and Henry, 1999), and absolute principal component analysis (Thurston and Spengler, 1985) (as cited in Austin et al., 2013).

Principal component analysis (PCA) is the process of computing the principal components and subsequently utilizing these components to understand the data; PCA attempts to find a low-dimensional data representation containing as much of the variance as possible (James et al., 2017). As an unsupervised learning approach, PCA is regularly performed as part of an exploratory data analysis (James et al., 2017). Not only does PCA simplify the complexity nature of a multivariate analysis, it can potentially help with an optimization of an air monitoring network via its combination with cluster analysis (Pires et al., 2008).

In performing PCA, the original correlated variables are transformed into uncorrelated new variables called principal components (PC) with the first few dimensions accounting for the majority of the total variance (Raschka and Mirjalili, 2017). More specifically, the first PC represents the maximum of the total variance; the second PC, uncorrelated to the first PC, accounts for the maximum of the remaining total variance, and so forth (Raschka and Mirjalili, 2017). After PCA was performed, Hierarchical Agglomerative Cluster Analysis (HACA) was carried out to identify spatial distribution of the variables of interest. HACA is a clustering method, which seeks to partition data points into distinct groups with minimal intra-cluster variation and maximal inter-cluster variation (James et al., 2017). The two best-known clustering methods are K-means clustering and hierarchical clustering (James et al., 2017). K-means partitions the data points into a pre-defined number of clusters while hierarchical clustering, via the construction of a dendrogram, allows a tree-like visualization of all possible clusters obtained for any number of clusters (James et al., 2017). In hierarchical clustering, which was the method of choice, there are two sub-divisions: agglomerative clustering (AGNES) and divisive hierarchical clustering (DIANA) (Hierarchical Cluster Analysis). The differences between these two approaches are illustrated by the adapted Figure 3-2 (Hierarchical Cluster Analysis).

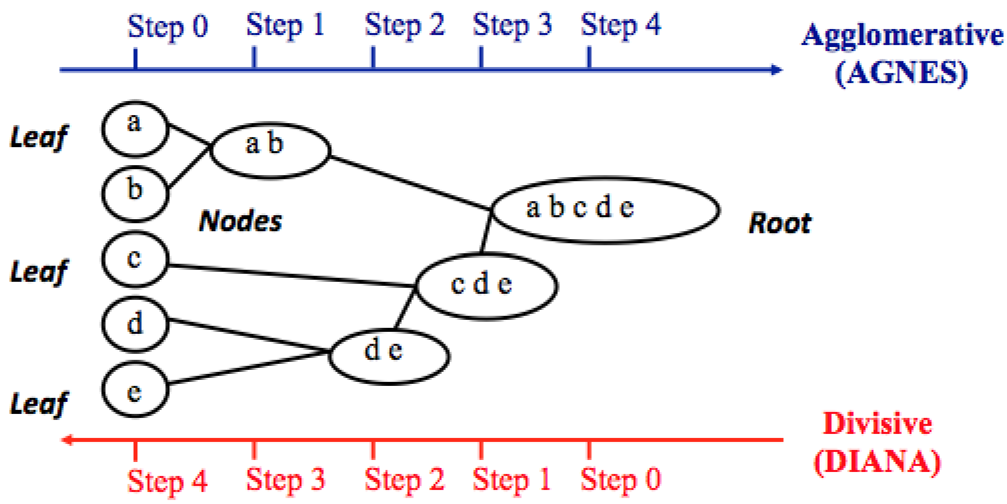


Figure 3-2: Process of Agglomerative and Divisive Hierarchical Clustering (adapted from Hierarchical Cluster Analysis)

PCA comprised the following steps: (1) Data extraction, (2) Standardization of all variables, (3) PCA analysis, (4) Scree test analysis, (5) Result interpretation. For HACA, the first two steps were similar to PCA. From step 3, the process was slightly different – (1) and (2) similar to PCA (3) Euclidean Distance computation (4) Cluster number determination (5) Dendrogram. All steps were performed using the R statistical program.

As mentioned above, the hourly recorded data for NO, NO_2, O_3, $PM_{2.5}$, outdoor temperature, and wind speed from various stations in the NCT was obtained. Utilizing missing data imputation and spatial interpolation method, which will be thoroughly explained in subsequent section, a 5-year average of all variables, for 20 stations was computed (Table 3-2).

Station/ Pollutant	NO	NO2	O3	PM2.5	Wind.Speed	Temperature
C13	3.91	9.25	27.2	10.29	7.68	67.13
C17	1.22	7.83	31.08	9.45	7.67	66.37
C31	1.74	7.31	33.36	9.32	8.17	66.32
C52	1.48	5.5	30.16	9.78	10.52	66.88
C56	1.71	6.5	29.85	8.63	7.73	65.51
C60	4.73	11.91	27.78	11.28	5.6	68.34
C61	2.52	7.57	28.19	9.15	8.15	66.77
C63	2.18	8.09	30.17	9.62	6.17	66.75
C70	1.42	7.31	30.45	9.51	6.69	66.63
C71	0.6	3.83	31.49	5.85	5.85	66.29
C75	0.85	6.15	29.25	9.41	9.62	65.83
C76	1.8	7.31	35.18	9.25	8.29	65.58
C77	1.74	6.72	30.66	9.28	9.62	66
C310	2.09	7.61	28.46	10.38	8.03	66.872
C312	1.81	7.08	28.96	10.71	6.44	67.36
C402	1.49	8.14	28.7	9.83	8.35	66.42
C1006	0.75	4.67	29.7	9.198	4.82	64.952
C1032	1.74	7.36	33.04	9.184	7.76	65.04
C1044	0.62	3.96	28.75	8.88	7.01	66.432
C1051	0.51	3.6	30.48	9.1	8.87	66.97

Table 3-2: 5-year averages for 20 CAMS in 2010-2014

The standardization of all variables was carried out after the 5-year averages were computed. Standardization simply means converting all variables to have mean of zero and standard deviation of one (James et al., 2017). This step was critical and indispensable for variables of vastly different ranges since if one variable had a much larger variance compared to the rest, it would dominate the first PC, skewing the analysis (James et al., 2017). The standardized values are shown in Table 3-3.

Station/ Pollutant	NO	NO2	O3	PM2.5	Wind.Speed
C13	2.06	1.21	-1.49	0.84	0.02
C17	-0.5	0.48	0.47	0.04	0.01
C31	-0.01	0.22	1.62	-0.08	0.36
C52	-0.25	-0.71	0.01	0.36	1.99
C56	-0.03	-0.2	-0.15	-0.73	0.05
C60	2.84	2.57	-1.19	1.78	-1.42
C61	0.74	0.35	-0.99	-0.24	0.35
C63	0.41	0.62	0.01	0.2	-1.03
C70	-0.31	0.22	0.15	0.1	-0.67
C71	-1.09	-1.56	0.68	-3.37	-1.25
C75	-0.85	-0.38	-0.45	0	1.36
C76	0.05	0.22	2.54	-0.15	0.44
C77	-0.01	-0.08	0.26	-0.12	1.36
C310	0.33	0.37	-0.85	0.92	0.26
C312	0.06	0.1	-0.6	1.24	-0.84
C402	-0.24	0.64	-0.73	0.4	0.48
C1006	-0.95	-1.13	-0.22	-0.2	-1.96
C1032	-0.01	0.24	1.46	-0.21	0.07
C1044	-1.07	-1.49	-0.7	-0.5	-0.45
C1051	-1.18	-1.68	0.17	-0.29	0.84

Table 3-3: Standardized values of variables of interest

After the standardized values were computed, PCA was carried out; the PCA results are illustrated in Figure 3-3. The eigenvectors are the dimensions with the largest eigenvalues corresponding to the dimensions having the strongest correlation in the dataset.

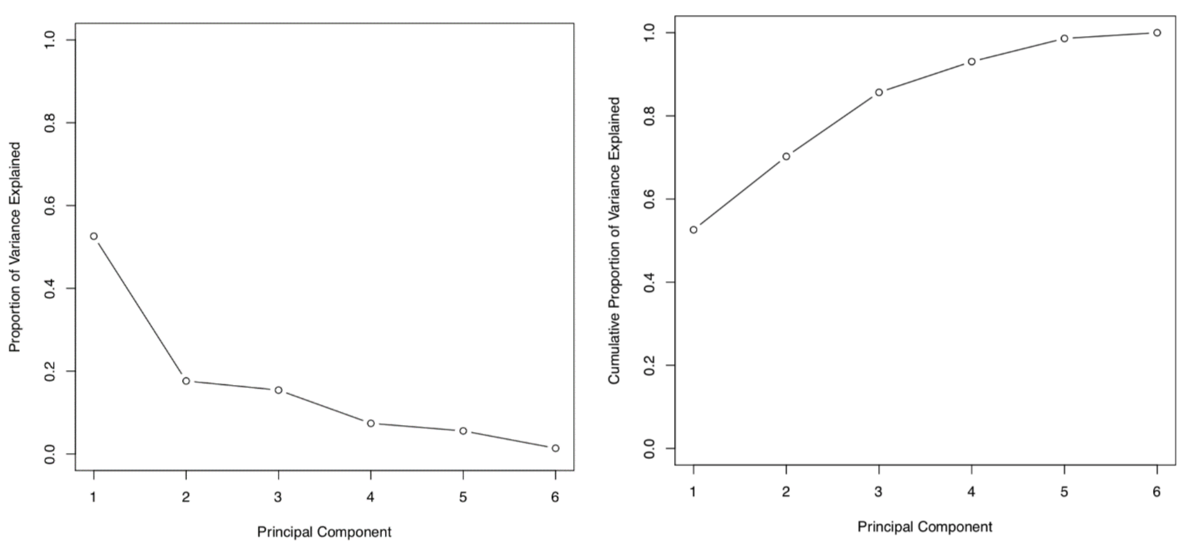
```
eig_vals = get_eigenvalue(pca)
eig_vals
```

```
      eigenvalue variance.percent cumulative.variance.percent
Dim.1 2.99552695        52.596972                    52.59697
Dim.2 1.00410634        17.630605                    70.22758
Dim.3 0.87814205        15.418861                    85.64644
Dim.4 0.42132599         7.397854                    93.04429
Dim.5 0.31723260         5.570130                    98.61442
Dim.6 0.07891207         1.385578                   100.00000
```

- 2.9955/6 = 0.525969 or 52.60% => about 52.60% of the total variance is explained by the first eigenvalue
- 1.0041/6 = 0.1763 or 17.63% => about 17.63% of the total variance is explained by the second eigenvalue
- Together, the first two dimensions (eigenvalues) explain 70.23% of the total variance

Figure 3-3: PCA results

To determine the number of PCs to keep, the Scree test was performed, which helped determine the sudden drop in slope, corresponding to the optimal number of PCs to keep. The Scree Test results (Figure 3-4) suggested keeping two PCs.



(a) **(b)**

Figure 3-4 Scree test results

(a) Proportion of Variance Explained (b) Cumulative Proportion of Variance Explained

After determining the number of PCs to keep, a biplot was constructed for result interpretation (Figure 3-5). A biplot represents principle components plotted against each other for a low-dimensional representation of the data; in a biplot, both the principal component scores and the variance are displayed (James et al., 2017). From the biplot, several observations could be made about the nature of the data.

(1) NO, NO_2, $PM_{2.5}$, and temperature are highly correlated;

(2) O_3 is more highly correlated with windspeed than it is with temperature and the other pollutants;

(3) NOx and O_3 are in opposite directions as the appearance of one variable will favour the disappearance of the other variable (NOx plays a key role in the formation of tropospheric O_3);

(4) the first loading vector (1st dimension) places approximately equal weight on NO_2, NO, $PM_{2.5}$, and temperature;

(5) the second loading vector (2nd dimension) corresponds to wind speed.

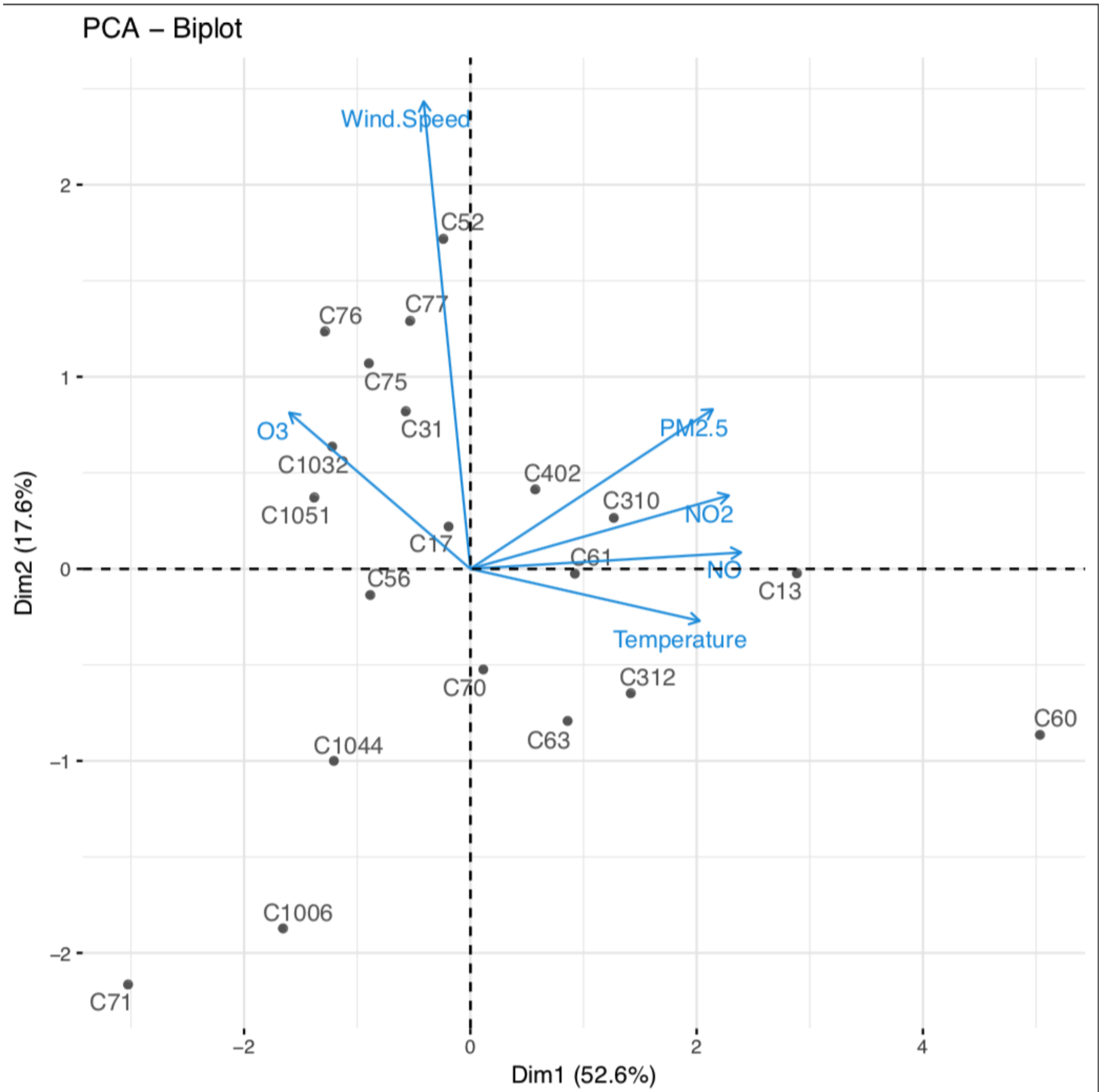


Figure 3-5: Biplot

Subsequently, for HACA, the Euclidean distance between every pair of stations in the dataset was computed. The Euclidean distance matrix is shown in the following table.

	C13	C17	C31	C52	C56	C60	C61	C63	C70	C71	C75	C76	C77	C310	C312	C402	C1006	C1032	C1044	C1051
C13	0	3.53	4.11	3.93	3.83	2.79	2.05	2.66	3.27	6.54	4.15	5.11	3.7	2.07	2.65	2.72	5.34	4.67	4.53	4.86
C17	3.53	0	1.33	2.47	1.68	5.42	2.03	1.55	0.88	4.22	2	2.42	1.63	1.92	2.3	1.37	3.21	2.02	2.47	2.56
C31	4.11	1.33	0	2.62	2.2	5.88	2.78	2.29	1.87	4.32	2.59	1.31	1.76	2.78	3.13	2.45	3.79	1.63	3.21	2.83
C52	3.93	2.47	2.62	0	2.87	6.22	2.48	3.37	2.85	5.18	1.71	3.56	1.53	2.36	3.2	2.23	4.73	3.51	2.97	1.89
C56	3.83	1.68	2.2	2.87	0	6.16	2.1	2.31	1.87	3.64	1.79	2.81	1.63	2.57	3.21	1.96	2.55	1.84	2.16	2.78
C60	2.79	5.42	5.88	6.22	6.16	0	4.52	4.21	5.02	8.31	6.6	6.8	6.09	4.26	4.04	4.96	7.14	6.61	6.62	6.96
C61	2.05	2.03	2.78	2.48	2.1	4.52	0	1.81	1.9	4.74	2.41	3.89	2.07	1.25	2.2	1.31	4.01	3.36	2.76	3.08
C63	2.66	1.55	2.29	3.37	2.31	4.21	1.81	0	0.93	4.54	3.14	3.33	2.73	1.74	1.57	1.86	3.32	2.89	2.85	3.41
C70	3.27	0.88	1.87	2.85	1.87	5.02	1.9	0.93	0	4.08	2.48	2.98	2.23	1.75	1.69	1.56	2.91	2.52	2.17	2.64
C71	6.54	4.22	4.32	5.18	3.64	8.31	4.74	4.54	4.08	0	4.61	4.68	4.59	5.41	5.38	4.98	3.78	4.38	3.29	3.85
C75	4.15	2	2.59	1.71	1.79	6.6	2.41	3.14	2.48	4.61	0	3.33	1.17	2.42	3.33	1.72	3.59	2.72	2.33	2.13
C76	5.11	2.42	1.31	3.56	2.81	6.8	3.89	3.33	2.98	4.68	3.33	0	2.53	3.92	4.29	3.52	4.1	1.33	4.09	3.73
C77	3.7	1.63	1.76	1.53	1.63	6.09	2.07	2.73	2.23	4.59	1.17	2.53	0	2.24	3.22	1.7	3.86	2.15	2.78	2.39
C310	2.07	1.92	2.78	2.36	2.57	4.26	1.25	1.74	1.75	5.41	2.42	3.92	2.24	0	1.38	1.02	4.02	3.46	2.87	3.06
C312	2.65	2.3	3.13	3.2	3.21	4.04	2.2	1.57	1.69	5.38	3.33	4.29	3.22	1.38	0	2.05	3.87	3.94	2.89	3.27
C402	2.72	1.37	2.45	2.23	1.96	4.96	1.31	1.86	1.56	4.98	1.72	3.52	1.7	1.02	2.05	0	3.68	2.92	2.63	2.85
C1006	5.34	3.21	3.79	4.73	2.55	7.14	4.01	3.32	2.91	3.78	3.59	4.1	3.86	4.02	3.87	3.68	0	3.12	2.48	3.83
C1032	4.67	2.02	1.63	3.51	1.84	6.61	3.36	2.89	2.52	4.38	2.72	1.33	2.15	3.46	3.94	2.92	3.12	0	3.48	3.62
C1044	4.53	2.47	3.21	2.97	2.16	6.62	2.76	2.85	2.17	3.29	2.33	4.09	2.78	2.87	2.89	2.63	2.48	3.48	0	1.72
C1051	4.86	2.56	2.83	1.89	2.78	6.96	3.08	3.41	2.64	3.85	2.13	3.73	2.39	3.06	3.27	2.85	3.83	3.62	1.72	0

Table 3-4: Euclidean distance matrix

Subsequently, optimal number of clusters was determined by the application of the three following tests: Gap statistic, Average Silhouette, and Elbow method (K-Means Cluster Analysis). The results of such tests are shown in Figures 3-6, 3-7, 3-8. The Elbow method determines the bend of a total variance plot; the Average Silhouette approach computes the observations' average silhouette for various number of clusters to measure the clustering result's quality; the Gap statistic compares the overall within cluster dissimilarity for various numbers of clusters with their expected values under a null distribution of data (K-means Cluster Analysis). The optimal number of clusters was determined based on the aggregated result from these three approaches. Both the Elbow method (Figure 3-6) and the Average Silhouette method (Figure 3-7) suggested two to be the optimal number of clusters while the Gap Statistics Method (Figure 3-8) recommended one. As a result, two clusters were chosen to be the optimal number

.

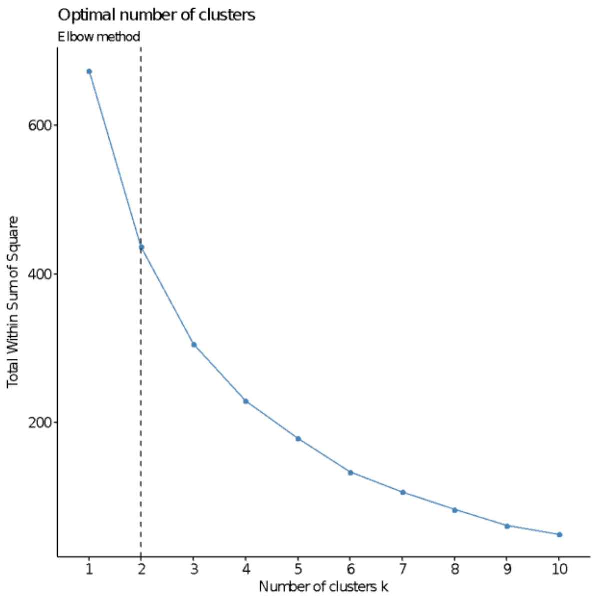


Figure 3-6: Elbow Method

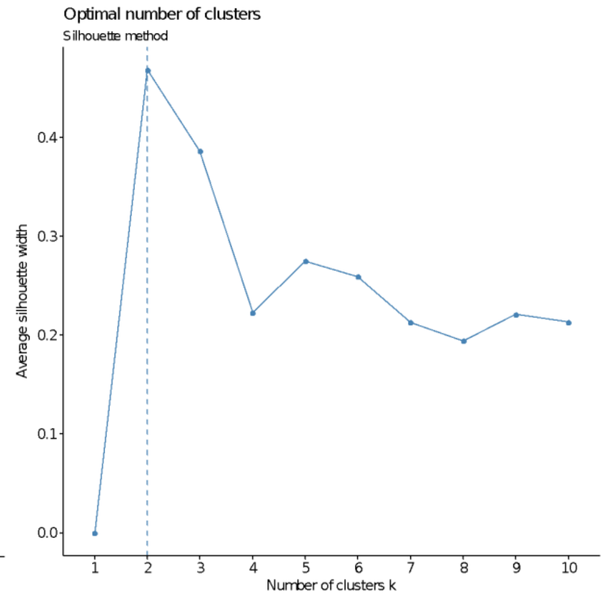


Figure 3-7: Silhouette Method

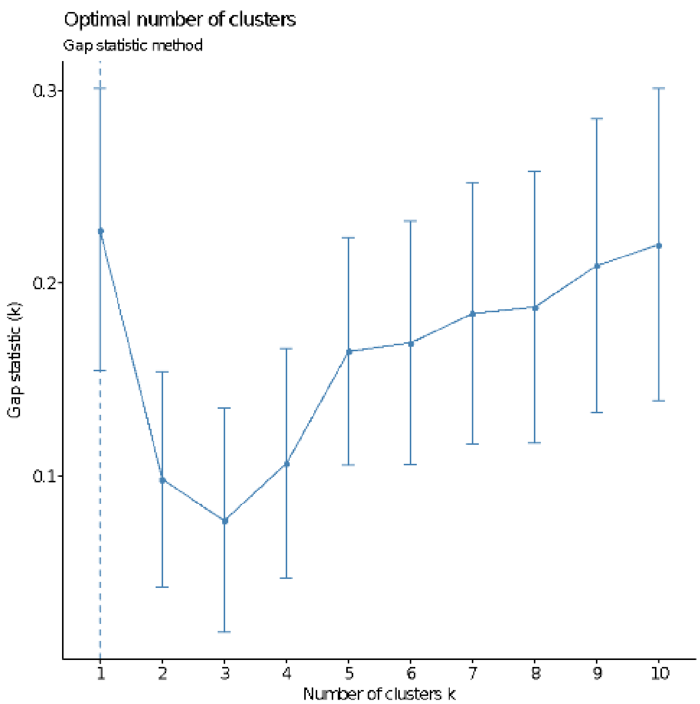
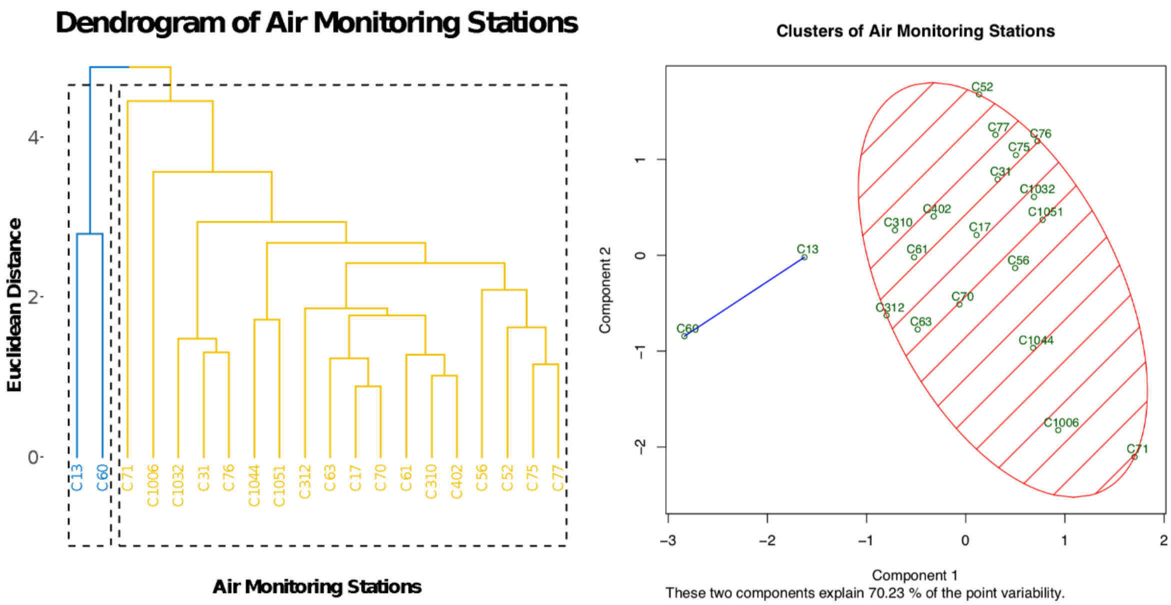


Figure 3-8: Gap Statistics Method

The outcome from the previous step was utilized to construct a dendrogram of the air monitoring stations and the two clusters resulted from such dendrogram (Figure 3-9). There were two stations in one cluster and 18 in the other one.

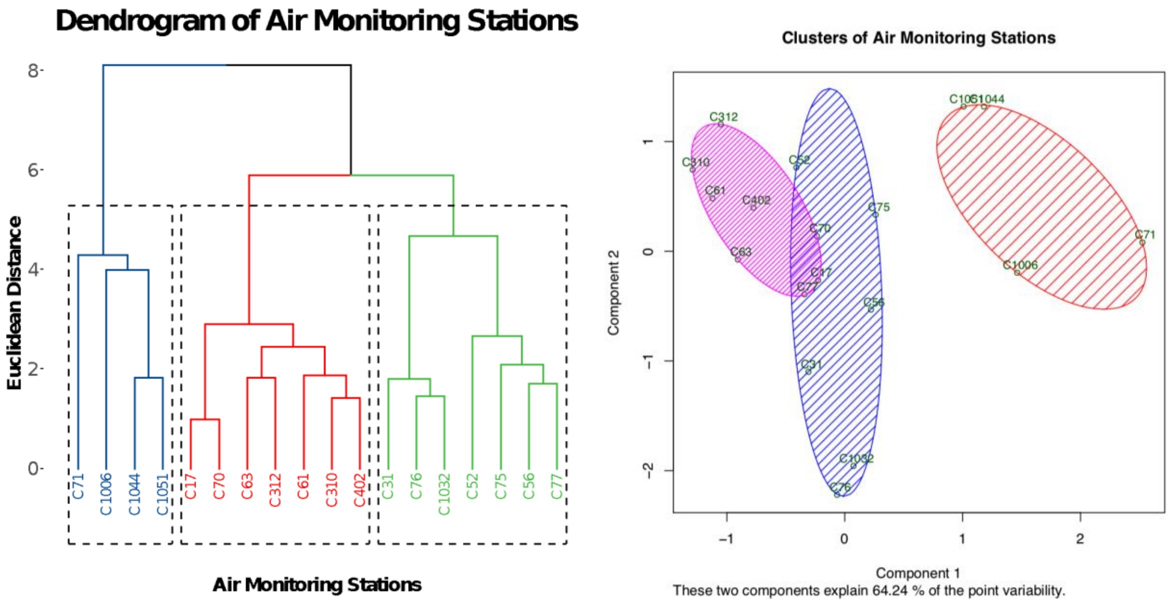


(a) (b)

Figure 3-9: First HACA analysis results

(a) Dendrogram of Air Monitoring Stations (b) Clusters of Air Monitoring Stations

The second cluster with 18 stations prompted further investigation. The same HACA approach was utilized to break down this cluster for constructing a new dendrogram and clusters. The resulting dendrogram and clusters are illustrated in Figure 3-10.



(a) (b)

Figure 3-10: Second HACA analysis results

(a) Dendrogram of air monitoring stations (b) clusters of air monitoring stations

Clusters of air monitoring stations can generally be used to explain asthma pattern. The clusters of air monitoring stations (Figure 3-11) are compared against the geographic clusters of asthma discharge cases in NCT during the summer (Figure 3-12 a) and during the winter (Figure 3-12 b). For example, the cluster of rural stations (blue cluster) corresponds to areas with extremely low asthma visits, regardless of the season. PCA results indicates that all stations included exhibit low concentration of air pollutants and low temperature (due to its rural nature). On the other hand, the red cluster comprises stations with the highest level of NO, NO_2, $PM_{2.5}$, and temperature. The green cluster consists of stations with highest level of O_3 and windspeed. These two clusters correspond to the high asthma cluster spreading across mostly three counties Tarrant, Dallas, and Denton.

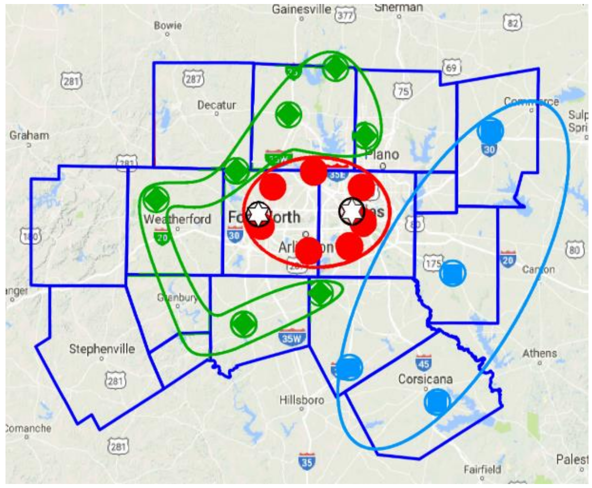
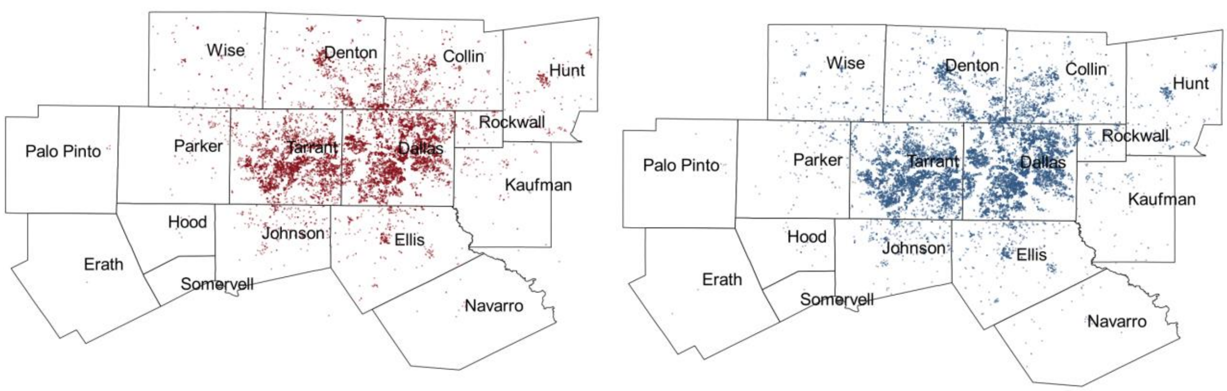


Figure 3-11: Clusters of air monitoring stations from the second HACA analysis



(a) **(b)**

Figure 3-12: Geographic clusters of asthma discharge cases

(a) Summer **(b) Winter**

3.3.1.2.2. Point Correlation Analysis

The point correlation analysis, more specifically the Pearson correlation analysis, consisted of the computation of pairs of ADR and air pollutants and their associated p-values. The Pearson product-moment correlation, Pearson correlation for short, is widely used as one of the principal methods to estimate a bivariate normal association, which means how closely related ordered pairs of parameters are to each other (Kutner et al., 2008)

The null hypothesis and alternative hypothesis in a Pearson's test are as follows:

(1) null hypothesis: there is no statistically significant correlation between the two variables of interest, (2) alternative hypothesis: there is a statistically significant correlation between the two variables of interest. The Pearson correlation coefficients and an associated p-value were computed for each association pair. Mathematically speaking, the correlation always falls in -1 to 1 range, indicating a range from a strong negative association to a strong positive association. As a rule of thumb, a moderate relationship yields the absolute value of the coefficient to be between 0.4 to 0.7; a weak relationship has the absolute value less than 0.4; and a strong association is denoted by a coefficient greater than 0.7. This rule is not set in stone and allows for certain flexibility depending on the analysis. The p-value, as always, determines the statistical significance of the association, or lack thereof.

GIS, a framework for spatial data analysis and management, is by and large, used for pattern and relationship recognition via the evaluation of spatial locations and maps (What is GIS?). Invented in the 1960s, GIS has substantially evolved from a mere spatial concept to an extensive application employed in numerous disciplines for a comprehensive understanding of geographical distribution of the variables of interests (History of GIS). In epidemiological studies, GIS has been proven to be immensely useful in disease mapping, monitoring, and management (Gorai et al., 2014). Similarly, in environmental health studies, GIS has been broadly employed for air pollutant estimation and various spatial applications in public health (Gorai et al., 2014). For this project, GIS is utilized for Ordinary Kriging (OK), spatial mapping, and spatial pattern analysis.

Three sets of spatial analyses were carried out for three different time frames: the entire study period (2010 – 2014), the summer period (summers 2010 to 2014), and the winter period (winters 2010 to 2014). The study period's values were the averaged value of each annual average for each concentration. Summer's values were the averaged values from the months of June, July, and August while the winter values were averages from the months of December, January, and February. To keep the spatial analysis consistent, all variables of interest, after spatial interpolation, were retrieved from the centroids of each census tract. Census tracts, delineated by the U.S. Census Bureau, are a county's small and comparatively permanent statistical subdivision with a 4000-inhabitant population average (Census Tracts). A centroid is simply the centre of a feature, geometrically speaking (GIS Dictionary). The centroids of the NCT's census tracts are indicated by the red dots in Figure 3-13.

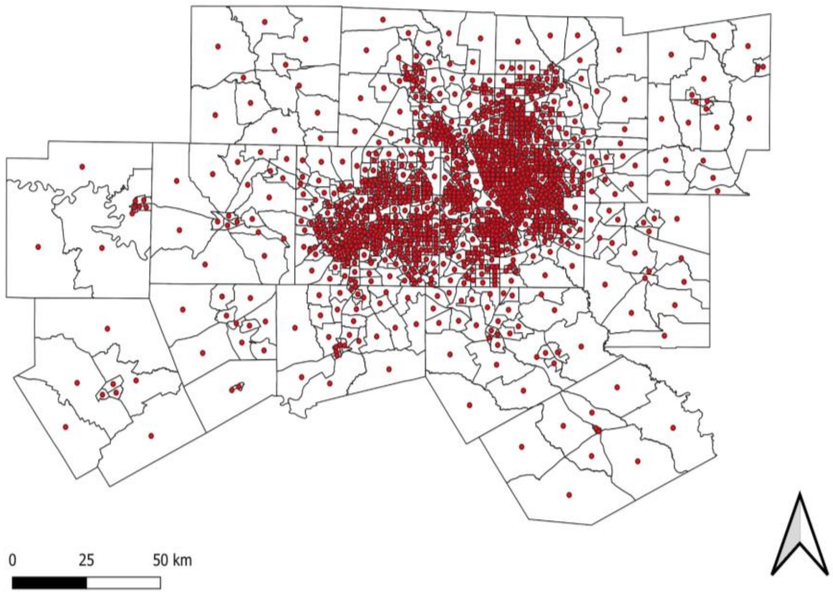


Figure 3-13: NCT Census Tract Centroids

ADR is the total of asthma hospital discharges per 10,000 populations within a specific timeframe (Gorai et al., 2014). To calculate ADR at the census tract level, there were two steps involved: (1) retrieving the number of asthma-related hospital discharges and the corresponding population for each census tract; (2) computing the ADR based on the retrieved values. In order to do so, the asthma cases with addresses were geocoded using Google Geocoding API services and the Python programming language. Subsequently, individual asthma cases with corresponding spatial coordinates (longitude and latitude) were entered into GIS, overlaying the NCT census tract shape file; consequently, the exact count of asthma cases for each tract was retrieved. The total population for each tract was aggregated based on population data obtained from the Census Bureau. Once that process was complete, the ADR computation was carried out. More specifically, the annual, summer, and winter ADR from 2010 to 2014 were calculated for each census tract and the average annual, summer, and winter ADRs for the 2010-2014 period were thereupon extracted.

Hourly measurements during the period of 2010 – 2014 for NO, NO_2, O_3, temperature, and windspeed were obtained from TCEQ's ambient monitoring stations. Due to data unavailability, the number of stations with records was different for each parameter. There were 13 stations for NO, 13 for NO_2, 19 for O_3, 13 for temperature, and 13 for wind speed. These stations had the most complete data. Missing data were examined and imputed, utilizing the R Statistical Program via the method of predictive mean matching. The predictive mean matching method, a stochastic regression technique, replaces a missing value with a value whose regression-predicted score is the closest to the missing's value regression-predicted score (Landerman et al., 1997). As cited in Landerman et al. (1997), Kalton and Kasprzyk (1986) and David et al. (1986) emphasized that the predictive mean matching method was superior to various other missing imputation methods such as deterministic regression methods and mean imputation. After the completeness of the dataset was established, the daily averages, annual averages, summer averages, and winter averages of all concentrations were computed.

Like all other states in the United States, to meet the Clean Air Act requirements, Texas has built an air monitoring network for criteria air pollutants (O_3, NO_2, CO, PM, lead, and SO_2) regulated by the EPA and major meteorological variables (Wong et al., 2004). As shown in Figure 3-2, the majority of these air monitoring stations were installed in the state's most populated urban regions. That leaves a large number locations without measures of air pollution concentration (Liao et al., 2006). To develop an understanding of the relationship between a respiratory disease and air pollutant concentration, such air pollutant concentrations have to be estimated, or predicted, via the application of geostatistical mapping, a map production technique utilizing auxiliary information and field observations (A Practical Guide to Geostatistical Mapping). More specifically, such geostatistical mapping methods are considered spatial interpolation methods and various interpolation approaches are readily available.

Overall, spatial interpolation methods belong to two categories: deterministic and statistical interpolation approaches (Gimond, 2019). Under deterministic group, proximity interpolation and Inverse Distance Weighting are prominent examples (Gimond, 2019; Wong, 2004). Proximity interpolation, also known as Thiessen interpolation, estimates values of unsampled locations based on the values from the closest sampled location; this technique is among the simplest interpolation method (Wong, 2004). Inverse Distance Weighted (IDW) assigns values of unsampled locations based on weighted values from nearby locations (Gimond, 2019). As the weights are determined based on the proximity of the sampled values to the unsampled monitoring stations, the closer the observed values are to the point of interest, the more heavily weighted they are (Wong, 2004). The statistical interpolation approaches include trend surfaces utilizing regression trend surface modelling and kriging, the arguably most complicated and extensively used in environmental health studies. Kriging assumes spatial variation of air pollutants' concentration, which is typically complex yet structured (Wong, 2004). Such spatial structure typically depends on some scale, and this dependence is considered spatial autocorrelation (as cited in in Wong, 2004).

Overall, the spatial variation and dependence can be summarized by a variogram (Figure 3-14) which describes the similarity degree of observation pairs separated by a distance (Wong, 2004). More definitively, variograms depict how the concentrations vary with the increased distance between location point pairs (Gimond, 2019). After a variogram is constructed, various mathematical models are fitted to the variogram, and the best fitted model is chosen (Gimond, 2019). The examples of various mathematical models available in the R statistical program are illustrated in Figure 3-15. Various model parameters such as nugget, range, and partial sill (Figure 3-16) were considered when picking the best fitted model. Range is the horizontal distance from the curve's starting point to its levelling off point; the nugget is the vertical distance between the point of zero variance to the point the model intercepts the y axis; the partial sill or sill is the vertical distance between the curve's levelling off part and the nugget (Gimond, 2019).

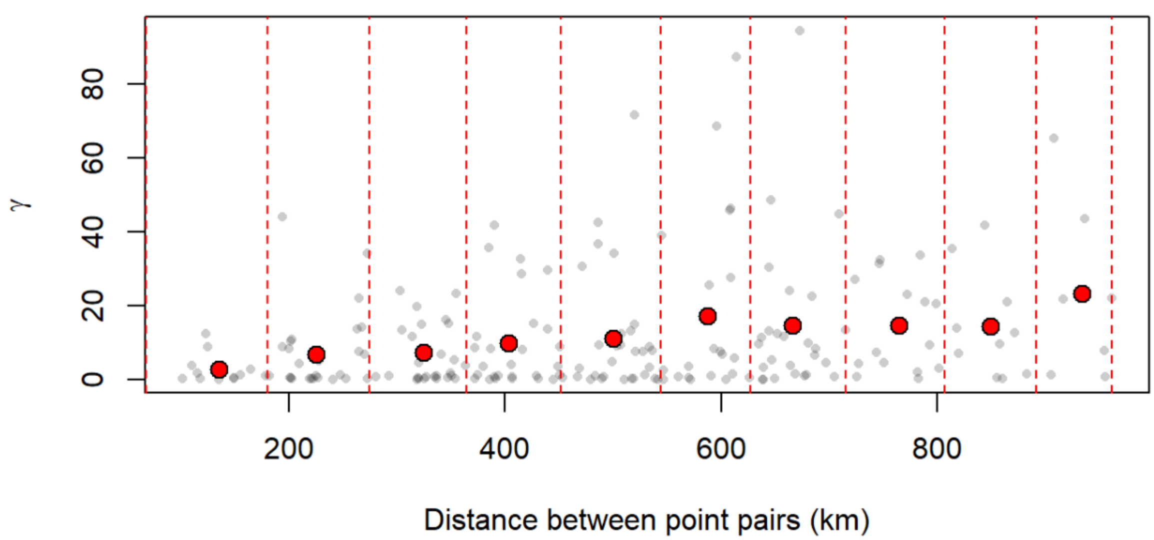


Figure 3-14: An example of a variogram (adapted from Figure 14.12 in Gimond, 2019)

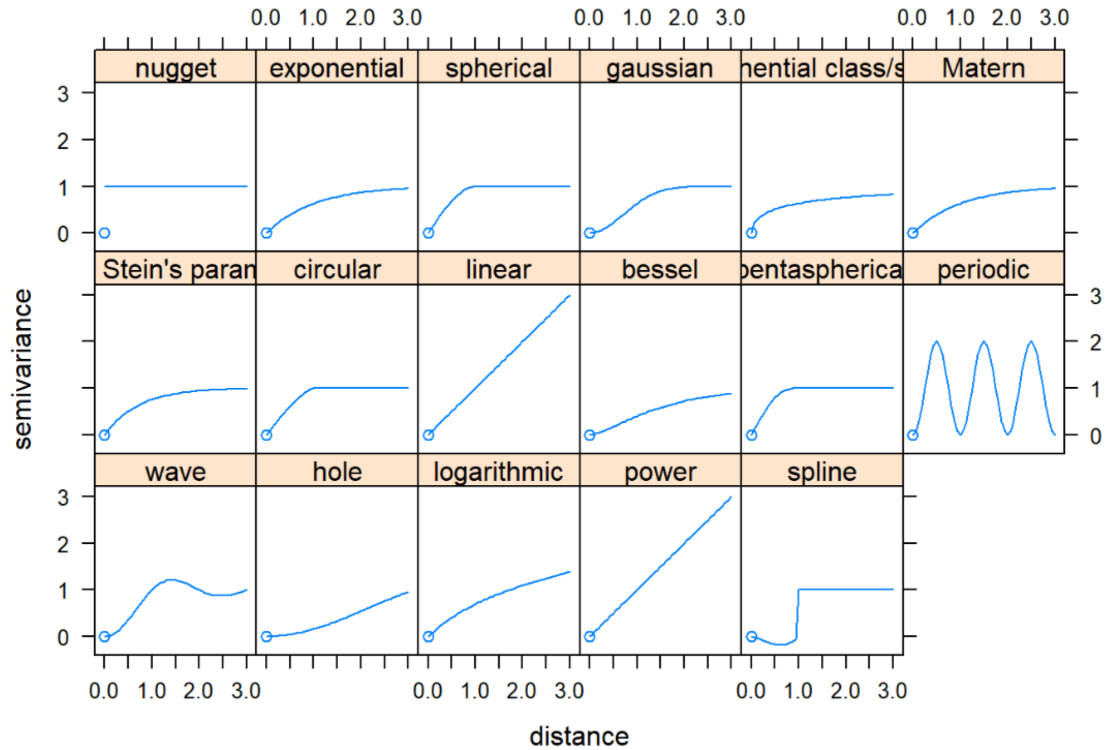


Figure 3-15: A subset of the available variogram models in R statistical program (adapted from Figure 14.13 in Gimond, 2019)

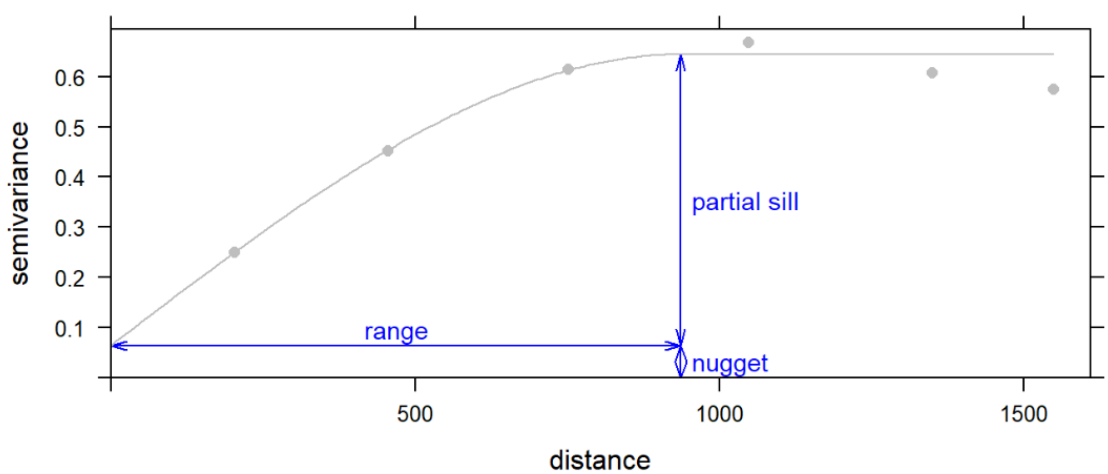


Figure 3-16: Graphical representation of partial sill, range, and nugget parameters in a variogram model (Adapted from Figure 14.14 in Gimond, 2019)

The best fitted model was determined by choosing the model with the lowest sum of squared error. After the best model was chosen, it was used to compute the weights with the minimal variance to the estimate values, and a kriged surface is generated (Wong, 2004). Predicted concentrations were generated from such kriged surface. The variance and confidence interval maps for each analysis are included in the Appendix.

Out of several forms of Kriging, including: ordinary, simple, and universal, ordinary kriging (OK) was employed to estimate the concentrations of unsampled regions (Gimond, 2019). While simple kriging assumes a known mean value, OK determines the mean value via the interpolation process (Wong, 2004). OK, generally based on a variable's spatial variance, typically involves four steps: 1) Spatial trend removal 2) Experimental variogram computation 3) Experimental variogram model definition 4) Surface interpolation (Gimond, 2019). All processes were carried out in the R statistical program.

Kriging process results in spatially interpolated maps for each variable of interest. The spatial interpolated maps resulting from OK for annual, summer, and winter analyses are indicated in Figure 3-17, 3-18, and 3-19. The descriptive statistics of all parameters are included in the appendices. The sum of squared errors (SSE) of the best models for each parameter in each analysis are listed in Table 3-5. The smaller these values, the better the models are at estimating the unsampled concentrations (Gimond, 2019). The 5-year annual, summer, and winter average of NO is 1.81, 0.58, and 3.26, respectively. The corresponding SSE values for NO estimated from the best model are 0.00004, 0.00004, and 0.12330. Similarly, NO_2 averages are 7.14, 4.62, and 8.84; the SSEs are 0.05676, 0.01998, and 0.11840. For the 24-hour ozone, the six values are

30.17, 34.11, 23.00, 0.02147, 0.01375, and 0.05830. The 8-hour maximum ozone's values are 42.3(), 45.33, 44.29, 0.00079, 0.00171, and 0.01225. For temperature, the values are: 66.66, 84.54, 47.94, 0.00094, 0.05354, and 0.00129. Lastly, wind speed's values are: 6.98, 6.70, 7.51, 0.00829, 0.00721, and 0.00166. All the SSE values are noticeably small, indicating how well the best models performed.

Parameter	Annual	Summer	Winter
NO	0.00004	0.00004	0.12330
NO2	0.05676	0.01998	0.11840
O3	0.02147	0.01375	0.05830
O3 - 8hrs	0.00079	0.00171	0.01225
Temperature	0.00094	0.05354	0.00129
Wind Speed	0.00829	0.00721	0.00166

Table 3-5: Sum of squared errors of the best model in Ordinary Kriging

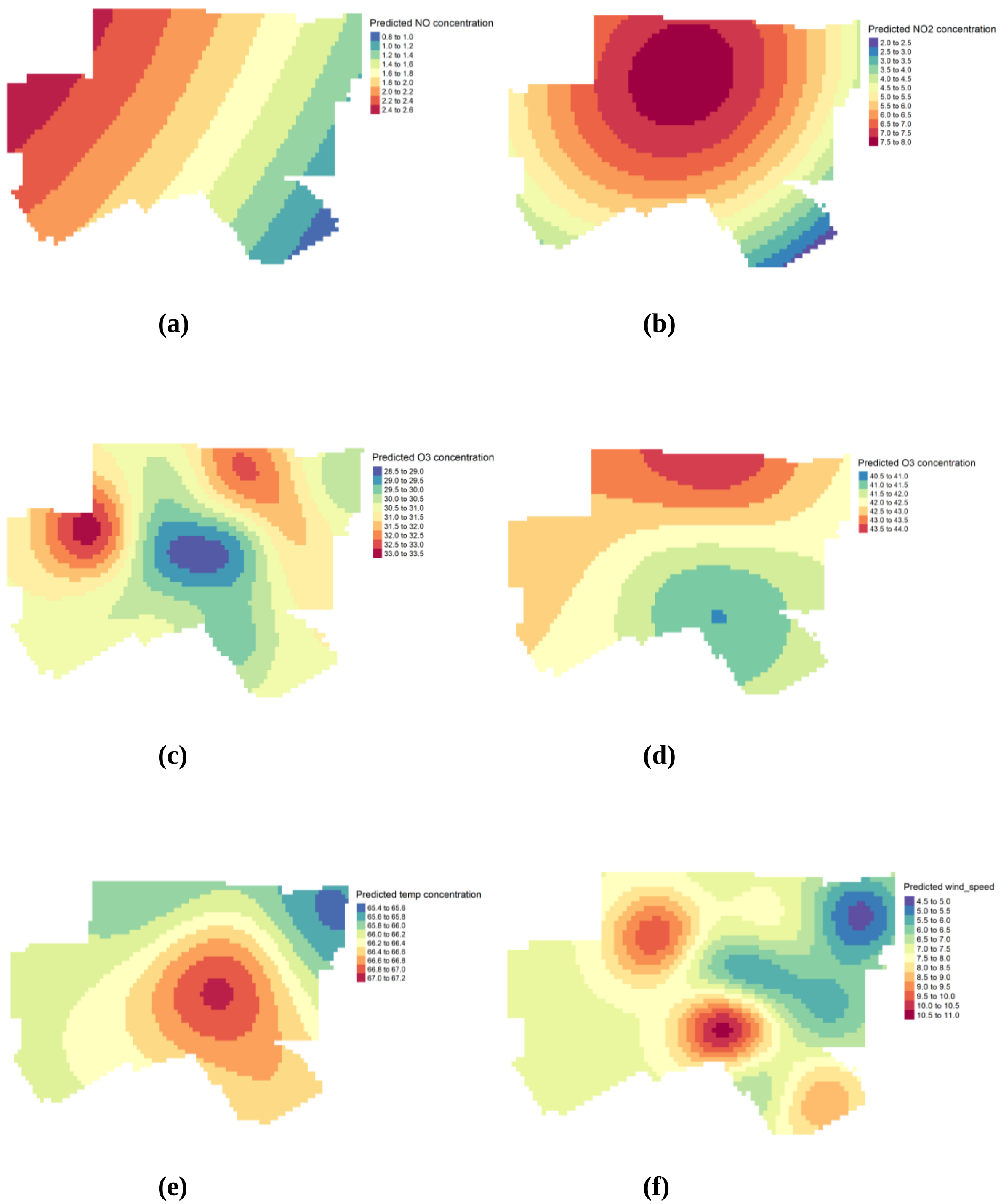


Figure 3-17: Spatial distribution of 5-year annual average

(a) NO **(b) NO2** **(c) O3**

(d) Maximum 8-hr O3 **(e) Temperature** **(f) Wind Speed**

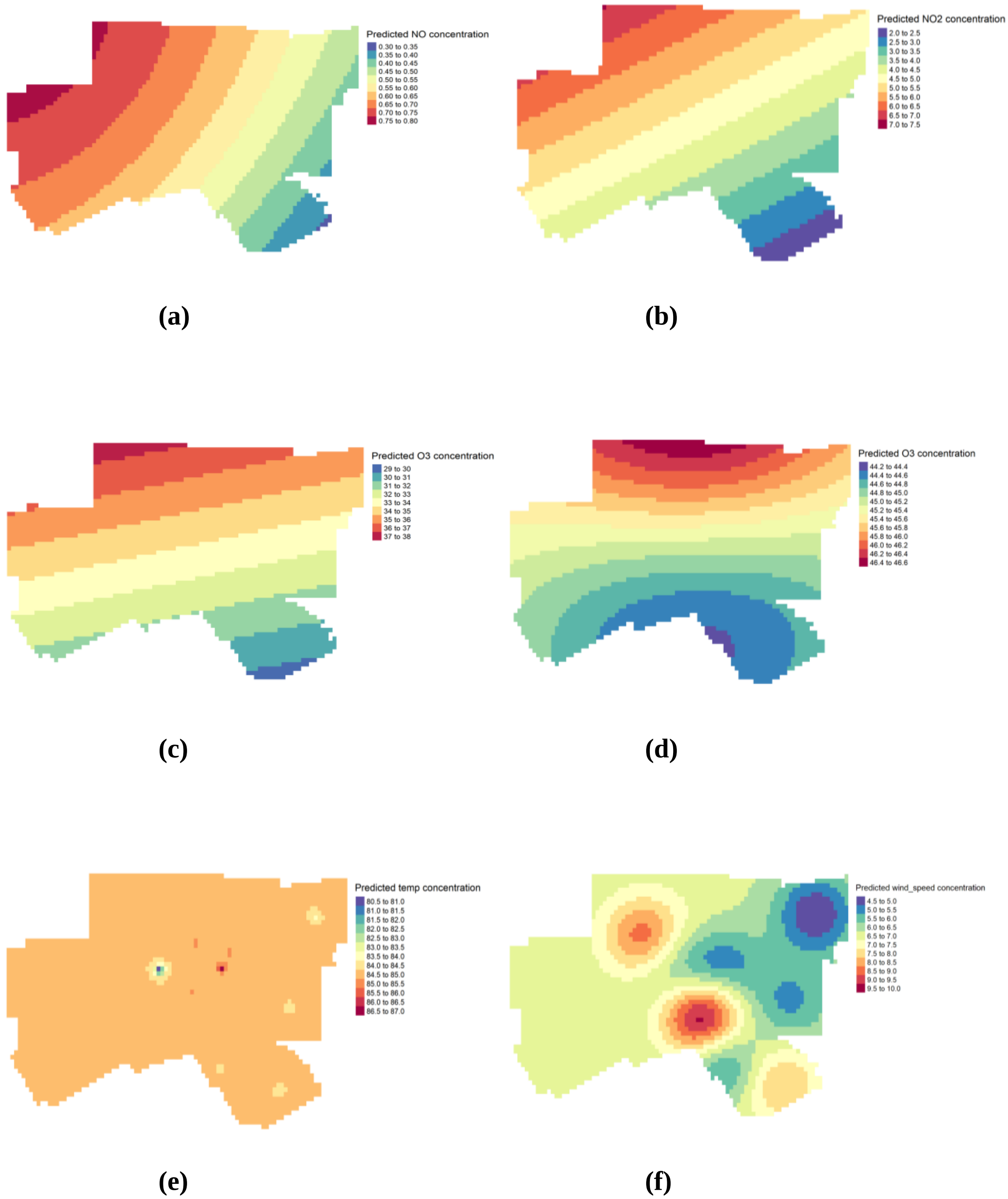
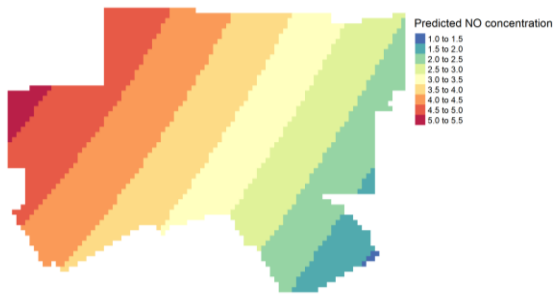


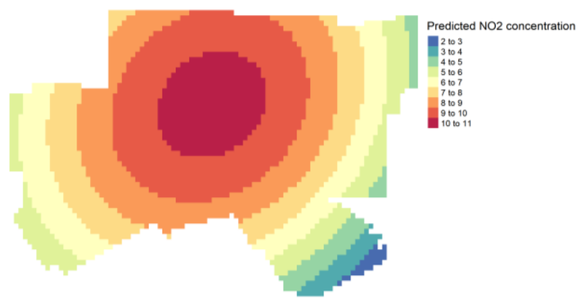
Figure 3-18: Spatial distribution of 5-year summer average

(a) NO **(b) NO_2** **(c) O_3**

(d) Maximum 8-hr O_3 **(e) Temperature** **(f) Wind Speed**



(a)



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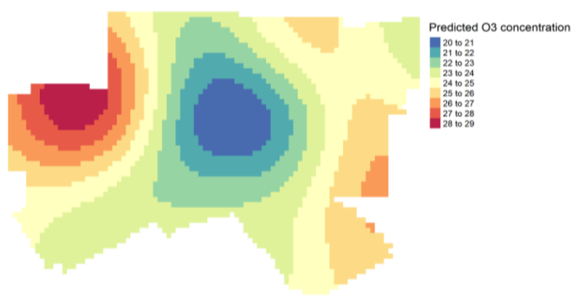

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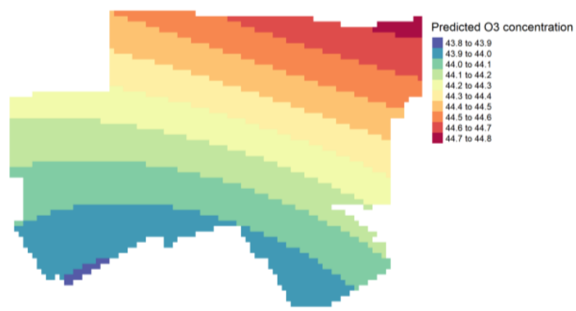

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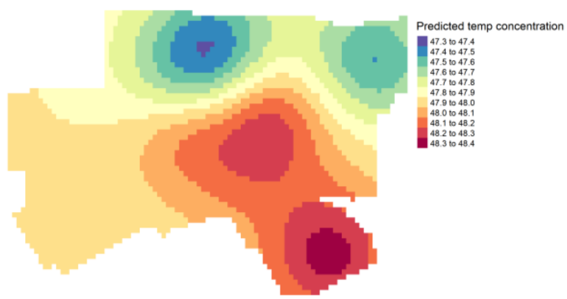

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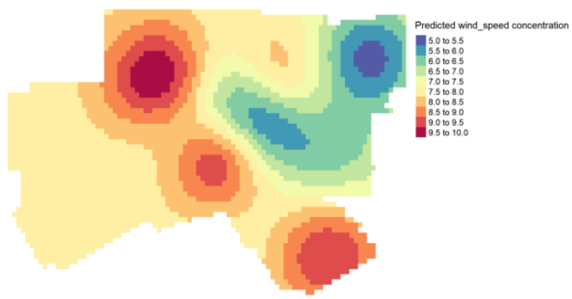


(f)

Figure 3-19: Spatial distribution of 5-year winter average

(a) NO **(b) NO_2** **(c) O_3**

(d) Maximum 8-hr O_3 **(e) Temperature** **(f) Wind Speed**

The generated kriged surfaces of all parameters were subsequently imported into GIS and combined with the census tract shapefile. As a result, the estimated values of all concentrations were retrieved from the centroids. There were a total of 1347 centroid values for the 5-year annual analysis, 1351 for 5-year summer analysis, and 1348 for 5-year winter analysis, out of a total of 1351 census tracts. The discrepancy was due to several missing ADR values, which were also extracted from centroids. After all the centroid values for air pollutants, meteorological variables, and ADR were extracted, the summary statistics were calculated and detailed in Table 3-6, 3-7, and 3-8.

	NO	NO2	O3	Temperature	Wind Speed	ADR
Mean	1.81	7.14	30.17	66.66	6.98	25.79
Stdev	0.19	0.63	1.08	0.28	0.98	25.09
Median	1.81	7.29	30.06	66.71	6.95	19.66
Minimum	1.00	2.95	28.72	65.57	4.82	0.00
Maximum	2.47	7.83	33.24	67.04	10.56	285.02
N	1347	1347	1347	1347	1347	1347

Table 3-6: 5-year Annual Summary Statistics (Tract Level)

	NO	NO2	O3	Temperature	Wind Speed	ADR
Mean	0.60	4.87	34.29	84.55	6.30	3.85
Stdev	0.05	0.49	0.87	0.22	0.78	4.32
Median	0.60	4.88	34.28	84.54	6.18	2.67
Minimum	0.37	2.38	30.07	80.88	4.53	0.00
Maximum	0.76	6.72	37.24	86.85	9.49	43.80
N	1351	1351	1351	1351	1351	1351

Table 3-7: 5-year Summer Summary Statistics (Tract Level)

	NO	NO2	O3	Temperature	Wind Speed	ADR
Mean	3.42	9.60	22.01	48.03	7.23	5.79
Stdev	0.41	0.92	1.47	0.20	0.94	5.83
Median	3.41	9.80	21.70	48.08	7.23	4.44
Minimum	1.73	3.51	20.05	47.41	5.30	0.00
Maximum	4.97	10.45	28.51	48.33	9.87	85.26
N	1348	1348	1348	1348	1348	1348

Table 3-8: 5-year Winter Summary Statistics (Tract Level)

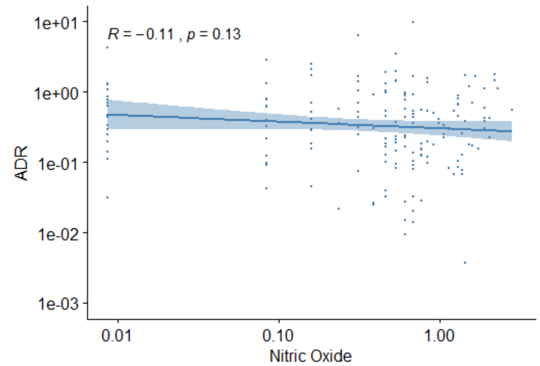
All parameters were log-transformed before the pairwise correlations were calculated.

The Pearson correlation and the p-value for each pair were computed. Three sets of pairwise results for the 5-year period, the 5-year summer period, and the 5-year winter period indicating the possible relationship of ADR and the common air pollutants and meteorological variables are shown in Figure 3-20, Figure 3-21, Figure 3-22. Across the entire time period, the asthma record is poorly correlated with all the parameters.

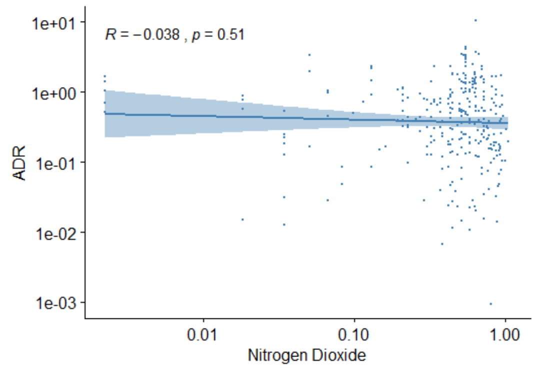
In the 5-year annual analysis, the Pearson correlation coefficients for ADR versus NO, ADR versus NO_2, ADR versus O_3, ADR versus max 8-hour O_3, ADR versus temperature, and ADR versus wind speed are -0.11, -0.38, -0.86, -0.11, 0.099, and 0.0036. Such values, coupled with the high corresponding p-values (0.13, 0.051, 0.29, 0.13, 0.051, 0.96) indicate a non-significant relationship. Only temperature and windspeed have a trivial positive correlation with ADR; the rest of the parameters exhibit a trivial negative correlation.

Previously, the distinct seasonality in the asthma record was discussed. Here, the seasonality in the relationship between ADR and pollutant concentrations is examined via the computation of Pearson correlations for the same possible relationships in the summer and winter. Pairwise correlation showing the possible association of ADR for the summer months across the entire period at census tract level is shown in Figure 3.21. The Pearson correlations are 0.14, -0.15, -0.14, -0.17, -0.14, and -0.11. The corresponding p-values are 0.046, 0.052, 0.11, 0.066, 0.12, and 0.14. Similar to the annual analysis, the associations are trivial and non-significant.

The winter month's Pearson correlations range from -0.018 to 0.14 and all p-values are greater than the significant 0.05, except for the ozone analysis's p-value (Figure 3.22). Such results confirm once again the non-significant correlation.



(a)



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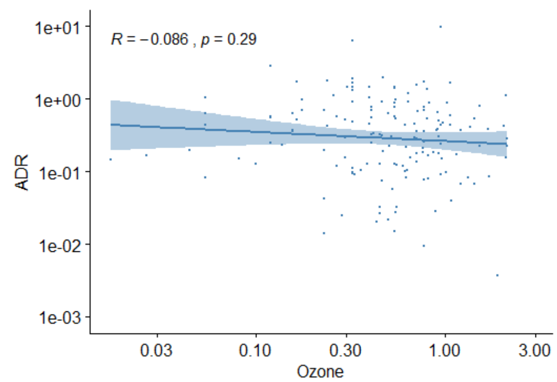

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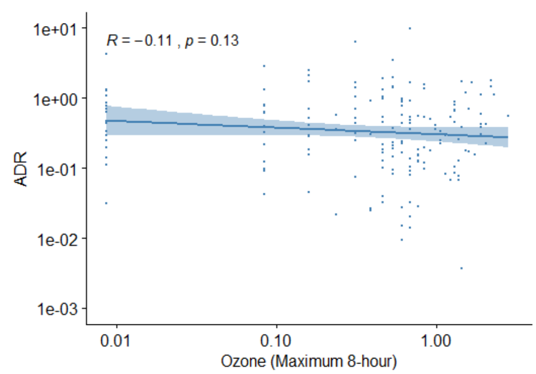

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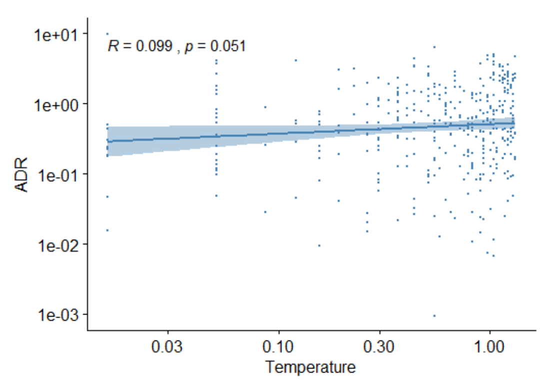

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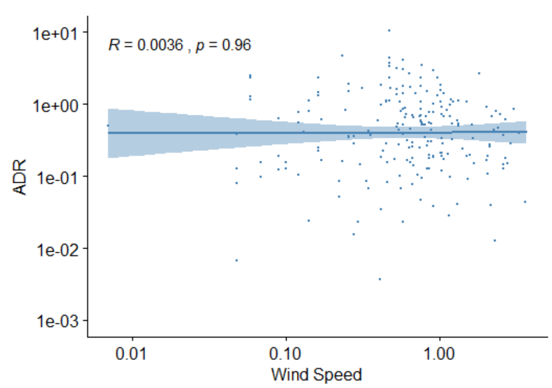


(f)

Figure 3-20: Pearson pairwise correlation between 5-year annual ADR and:

(a) NO **(b) NO2** **(c)O3**

(d) Maximum 8-hr O3 **(e) Temperature** **(f) Wind speed**

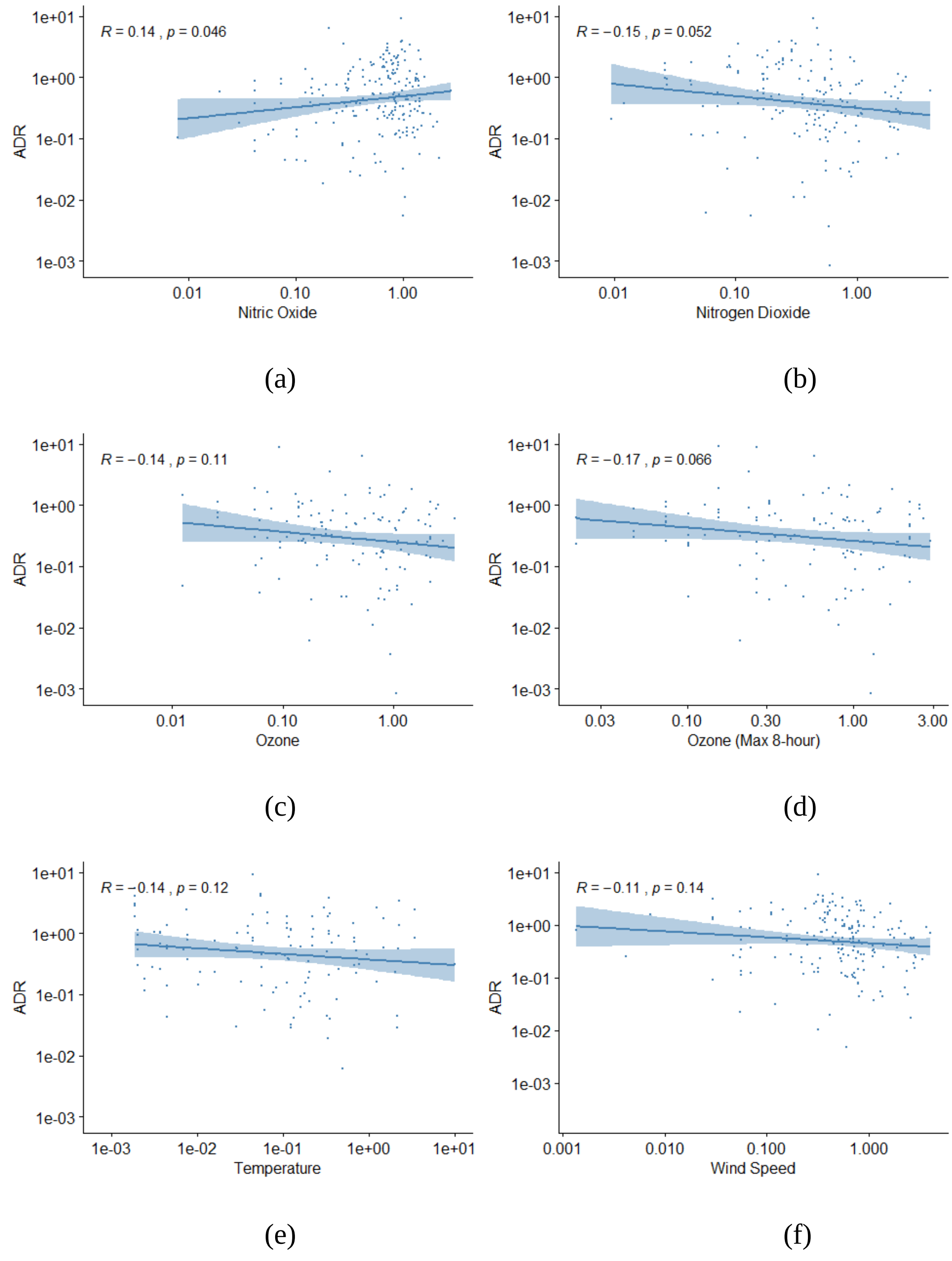
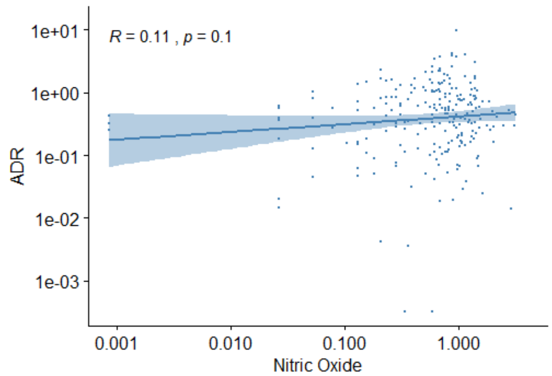


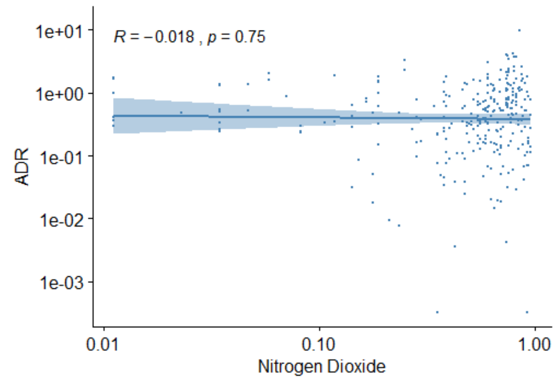
Figure 3-21: Pearson pairwise correlation between 5-year summer ADR and:

(a) NO **(b) NO2** **(c)O3**

(d) Maximum 8-hr O3 **(e) Temperature** **(f) Wind speed**



(a)



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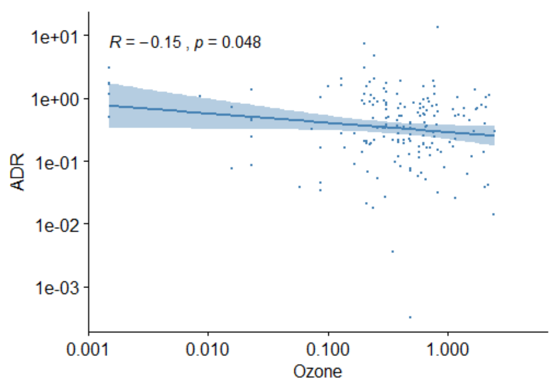

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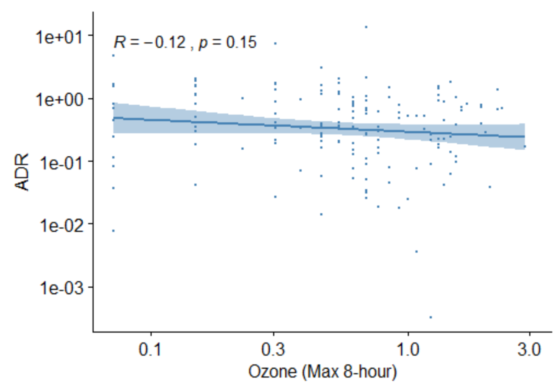

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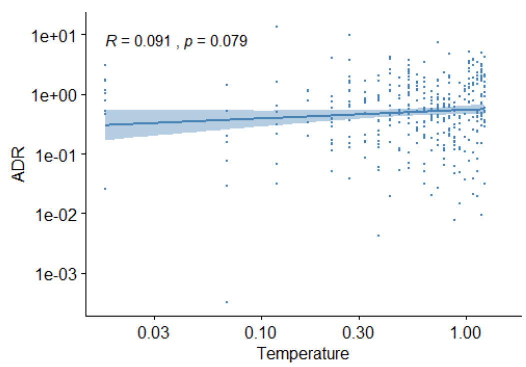

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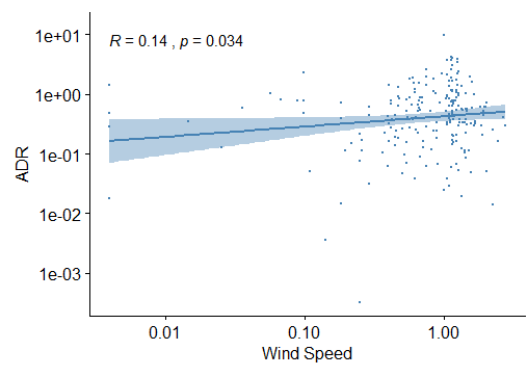


(f)

Figure 3-22: Pearson pairwise correlation between 5-year winter ADR and:

(a) NO **(b) NO2** **(c)O3**

(d) Maximum 8-hr O3 **(e) Temperature** **(f) Wind speed**

3.3.1.2.3. Hot Spot Analysis

Locations of statistically significant hot spots and cold spots in our data for all the parameters were identified utilizing the Getis-Ord Gi* statistic; this process is called a hot spot analysis (How Hot Spot Analysis (Getis-Ord Gi*) works). Fundamentally, the hot spot analysis tool in ArcGIS, a commercial GIS software, computes the Getis-Ord Gi* statistic for each feature of interest, resulting in the z-scores and p-values (How Hot Spot Analysis (Getis-Ord Gi*) works). The Z-scores are standard deviation and the p-value is a probability in the hot spot analysis statistical test (What is a z-score? What is a p-value?). In a hotspot analysis, the null hypothesis is a complete spatial randomness while an alternative hypothesis is a non-randomness of spatial distribution (What is a z-score? What is a p-value?). The Z-scores and p-values come from the distribution illustrated in Figure 3-23, which shows the probability that a spatial pattern was due to some random process (What is a z-score? What is a p-value?).

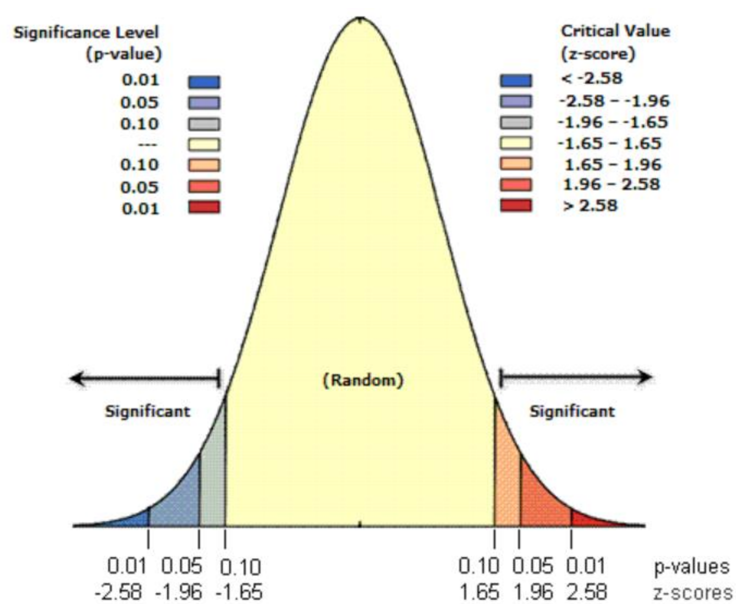


Figure 3-23: Probability distribution of an observed spatial pattern

(adapted from What is a z-score? What is a p-value?)

A statistically significant hot spot is indicated via a high positive Z score and a small p-value, and a statistically significantly cold spot is revealed via a low negative Z score and a small p-value (How Hot Spot Analysis (Getis-Ord Gi*) works). The Getis-Ord Gi* statistic is demonstrated in Figure 3-24.

The Getis-Ord local statistic is given as:

$$G_i^* = \frac{\sum_{j=1}^{n} w_{i,j} x_j - \bar{X} \sum_{j=1}^{n} w_{i,j}}{S \sqrt{\frac{\left[n \sum_{j=1}^{n} w_{i,j}^2 - \left(\sum_{j=1}^{n} w_{i,j} \right)^2 \right]}{n-1}}} \quad (1)$$

where x_j is the attribute value for feature j, $w_{i,j}$ is the spatial weight between feature i and j, n is equal to the total number of features and:

$$\bar{X} = \frac{\sum_{j=1}^{n} x_j}{n} \quad (2)$$

$$S = \sqrt{\frac{\sum_{j=1}^{n} x_j^2}{n} - (\bar{X})^2} \quad (3)$$

The G_i^* statistic is a z-score so no further calculations are required.

Figure 3-24: Getis-Ord Gi* statistic computation (adapted from How Hot Spot Analysis (Getis-Ord Gi*) works)

There are three confidence levels of a hot spot analysis: 90%, 95%, and 99% (What is a z-score? What is a p-value?). The colors of hot spots and cold spots correspond to the colors in the probability distribution. The intensity of the clustering corresponds to a higher or lower Z-scores (How Hot Spot Analysis (Getis-Ord Gi*) works).

After the hot spot analysis was performed on each parameter, the Cluster and Outlier Analysis with the Anselin Local Moran's I statistic (Figure 3-25) was utilized to identify the outliers from the hot spot analysis at a 95% confidence level (Cluster and Outlier Analysis (Anselin Local Moran's I))

The Local Moran's I statistic of spatial association is given as:

$$I_i = \frac{x_i - \bar{X}}{S_i^2} \sum_{j=1, j \neq i}^{n} w_{i,j}(x_j - \bar{X}) \qquad (1)$$

where x_i is an attribute for feature i, $\bar{X}$ is the mean of the corresponding attribute, $w_{i,j}$ is the spatial weight between feature i and j, and:

$$S_i^2 = \frac{\sum_{j=1, j \neq i}^{n} (x_j - \bar{X})^2}{n - 1} \qquad (2)$$

with n equating to the total number of features.

The z_{I_i}-score for the statistics are computed as:

$$z_{I_i} = \frac{I_i - \mathrm{E}[I_i]}{\sqrt{\mathrm{V}[I_i]}} \qquad (3)$$

where:

$$\mathrm{E}[I_i] = -\frac{\sum_{j=1, j \neq i}^{n} w_{ij}}{n - 1} \qquad (4)$$

$$\mathrm{V}[I_i] = \mathrm{E}[I_i^2] - \mathrm{E}[I_i]^2 \qquad (5)$$

Figure 3-25: Anselin Local Moran's I Statistic

(Adapted from How Cluster and Outlier Analysis (Anselin Local Moran's I) works)

A positive value of I specifies that a feature belongs to a cluster as its neighboring features have similarly low or high attribute values; in contrast, a negative I value indicates that the feature is an outlier, having dissimilar values from its neighbors (Cluster and Outlier Analysis (Anselin Local Moran's I))

The hot spot and cluster and outlier analysis were performed on each parameter (ADR, NO, NO_2, O_3, temperature, and windspeed for three periods: the annual, summer, and winter ADR from 2010 to 2014. Results for all analyses are shown in Figures 3-27 to 3-68. Map of NCT counties is illustrated in Figure 3-26 for reference. The outlier tracts were indicated by the darker red (high low outliers – outliers of high values in a cold spot) or darker blue (low-high outliers – outliers of low values in a warm spot).

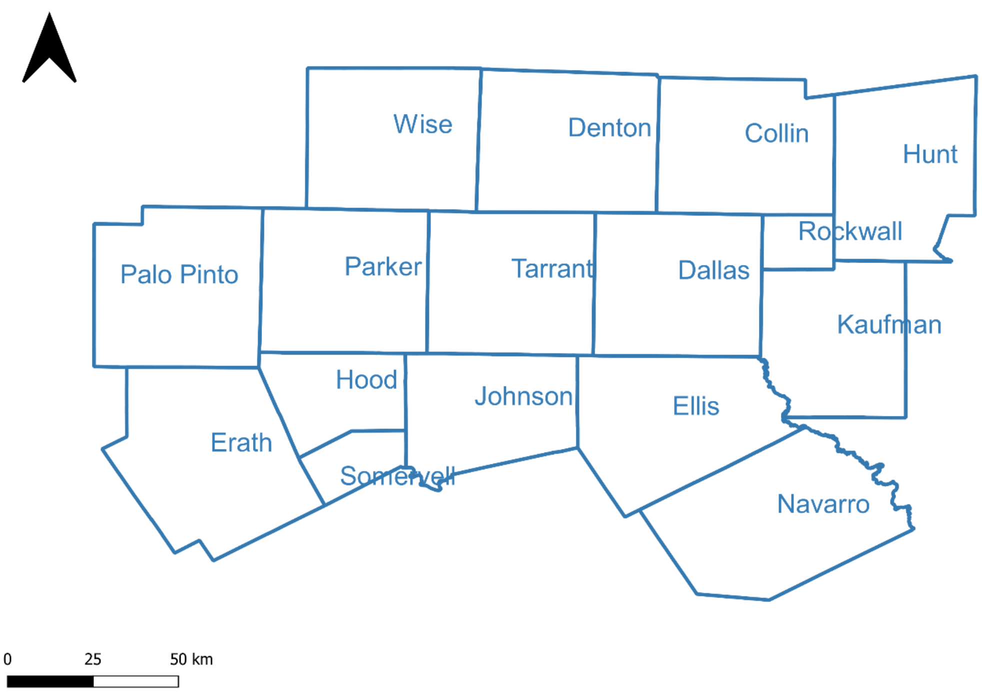


Figure 3-26: NCT Counties

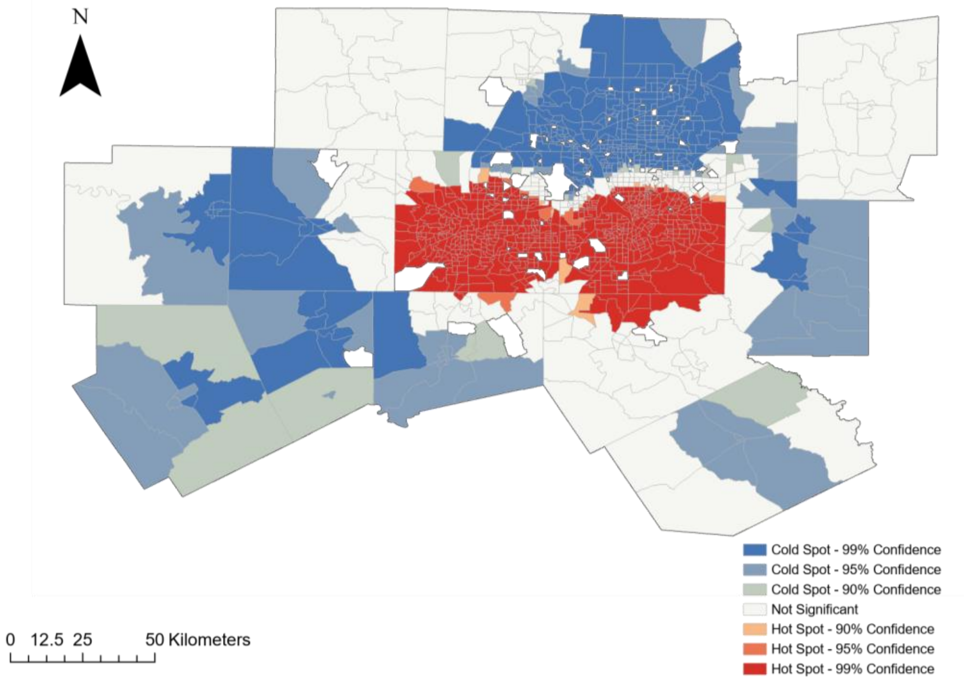


Figure 3-27: Annual ADR hot spots and cold spots

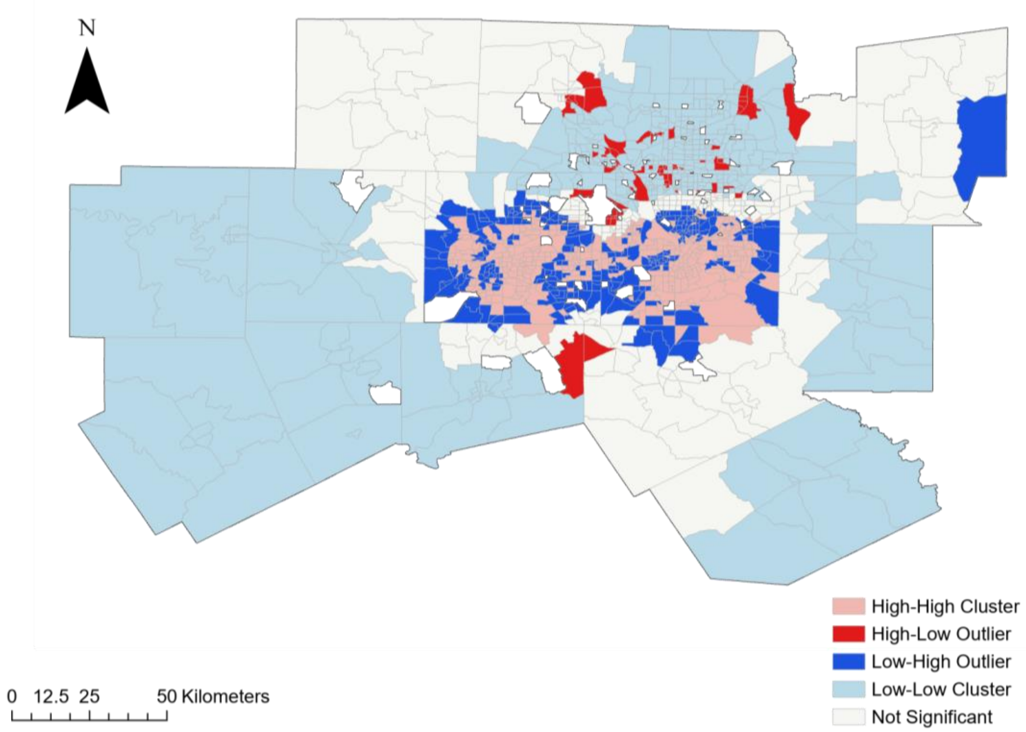


Figure 3-28: Annual ADR clusters and outliers

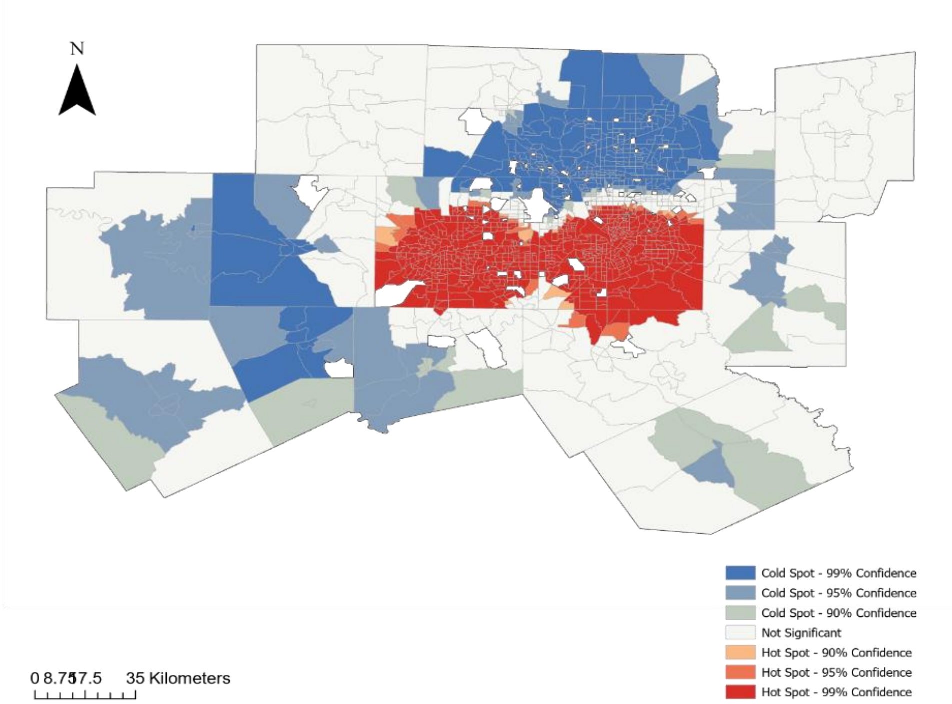


Figure 3-29: Summer ADR hot spots and cold spots

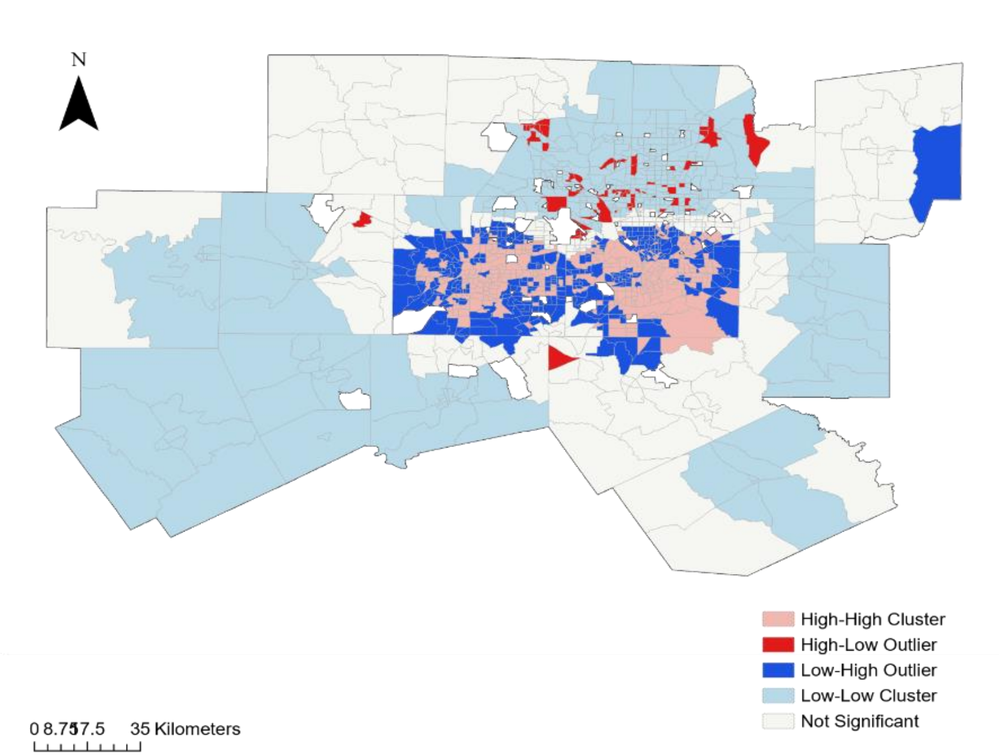


Figure 3-30: Summer ADR clusters and outliers

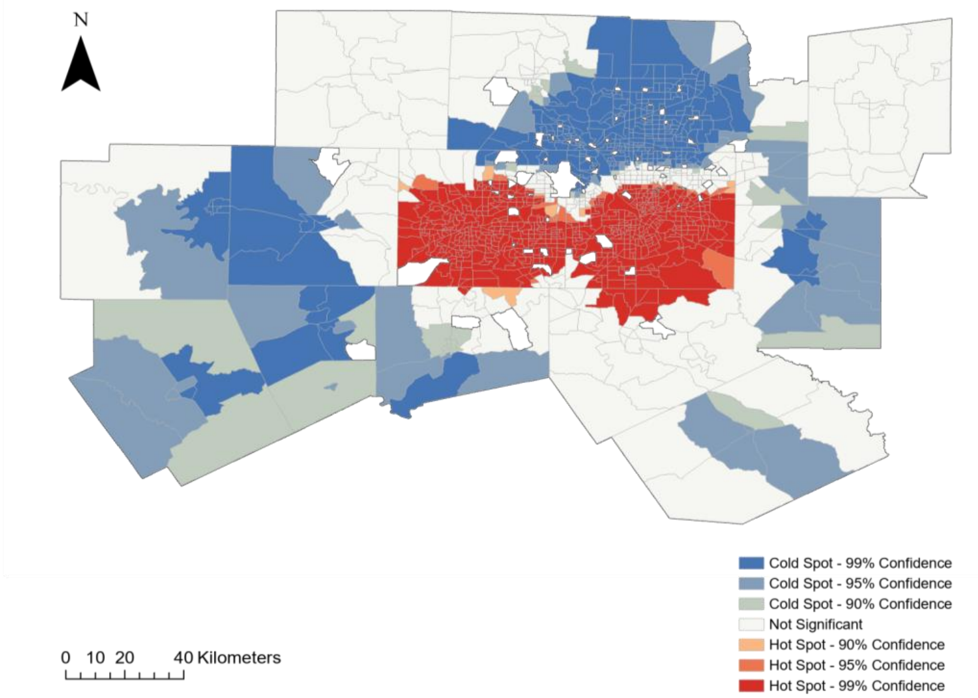


Figure 3-31: Winter ADR hot spots and cold spots

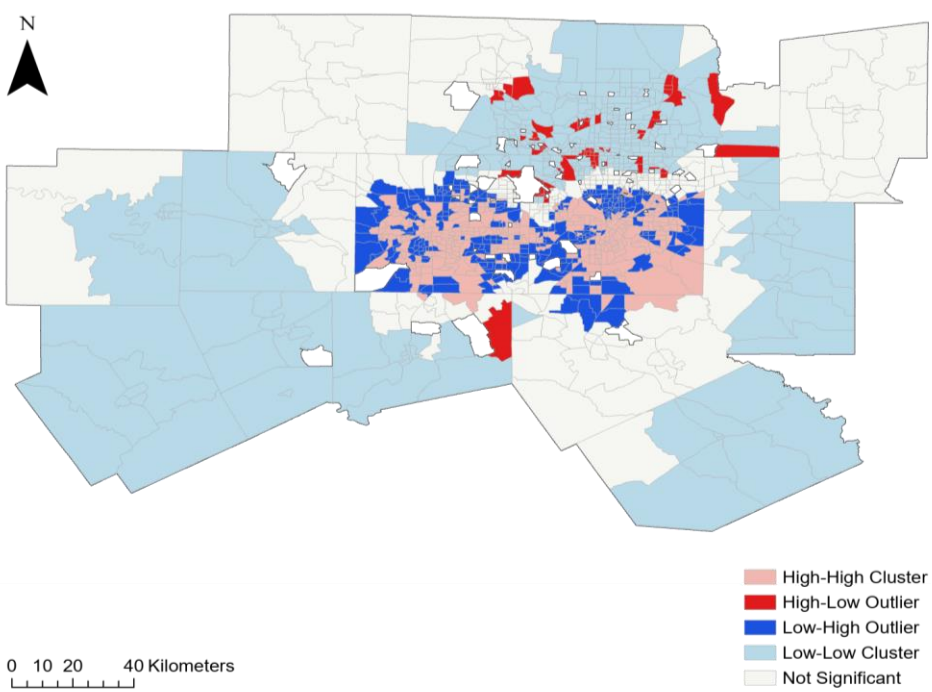


Figure 3-32: Winter ADR clusters and outliers

Results from ADR hot spot and cluster and outlier analysis suggest a statistically high concentration area in both Tarrant and Dallas counties at various times of the year. The areas of low concentration are in most tracts in Palo Pinto, Erath, Hood, Somervell, and Collin. As noted in chapter 1, three out of these five counties (Palo Pinto, Erath, and Somervell) are rural counties; Collin, however, is one of the four populous counties in the NCT. Approximately half the tracts in Tarrant and Dallas have low ADR in a high ADR hot spot, signifying a strong disparity within these two counties. On the other hand, a small number of tracts, having high ADR in a low ADR concentration, is in Denton and Collin counties. Denton and Collin, similar to Dallas and Tarrant, are two populous counties. However, their being cold spots with very few outliers signifies a stark difference from Dallas and Tarrant. Other factors like socioeconomic ones, which will be explored in chapter 4, might play a role in such difference.

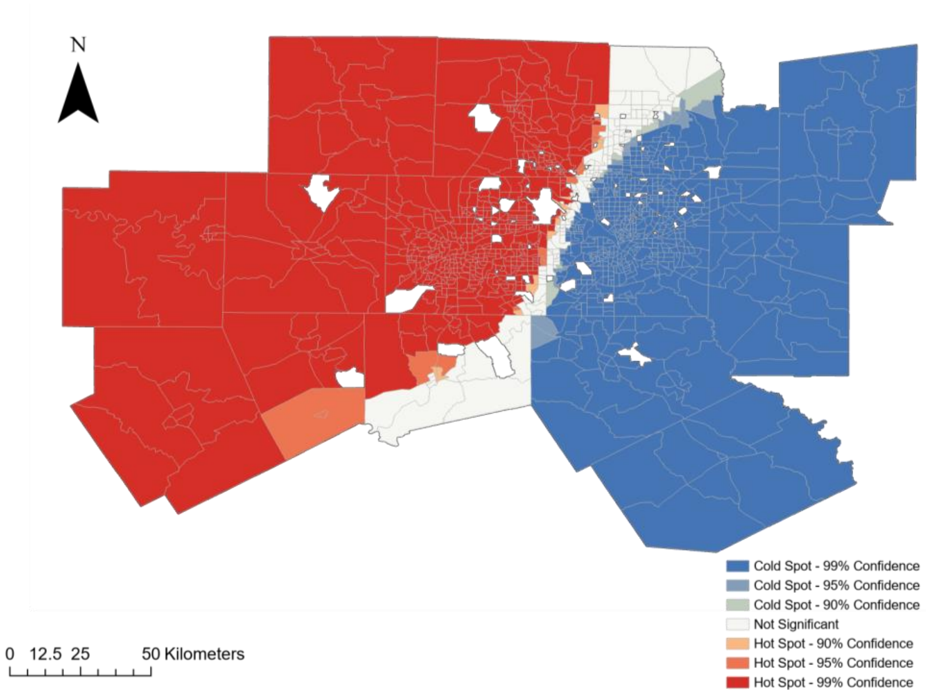


Figure 3-33: Annual NO hot spots and cold spots

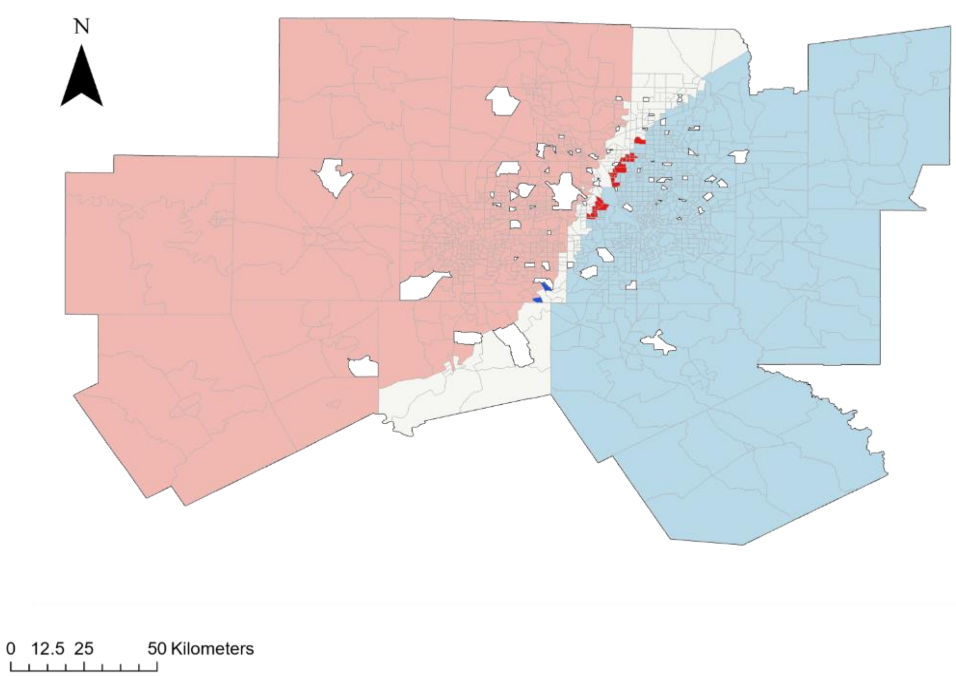


Figure 3-34: Annual NO clusters and outliers

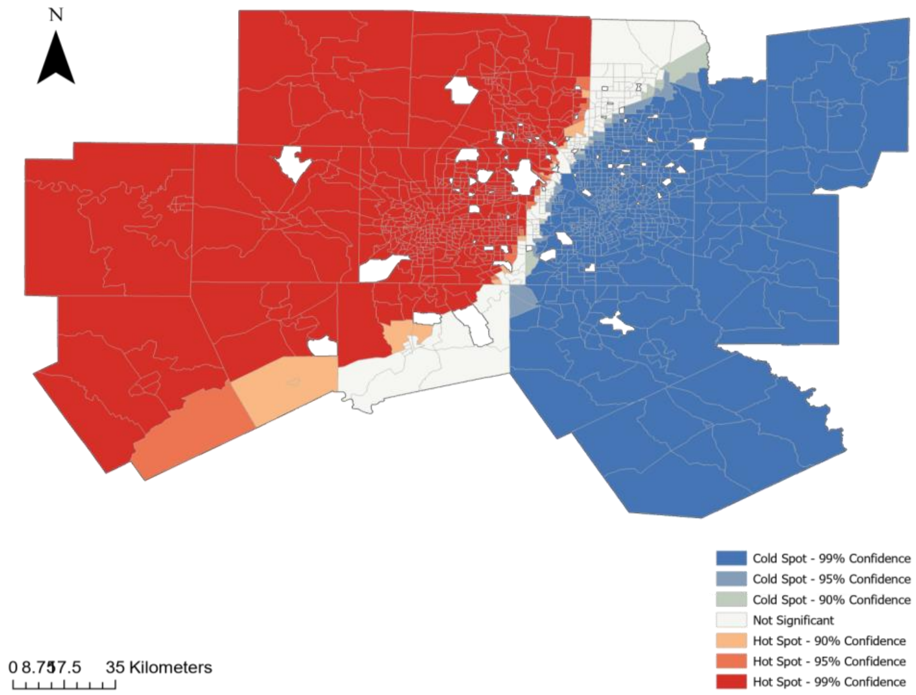


Figure 3-35: Summer NO hot spots and cold spots

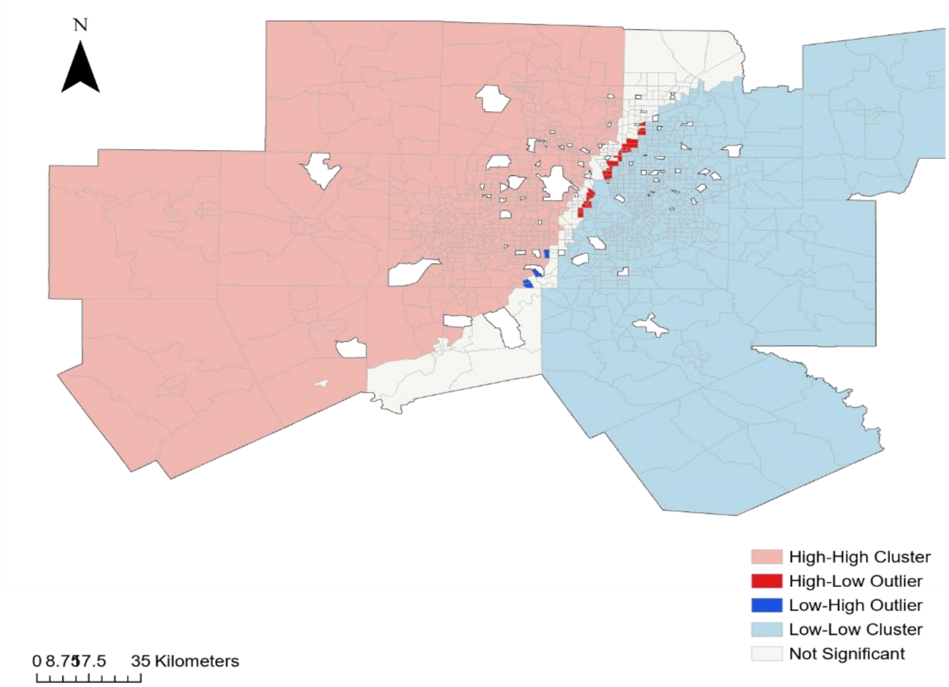


Figure 3-36: Summer NO clusters and outliers

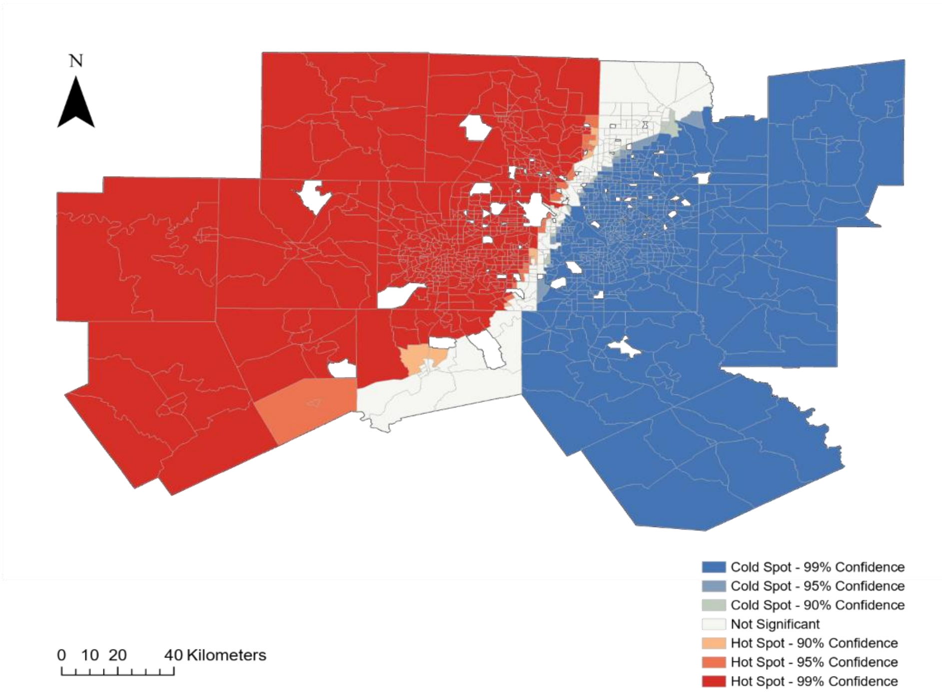


Figure 3-37: Winter NO hot spots and cold spots

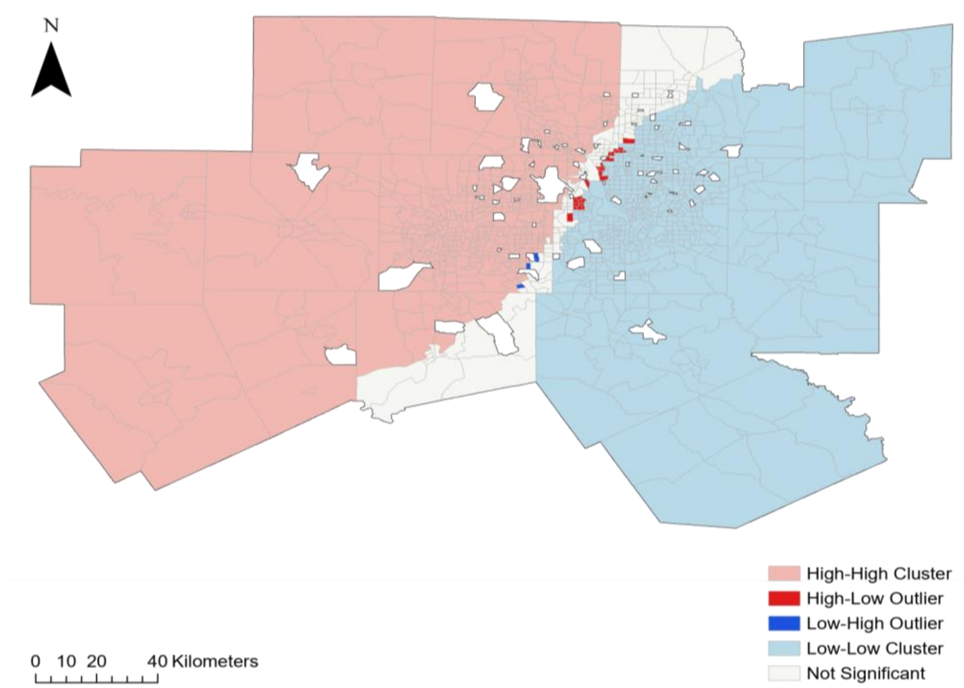


Figure 3-38: Winter NO clusters and outliers

For NO, the areas of high and low concentration seem to be equally divided, with the left half of the NCT being hot spot and the right half being cold spot. There are only a few high-low outlier tracts. No association can be drawn between ADR and NO.

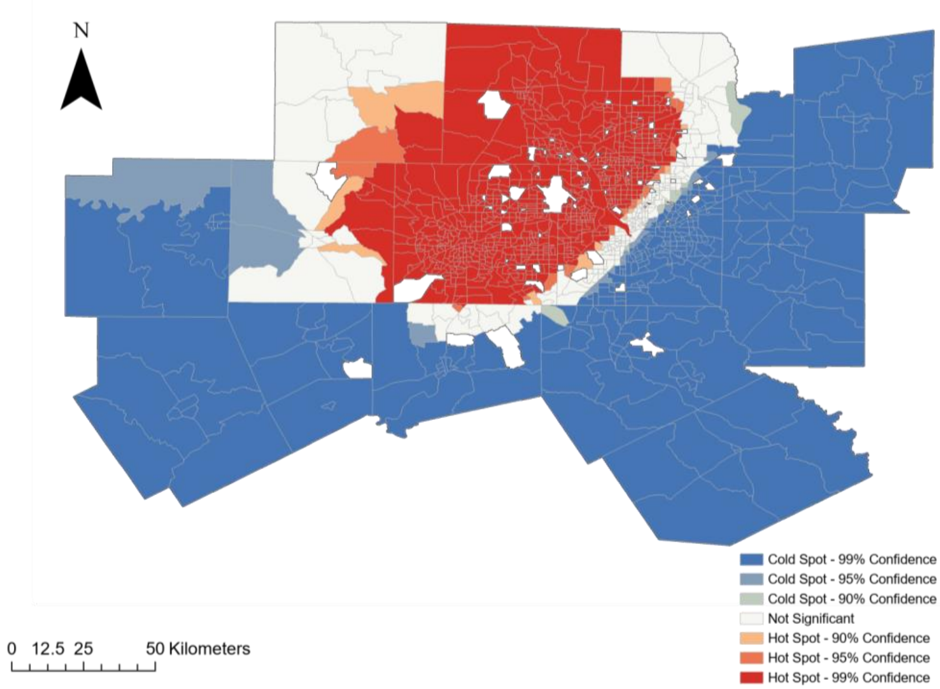


Figure 3-39: Annual NO_2 hot spots and cold spots

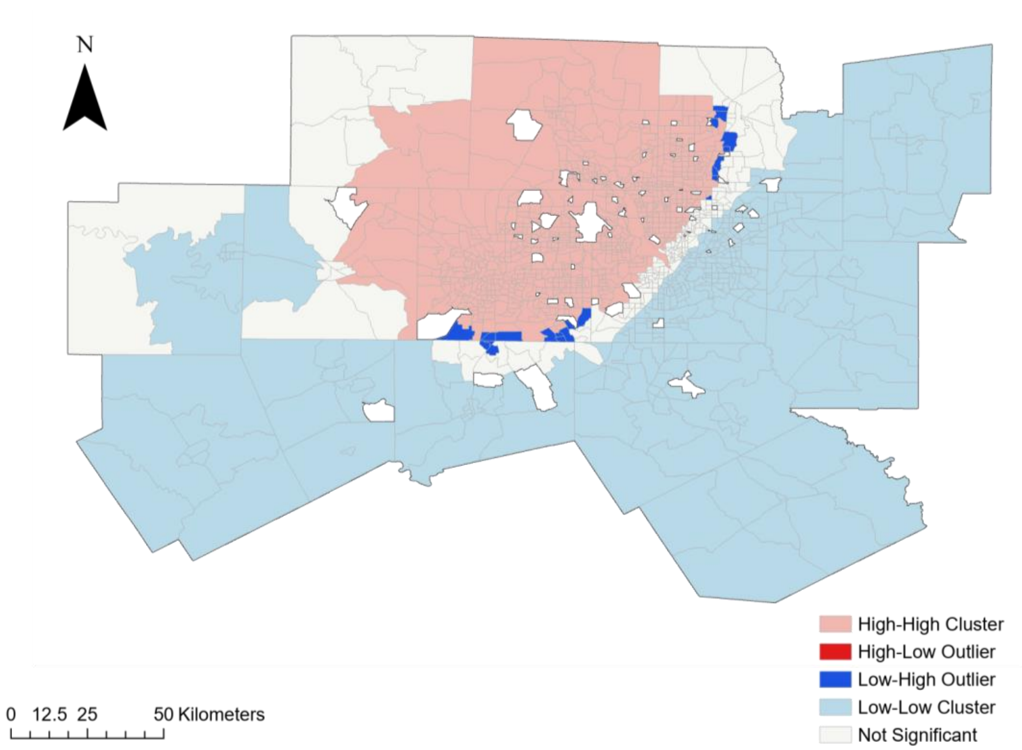


Figure 3-40: Annual NO_2 clusters and outliers

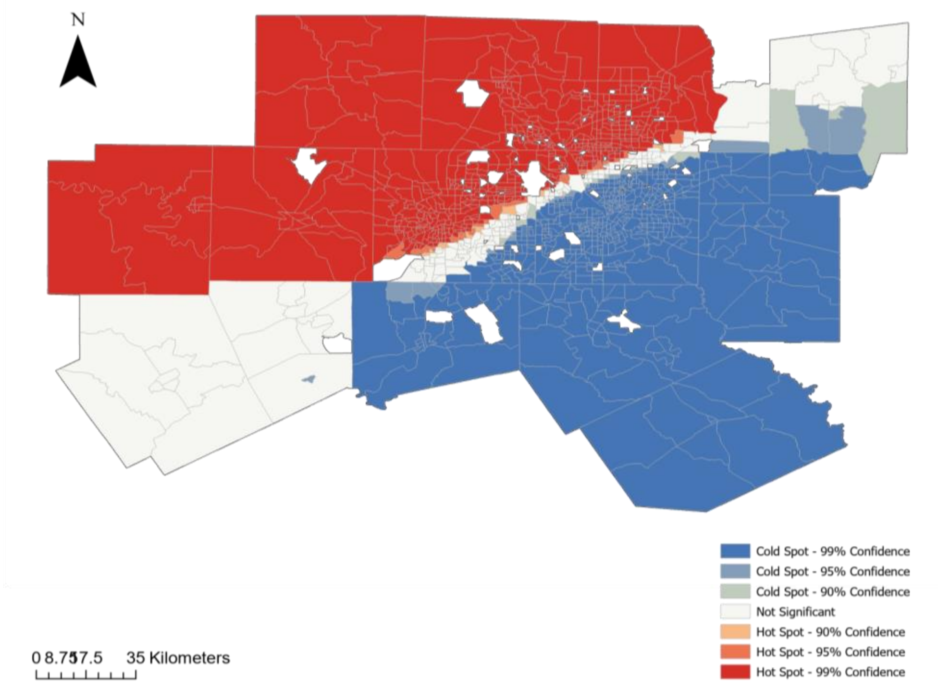


Figure 3-41: Summer NO_2 hot spots and cold spots

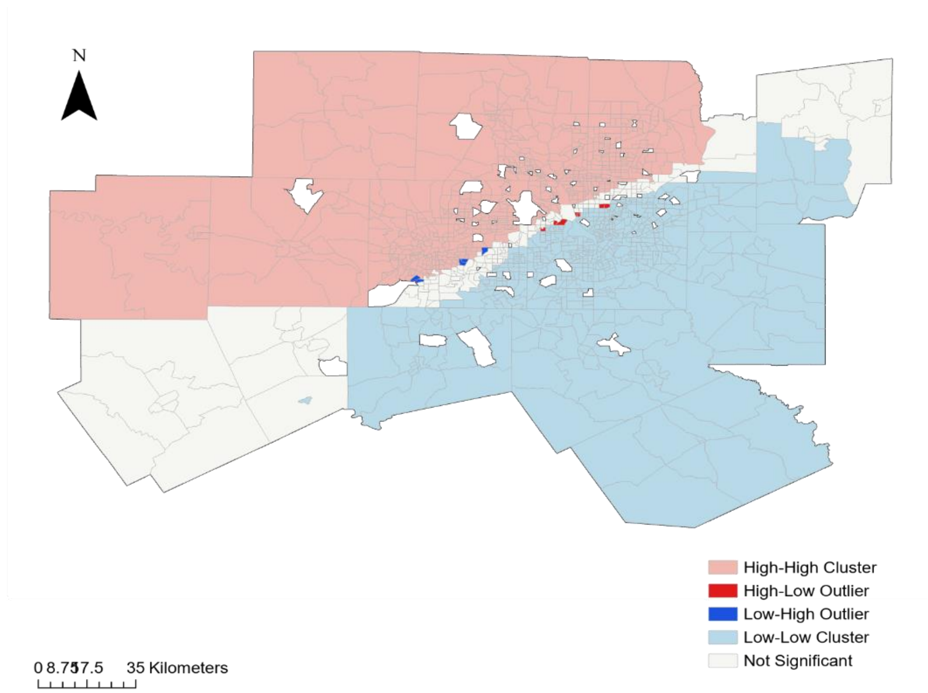


Figure 3-42: Summer NO_2 clusters and outliers

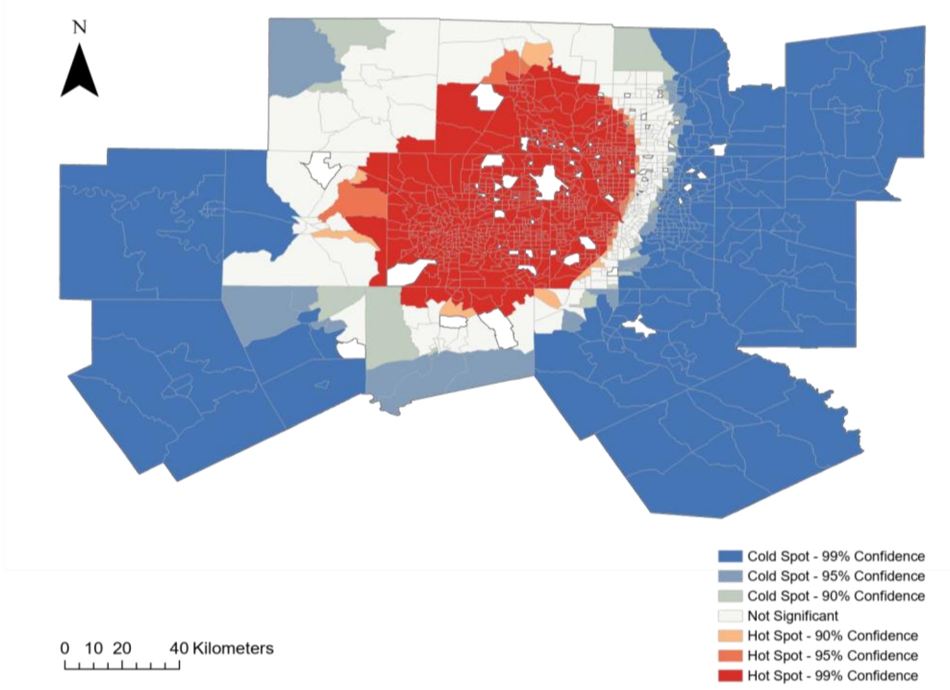


Figure 3-43: Winter NO_2 hot spots and cold spots

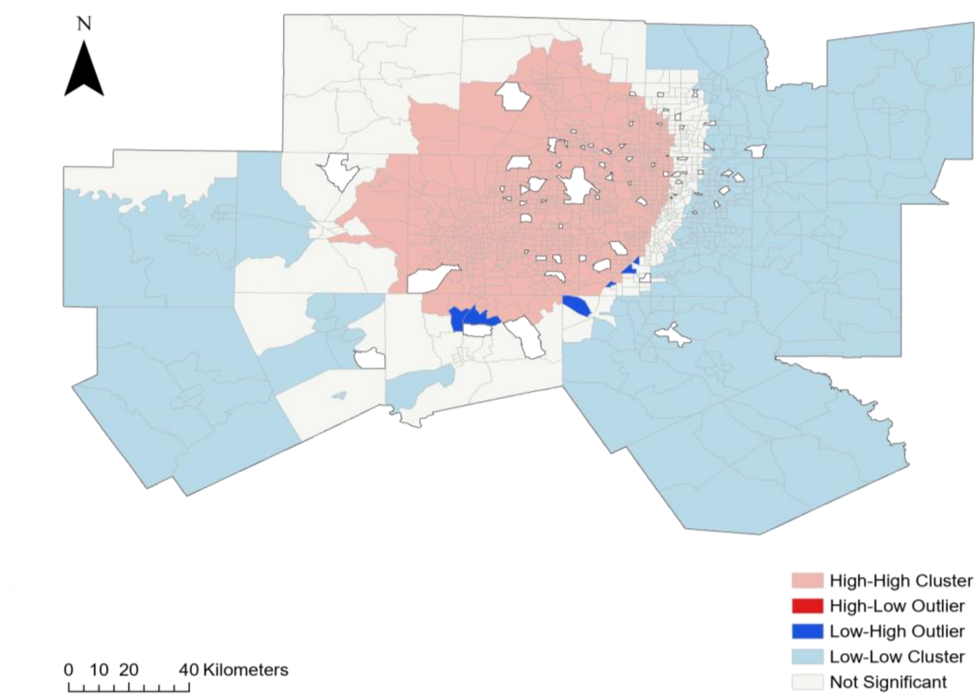


Figure 3-44: Winter NO_2 clusters and outliers

When it comes to NO_2, the areas of high concentration are Tarrant, Denton, and Collin for annual and winter analysis, Tarrant, Parker, Palo Pinto, Wise, Denton, and Collin for summer analysis. Conversely, besides the non-significant Wise for annual and winter analysis, and Erath, Hood, and Somervell for winter analysis, the rest of the counties indicates a statistically significant cold spot. There is hardly any outlier. Not a strong correlation between ADR and NO_2 can be established.

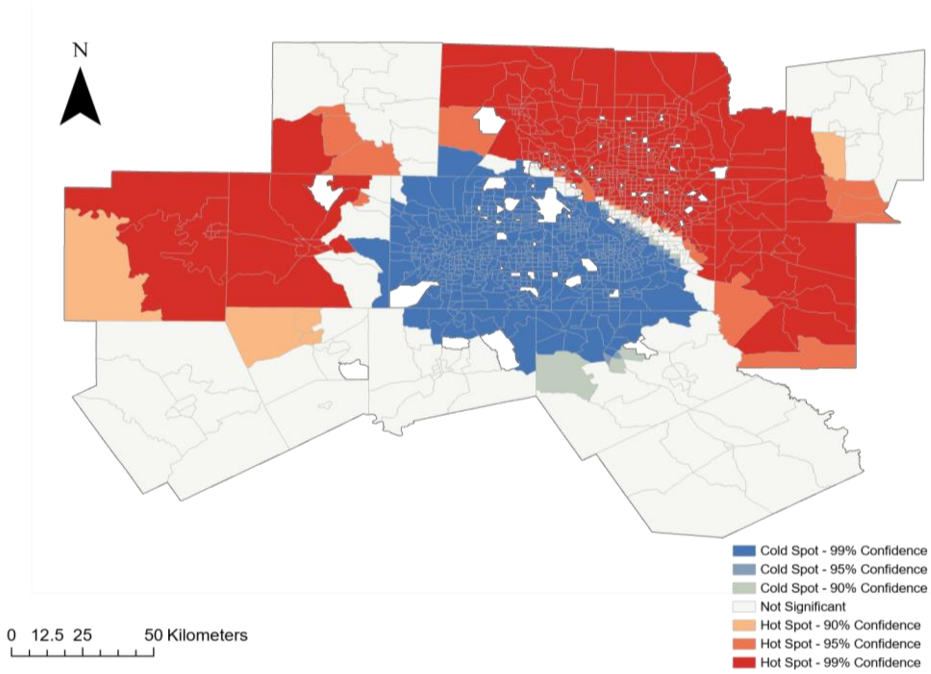


Figure 3-45: Annual O_3 hot spots and cold spots

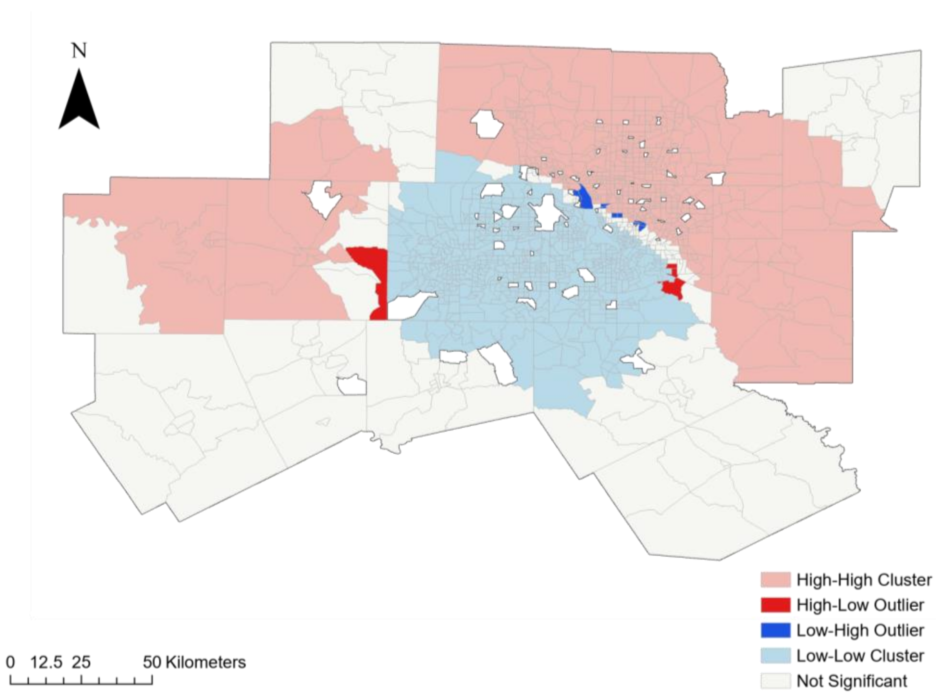


Figure 3-46: Annual O_3 clusters and outliers

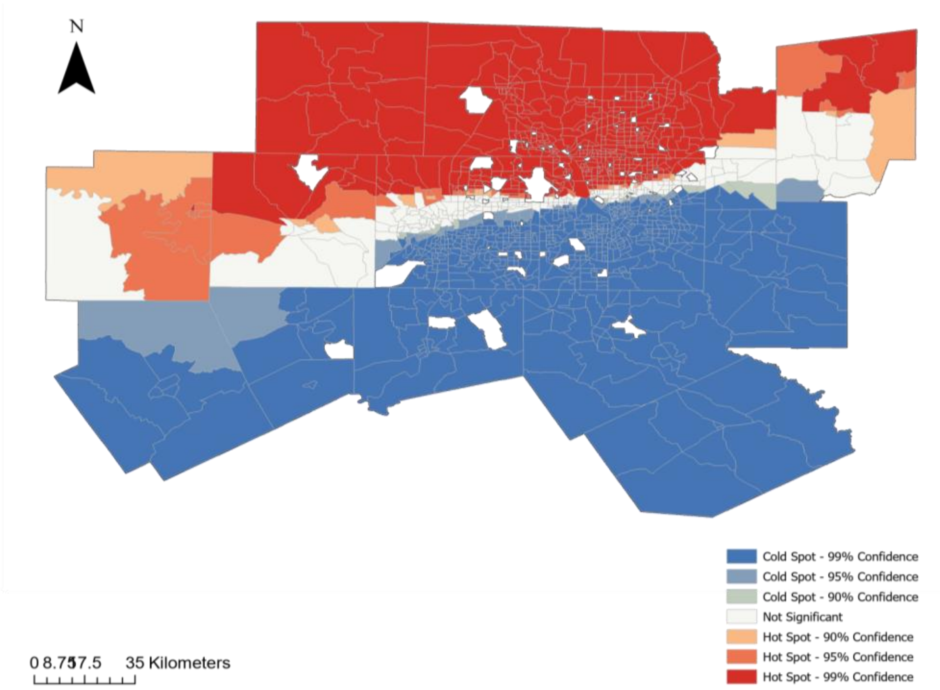


Figure 3-47: Summer O_3 hot spots and cold spots

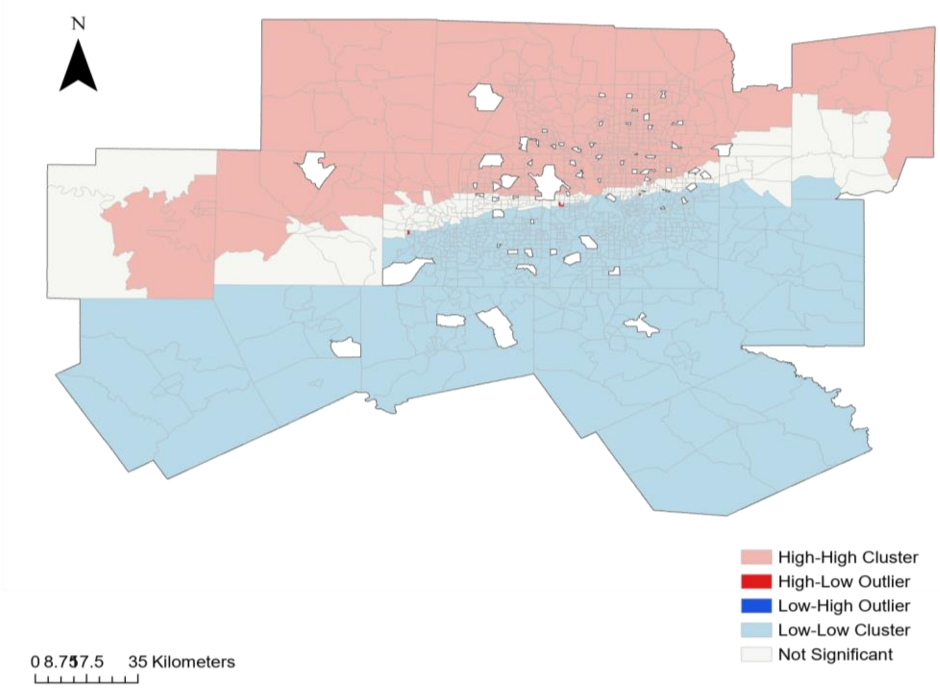


Figure 3-48: Summer O_3 clusters and outliers

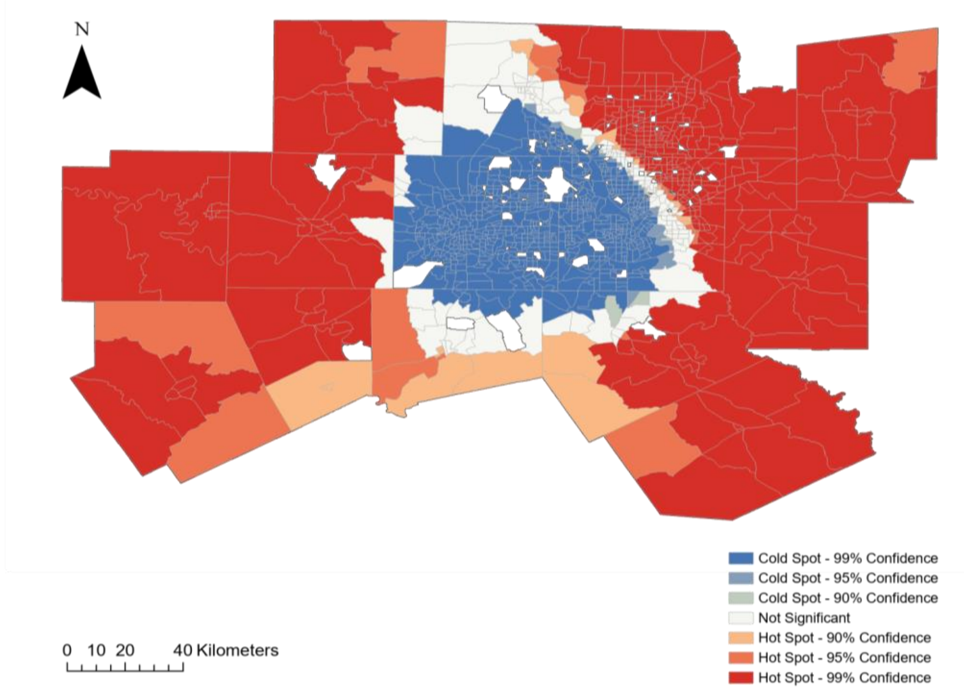


Figure 3-49: Winter O_3 hot spots and cold spots

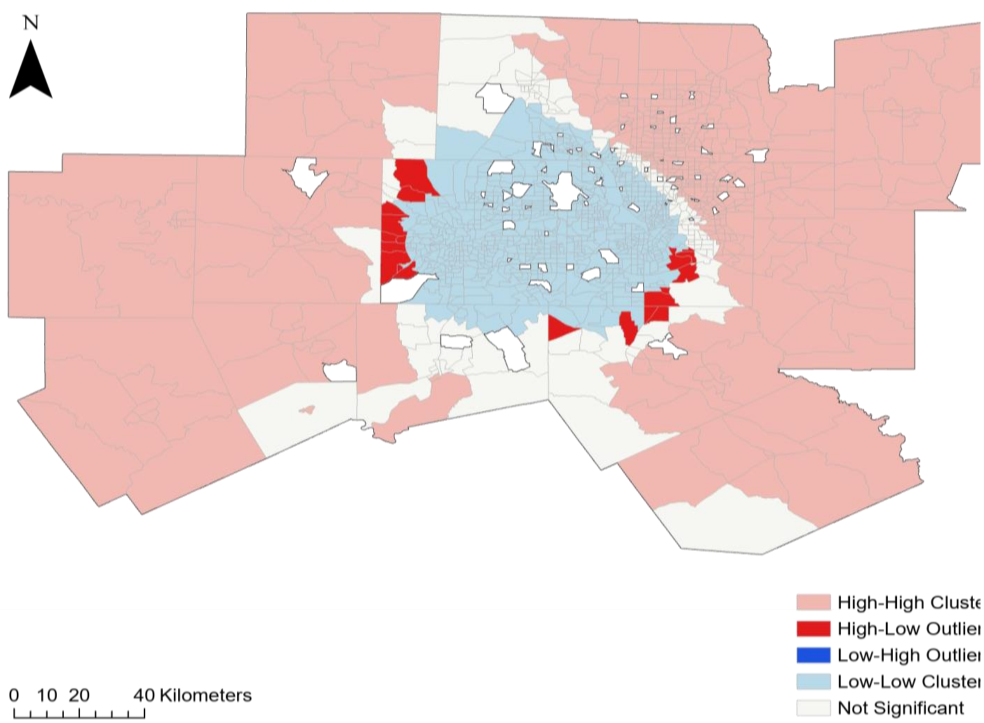


Figure 3-50: Winter O_3 clusters and outliers

The annual and winter O_3 variations exhibit similar pattern with Tarrant, Dallas, Johnson, and Ellis being the cold spots while most of the rest of the counties are in hot spots. Summer O_3 diverges as the upper left half is region of high concentration and the lower right half is region of low concentration. No clear association can be drawn between ADR and O_3.

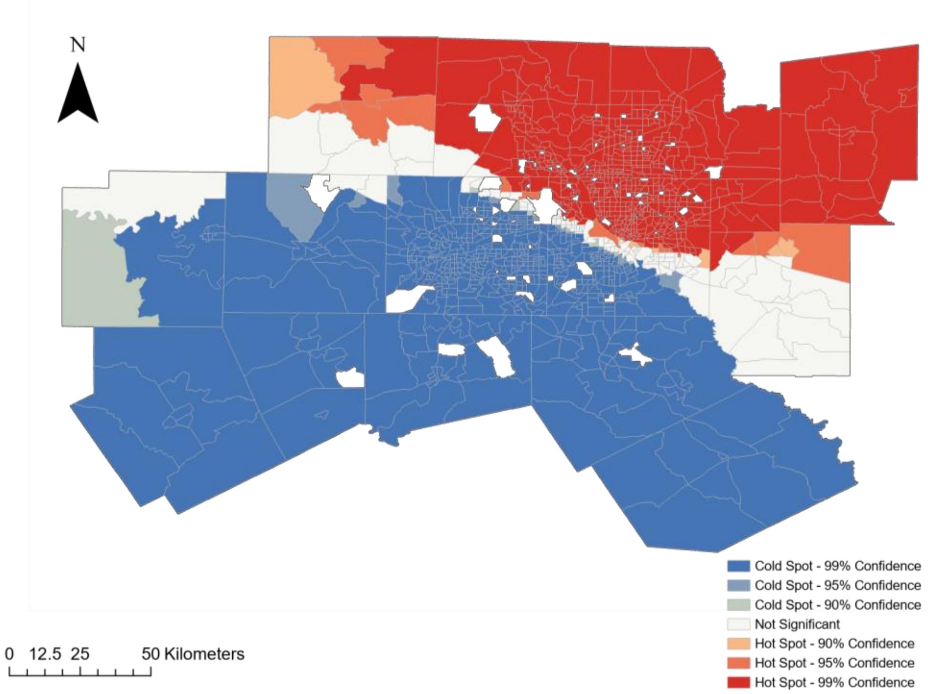


Figure 3-51: Annual 8-hr O_3 hot spots and cold spots

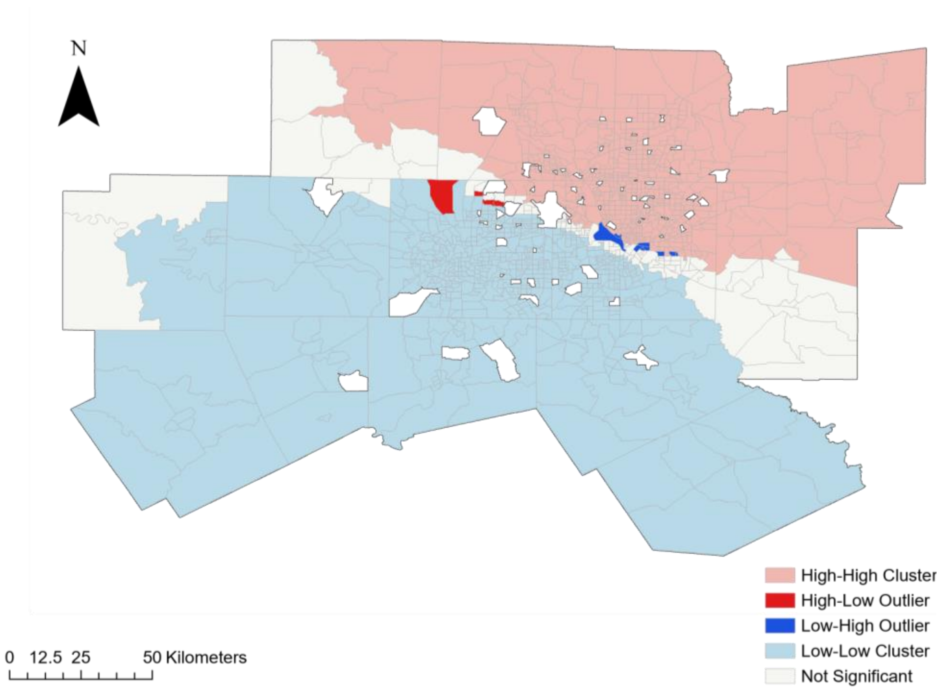


Figure 3-52: Annual 8-hr O_3 clusters and outliers

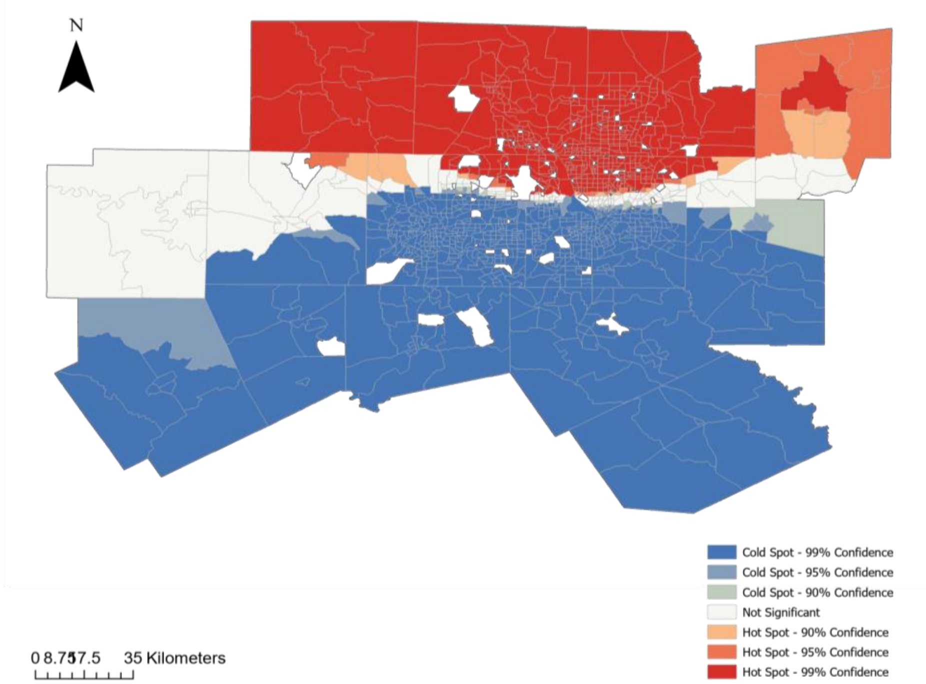


Figure 3-53: Summer 8-hr O_3 hot spots and cold spots

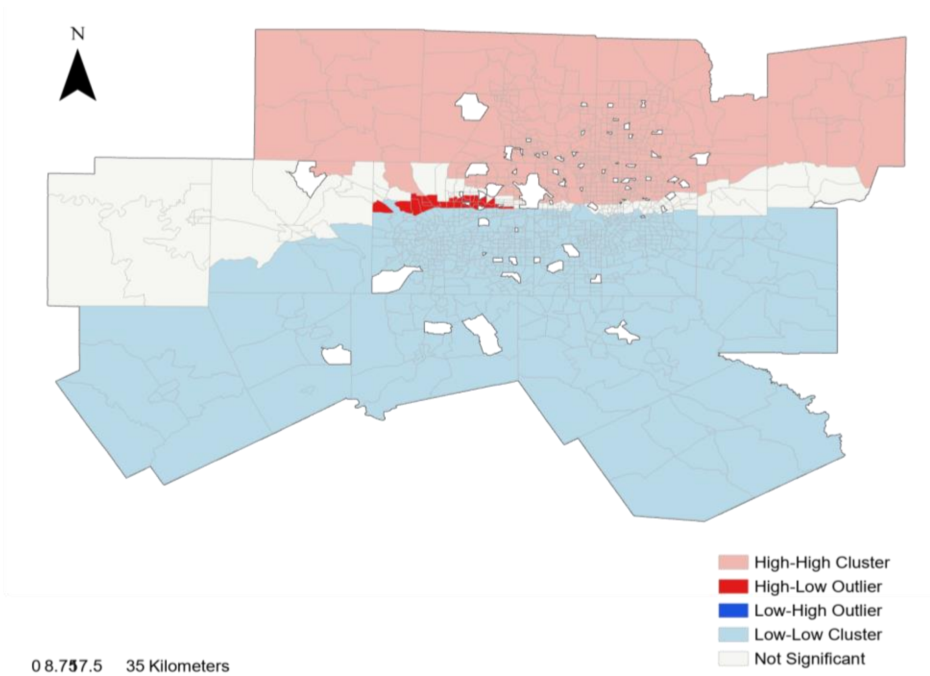


Figure 3-54: Summer 8-hr O_3 clusters and outliers

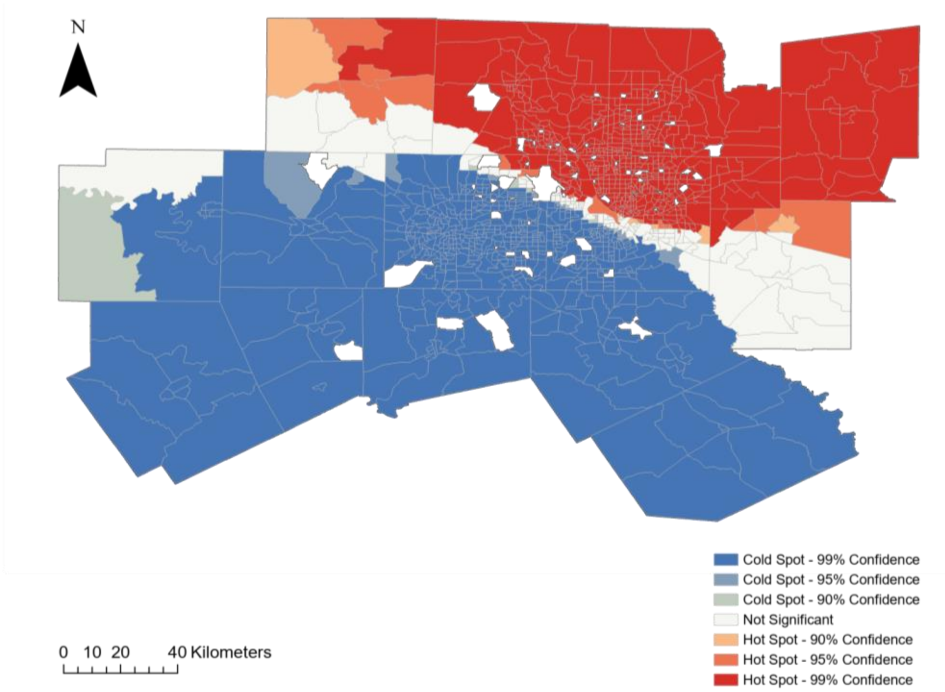


Figure 3-55: Winter 8-hr O_3 hot spots and cold spots

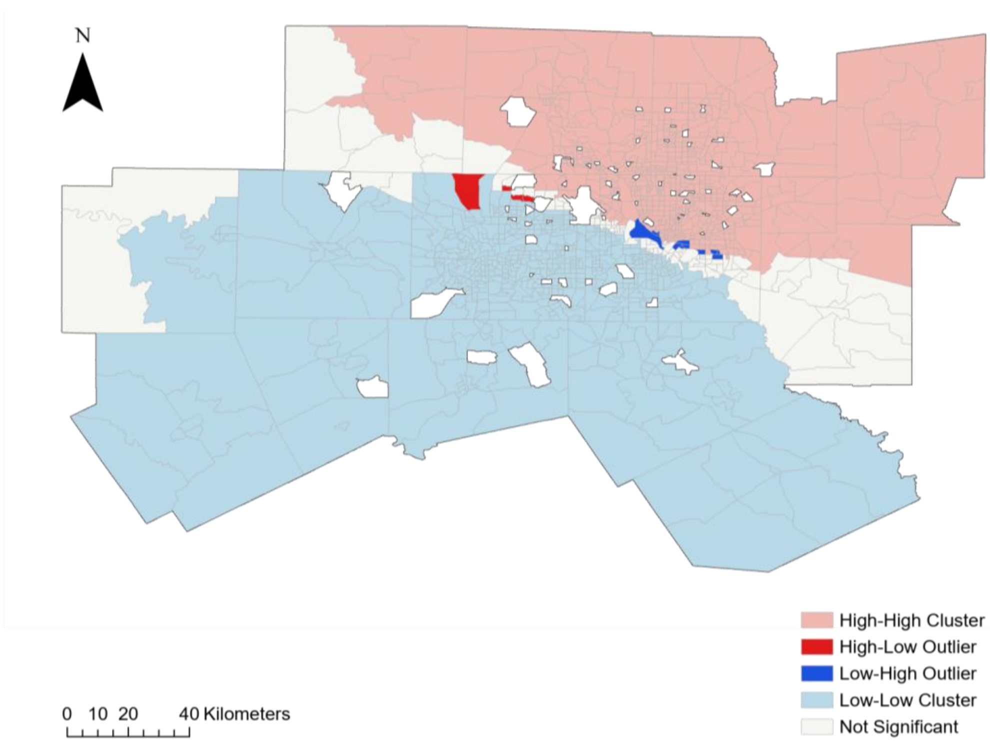


Figure 3-56: Winter 8-hr O_3 clusters and outliers

The 8-hour O_3 pattern seems to be consistent in all three analyses with Wise, Denson, Collin, and Hunt tracts are hot spots and the majority of the rest of the tracts are in cold spots. The outliers are few and far in between.

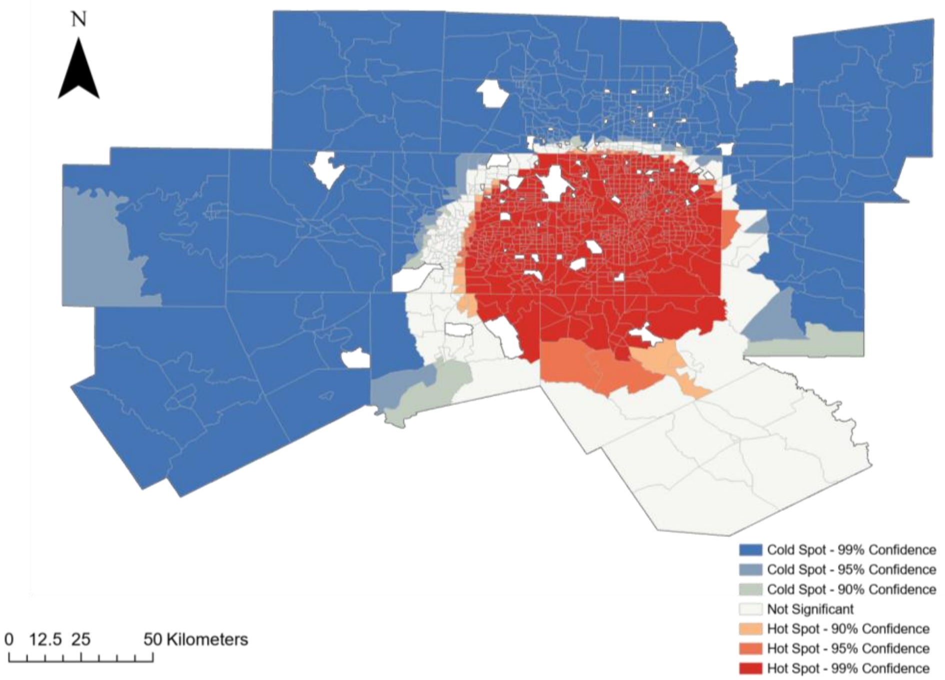


Figure 3-57: Annual temperature hot spots and cold spots

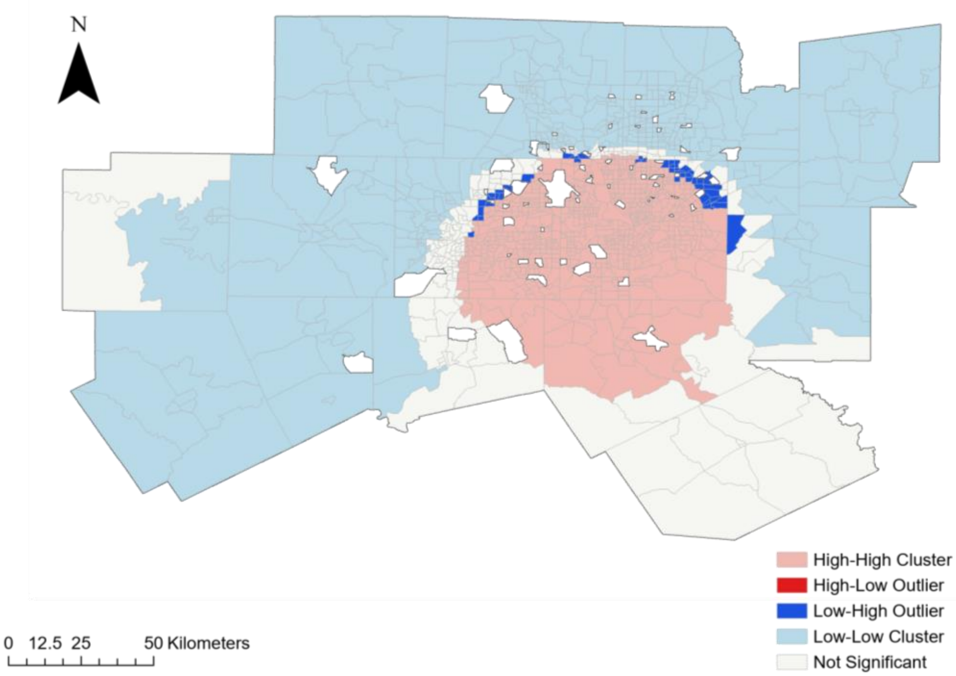


Figure 3-58: Annual temperature clusters and outliers

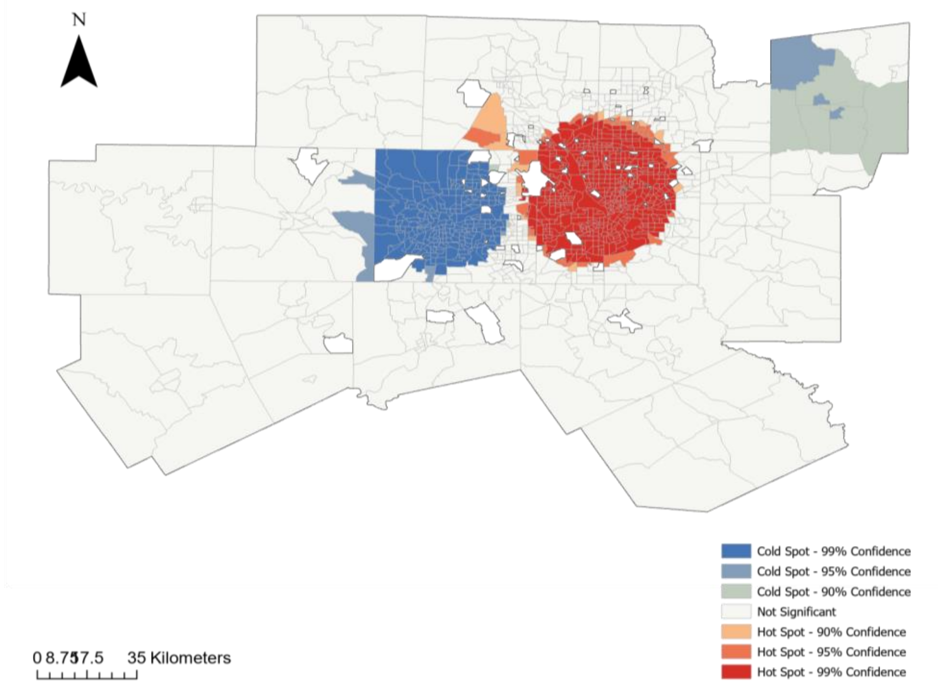


Figure 3-59: Summer temperature hot spots and cold spots

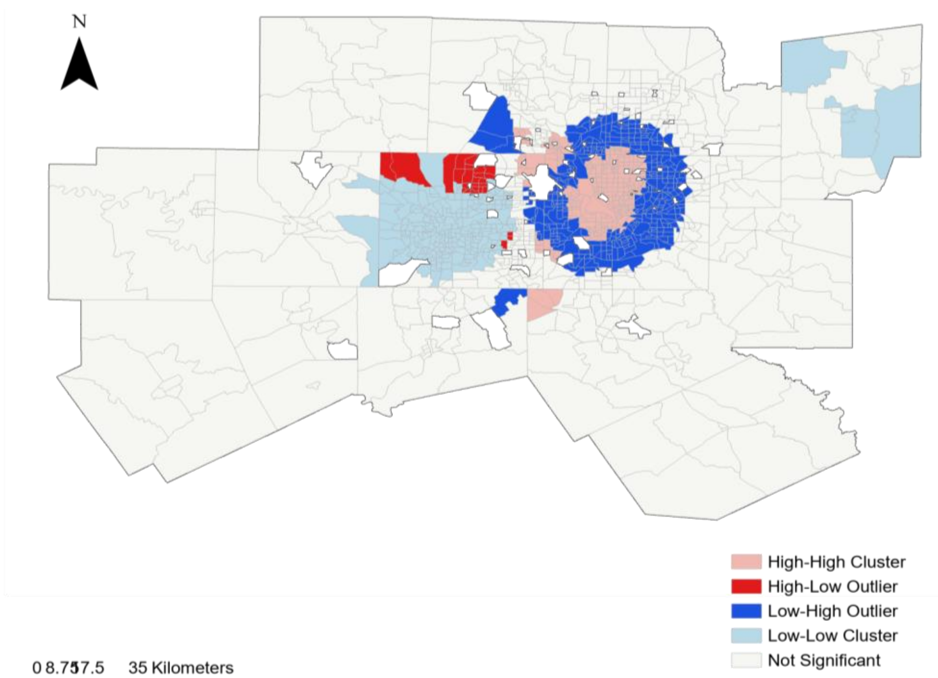


Figure 3-60: Summer temperature clusters and outliers

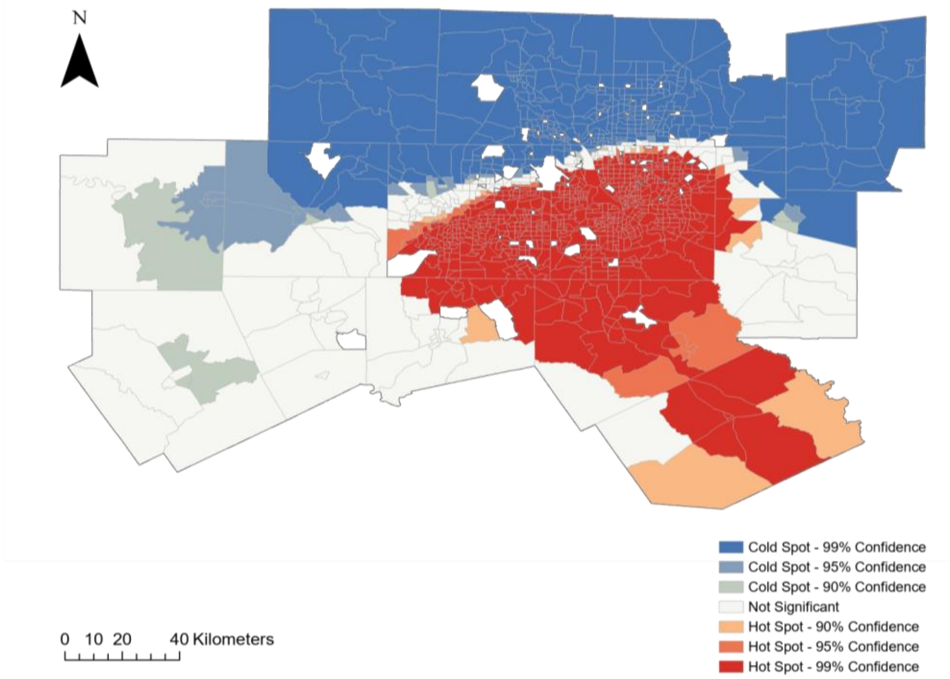


Figure 3-61: Winter temperature hot spots and cold spots

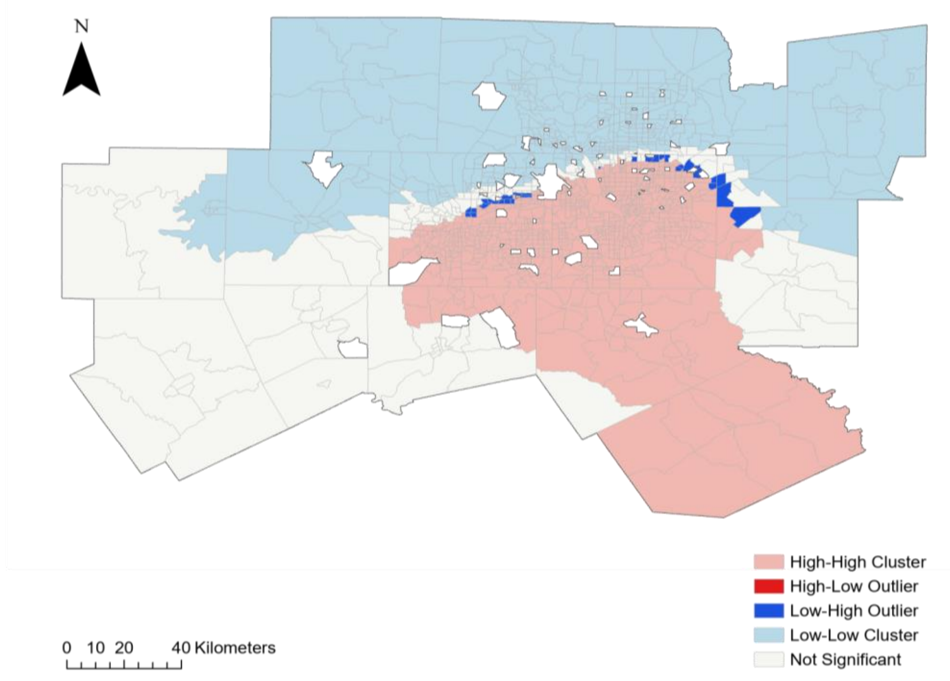


Figure 3-62: Winter temperature clusters and outliers

There exists a temperature hot spot in Dallas for all there sets of analyses. Temperature varies greatly at different times of the year, as expected. No clear pattern can be inferred from the hot spot and cluster and outlier analysis when it comes to temperature. Even though the high concentration in Dallas does seem to be similar to the ADR pattern, not a small number of Dallas tracts is an outlier, suggesting a non-existent relationship.

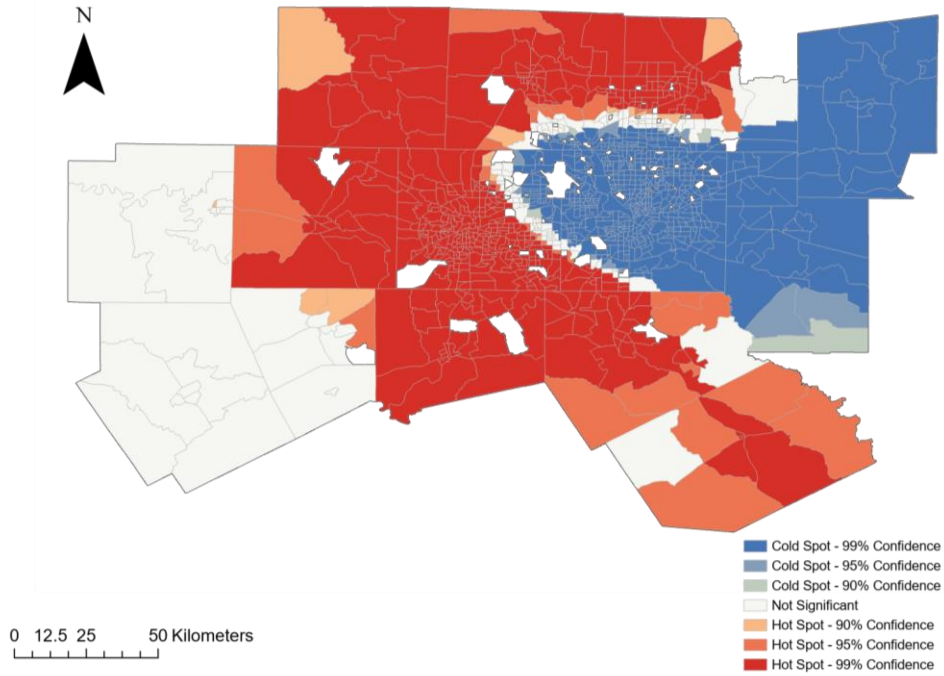


Figure 3-63: Annual wind speed hot spots and cold spots

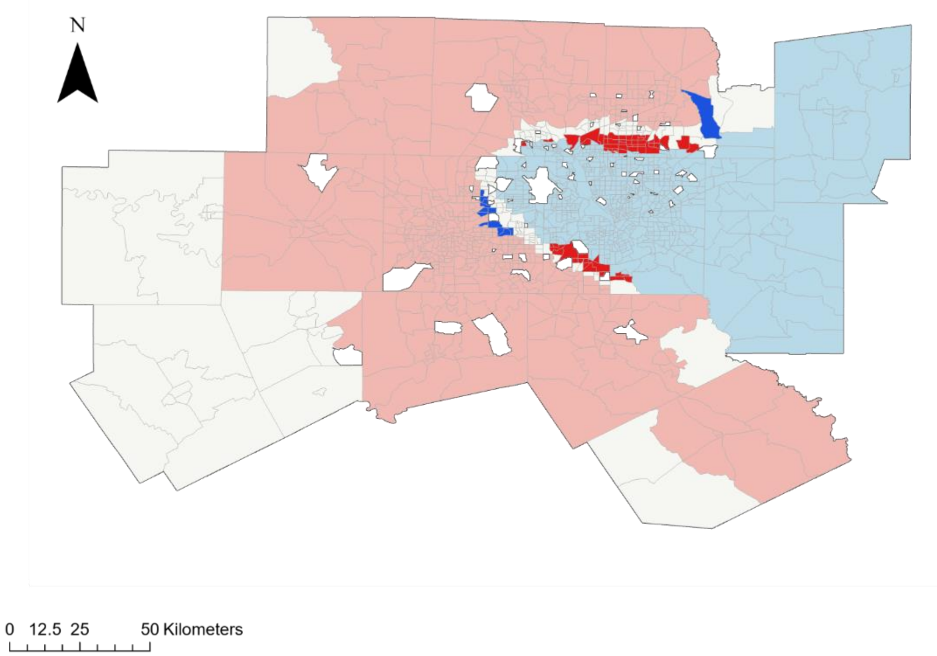


Figure 3-64: Annual wind speed clusters and outliers

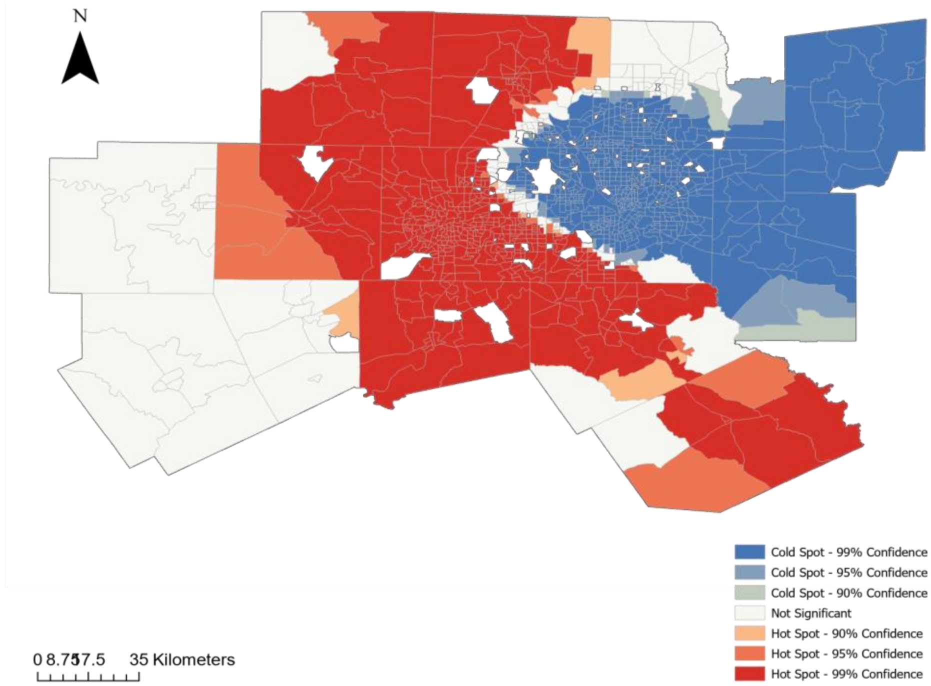


Figure 3-65: Summer wind speed hot spots and cold spots

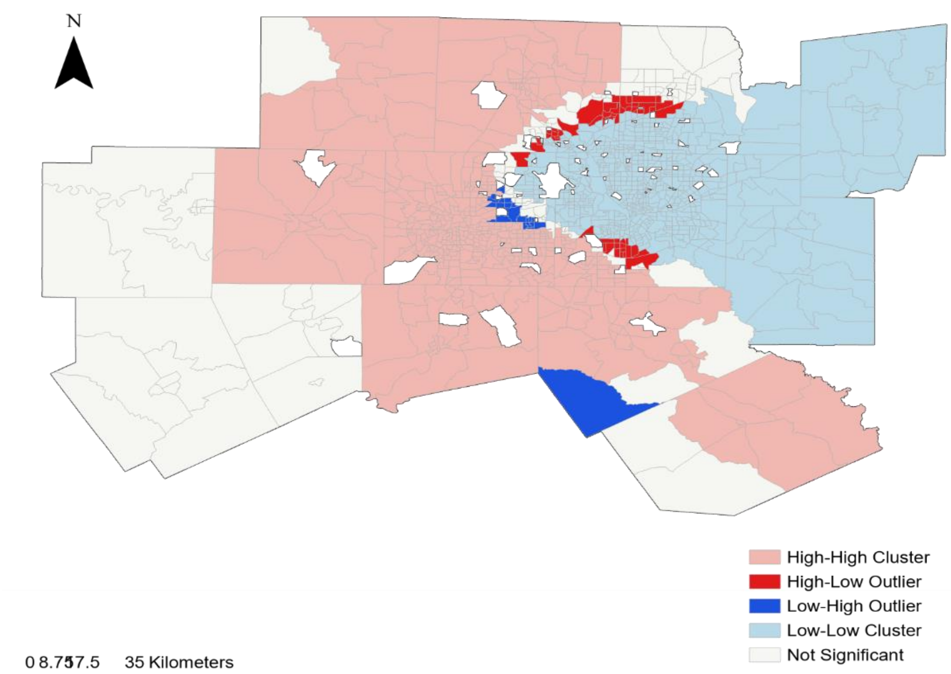


Figure 3-66: Summer wind speed clusters and outliers

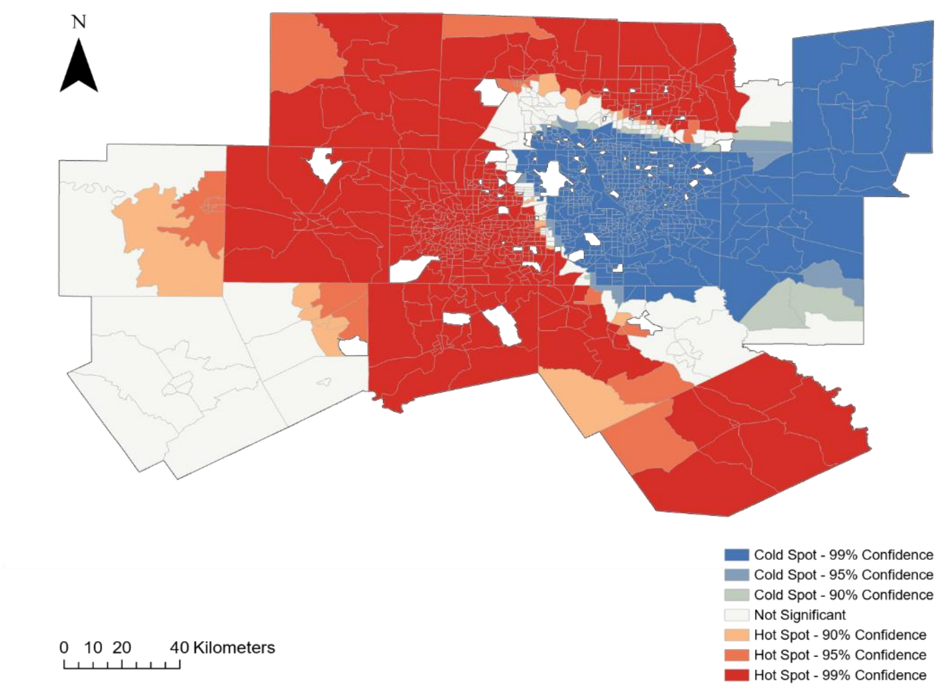


Figure 3-67: Winter wind speed hot spots and cold spots

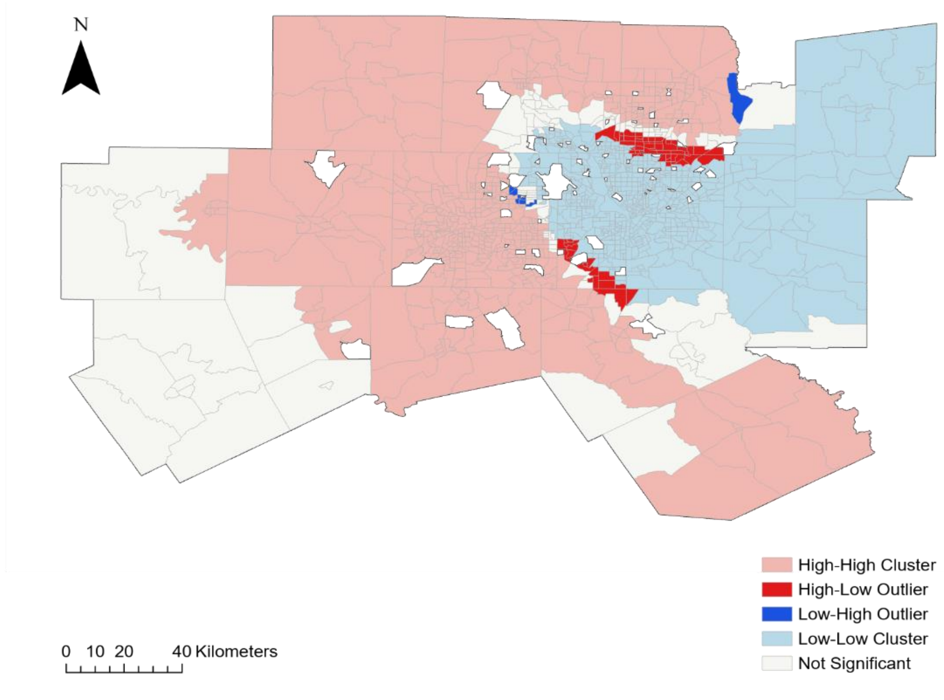


Figure 3-68: Winter wind speed clusters and outliers

Wind speed pattern from all three analyses are similar to one another. The counties with high concentration areas are Wise, Denton, Parker, Tarrant, Johnson, Ellis, and Navarro and the cold-spot-counties are Hunt, Rockwall, Kaufman, and Dallas. There is only a small number of outliers. Again, no association between ADR and windspeed can be drawn.

3.4. Discussion

This analysis investigated the association between adult asthma cases, represented by asthma discharge rate (ADR), and exposure to various common air pollutants and associated meteorological variables, including ozone, particulate matter ($PM_{2.5}$), nitrogen dioxide, nitric oxide, temperature, and wind speed. It was hypothesized that the emergency room asthma discharges in NCT were related to these environmental exposures/ factors, and such variables might act as triggers for seasonal asthma discharge variability.

Three chief analyses were carried out: an exploratory data analysis (EDA) via the application of Principal Component Analysis (PCA) and Hierarchical Agglomerative Clustering Analysis (HACA); a point correlation analysis via the application of Pearson product-moment method, and hot spot and cluster and outlier analyses, utilizing Getis-Ord Gi* statistic and Anselin Local Moran's I Statistic.

Prior to analysis, three data sets were obtained: air pollution and meteorological data were obtained from the TCEQ's air monitoring stations, the NCT's adult asthma hospital discharges were provided by the DFWHCF, and GIS boundary data from the North Central Texas Council of Governments' Regional Data Site.

PCA and HACA were performed together for the purpose of obtaining the initial understanding of the air pollution data and investigating whether the pattern of air monitoring stations was similar to the asthma discharge pattern. The former can be explained from the PCA results and the latter can be inferred from HACA computation. PCA results included:

(1) There is a high correlation among NO, NO_2, $PM_{2.5}$, and temperature

(2) O_3 is highly associated with windspeed; it is not as highly associated with temperature and the other pollutants;

(3) NOx plays a vital role in the formation of tropospheric O_3

HACA results suggested that pattern of air monitoring stations could be used to explain asthma discharge pattern with rural clusters corresponding to an area with low asthma discharges and urban clusters relating to an area with high asthma discharges.

The Pearson point correlation analysis sought to compute the association of pairs of ADR and air pollutants along with their associated p-values. Regardless of the time of the year, all associations were trivial and non-significant. Such trivial effects appeared to be counterintuitive, especially for ozone, a recognized asthma trigger. Ozone is typically at its highest during the summer and as Dallas has never been in compliance with ozone air quality standards, it certainly has poor outdoor air quality conditions in the summer that are unhealthy for asthmatics. Asthma discharge seasonality discussed in the previous chapter demonstrated a minimum in July and a maximum in January, which strengthened the conclusion that the effects were trivial. These results clearly suggested that outdoor air pollution levels were not a driver of emergency room visits for asthma.

While HACA provided a preliminary assessment of air pollution and asthma clustering, it was an exploration phase when no statistically significant conclusions could be made. Hot spot and cluster and outlier analyses, on the other hand, resulted in the identification of statistically significant hot spots, cold spots, and outliers at a very high confidence level (95% to 99% for hot spot analysis and 95% for cluster and outlier analysis). The findings from these analyses suggested a non-existent correlation between the air pollution and ADR as no pattern of similar hot spots and cold spots could be found. Furthermore, there appeared to be a stark difference among the most populous and adjacent counties in NCT: Dallas, Tarrant, Denton, and Collin. Dallas for ADR. This further confirmed the suggestion that in the NCT, outdoor air pollution did not, in general, drive emergency room visits for asthma. As ozone can be a potent asthmagen, it is recognized that some proportion of emergency room visits for asthma symptomology likely result from ozone exposure in the summer months, but in terms of the total annual emergency room visits for asthma it appears that summer ozone exposure is not a major cause.

The asthma discharge pattern suggested a possible link to respiratory infections and/or allergens. This case was made stronger with air pollution concluded to not be a driver of asthma. Seasonal variations in the occurrence of respiratory infections, and elevated levels of allergenic pollen in the winter (cedar pollen peaks across the region in January) likely contribute to the seasonality in the asthma data, far more than elevated levels of outdoor pollutants. Socioeconomic indicators will also likely contribute to the seasonality of emergency asthma visits. Such association will be examined in the next chapter.

CHAPTER 4

ASSOCIATION BETWEEN SOCIOECONOMIC STATUS AND ADULT ASTHMA DISCHARGE IN NCT DURING THE PERIOD 2010 – 2014

4.1. Literature Review

In epidemiologic investigations, socioeconomic status (SES) is commonly assessed by the utilization of a multitude of indicators in two distinct groups: individual-level and area-level indicators (Cesaroni et al., 2003; Davoodi et al., 2013). While individual-level indicators are obtained via questionnaires on factors reporting on social status such as education, occupation, and income, the area-level indicators are obtained from census data and are used to evaluate the status of communities or neighborhoods within close proximity (Blanc et al., 2006; Cesaroni et al., 2003). According to Kant (2013), SES is a crucial marker of health status, mortality, and morbidity; it also affects the accessibility and utilization of available healthcare resources. Many studies have linked SES to a variety of health consequences; for instance, higher morbidity and mortality rates from obstructive pulmonary disease, diabetes, and cardiovascular diseases are linked to a lower SES (as cited in Bacon et al., 2009).

SES, while being tied to many chronic conditions, is of interest to asthma-related studies as there are various mechanisms in which SES variables could unfavorably affect asthma (Blanc et al., 2005; Bacon et al., 2009). For example, at the individual level, asthma patients with lower SES are, in many cases, believed to experience higher exposures to both indoor (i.e. tobacco smoke, cockroaches) and outdoor (i.e. air pollution) asthma triggers, leading to an increased risk of asthma exacerbations (Bacon et al., 2009). At the area level, asthmatics with lower SES may suffer from the health consequences of being exposed to poor air quality resulting from heavy traffic density or point-source pollution from nearby industrial activity (Blanc et al., 2006).

A number of studies have investigated the association between SES and asthma in different world regions. Such an association was identified in numerous investigations (Basagaña et al., 2004; Chen et al., 2002; Gupta et al., 2018), yet was not found to be significant, or prompted further discussions due to its complexity, in others (Hancox et al., 2004; Court; 2002). In the findings that confirmed the association, both higher number of children and adult asthma cases were believed to be linked to lower SES (Trupin et al., 2013; Sarpong et al., 1996; Mielck et al., 1996). Such an association for different types of asthma, though, is not unambiguous as in some reports, several groups of asthma patients exhibited different levels of connection to SES; for instance, findings from Patel et al. (2012) suggested that lower SES in early life increased the odds of nonatopic asthma while Chen et al. (2002) and Thakur et al. (2013) proposed that the risk factors for atopic and nonatopic asthma were likely different and may even oppose each other.

Not only does such association depend on the asthma type, it has been reported to exhibit ethnic variations. As discussed by Miller (2000), reports over the years have concluded that asthma morbidity and mortality is considerably higher among Black members of the population compared to White. And it is worth noting that Black individuals tend to have a lower SES than White (Federal Interagency Forum on Child and Family Statistics).

In short, the intricacies of the association are amplified by how asthma is defined, what groups are involved, what socioeconomic indicators are chosen, and in which geographic area a study is based (as cited in Basagaña et al., 2004).

Establishing the relationship between SES and asthma has prompted the need for a construction of an easily accessible and broadly applicable socioeconomic deprivation index (SDI) which would allow an inclusive view of the various aspects constituting the well-being and social status of different communities (Salmond et al., 2006).

It is noteworthy that SDIs has been constructed at different levels across the globe, namely in: New Zealand, France, Portugal, and in multiple European countries (see e.g., Salmond et al., 2005; Havard et al., 2008; Ribeiro et al., 2017; Guillaume et al., 2016)

The common theme in these studies was that SDI formulation was a response to the need for a development of a standardized measure of social inequality in relation to health status. The successful construction of an SDI would promote assessment, research, and implementation of updated and improved policies to narrow the gap when it comes to social inequalities (Guillaume et al., 2016).

There has not been a specific study that attempted to construct the SDI concerning asthma for the NCT. Among a few local SDI investigations, Powell-Wiley et al. (2014) explored the relationship between weight change between socioeconomic deprivation and weight change while Claudel et al. (2018) constructed an SDI reflecting the relationship between social inequalities and hypertension.

4.2. Hypotheses

It was hypothesized that area-level socioeconomic deprivation is associated with higher rates of adult asthma prompted hospital ER visits in the NCT region during the period 2010-2014.

The aim of the study was to (1) examine the relationship between common socioeconomic indicators and ADR (2) determine the significant area-level SES indicators to be retained and utilize such to compute the SDI to investigate the differential levels of social inequalities in relation to asthma.

4.3. Methodology

4.3.1. Overview of the methods used

Two approaches were taken to assess the relationship between areal SES and asthma. The first step –exploratory data analysis (EDA) – served to provide an initial glimpse into potential associations. The second step involved the formulation of an SDI through the utilization of principal component analysis (PCA) and factor analysis. All analyses were performed at the census tract level.

The EDA stage consisted of two key analyses: Pearson pairwise correlation computation and hot spot and clustering and outlier analysis. The correlations between ADR and each socio-economic indicator at census tract level were computed. This yielded a preliminary analysis of the associative strength of each indicator with ADR. The hot spot analysis step was crucial in providing the visually statistical significance to either strengthen or weaken the initial association assessment. With more than 1000 census tracts in the dataset, EDA was an essential step and the combination of these analyses was needed for a more thorough understanding of the subsequent step which was the construction of an index of area-level SES.

The SDI construction step provided a holistic view of the association and focused on the core indicators that would define the strengths of the associations. This step included two key evaluations: a PCA and a factor analysis. The results from the factor analysis led to the identification of principal components that accounted for the most variance of the data. Such principal components, combined with factor loadings, were utilized to formulate the SDI.

4.3.2. Data Extraction

4.3.2.1. Adult Asthma Discharge

Adult asthma hospital discharges, as noted previously, were obtained from the dataset provided by the Dallas Fort-Worth-Hospital Council Foundation (DFWHCF) and were approved by the Texas Health Resources Institutional Review Board (Newcome and Li, 2019). The dataset consisted of asthma discharges from hospitals in NCT during the period 2010 – 2014. The evaluated dataset contained 78,444 geocoded cases of asthma patients from age 18 to 65 with various ethnic makeups: White, Black, Native Americans and Alaska Native, and Asian/ Pacific Islanders. Most patients were non-Hispanic or Latino.

4.3.2.2. Socio-economic Status Indicators

The socio-economic status indicators (SSIs) were obtained from the American Community Survey (ACS) for the study period. The ACS is one of the 130 different surveys conducted by the Census Bureau (Census Bureau 101 for Students). The ACS, a crucial element of the Census Bureau's decennial platform, surveys roughly 3.5 million housing unit addresses annually and provides vital population and housing information via two types of coverages: single-year estimates and multi-year estimates (American Community Survey).

The SSIs for the 2010-2014 period were extracted from the 5-year estimates released by ACS for the same time period. Many studies have agreed on the core measures of the SES: occupation, income, education, social status or prestige, social class, or a composite approach (Krieger et al., 1997; Krieger, 2001; Berkman & Macintyre, 1997). However, there has been no unanimity as to which variables to be included in such composite SDI. One general guideline which has been followed is that the selected indicators comprising the composite should generally reflect the social good and normative value of a given community (as cited in Singh and Siahpush, 2002). Following this recommendation, a total of 28 indicators encompassing various sub-domains, ranging from employment, housing, education, income, and transportation were selected. They were demarcated as follows:

(1) percentage of families living with poverty status in the past 12 months,

(2) percentage of people that are currently unemployed and last worked 1 to 5 years ago,

(3) percentage of population with white collar occupation (management, sciences, arts etc.),

(4) percentage of population 25 years and over with education less than 9th grade,

(5) percentage of population 25 years and over with a with Bachelor's degree or higher

(6) percentage of people with income less than $15,000,

(7) percentage of householders that moved into housing units 2010 or later,

(8) percentage of people living in overcrowded conditions (more than 1 person per room),

(9) percentage of population who divorced last year,

(10) percentage of population under 5 years,

(11) percentage of elderly population (65 years and over),

(12) percentage of black population,

(13) percentage of people who are foreign born and not a U.S. citizen,

(14) percentage of ethnic minority as a householder,

(15) percentage of occupied housing units heating with utility gas,

(16) percentage of occupied housing units heating with fuel, oil, kerosene, etc.,

(17) percentage of occupied housing units heating with wood,

(18) percentage of total housing units built 1969 or before,

(19) percentage of occupied housing units lacking complete kitchen facilities,

(20) percentage of houses lacking complete plumbing facilities,

(21) percentage of renter-occupied housing units,

(22) percentage of households with no vehicle,

(23) percentage of people using public transportation to work,

(24) percentage of population with no health insurance,

(25) percentage of population who speak a language other than English,

(26) percentage of population who have no wage or salary income,

(27) percentage of households receiving Food Stamps/ Supplement Nutrition Assistance Program (SNAPS)

(28) percentage of single mom with children under 18 years.

4.3.3. Data Analysis

4.3.3.1. Pearson's Pairwise Correlation

Two sets of Pearson estimates were carried out. The first set utilized the population data; the second set investigated the association by gender. For the first set, three Pearson estimates were carried out: one pairwise correlation set during the study period, one during the study period summer, and one for the winter period. The ADR values were the same set obtained from the computation for spatial analysis from the previous chapter.

The unrecorded values were dropped and subsequently, a correlation funnel was constructed. The correlation funnel concept was introduced by Matt Dancho and its purpose is to provide a visualization tool for understanding the relationship of all features of interest and the response variable via point correlation analysis (correlationfunnel). ADR was the response variable the relationship between each SSI and ADR was examined via the correlation funnel.

The initial combination of ADR and all indicators yielded 1345 values for all five sets of parameters: period 2010 – 2014, summers 2010 – 2014, winters 2010 – 2014, period 2010 – 2014 for female ADR, and period 2010 – 2014 for male ADR. The missing values were dropped before proceeding further (Figure 4-1). The summary statistics of the dataset are shown in Table 4-1.

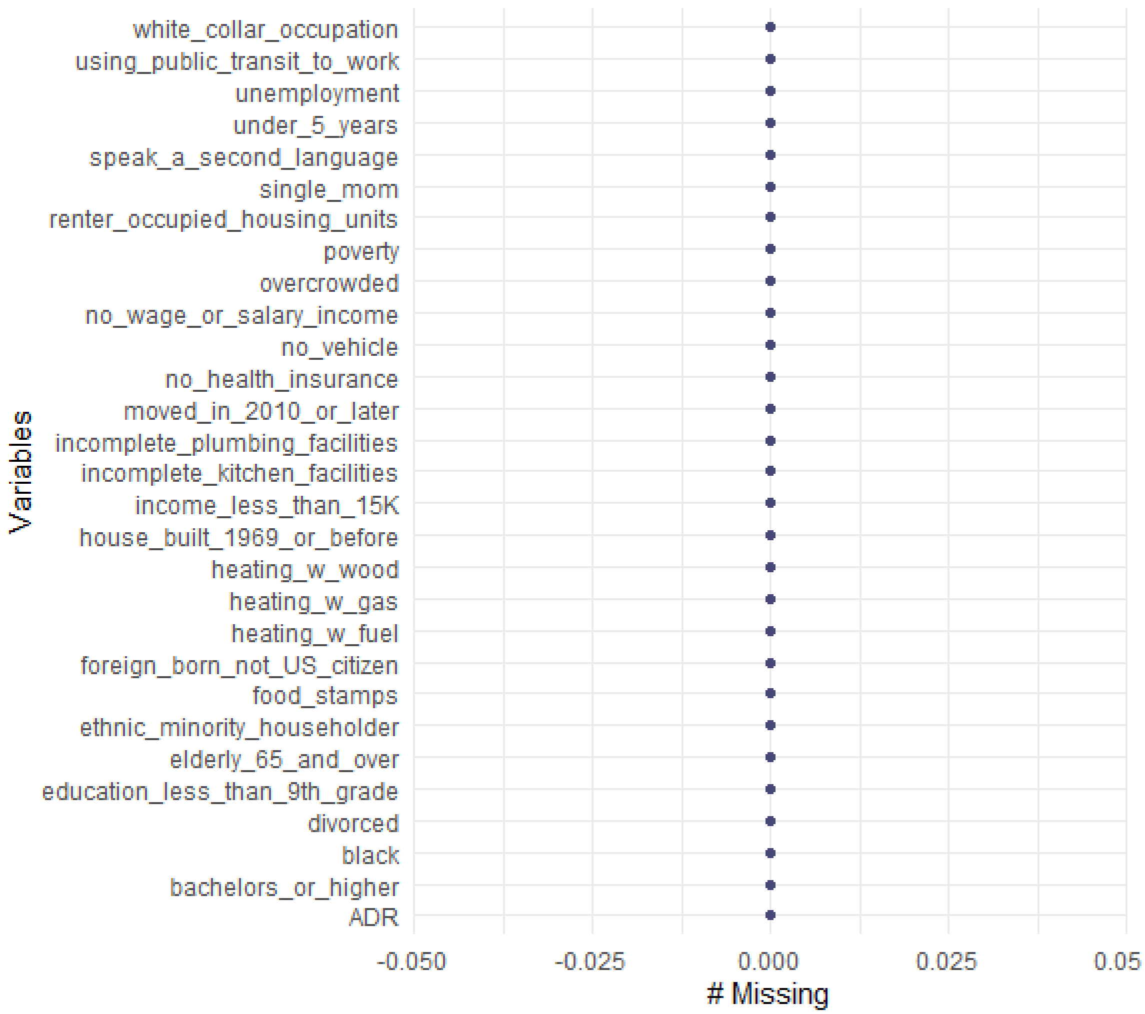


Figure 4-1: Number of missing values for all the variables in the dataset

Simple Statistics						
Variable	N	Mean	Std Dev	Sum	Minimum	Maximum
ADR	1345	25.74074	24.98876	34621	0	285.00000
Poverty	1345	15.85331	12.65313	21323	0	78.90000
Unemployment	1345	7.98015	4.51192	10733	0	40.60000
White_Collar_Occupation	1345	36.08320	17.46122	48532	1.50000	81.00000
Education_less_than_9th_grade	1345	8.36833	9.24757	11255	0	57.40000
Bachelor_degree_or_higher	1345	28.99442	20.21827	38998	0.50000	91.00000
Income_less_than_15000	1345	10.92959	9.11969	14700	0	64.20000
Moved_2010_or_later	1345	30.63175	14.86010	41200	3.50000	82.90000
Overcrowded_Conditions	1345	5.01086	5.77341	6740	0	52.50000
Divorced	1345	11.37978	4.26597	15306	1.00000	37.60000
Under_5_years	1345	7.26171	2.86736	9767	0	15.80000
Elderly_65andover	1345	10.19264	5.74622	13709	0	57.50000
Black	1345	16.04625	18.31036	21582	0	99.00000
Single_mother_with_children	1345	25.45063	16.03574	34231	0	100.00000
Foreign_Born_Not_US_Citizen	1345	11.91561	10.37341	16026	0	56.80000
Ethnic_Minority_Householder	1345	19.13911	17.36510	25742	0	89.10000
Heating_with_gas	1345	2.13636	4.65724	2873	0	38.30000
Heating_with_fuel	1345	0.05509	0.32310	74.10000	0	6.60000
Heating_with_wood	1345	0.21405	0.70391	287.90000	0	8.70000
House_built_1969_or_before	1345	27.22699	27.98877	36620	0	96.20000
Incomplete_kitchen_facilities	1345	0.83636	1.46436	1125	0	15.30000
Incomplete_plumbing_facilities	1345	0.42454	0.84106	571.00000	0	6.90000
Renter_occupied_housing_units	1345	39.57442	25.55709	53228	0.40000	100.00000
No_vehicles	1345	5.55799	6.20288	7476	0	45.40000
Public_transportation_to_work	1345	1.71703	2.87404	2309	0	28.30000
No_health_insurance	1345	21.62714	12.02309	29089	0.20000	60.70000
Speak_other_than_English	1345	6.43881	2.22131	8660	0.90000	17.40000
No_wage_or_salary_income	1345	18.53234	8.96132	24926	1.00000	52.50000
Public_assistance_or_Food_Stamps	1345	12.32379	10.79598	16576	0	68.80000

Table 4-1: Summary statistics of the 28 SSIs and ADR at the census tract level

A correlation funnel of Pearson product correlation coefficients was generated to provide a visualization of the association of all indicators with ADR for each period of intertest. The correlation funnel helps eliminate any trivial relationships and shifts the focus towards variables with strong associations. Figure 4-2, Figure 4-3, Figure 4-4, Figure 4-5, and Figure 4-6 depict the correlation funnels for the three indicated sets of association.

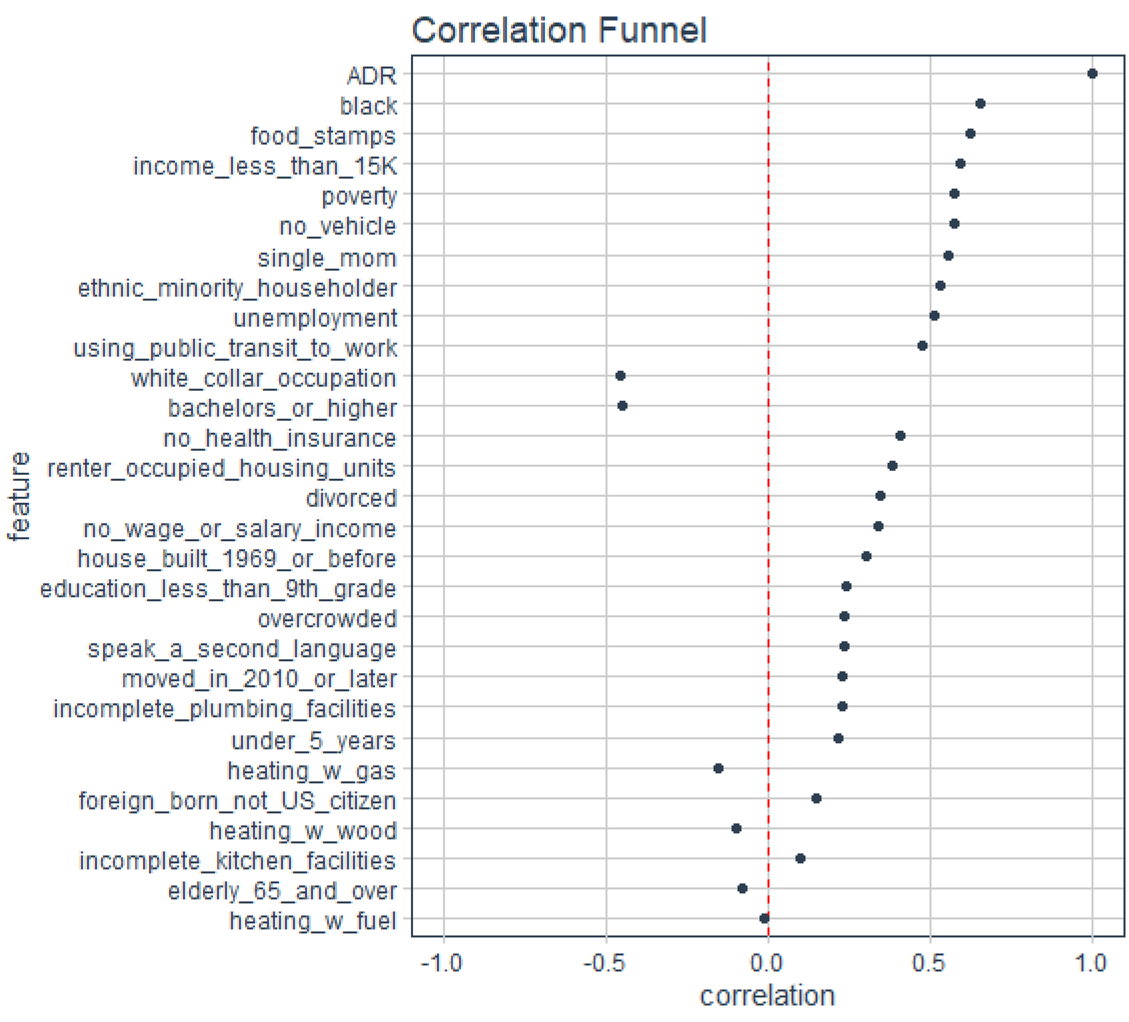


Figure 4-2: Correlations between SSIs and ADR during period 2010 – 2014

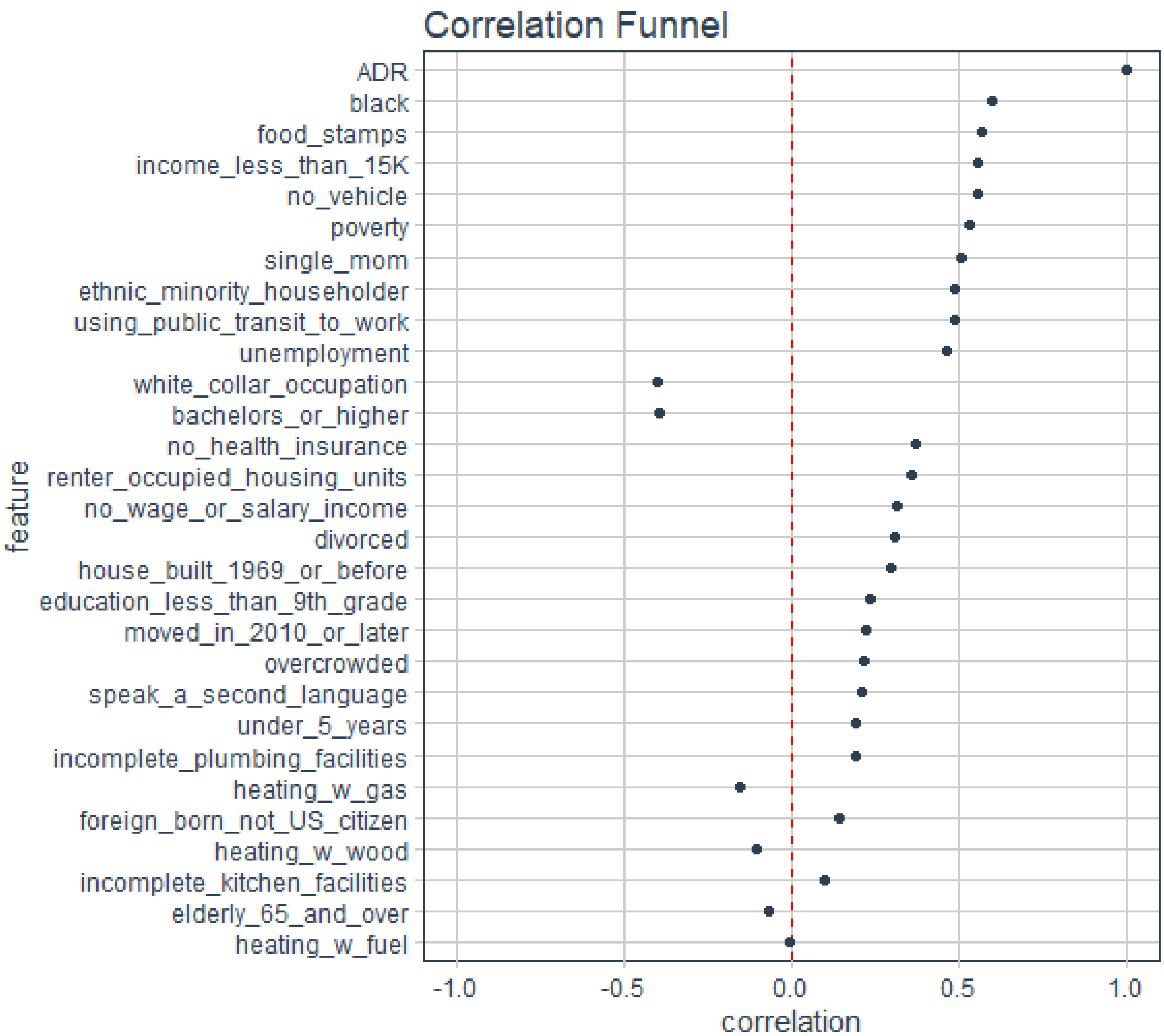


Figure 4-3: Correlations between SSIs and ADR during summers 2010 – 2014

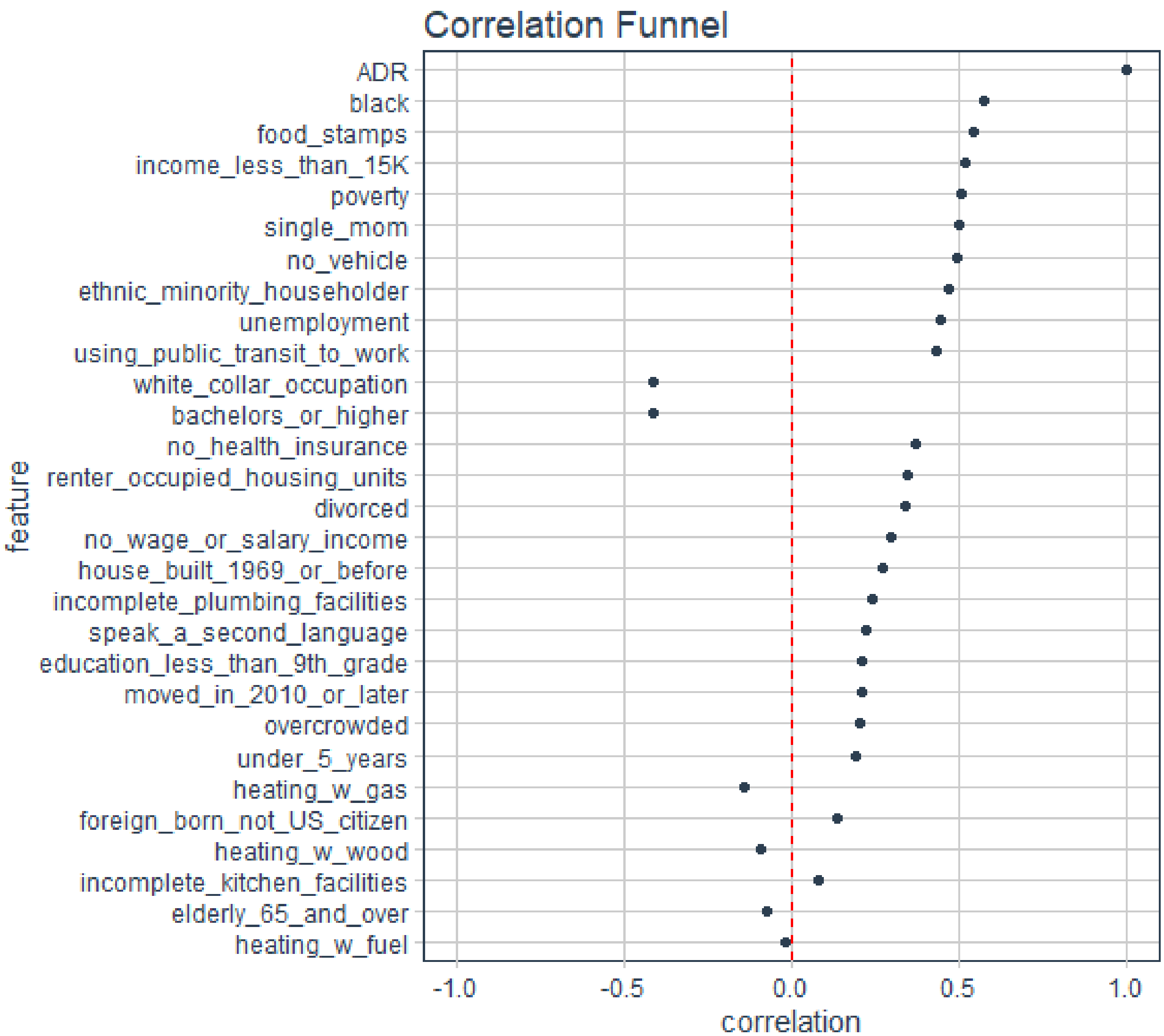


Figure 4-4: Correlations between SSIs and ADR during winters 2010 – 2014

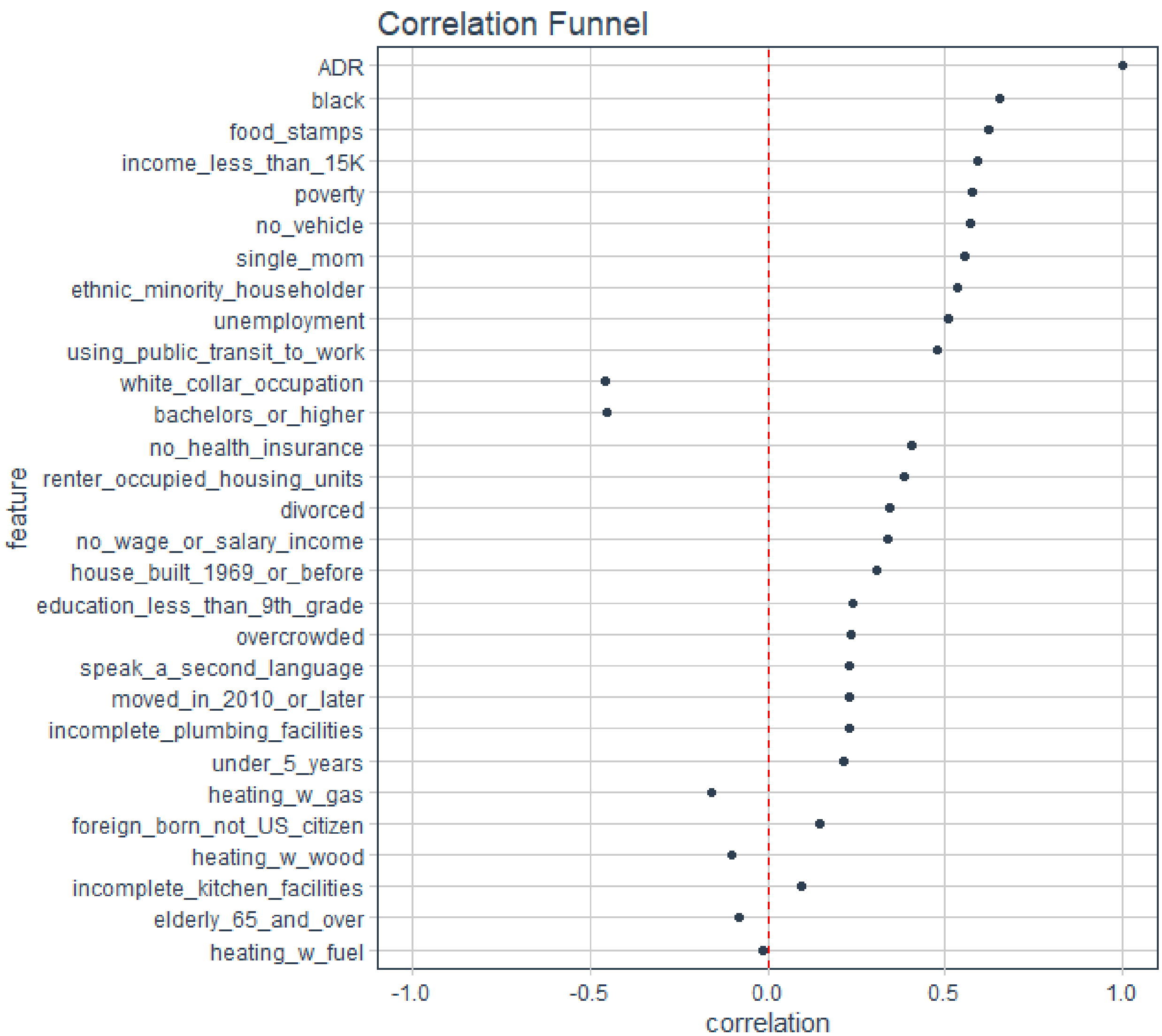


Figure 4-5: Correlations between SSIs and female ADR during period 2010 – 2014

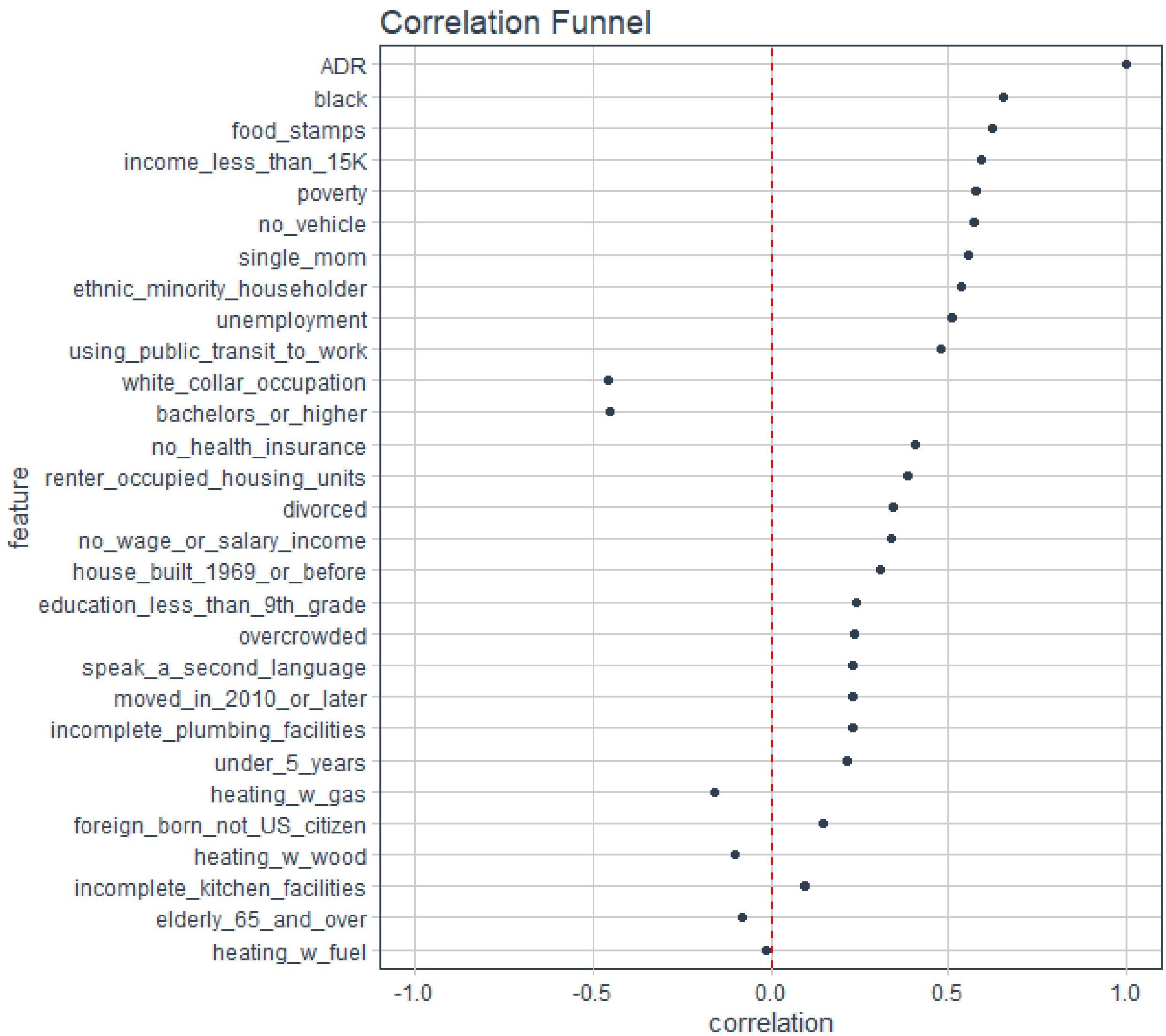


Figure 4-6: Correlations between SSIs and male ADR during period 2010 – 2014

All five EDA analyses, regardless of seasonality and gender, yielded approximately the same result. Out of all the SSIs negatively correlated with ADR, two indicators exhibited a moderate association, with the absolute values of the coefficients close to 0.5. These two indicators were (1) percentage of population with white collar occupation (management, sciences, arts etc.), (2) percentage of population 25 years and over with a with Bachelor's degree or higher. This suggested a higher social status and better education attainment was negatively linked to a higher asthma discharge rates.

Conversely, out of the 22 variables positively associated with ADR, nine exhibited a moderate to strong correlation. The variables with moderately strong and strong associative strengths were:

(1) percentage of families living with poverty status in the past 12 months,

(2) percentage of people that are currently unemployed and last worked 1 to 5 years ago,

(3) percentage of people with income less than $15,000

(4) percentage of black population,

(5) percentage of ethnic minority as a householder,

(6) percentage of households with no vehicle

(7) percentage of people using public transportation to work,

(8) percentage of households receiving Food Stamps/ Supplement Nutrition Assistance Program (SNAPS)

(9) percentage of single mom with children under 18 years.

Two groups that stood out from these SSIs: ethnically identified group (4, 5) and poverty-indicator group (1,2,3,6,7,8,9).

Apparently, it appeared that SSIs related to housing, such as percentage of occupied housing units lacking complete kitchen facilities, and percentage of occupied housing units heating with fuel, oil, kerosene, etc. and population age such as percentage of population under 5 years, percentage of elderly population (65 years and over), displayed trivial correlation with ADR.

Such preliminary findings were in accord with various studies on the ethnic and social variations on the associations between asthma and SES.

As noted previously, the results from the correlation funnel construction narrowed down the choices for variables used for the Pearson correlation test. As the correlation funnel yielded similar result regardless of season, the Pearson test was carried out for only one set of data: the period 2010 – 2014 for the general population. The nine indicators with moderately strong to strong associative strength were selected for the test. All selected indicators were log-transformed prior to the test, and the result was shown in the series of nine figures – from Figure 4-7 to Figure 4-15.

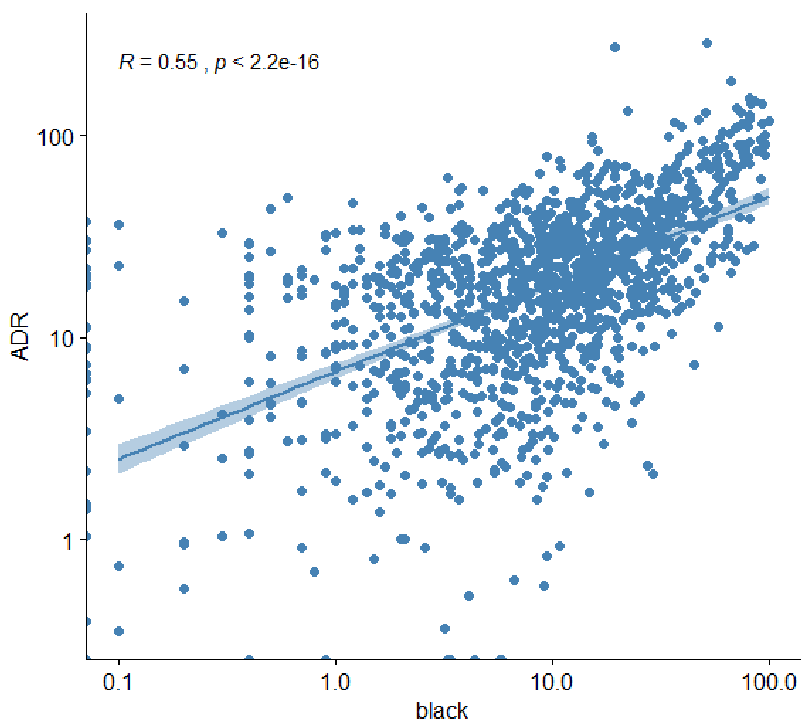


Figure 4-7: Association between percentage of black population and ADR

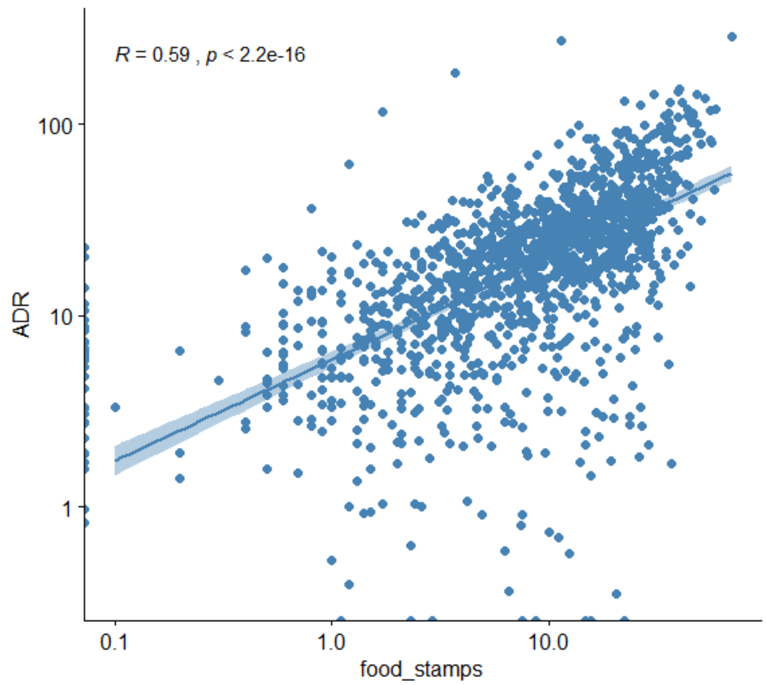


Figure 4-8: Association between percentage of households receiving Food Stamps/ Supplement Nutrition Assistance Program (SNAPS) and ADR

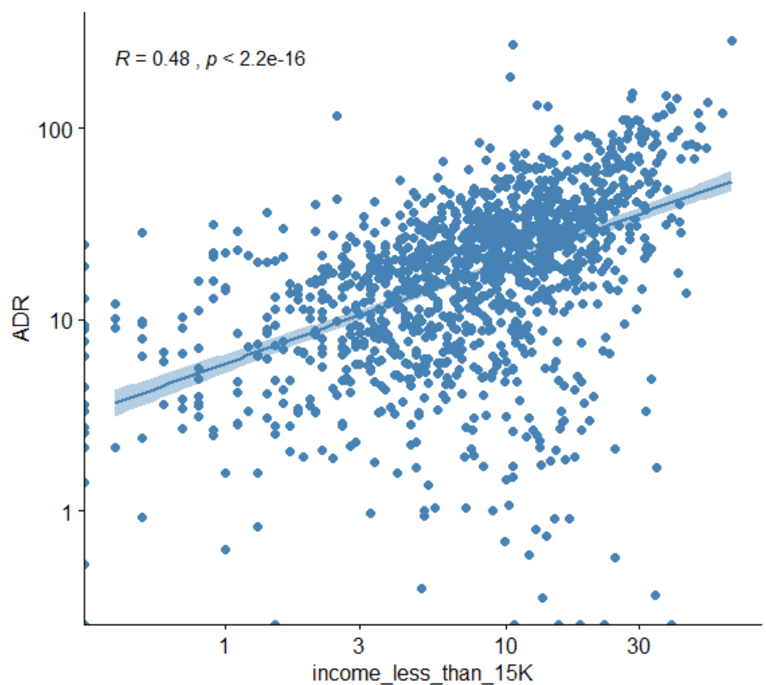


Figure 4-9: Association between percentage of people with income < $15,000 and ADR

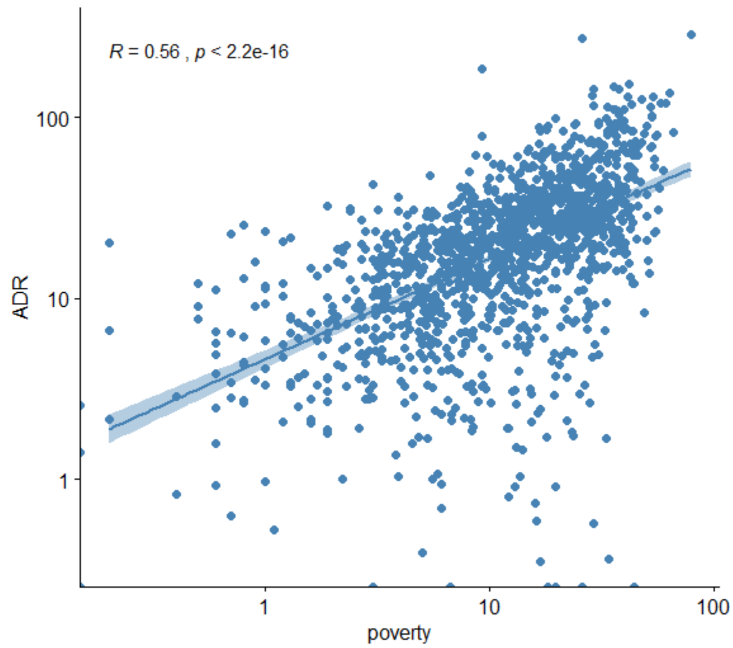


Figure 4-10: Association between percentage of families living with poverty status in the past 12 months and ADR

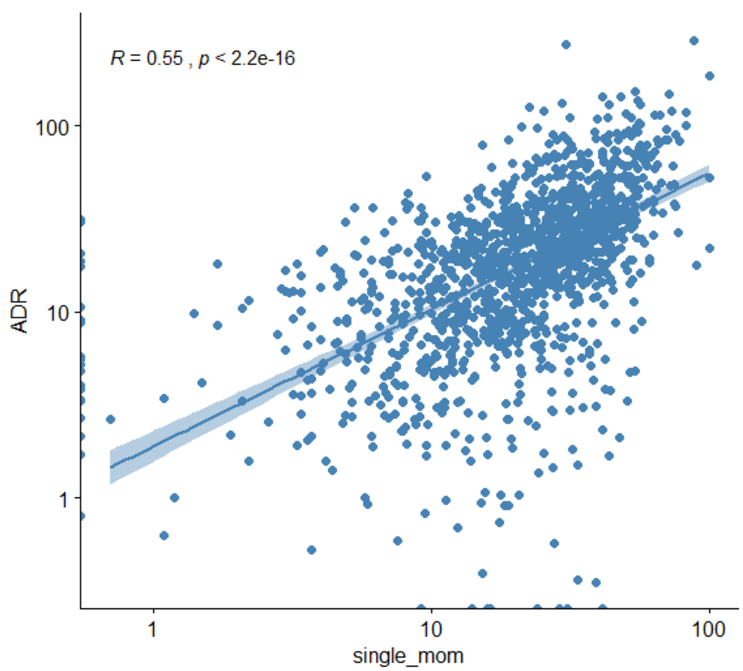


Figure 4-11: Association between percentage of single mom with children under 18 years and ADR

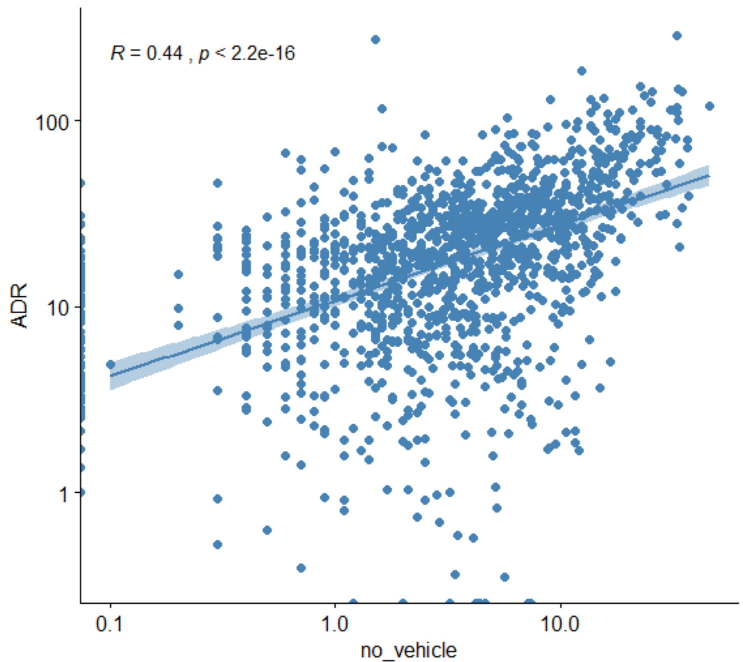


Figure 4-12: Association between percentage of households with no vehicle and ADR

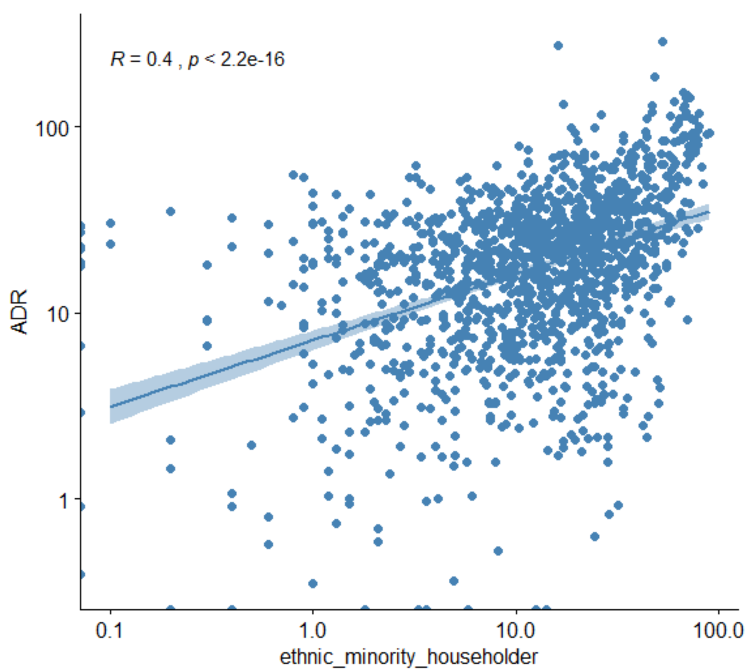


Figure 4-13: Association between percentage of ethnic minority as a householder and ADR

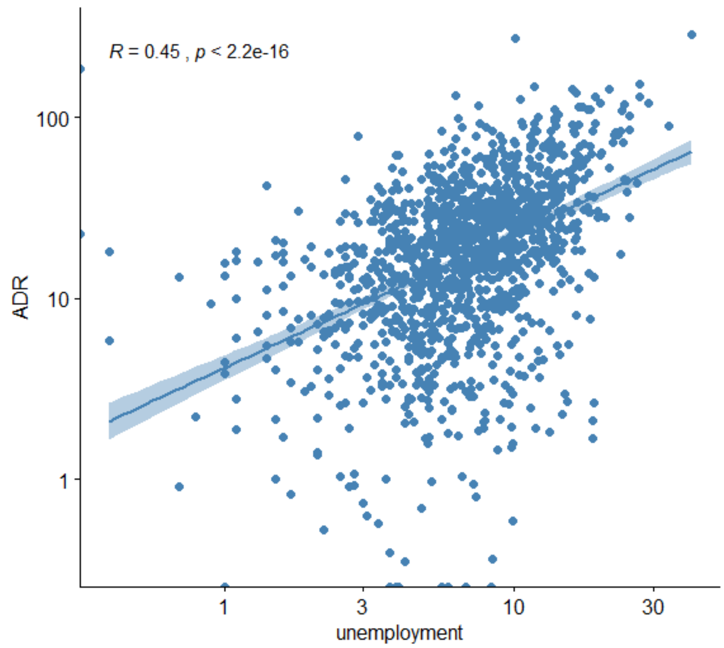


Figure 4-14: Association between percentage of people that are currently unemployed and last worked 1 to 5 years ago and ADR

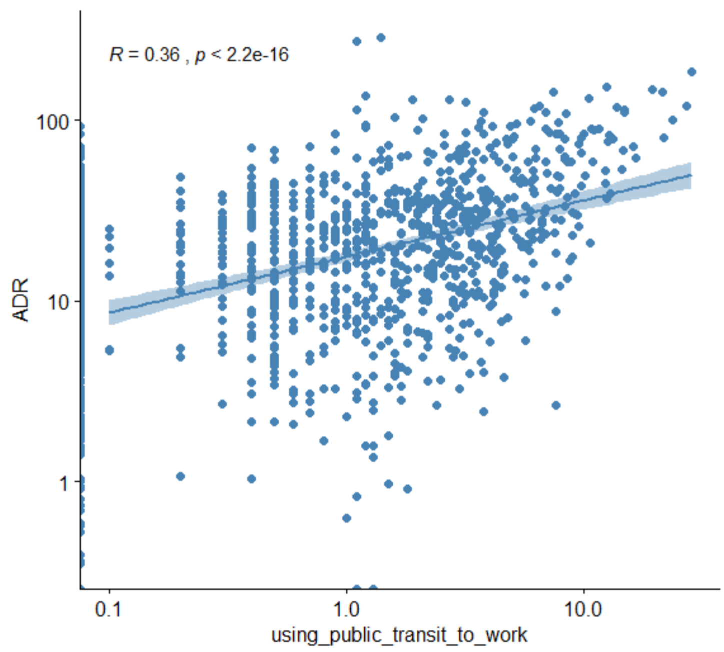


Figure 4-15: Association between percentage of people using public transportation to work and ADR

Results from Pearson's pairwise correlation showed strong, positive, and statistically significant associations across all chosen nine indicators. The SSIs with the highest correlations – ranging from 0.55 to 0.59 – were

1. percentage of households receiving Food Stamps/ Supplement Nutrition Assistance Program (SNAPS),
2. percentage of families living with poverty status in the past 12 months,
3. percentage of black population,
4. percentage of single moms with children under 18 years.

These SSIs had one theme in common: they clearly report on socially disadvantaged groups: the poor (food stamps and poverty status), the non-traditional family units (single mom), and the ethnic minority (black population). This initial finding suggested that poverty and being Black seemed to be highly correlated with the use of emergency room for asthma. The racial and social class disparity seemed to be fairly strong in the NCT, the subsequent hot spot and outlier analysis was expected to provide the spatial perspectives of this initial finding.

4.3.3.2. Hot spot analysis

As previously noted, the goal of a hot spot analysis is to locate the statistically significant hot spots and cold spots of a variable of interest via the utilization of the Getis-Ord Gi* statistic (Figure 3-24 and Figure 3-25). On the other hand, the purpose of performing a Cluster and Outlier analysis is to detect the outliers from the hot spot analysis at a 95% confidence level (Cluster and Outlier Analysis (Anselin Local Moran's I)). There are two types of outliers: the high-low outliers signifying regions of high concentration in a low concentration neighboring region and low-high outliers denoting regions of low concentration in a high concentration neighboring region (How Cluster and Outlier Analysis (Anselin Local Moran's I) works).

The hot spot analysis and Cluster and Outlier Analysis were utilized for 10 variables: the ADR and the 9 indicators selected from the previous steps. Figures 4-16 to 4-35 depict the hot spots and cold spots of the previously indicated SSIs; Figure 4-36 and figure 4-37 provide the legend of the hot spot and cluster and outlier analyses; figure 4-44 has all the NCT counties’ names for reference.

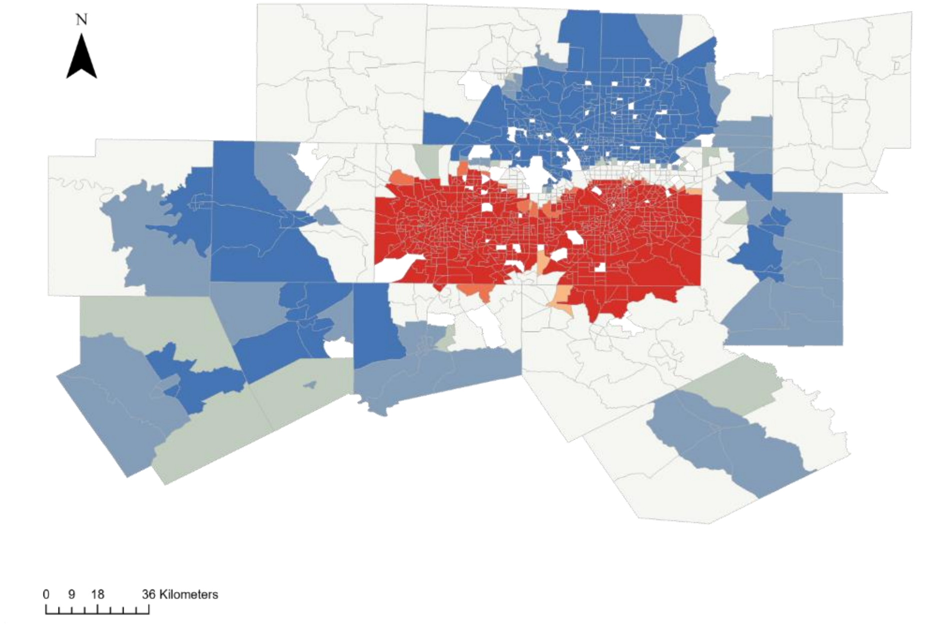


Figure 4-16: ADR hot spots and cold spots

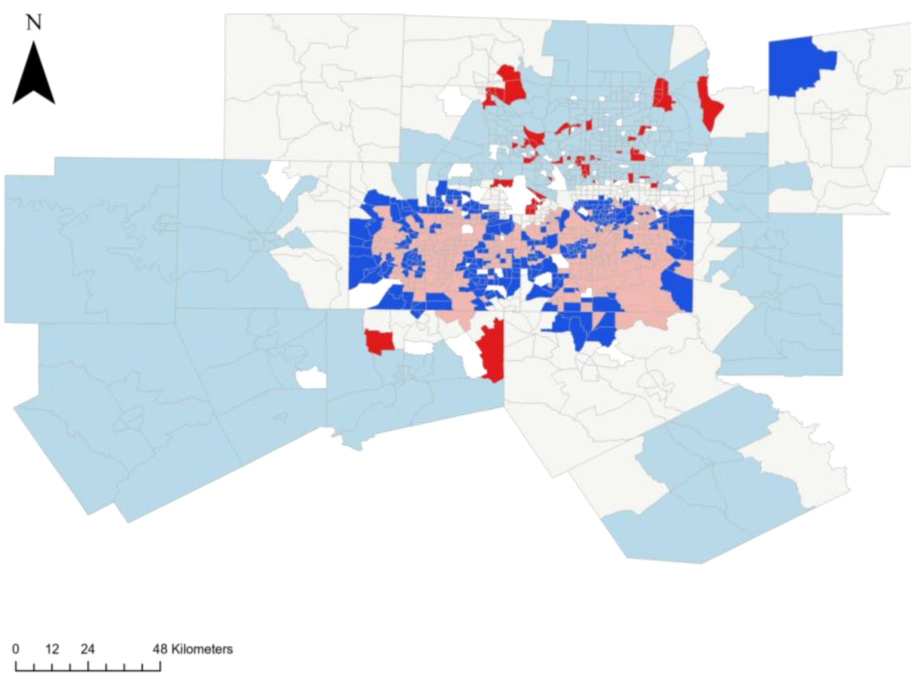


Figure 4-17: ADR clusters and outliers

The areas of high ADR are in Dallas and Tarrant counties, the two populous counties in the NCT; however, there exists a number of low-high outlier tracts, signifying the variability of the ADR across the tracts in these counties. The other two populous counties, Denton and Collin, are regions of low ADR. There are a smaller number of high-low outliers in this region, denoting a more evenness of ADR across the tracts.

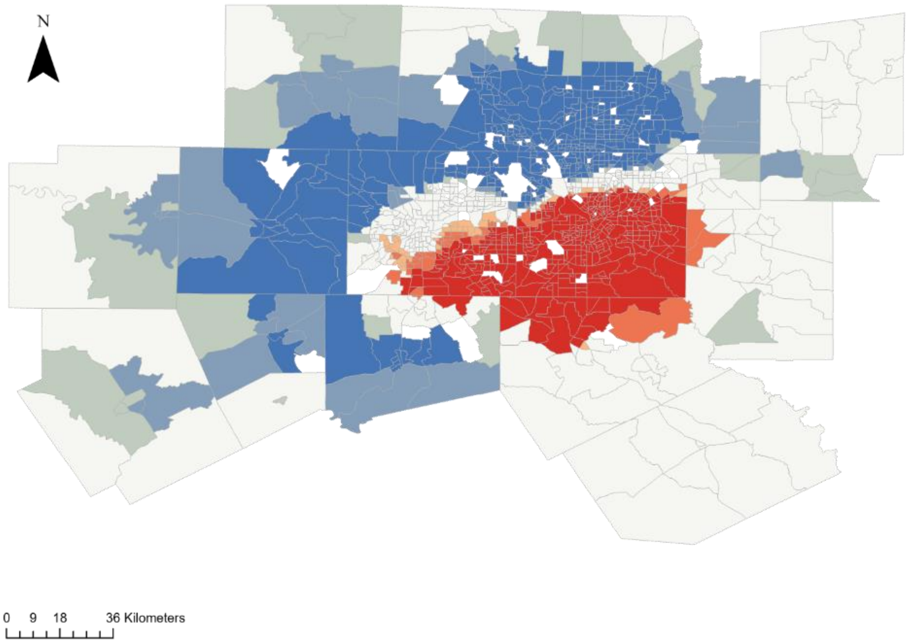


Figure 4-18: Percentage of black population hot spots and cold spots

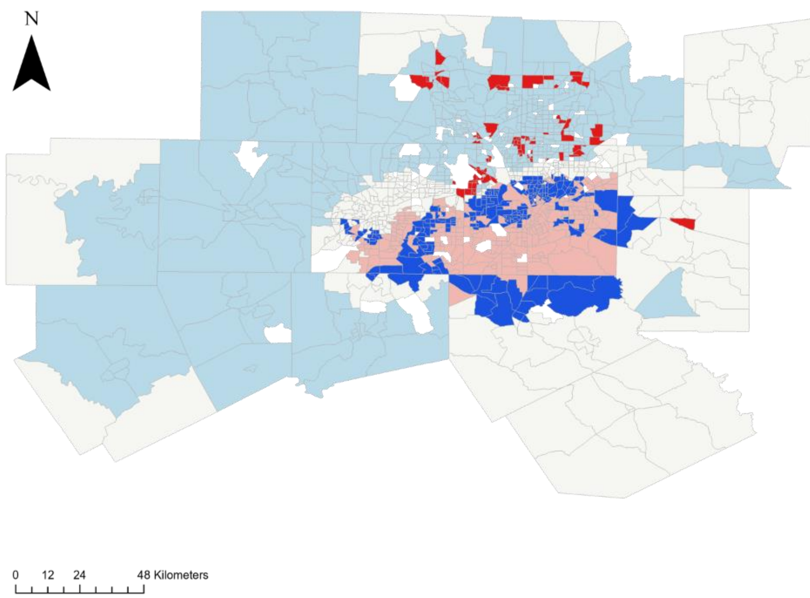


Figure 4-19: Percentage of black population clusters and outliers

For percentage of black population, the hot spot falls mostly in the Dallas and Tarrant counties with the majority of the tracts having a high value of black percentage population. However, the cluster and outlier analysis designates the outer tracts to be low-high outlier; this suggests an unevenness in the distribution of the black population across the region. It’s worth noting that the cold spots are in various counties such as Denton, Collin, Parker, and Johnson. The highly significant cold spots at 99% confidence level are predominantly located in Denton and Collin; also, there are few outliers in the cold spot regions.

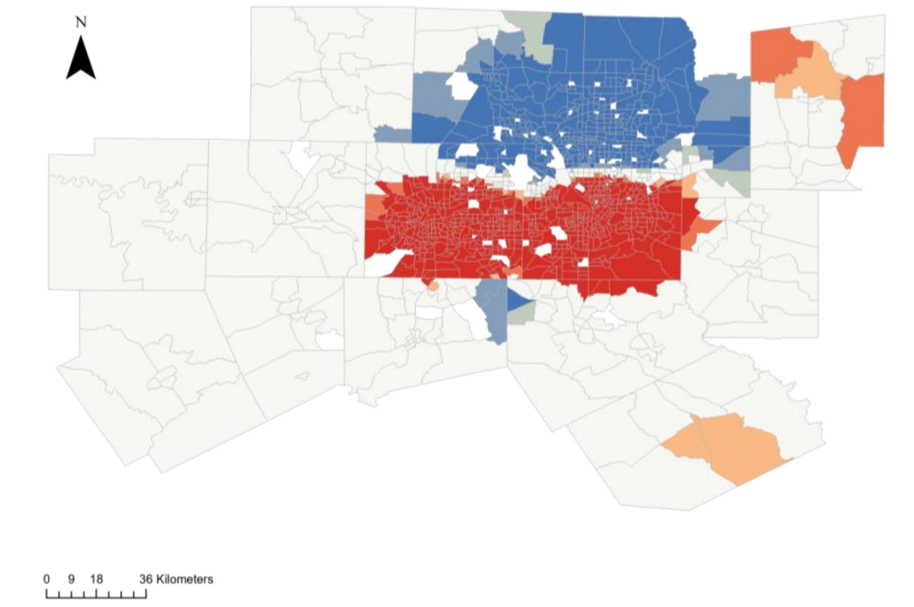


Figure 4-20: Percentage of households receiving Food Stamps/ Supplement Nutrition Assistance Program (SNAPS) hot spots and cold spots

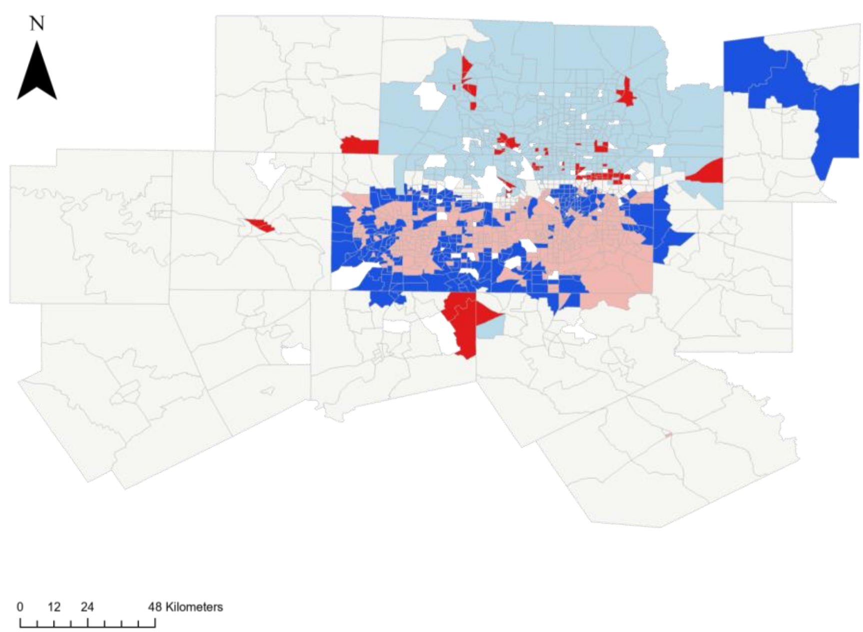


Figure 4-21: Percentage of households receiving Food Stamps/ Supplement Nutrition Assistance Program (SNAPS) clusters and outliers

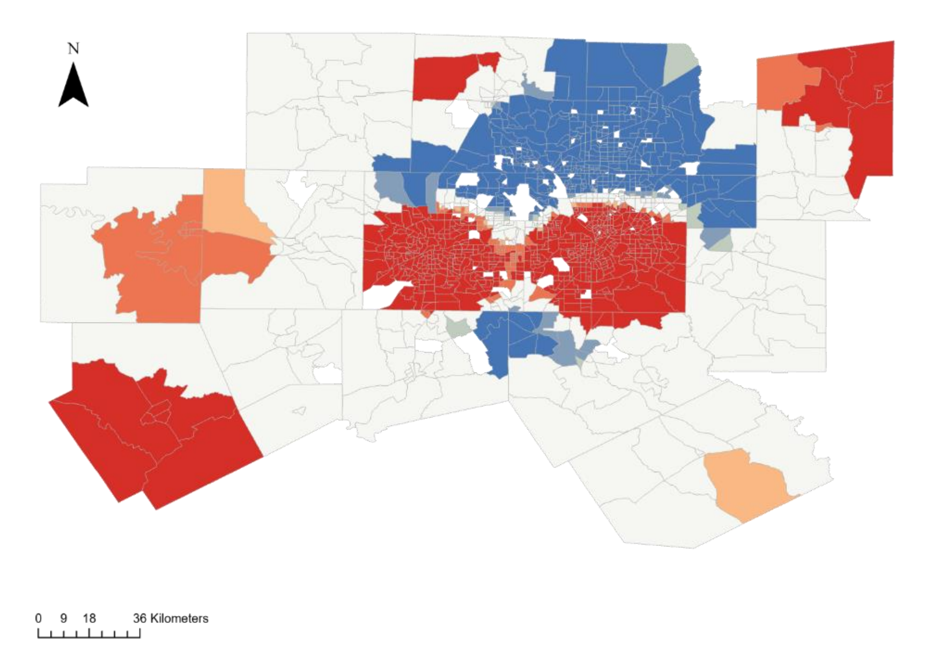


Figure 4-22: Percentage of people with income less than $15,000 hot spots and cold spots

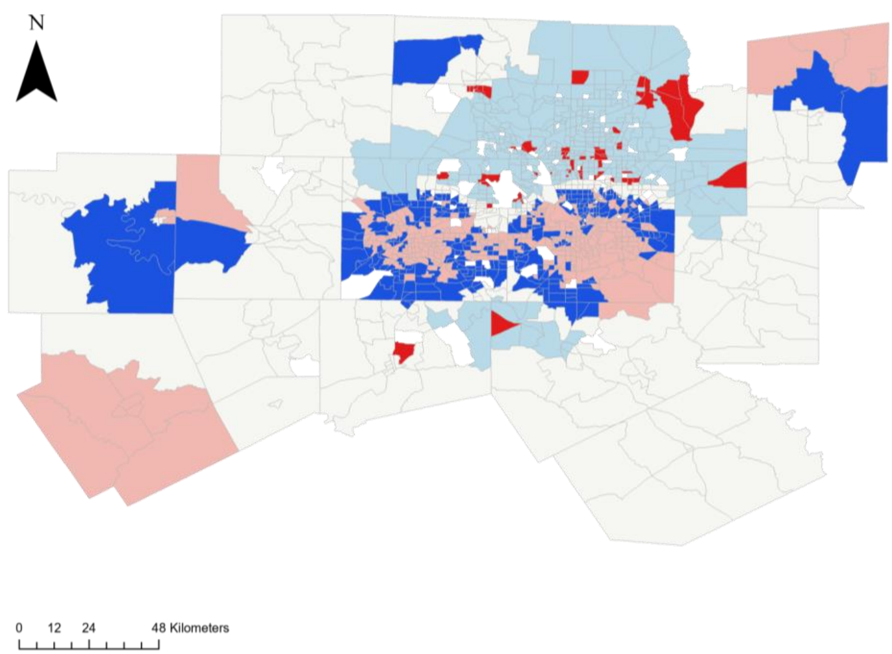


Figure 4-23: Percentage of people with income less than $15,000 clusters and outliers

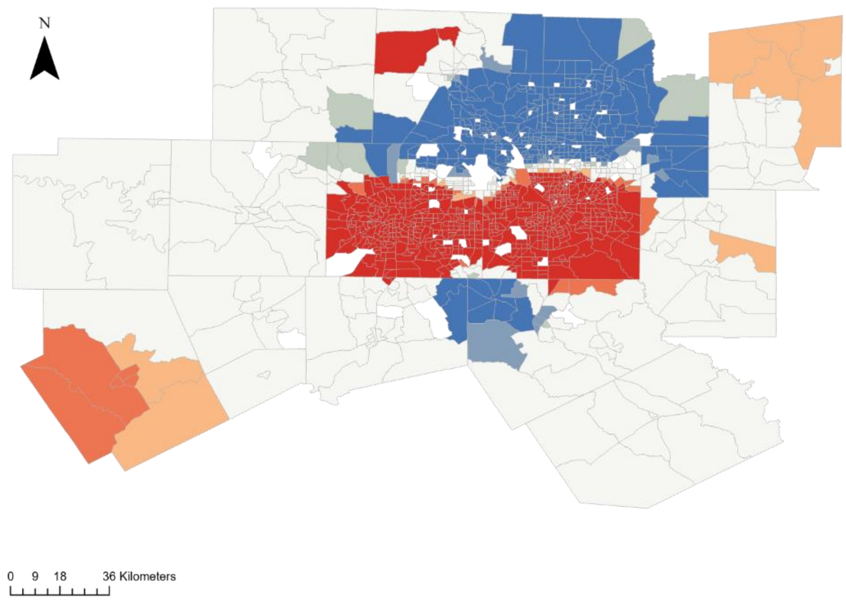


Figure 4-24: Percentage of families living with poverty status in the past 12 months hot spots and cold spots

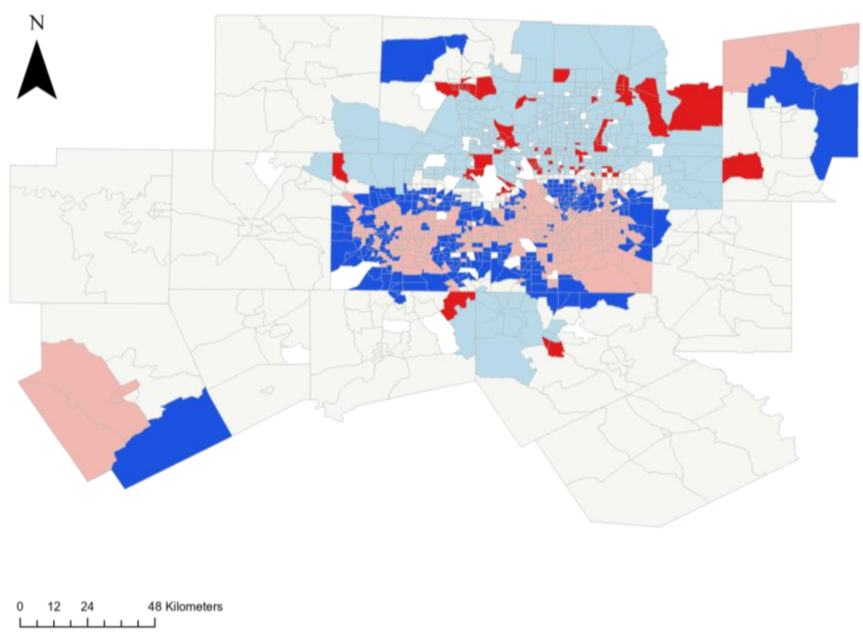


Figure 4-25: Percentage of families living with poverty status in the past 12 months clusters and outliers

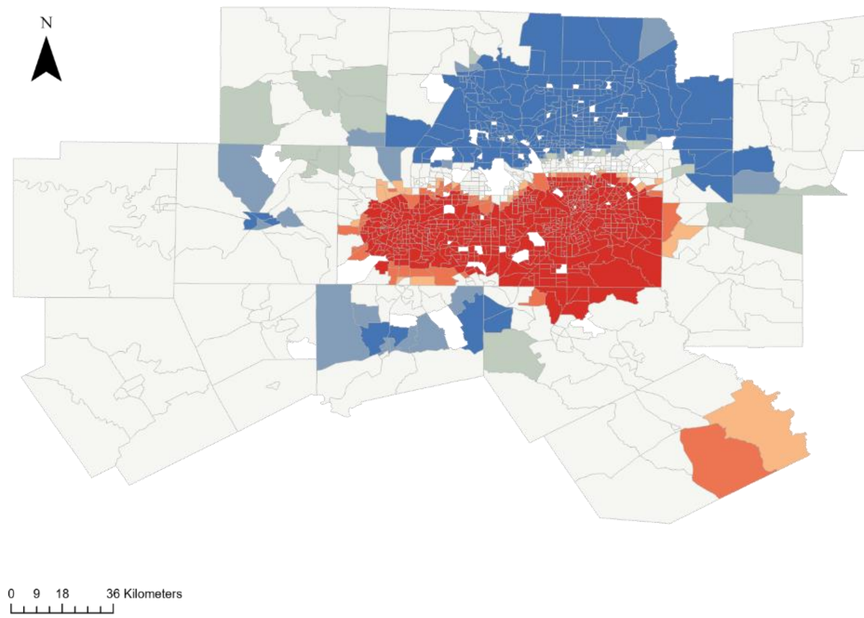


Figure 4-26: Percentage of single mom with children under 18 hot spots and cold spots

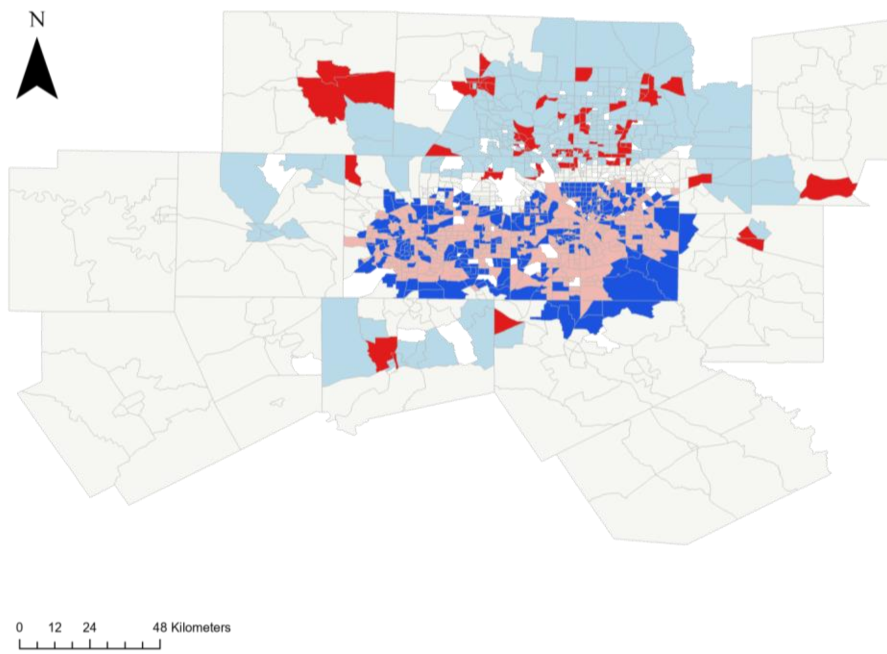


Figure 4-27: Percentage of single mom with children under 18 years clusters and outliers

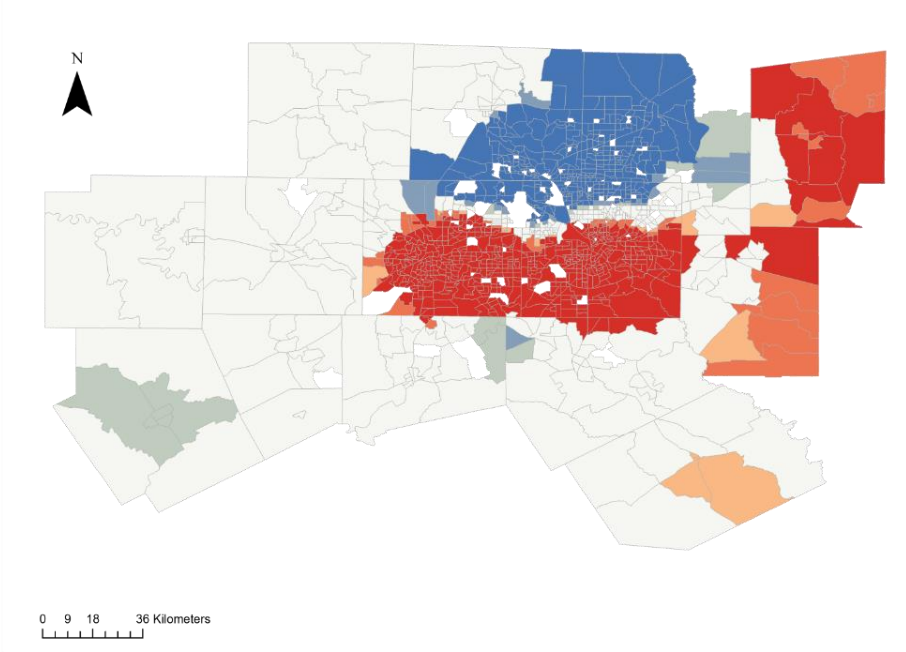


Figure 4-28: Percentage of people that are currently unemployed and last worked 1 to 5 years ago hot spots and cold spots

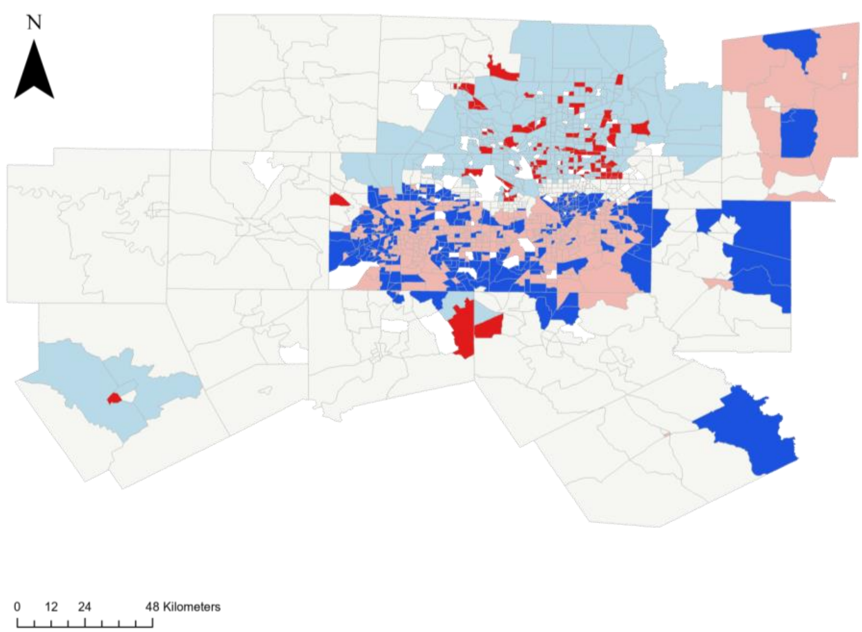


Figure 4-29: Percentage of people that are currently unemployed and last worked 1 to 5 years ago clusters and outliers

Results for percentage of households receiving food stamps, people with income less than $15,000, families living with poverty, unemployment, and single mom are generally similar to that of percentage of black population, with the hot spots concentrating in Dallas and Tarrant and cold spots locating in Denton and Collin. Once again, there is a clear region of low-high outlier in Dallas and Tarrant and there is hardly high-low outlier in the cold spots.

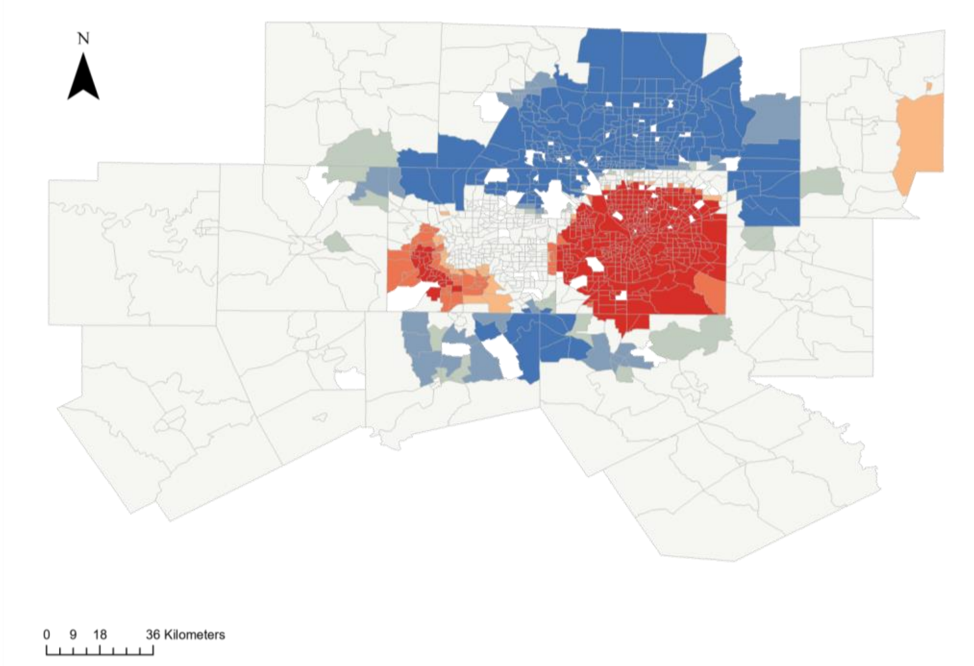


Figure 4-30: Percentage of households with no vehicle hot spots and cold spots

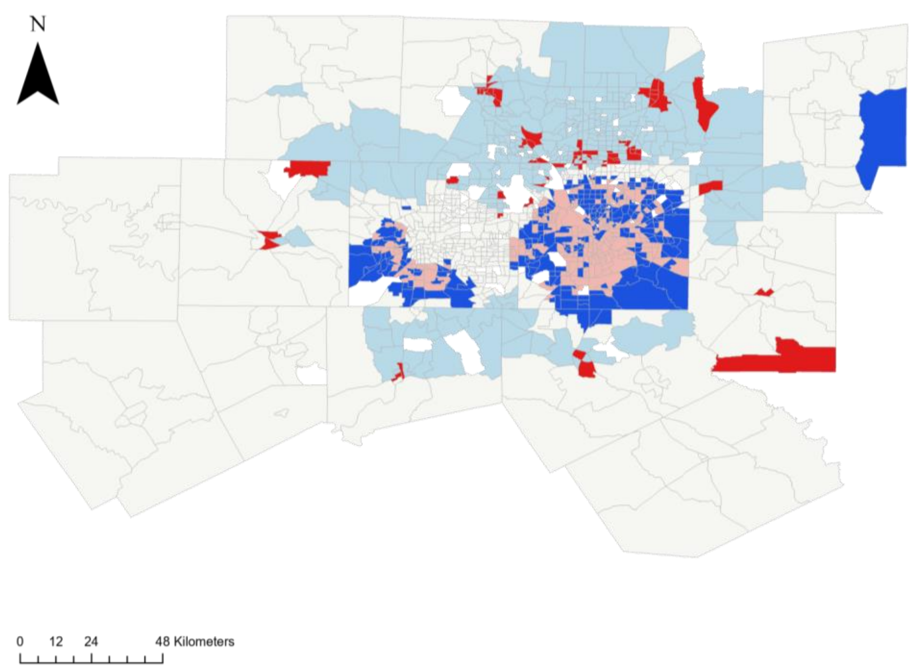


Figure 4-31: Percentage of households with no vehicle clusters and outliers

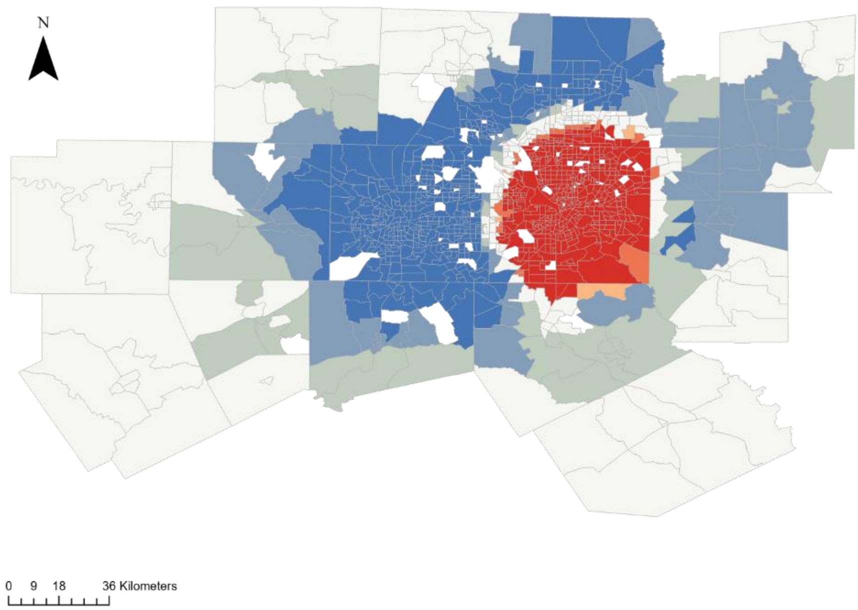


Figure 4-32: Percentage of people using public transportation to work hot spots and cold spots

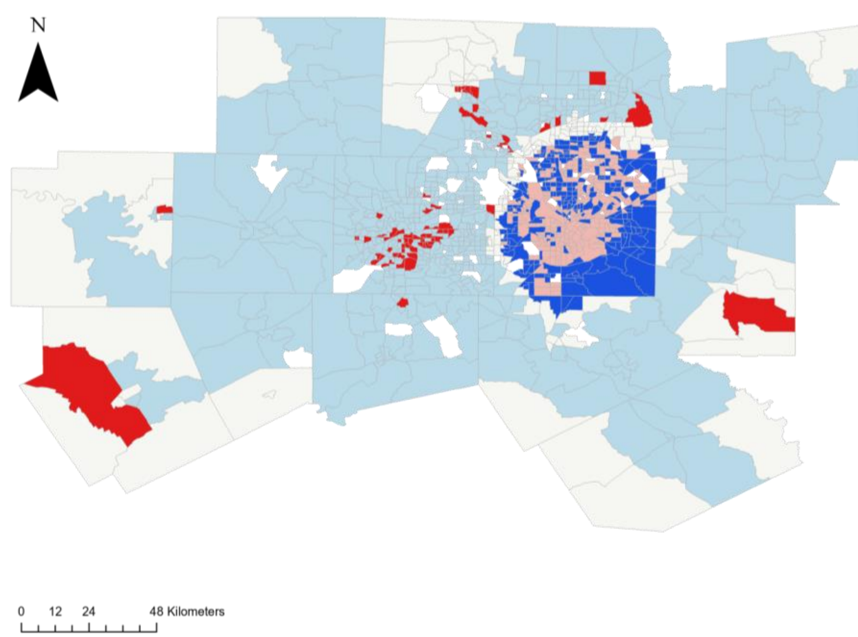


Figure 4-33: Percentage of people using public transportation to work clusters and outliers

For percentage of households with no vehicle, the majority of the tracts in Dallas belongs to the hot spot with 99% confidence. Similarly, for percentage of people using public transportation to work, the hot spot is located in Dallas, with some low-high outliers. The stark contrast between Dallas and Denton/ Collin is similarly observed. However, Tarrant county is either a non-significant spot (in the case of no vehicle) or a cold spot (in the case of public transit), unlike the previously discussed situations.

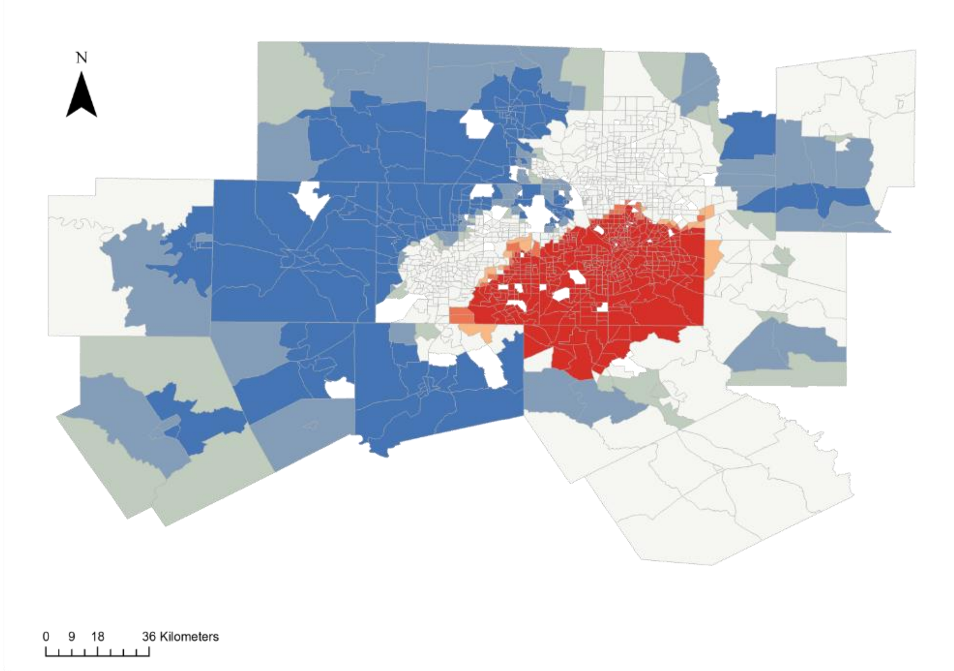


Figure 4-34: Percentage of ethnic minority as a householder hot spots and cold spots

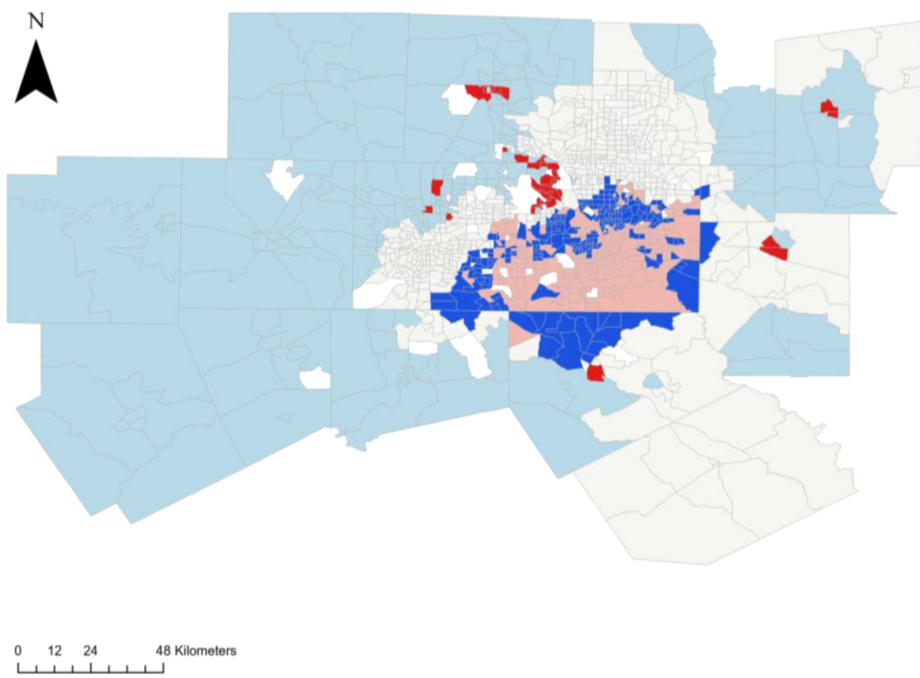


Figure 4-35: Percentage of ethnic minority as a householder clusters and outliers

There is one clear hot spot indicating the high percentages of ethnic minority as a householder and that hot spot is in Dallas. The majority of the rest of the counties belongs to various cold spots. The low-high outliers are observed in Dallas while the smaller number of high-low outliers scatter across the NCT.

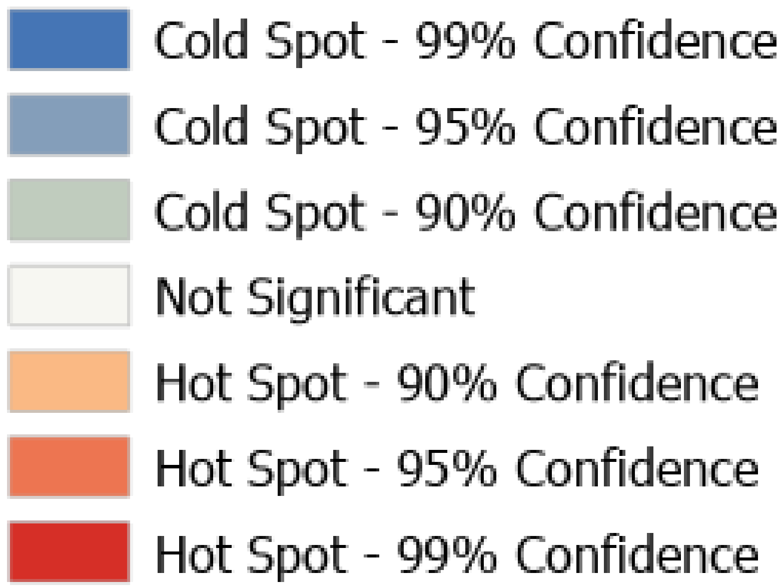


Figure 4-36: Hot spots and cold spots legend

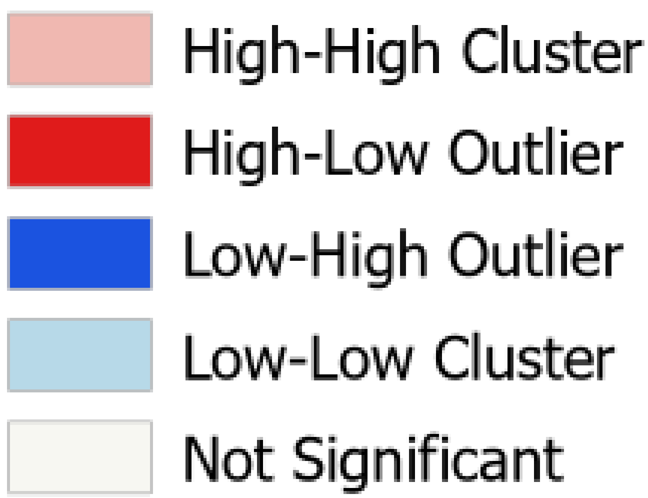


Figure 4-37: Clusters and outliers legend

Overall, across all indicators, several observations can be made:

1. The statistically significant hot spots (with 99% confidence level) corresponded with the counties with the highest population density (Dallas and Tarrant). These hot spots also corresponded to the urbanized area (Figure 4-38). The urbanized shapefile was obtained from the North Central Texas Council of Government's Regional Data Center Site (Regional Data Center).
2. There exists a low-high outlier region for most indicators in hot spot regions, signifying the unevenness of the socioeconomic status among tracts in such regions.
3. The statistically significant cold spots spread across regions and are consistently located in Denton and Collin in most cases.
4. The high-low outliers are far and few in between. Cold spot regions experience a more consistent concentration compared to hot spot regions.

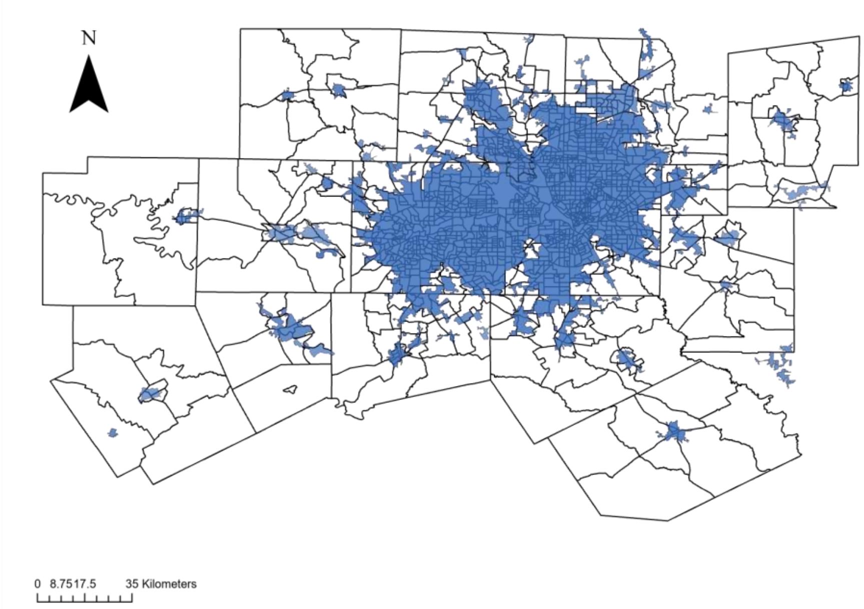


Figure 4-38: Urbanized area in the NCT

4.3.3.3. Socioeconomic Deprivation Index Construction

As previously stated, there has not been a consensus in choosing a definitive set of SSIs for any Socioeconomic Deprivation Index (SED Index). A variety of previously published empirical research studies have agreed on the basis of choosing relevant indicators: each indicator should approximate diverse facets of either socio-economic hindrances or living circumstances in a community (Singh and Siahpush, 2002). Moreover, such indicators should encompass broad sub-domains concerning income, housing, employment, education, and transportation (Singh and Siahpush, 2002). Therefore, the listed 28 indicators chosen from the ACS were based on previous studies and the “of interest” sub domains; broadly reflect on and represent the labor forces, the housing and economic conditions, and educational prospects in a community (Singh and Siahpush, 2002). For instance, divorce rate tends to be associated with a higher poverty rate; having no access to vehicles usually reflects economic financial deprivation; unemployment and lower income is indicative of substandard living conditions and social fragmentation; white collar occupations suggest higher wages and stable labor conditions, and so forth (Singh and Siahpush, 2002).

The tract level ADR and 28 SSIs were utilized for the construction of a tract-by-tract SED index via the application of factor analysis. Each analysis was carried out in SAS on Demand for Academics: Studio software, Version 9 (SAS Institute 2019). The index was developed followed the suggested approach in Krieger et al., (1997) and Singh and Siahpush (2002).

The 28 SSIs, despite providing a great deal of information about the NCT community at CT level, was too complex for a comprehensive and thorough construction of an SED index.

Therefore, a crucial step in arriving at a SED index was to utilize a data reduction technique. As one of the most utilized data reduction techniques, taking into account the presence of latent variables, is factor analysis, which was applied to preserve the most variance of the 28 variables. Factor analysis is similar to PCA as they are both data reduction techniques and are both designed to simplify the convolution of any multivariate analysis by extracting the dimensions that would yield the most variance, representing the original dataset in a much simpler, digestible, yet highly representative nature (O'Rourke and Hatcher, 2013). Both PCA and factor analysis yield the principal components (PC) as part of the result with the first PC accounting for the highest variance while the uncorrelated second PC representing the maximum of the remaining total variance, and so on (Raschka and Mirjalili, 2017). The major difference between a PCA and factor analysis is the assumption regarding the underlying causal structures. Factor analysis is used when there is an assumption that one or several latent factors exerting directional influence on the variables in a dataset; PCA, on the other hand, is used when such assumptions are not made (O'Rourke and Hatcher, 2013).

Constructing an SED index required 5 steps:

(1) choosing the significant variables with correlation with ADR greater than 0.23,

(2) extracting the PCs and determining the number of meaningful PCs to retain,

(3) applying varimax rotation

(4) extracting variables with the standardized regression coefficients greater than 0.3

(5) calculating SED Index

Initially, the Pearson correlations between ADR and the 28 indicators were computed. This was considered the first step of data reduction. Table 4-1 illustrates the correlation coefficients and the p-value for each pair of correlation; this step was similar yet simpler compared to the correlation funnel constructed from the previous step. All the correlation coefficients and their associated p-values are displayed in Table 4-2. The indicators retained, in the order of highest to lowest correlation coefficient, are shown in Table 4-3.

Pearson Correlation Coefficients, N = 1345
Prob > |r| under H0: Rho=0

Poverty	ADR 0.57406 <.0001
Unemployment	ADR 0.50926 <.0001
White_Collar_occupation__manage	ADR -0.45766 <.0001
Education_less_than_9th_grade	ADR 0.24183 <.0001
Bachelor_s_degree_or_higher	ADR -0.45349 <.0001
Income_less_than_15000	ADR 0.59166 <.0001
Moved_in_2010_or_later	ADR 0.22918 <.0001
Overcrowded_Conditions	ADR 0.23279 <.0001
Divorced	ADR 0.34452 <.0001
Under_5_years	ADR 0.21598 <.0001
Elderly_65andover	ADR -0.07912 0.0037
Black	ADR 0.65162 <.0001
Foreign_Born_Not_a_US_Citizen	ADR 0.14596 <.0001
Ethnic_Minority_Householder	ADR 0.53354 <.0001
Heating_with_gas	ADR -0.15708 <.0001

Pearson Correlation Coefficients, N = 1345
Prob > |r| under H0: Rho=0

Heating_with_fuel	ADR -0.01495 0.5838
Heating_with_wood	ADR -0.09938 0.0003
House_built_1969_or_before	ADR 0.30479 <.0001
Incomplete_kitchen_facilities	ADR 0.09666 0.0004
Incomplete_plumbing_facilities	ADR 0.22866 <.0001
Renter_occupied_housing_units	ADR 0.38256 <.0001
No_vehicle	ADR 0.57350 <.0001
People_using_public_transportati	ADR 0.47731 <.0001
No_health_insurance	ADR 0.40612 <.0001
Speak_a_language_other_than_Engl	ADR 0.23214 <.0001
No_wage_or_salary_income	ADR 0.33938 <.0001
Food_Stamps	ADR 0.62066 <.0001
Single_mom	ADR 0.55474 <.0001

Table 4-2: Pearson correlation coefficients and associated p-values of all SSIs with ADR

SSIs	Correlation coefficient	p-value
% Black	0.65162	<0.0001
% Food Stamps/ SNAPS	0.62066	<0.0001
% Income less than 15,000	0.59166	<0.0001
% Poverty	0.57406	<0.0001
% No vehicle	0.57350	<0.0001
% Single mom	0.55474	<0.0001
% Ethnic minority householders	0.53357	<0.0001
% Unemployment	0.50926	<0.0001
% Using public transit to work	0.47731	<0.0001
% White collar occupation	-0.45766	<0.0001
% Bachelor's degree or higher	-0.45349	<0.0001
% No health insurance	0.40612	<0.0001
% Renter-occupied housing units	0.38256	<0.0001
% Divorced	0.34452	<0.0001
% No wage or salary income	0.33938	<0.0001
% House built 1969 or prior	0.30479	<0.0001
% Education less than 9th grade	0.24183	<0.0001
% Overcrowded condition	0.23279	<0.0001
% Speak a language other than English	0.23214	<0.0001

Table 4-3: Pearson correlation coefficients and p-values of the significant SSIs with ADR

It’s important to assess the multicollinearity and further remove variables that are highly correlated with each other. Therefore, the variance inflation factor (VIF) test for all remained indicators was carried out, as illustrated in Table 4-4. When multicollinearity exists, the variances of the involved predictors are inflated; the VIF tests for such inflation and the higher the value of VIF, the more likely there exists multicollinearity (Detecting Multicollinearity Using Variance Inflation Factors).

Indicators	Variance Inflation Factor (VIF)
% White collar occupation	13.84
% Bachelor's degree or higher	10.37
% Black	9.97
% Ethnic minority householder	8.23
% Poverty	7.55
% Income less than 15000	7.35
% No health insurance	6.42
% Food stamps	6.39
% Education less than 9th grade	5.54
% No vehicle	3.87
% Overcrowded contioin	3.80
% Renter-occupied housing units	3.25
% Single mom	2.64
% No wage or salary income	2.43
% Unemployment	2.11
% House built 1969 or before	2.07
% Using public transit to work	1.88
% Divorced	1.62
% Speak a language other than English	1.35

Table 4-4: Variance Inflation Factor (VIF)

A general rule of thumb for VIF is to investigate the VIF with the value greater than 10 and retain a smaller subset of these corresponding variables to avoid multicollinearity (Detecting Multicollinearity Using Variance Inflation Factors). As the VIF value for % Black was approximately 10, the examination on the relationship of % Black and % Ethnic minority householder was also carried out. The Pearson test for these two pairs was performed, yielding two highly statistically significant correlated pairs: % white collar occupation – % Bachelor's degree or higher, % Black – % Ethnic minority householder (Figure 4-39 and Figure 4-40)

Pearson Correlation Coefficients, N = 1345
Prob > |r| under H0: Rho=0

	White_Collar_occupation__manage
Bachelor_s_degree_or_higher	0.93794 <.0001

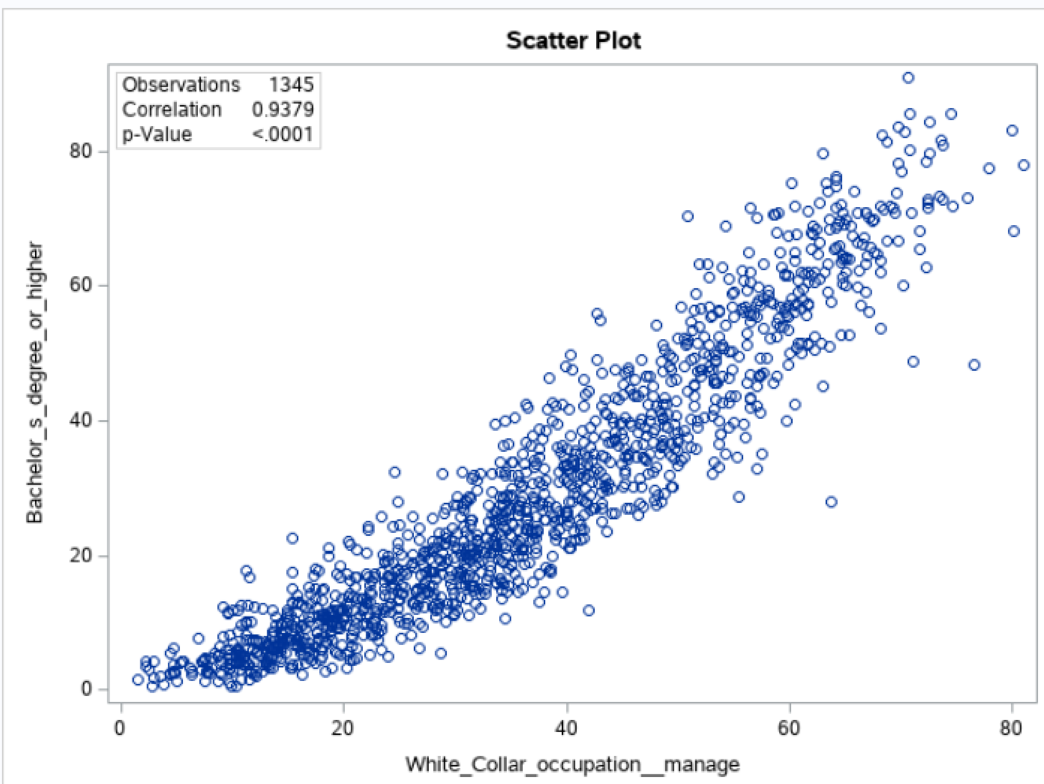


Figure 4-39: Scatterplot for % White collar occupation vs. % Bachelor's degree or higher

Pearson Correlation Coefficients, N = 1345 Prob > |r| under H0: Rho=0	
	Black
Ethnic_Minority_Householder	0.90969 <.0001

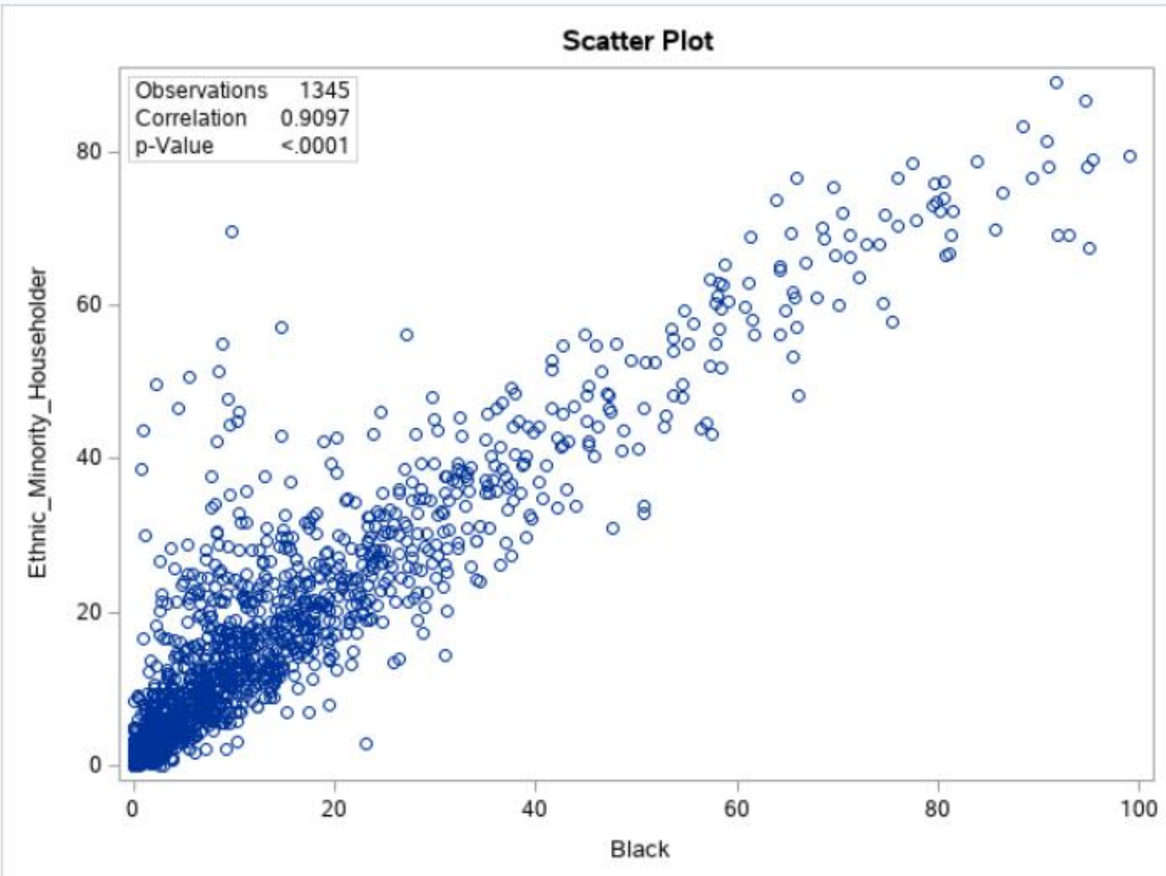


Figure 4-40: Scatterplot for %Black vs. %Ethnic minority householder

These results prompted the removal of two more indicators: % White collar occupation and % Black. The correlation analysis from the first step reduced the initial 28 indicators to 17 indicators, finding the moderately strong to strong association between ADR and the following indicators:

(1) percentage of households receiving Food Stamps/ Supplement Nutrition Assistance Program (SNAPS),

(2) percentage of people with income less than $15,000(3) percentage of families living with poverty status in the past 12 months,

(4) percentage of households with no vehicle,

(5) percentage of single mom with children under 18 years,

(6) percentage of ethnic minority as a householder,

(7) percentage of people that are currently unemployed and last worked 1 to 5 years ago,

(8) percentage of people using public transportation to work,

(9) percentage of population 25 years and over with a with Bachelor's degree or higher,

(10) percentage of population with no health insurance,

(11) percentage of renter-occupied housing units,

(12) percentage of population who divorced last year,

(13) percentage of population who have no wage or salary income,

(14) percentage of total housing units built 1969 or before,

(15) percentage of population 25 years and over with education less than 9th grade,

(16) percentage of people living in overcrowded conditions,

(17) percentage of population who speak a language other than English

After the correlation analysis, principal component analysis (PCA) and factor analysis were carried out with the first main task being the extraction of the meaningful principal components. PCA and factor analysis are both data reduction technique; however, PCA assumes no latent groups of variables while factor analysis does, as noted in O'Rourke and Hatcher (2013). As there were a total of 17 indicators in the analysis, the factor analysis yielded 17 eigenvalues, which related to the amount of variance captured by a component (O'Rourke and Hatcher, 2013). According to Kaiser (1960), whose criterion for choosing eigenvalues to keep was named after, components with eigenvalues greater than 1 should be kept. As cited in O'Rourke and Hatcher (2013), the rational of this criterion was based on the fact that one unit of variance was contributed by each observed variable. Therefore, it was meaningful to retain the eigenvalues greater than 1.0 as they accounted for a larger amount of variance contributed by one variable. Two other criteria for retaining eigenvalues was to review the individual amount of variance accounted for by each eigenvalue and evaluate the total variance explained (The Analysis Factor) and combining these criteria, the first five eigenvalues were retained. Table 4-5 indicates the eigenvalues and their proportion of variance explained; Table 4-6 shows the retained five factors.

Eigenvalues of the Reduced Correlation Matrix: Total = 10.8764495 Average = 0.63979115				
	Eigenvalue	Difference	Proportion	Cumulative
1	7.30137301	5.57925530	0.6713	0.6713
2	1.72211771	0.54773742	0.1583	0.8296
3	1.17438029	0.53466449	0.1080	0.9376
4	0.63971579	0.13927632	0.0588	0.9964
5	0.50043948	0.29561401	0.0460	1.0424
6	0.20482546	0.10237247	0.0188	1.0613
7	0.10245299	0.04109684	0.0094	1.0707
8	0.06135615	0.05446152	0.0056	1.0763
9	0.00689463	0.03657175	0.0006	1.0770
10	-.02967711	0.02214043	-0.0027	1.0742
11	-.05181754	0.02619182	-0.0048	1.0695
12	-.07800936	0.00689400	-0.0072	1.0623
13	-.08490336	0.02336571	-0.0078	1.0545
14	-.10826906	0.03841621	-0.0100	1.0445
15	-.14668527	0.00823973	-0.0135	1.0311
16	-.15492500	0.02789436	-0.0142	1.0168
17	-.18281935		-0.0168	1.0000

Table 4-5: Eigenvalues and their proportion of variance explained

Factor Pattern					
	Factor1	Factor2	Factor3	Factor4	Factor5
Poverty	0.91668	-0.00625	-0.02437	0.05866	-0.01283
Unemployment	0.65248	0.02835	-0.20718	-0.08528	-0.28146
Bachelor_s_degree_or_higher	-0.72456	0.28424	0.06105	0.35445	0.16967
Income_less_than_15000	0.85017	0.25185	-0.22908	0.10780	0.05175
Overcrowded_Conditions	0.67506	-0.47714	0.24259	0.14514	0.00723
House_built_1969_or_before	0.51414	-0.28038	-0.32302	0.01256	0.25396
No_vehicle	0.75841	0.31927	-0.09682	0.27673	0.10871
No_health_insurance	0.82082	-0.35702	0.22011	-0.12499	0.04055
Speak_a_language_other_than_Engl	0.31515	0.03009	0.36378	-0.05758	0.03026
Food_Stamps	0.90733	-0.01224	-0.10766	-0.03786	-0.19241
Education_less_than_9th_grade	0.70525	-0.58373	0.08568	0.09756	0.05068
Divorced	0.24638	0.35533	0.03686	-0.45317	0.21475
Ethnic_Minority_Householder	0.38634	0.46500	0.13482	0.08476	-0.35811
Renter_occupied_housing_units	0.57828	0.31350	0.48885	0.03792	0.26402
People_using_public_transportati	0.52332	0.26555	0.03537	0.31065	0.00847
No_wage_or_salary_income	0.43027	0.15797	-0.63490	-0.06084	0.16326
Single_mom	0.62872	0.40416	0.19881	-0.22332	0.01678

Table 4-6: Retained top five eigenvalues

It is important to note that the initial PCs extracted were unrotated and yielded little information about the construct measured by each PC; therefore, a promax rotation was carried out (O’Rourke and Hatcher (2013). This resulted in a rotated factor pattern matrix with standardized regression coefficients (Table 4-7).

Rotated Factor Pattern (Standardized Regression Coefficients)					
	Factor1	Factor2	Factor3	Factor4	Factor5
Poverty	0.46051	0.37497	0.17578	0.03126	0.19689
Unemployment	0.21168	0.11712	0.13793	-0.05857	0.52129
Bachelor_s_degree_or_higher	-0.63845	0.28475	-0.07591	-0.18802	-0.39946
Income_less_than_15000	0.09297	0.52720	0.41812	0.05802	0.16402
Overcrowded_Conditions	0.90341	0.11868	-0.14801	-0.16659	-0.01230
House_built_1969_or_before	0.43267	-0.04500	0.54824	0.00973	-0.20069
No_vehicle	0.02378	0.72972	0.30795	-0.01580	0.03109
No_health_insurance	0.86827	-0.01211	-0.05609	0.15709	0.06863
Speak_a_language_other_than_Engl	0.27642	0.15434	-0.26782	0.21115	0.00495
Food_Stamps	0.42346	0.25126	0.14107	-0.01055	0.43946
Education_less_than_9th_grade	0.96999	-0.01682	0.03149	-0.17306	-0.04397
Divorced	-0.17143	-0.09640	0.19771	0.71268	-0.03418
Ethnic_Minority_Householder	-0.24129	0.53874	-0.26657	-0.04269	0.54509
Renter_occupied_housing_units	0.18741	0.56059	-0.17284	0.42625	-0.20557
People_using_public_transportati	-0.00075	0.66636	0.06779	-0.11798	0.06550
No_wage_or_salary_income	-0.16688	0.07381	0.80762	0.09409	0.01965
Single_mom	0.01075	0.31859	-0.02737	0.48517	0.21187

Table 4-7: Rotated factor pattern (Standardized Regression Coefficients)

The standardized regression coefficients denote the relative weight of each indicator. The indicators with standardized regression coefficients' absolute values greater than 0.3 were considered significant and therefore retained. Only indicators with significant standard regression coefficients for factor 1 and factor 2 (the largest eigenvalues) were chosen for the final analysis prior to the construction of the SED index; this practice was deliberate for a unified, simple, yet comprehensive SED construction. Under factor 1, poverty, bachelor's degree or higher, overcrowded conditions, house built 1969 or prior, no health insurance, food stamps, and education less than 9th grade were retained. Under factor 2, income less than 15000, no vehicle, ethnic minority householder, renter occupied housing units, puclic transit, and single mom were retained. The factor analysis was then carried out again with only these indicators. The standardized scoring coefficients, as shown in Table 4-8, were utilized for the final step: SED computation, the partial result of which is displayed in Table 4-9.

Standardized Scoring Coefficients	
	Factor1
Poverty	0.35499
Bachelor_s_degree_or_higher	0.05219
Overcrowded_Conditions	0.01125
House_built_1969_or_before	-0.00575
No_health_insurance	0.28146
Food_Stamps	0.31017
Education_less_than_9th_grade	0.01351
Income_less_than_15000	0.01120
No_vehicle	0.11007
Ethnic_Minority_Householder	-0.02266
Renter_occupied_housing_units	0.00953
People_using_public_transportati	0.04678
Single_mom	0.05052

Table 4-8: Standardized scoring coefficients

County	Tract	SED Index
Collin	Census Tract 316.24	24.8
Collin	Census Tract 316.30	9.1
Collin	Census Tract 316.23	9.8
Collin	Census Tract 316.25	7.5
Collin	Census Tract 317.08	12.8
Collin	Census Tract 315.05	8.4
Collin	Census Tract 315.04	7.1
Collin	Census Tract 315.06	23.3
Collin	Census Tract 320.08	12.8
Collin	Census Tract 318.05	10.3
Collin	Census Tract 320.12	22.8
Collin	Census Tract 305.20	9.5
Collin	Census Tract 305.21	7.4
Collin	Census Tract 305.24	6.3
Collin	Census Tract 305.19	5.8
Collin	Census Tract 316.21	11.4
Collin	Census Tract 317.04	13.6
Collin	Census Tract 316.47	6.4
Collin	Census Tract 316.53	9.1
Collin	Census Tract 316.49	9.4
Collin	Census Tract 316.43	13.4
Collin	Census Tract 316.32	12.3
Collin	Census Tract 305.30	8.6
Collin	Census Tract 305.15	9.2
Collin	Census Tract 304.04	10.0
Collin	Census Tract 303.01	6.9
Collin	Census Tract 305.27	7.3
Collin	Census Tract 316.22	8.6
Collin	Census Tract 309	29.5
Collin	Census Tract 306.01	7.7
Collin	Census Tract 311	17.1

Table 4-9: SED Index

Several cut-off points for categorizing SED index have been proposed (Filmer and Pritchett, 2001; Howe et al., 2011; Tajik and Maidzadeh, 2014); however, the cut-off values are arbitrary and do not follow a consensus approach. The quartile cut-off values: 25%, 50%, 75% were utilized to categorize the SED index into four groups with the higher indices correponding to the higher deprivation levels: the least affluent (top 25%), the lower average affluent (25%-50%), the upper average affluent (25%-75%), and the most affluent (bottom 25%). Table 4-10 denotes such quartiles and Figure 4-30 illustrates the distribution of the four SED index classifications.

Classification	Most Affluent	Upper Average	Lower Average	Least Affluent
SED Index	4 - 10.4	10.4 - 16.6	16.6 - 25.7	25.7 - 66.3

Table 4-10: Classification of SED index

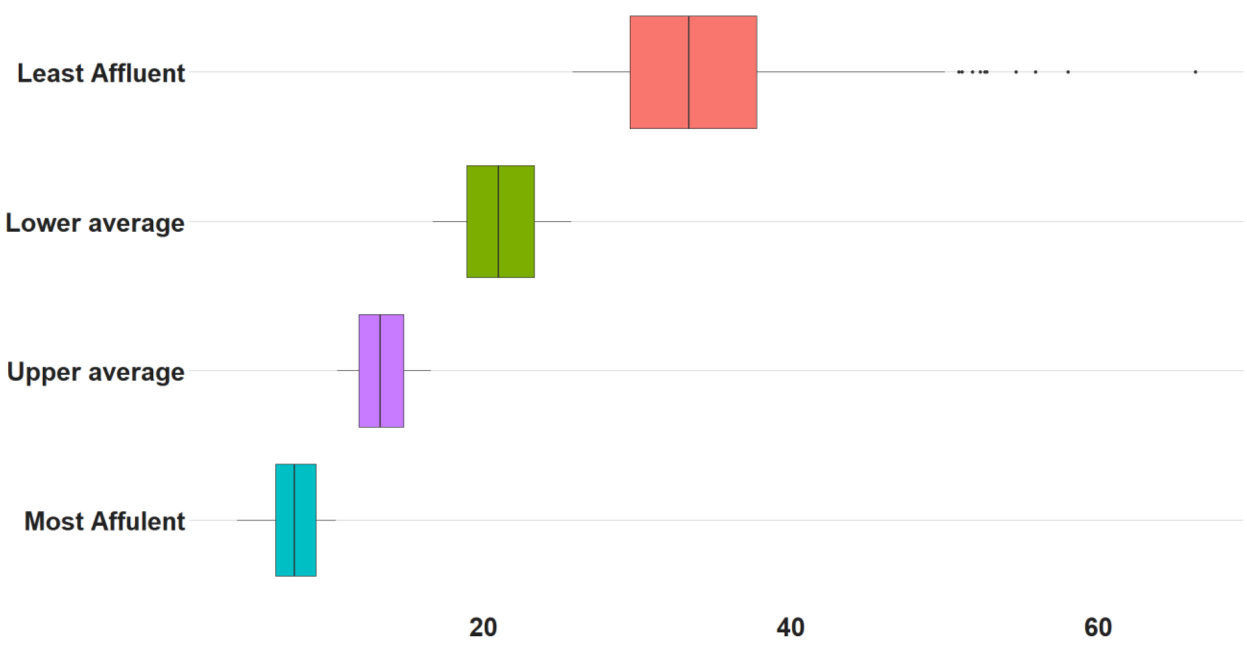


Figure 4-41: Distribution and outliers of SED index classification

The social deprivation inequal distribution is clearly shown in Figure 4-41. There is a stark difference between the values of the least affluent compared to the rest. This group, consisting of 336 census tracts, contains SED index from 25.7 to 66.3, a rough 40 unit difference while in the other three groups, the range of values is approximately 10, denoting a more uniform social status. Furthermore, there are eight outliers in the least affluent group, indicated by the eight dots next to the box plot, signifying an even less prosperous portrait of the socially deprived census tracts. These eight highly socially deprived tracts are in Tarrant and Dallas county.

It is important to note that each county has a different number of tracts (Table 4-11) and the level of discrepancy in terms of SED index for each county is largely a function of whether or not there is a large number of tracts present in each county.

County	Total tracts
Dallas	525
Tarrant	356
Collin	151
Denton	137
Ellis	31
Johnson	28
Hunt	19
Parker	19
Kaufman	18
Rockwall	11
Wise	11
Hood	10
Navarro	10
Palo Pinto	9
Erath	8
Somervell	2

Table 4-11: Census tracts of NCT counties

With that in mind, it seems appropriate to conduct a further investigation into the social deprivation distribution within each county and to conduct a more thorough investigation for the most populous counties. Figure 4-42 illustrates the SED index by county order by the median value and Figure 4-43 depicts the percentage of SED index proportion in each county. Somervell with only two tracts was excluded.

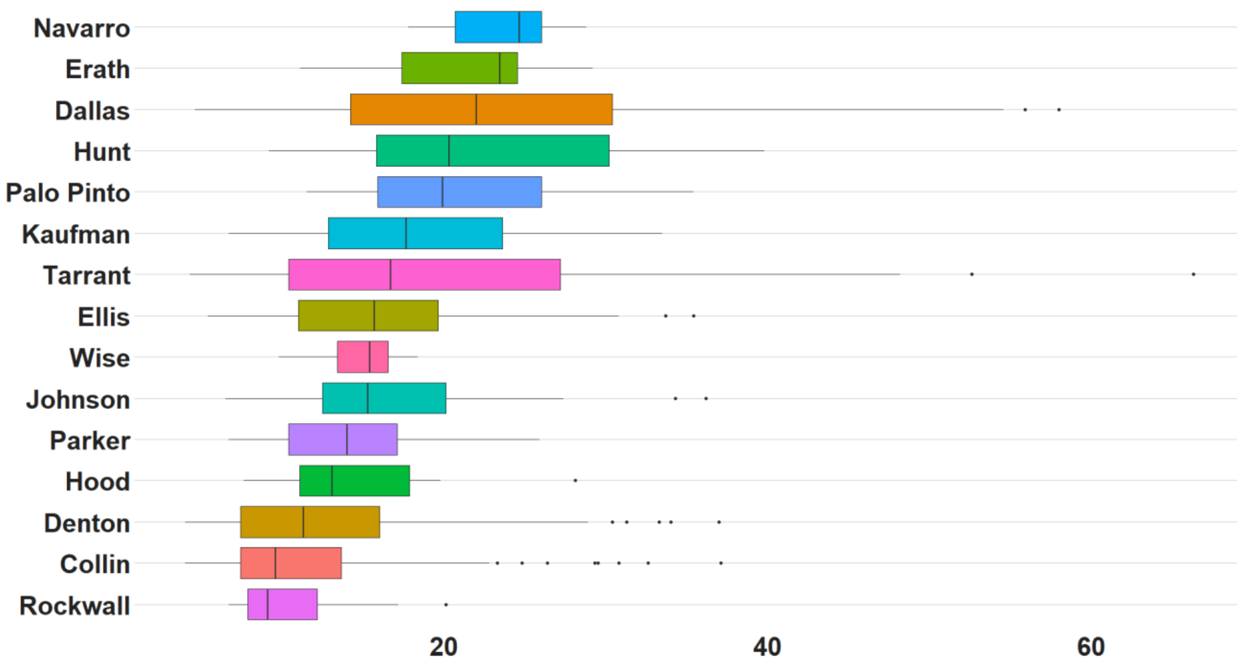


Figure 4-42: SED index by county ordered by median value

The county with the highest range of SED index is Dallas, followed by Tarrant; Denton and Collin do not exhibit a high range of SED index. These four counties are the most populous in the NCT and the ones with the highest number of tracts (Table 4-9). It is worth noting that the SED index in Dallas ranges from roughly five to approximately 60, signifying a stark difference among census tracts in the county. This most likely corresponds to a high social status inequality and high-income inequality situation. Tarrant exhibits a similar characteristic, albeit at a smaller scale. These counties correspond to the highly urbanized area, which prompts the question of whether urbanization intensifies inequalities.

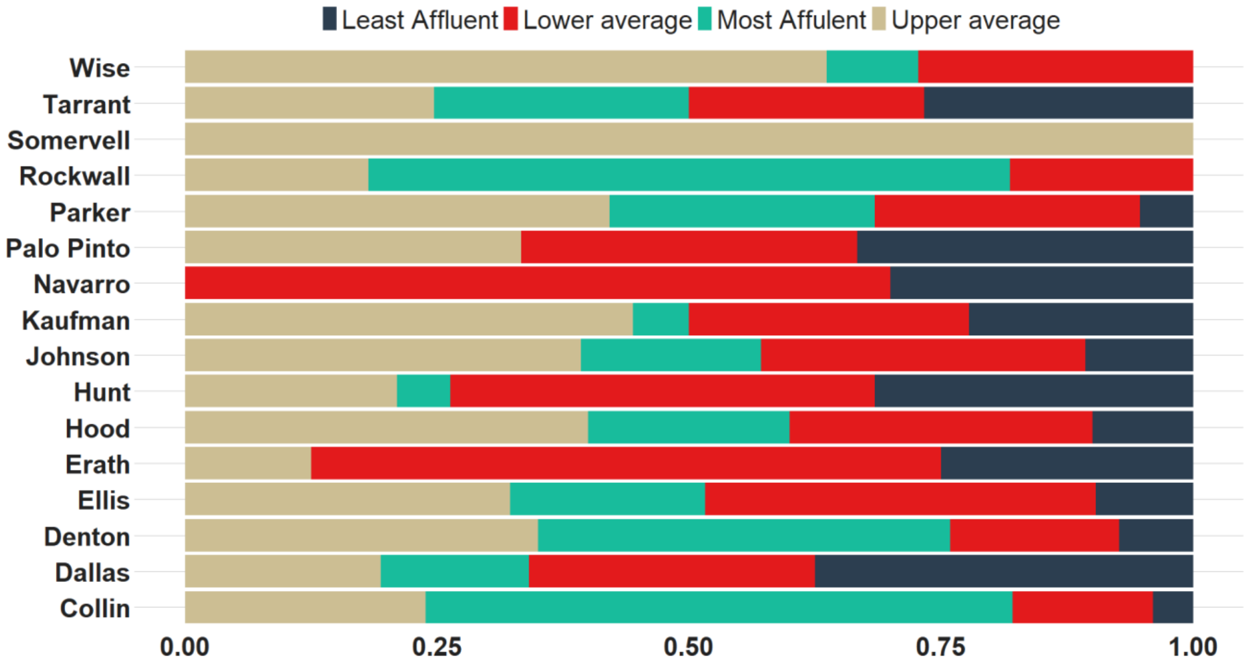


Figure 4-43: SED index proportion by county

Out of the four populous counties, Collin and Denton are the two counties with the least deprivation range, with the majority of their census tracts being the most affluent, the upper average affluent, and the lower average affluent. Dallas county, on the other hand, has many tracts corresponding to the least affluent SED index (roughly 40%). Tarrant has an equal distribution of all four classifications, separating itself from the rest. The rural counties, interestingly enough, demonstrate a different story: a very small percentage of the least and most affluent group and an approximately equal percentage of the lower and upper average. This suggest a much lower social inequality status.

Figure 4-45 spatially illustrates the distribution of SED indices in the NCT and Figure 4-44 enumerates the names of the NCT counties for reference purposes. As previously stated, most peripheral/ rural counties exhibit little social inequality status, with the majority of the census tracts in the lower or upper average group (tracts with blue and green in color). Tarrant and Dallas are clearly the two counties with the most diverse deprivation indices, containing the least deprived groups (indicated by the yellow color on the map) and the most deprived groups (red). Overall, it seems there is a stark difference between urbanized area and rural area in the NCT when it comes to social inequality. Further research may validate or extend the current finding.

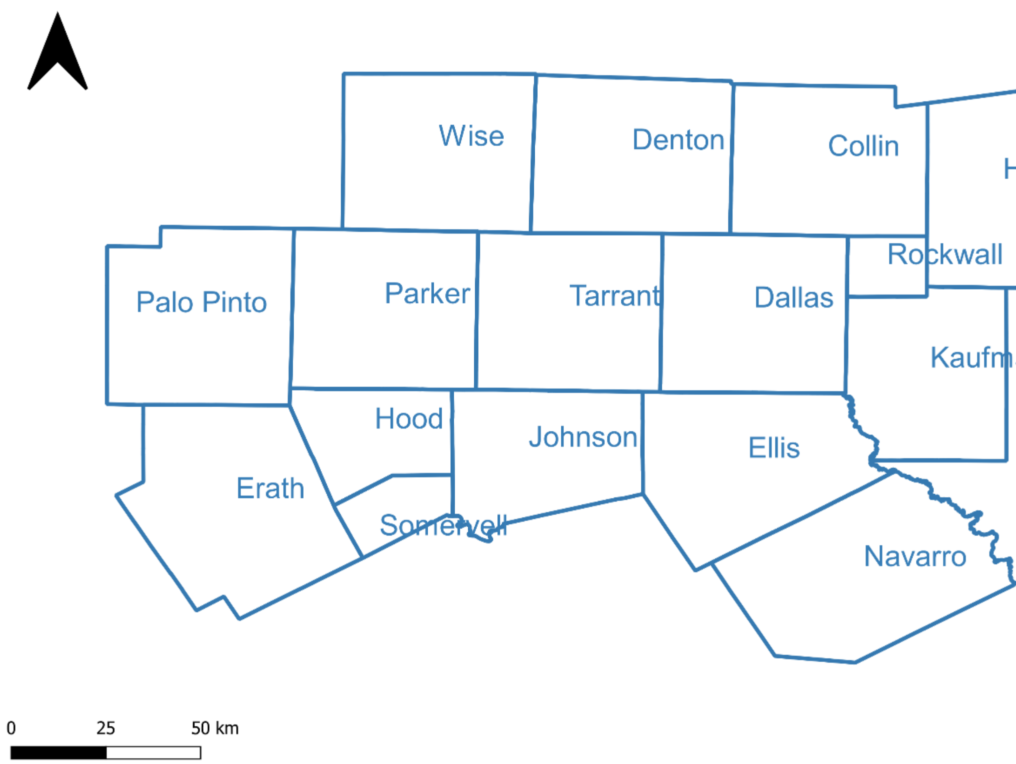


Figure 4-44: NCT Counties

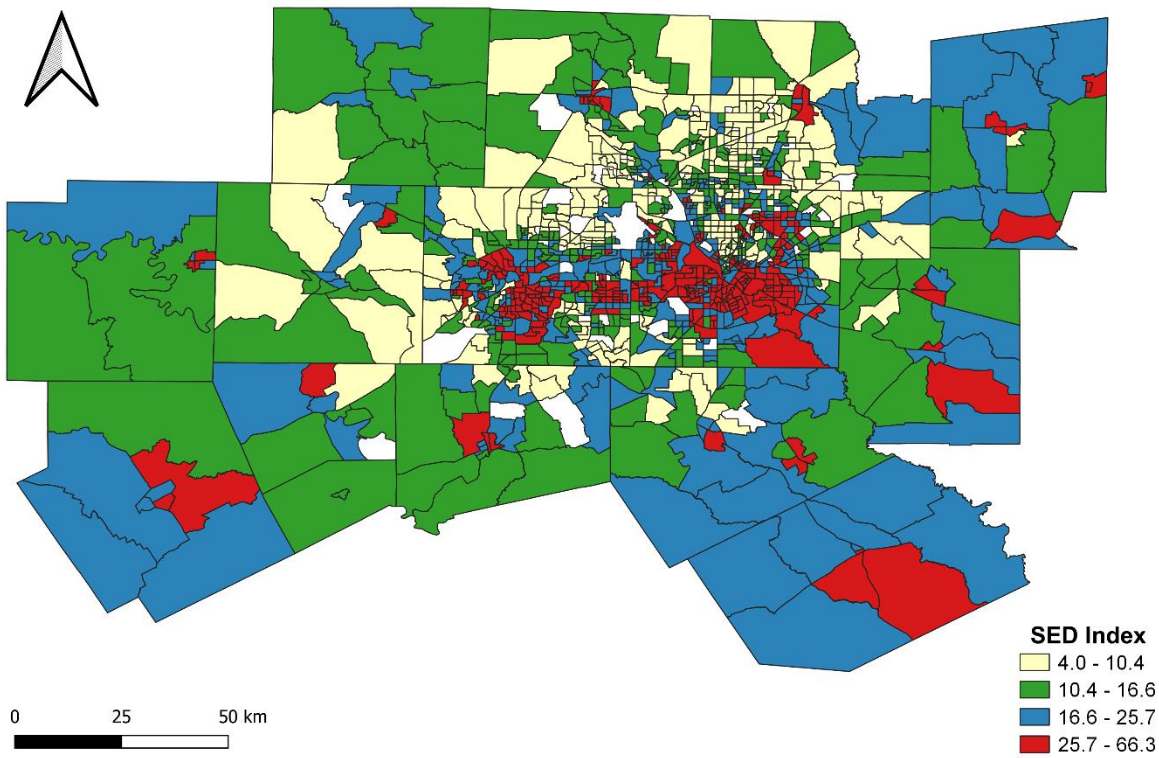


Figure 4-45: Spatial distribution of SED Index

4.4. Discussion

Association between asthma and socioeconomic status (SES) has been identified in various studies. This chapter attempted to investigate such association via two approaches: exploratory data analysis (EDA) involving the use of Pearson correlation and a hot spot analysis and a construction of a socioeconomic deprivation index (SDI) via the application of principal component analysis (PCA) and factor analysis.

Prior to EDA and SDI construction, two sources of data were obtained: the adult asthma hospital visits and discharges, provided by the Dallas Fort-Worth-Hospital Council Foundation (DFWHCF) and the SSIs, obtained directly from the U.S. Census Bureau via the American Community Survey's 5-year estimates. 28 indicators reflecting the normative value and social good of a given community were extracted.

Pearson correlation results suggested a moderately strong to strong associative strength between 22 variables with asthma discharge rate (ADR). Nine out of 22 variables belonged to either the poverty-indicator group or ethnically identified group. The SES indicators with trivial correlation with ADR were those related to housing and population age. These preliminary findings agreed with the many published reports on social and ethnic variables important in the correlations between SES and asthma.

The findings from Pearson correlations were supported by the results of the hot spot and cluster and outlier analyses. The 99% statistically significant hot spots of ADR and socioeconomic indicators were in approximately the same locations of the highest population density and highly urbanized areas of Dallas and Tarrant counties. The low-high outlier region, denoting the low concentration in a hot spot, was observed in these hot spots, signifying the disparity of the socioeconomic status within these counties. The high-low outlier region, indicating the high concentration in a cold spot, was rare. These regions appeared to have a more even socioeconomic status.

The original 28 SSIs were used for a construction of an SED index, which required five steps: choosing the significant variables, extracting the number of meaning principal components to retain, extracting meaningful variables from factor analysis, applying varimax rotation, and constructing the index. The index' cut-off values followed a quartile approach: with the bottom 25% of values were the most affluent, the next 25% being the upper average, the subsequent 25% being the lower average, and the top 25% denoting the least affluent. The SDI value for the least affluent was substantially higher than the rest of the groups. Such marked difference suggested a very uneven distribution of social wealth. At the county level, the urban counties exhibited a higher social inequality level than the rural counties. The urban counties' SDIs ranged from the least affluent to most affluent while the rural counties' SDIs were mostly corresponding to the lower and upper average (affluence levels). This suggested that urbanization intensified inequalities. Furthermore, the disparity among the four most populous counties were once again observed. The diverse and mostly equal distribution of deprivation indices were observed in Dallas and Tarrant counties while Collin and Denton counties had deprivation indices mostly restricted to the upper average affluent range – most affluent range. This finding agreed with the hot spot and cluster and outlier analyses.

CHAPTER 5

DISCUSSION

The study attempted to understand factors associated with adult asthma related emergency room discharges in North Central Texas (NCT) during the period 2010 – 2014. The results, significant, and limitation can be summarized as follows.

5.1. Summary of Results

5.1.1. NCT asthma discharge

The comprehensive data analysis of the NCT adult asthma discharges suggested the following:

1) The younger adults (aged 20 – 30) appeared to be the largest group of asthma hospital discharge cases.
2) A clear gender reversal was observed in the population. Namely, a considerably larger number of female asthma cases (compared to male asthma cases) was observed; this very much contrasts with the well-documented phenomenon of childhood asthma being more common in boys than girls.
3) A progressively smaller percentage of asthma discharges was observed in females post 49. This appeared to support the notion that asthma appeared to improve post menopause. This pattern was observed in all races and ethnic groups.
4) There was a distinct seasonality in asthma discharges: a minimum in July, a maximum in January and the second (lower) maximum in April. The maxima and minima in discharge rates were in agreement with U.S.'s seasonal asthma hospitalization data. The second maxima could potentially be explained by the local spring allergy season.

5.1.2. Association between NCT asthma discharge with air pollution

The association between NCT asthma discharge data and air pollution was examined via the application of various methods: Principal Component Analysis (PCA), Hierarchical Agglomerative Clustering Analysis (HACA), Pearson product-moment correlation, hot spot and cluster and outlier analyses. Major findings are as follows:

1) The pattern of air monitoring stations was correlated with asthma discharge geographical distribution. Specifically, urban clusters of air monitoring stations corresponded to areas with high asthma discharges while rural clusters and low asthma discharges overlapped.
2) Outdoor air pollution levels were non-significantly correlated with the asthma discharge data. This suggested that air pollutants were not a driver of emergency room visits for asthma.
3) There was no correlation between the statistically significant asthma hot spots and statistically significant air pollutants' hot spots, further strengthening the conclusion that air pollution was not a significant cause of asthma emergency room visits in NCT.

5.1.3. Association between NCT asthma discharge data with socioeconomic status (SES)

The association between asthma and SES was investigated via a two-step process: an exploration phase involving Pearson correlation computation and hot spot and cluster and outlier analyses and a socioeconomic deprivation index (SDI) construction phase. The findings of these analyses can be summarized as follows:

1) There was a moderate strong to strong association between asthma discharges and many of the socioeconomic status indicators (SSIs). These indicators were important in either ethnic-specific groups or high poverty groups.
2) The 99% statistically significant hot spots of SDIs and asthma discharges overlapped, confirming the previously identified association. However, there was a difference of the socioeconomic status within the counties and tracts in the hot spot regions. Such a pattern was not as extensively observed in the cold spots.
3) The resulting SDI values indicated an unequal distribution of social wealth. Rural counties did not exhibit as high a social inequality status as urban counties. Urbanization appeared to play a role in intensifying inequalities.
4) Dallas, Tarrant, Collin, and Denton – the major and most populous counties in the region – exhibited different patterns for SDI. Approximately equal distribution of all categories of SDIs was observed in Dallas and Tarrant while mostly the deprivation indices in the lower range were observed in Collin and Denton.

5.2. Significance

This study is significant for a variety of reasons:

1) Asthma has been traditionally investigated from a single perspective: mostly this has been in terms of an association either with air pollution or socioeconomic factors. This study looked at such association from multiple perspectives and each hypothesized association was either confirmed or disproved by the multiple approaches that were used.

2) There has not previously been a comprehensive study of this type that has focused exclusively on North Central Texas (NCT). Of all the asthma-related studies, only Newcomb and Li (2019) reported on asthma discharge in NCT. The study by Newcomb and Li covered only a one-year period and was confined mostly to the socioeconomic correlates of asthma.

3) The study period, 2010 – 2014, is a recent period, and the findings from this study can potentially be used as a foundation for a more comprehensive understanding of asthma and its causes in this region.

4) Various novel approaches (construction of Socioeconomic Deprivation Index and hot spot and cluster and outlier analyses) were utilized; this suggests that a more holistic approach to understanding the complexities of asthma causation is warranted.

5.3. Limitation

Several limitations may have affected the final interpretation of results. They are listed as follows:

1) There has been a lack of specific studies on asthma in the NCT region. This meant that the findings of this study could not be directly substantiated or if there might have been discrepancies they could not to be explained.
2) Air pollution and meteorological data were incomplete. The network of air monitoring stations did not cover the region equally. Incomplete data resulted in the use of various imputation methods such as predictive mean matching and spatial interpolation. Even though the imputation was implemented completely, it undoubtedly served as a source of potential errors.
3) Several assumptions had to be made due to the lack of consensus in the literature. For example, the socioeconomic indicators were chosen based on the general agreement in the literature about what indicators should represent what, there is not a set of specific indicators universally agreed upon. Another example was the classification of the SDI index. Quartile classification was chosen, as a rule of thumb. But other possible cut-off values could have been chosen, leading to a possibly different interpretation.

Appendix A: Chapter 3

<u>Summary Statistics</u>:

I. Summer

1. Nitric Oxide

Station	County	2010	2011	2012	2013	2014	2010-2014
C13	Tarrant	1.32	0.91	1.35	1.35	1.11	1.21
C17	Tarrant	0.56	0.40	0.39	0.36	0.48	0.44
C52	Ellis	0.73	0.50	0.60	0.63	0.41	0.57
C56	Denton	0.97	0.76	0.73	0.63	0.66	0.75
C60	Dallas	1.14	1.13	1.01	1.26	0.85	1.08
C61	Tarrant	0.91	0.90	1.09	0.69	0.68	0.85
C63	Dallas	0.65	0.64	0.80	0.86	0.34	0.66
C70	Tarrant	0.30	0.67	0.48	0.62	0.41	0.49
C71	Kaufman	0.22	0.30	0.33	0.35	0.35	0.31
C75	Tarrant	0.15	0.35	0.43	0.31	0.46	0.34
C1006	Hunt	0.28	0.42	0.30	0.29	0.30	0.32
C1044	Ellis	0.19	0.20	0.30	0.37	0.12	0.23
C1051	Navarro	0.35	0.13	0.64	0.10	0.08	0.26

Table: CAMS Stations (Nitric Oxide /Summer 2010 - 2014)

	2010	2011	2012	2013	2014	2010 - 2014
Mean	0.60	0.56	0.65	0.60	0.48	0.58
Stdev	0.39	0.30	0.33	0.37	0.29	0.32
Median	0.56	0.50	0.60	0.62	0.41	0.49
Minimum	0.15	0.13	0.30	0.10	0.08	0.23
Maximum	1.32	1.13	1.35	1.35	1.11	1.21
N	13	13	13	13	13	13

Table: Descriptive statistics of summer average concentrations for nitric oxide

2. Nitrogen Dioxide

Station	County	2010	2011	2012	2013	2014	2010-2014
C13	Tarrant	5.01	5.20	7.61	6.74	5.70	6.05
C17	Tarrant	9.28	5.27	6.03	5.97	5.00	6.31
C52	Ellis	3.69	3.85	2.03	3.62	2.42	3.12
C56	Denton	4.53	5.65	2.85	6.64	5.61	5.06
C60	Dallas	8.74	9.66	8.44	8.94	7.79	8.71
C61	Tarrant	5.73	4.94	5.79	3.00	4.58	4.81
C63	Dallas	6.03	5.61	5.94	4.35	3.25	5.04
C70	Tarrant	5.38	6.40	5.16	4.25	3.72	4.98
C71	Kaufman	3.12	3.33	3.16	2.68	2.42	2.95
C75	Tarrant	4.49	4.71	4.48	4.74	3.60	4.40
C1006	Hunt	3.63	5.39	4.07	3.93	3.44	4.09
C1044	Ellis	1.84	2.06	2.37	2.47	1.34	2.02
C1051	Navarro	3.15	3.09	3.09	2.74	0.57	2.53

Table: CAMS Stations (Nitrogen Dioxide /Summer 2010 - 2014)

	2010	2011	2012	2013	2014	2010 - 2014
Mean	4.97	5.01	4.69	4.62	3.80	4.62
Stdev	2.14	1.85	2.01	1.94	1.95	1.79
Median	4.53	5.20	4.48	4.25	3.60	4.81
Minimum	1.84	2.06	2.03	2.47	0.57	2.02
Maximum	9.28	9.66	8.44	8.94	7.79	8.71
N	13	13	13	13	13	13

Table: Descriptive statistics of summer average concentrations for nitrogen dioxide

3. Ozone

Station	County	2010	2011	2012	2013	2014	2010-2014
C13	Tarrant	27.12	34.91	32.58	34.02	30.91	31.91
C17	Tarrant	31.92	42.69	38.83	37.09	32.20	36.55
C31	Collin	33.34	42.91	43.48	38.73	35.70	38.83
C52	Ellis	26.59	36.91	35.83	35.24	29.27	32.77
C56	Denton	29.45	40.97	37.55	36.81	33.31	35.89
C60	Dallas	29.42	34.75	35.69	34.26	29.59	32.74
C61	Tarrant	28.59	36.65	36.88	30.15	27.57	31.97
C63	Dallas	29.05	39.70	39.75	35.86	31.64	35.20
C69	Rockwall	31.19	38.77	38.71	36.21	31.43	35.26
C70	Tarrant	31.38	39.30	40.12	36.33	33.05	36.03
C71	Kaufman	27.26	36.85	36.52	34.44	28.56	32.73
C73	Hood	28.37	35.71	35.69	34.42	31.26	33.09
C75	Tarrant	31.11	37.21	36.45	32.96	28.88	33.32
C76	Parker	31.64	44.53	40.40	36.43	28.94	36.39
C77	Johnson	28.45	36.19	37.00	35.38	31.30	33.67
C1006	Hunt	29.42	36.71	35.56	32.28	27.72	32.34
C1032	Denton	34.26	43.79	39.08	39.49	34.52	38.23
C1044	Ellis	25.02	33.79	32.20	30.94	26.42	29.68
C1051	Navarro	27.77	35.66	33.07	33.33	27.24	31.42

Table: CAMS Stations (Ozone /Summer 2010 - 2014)

	2010	2011	2012	2013	2014	2010 - 2014
Mean	29.54	38.32	37.13	34.97	30.50	34.11
Stdev	2.39	3.27	2.86	2.41	2.57	2.43
Median	29.42	36.91	36.88	35.24	30.91	33.32
Minimum	25.02	33.79	32.20	30.15	26.42	29.68
Maximum	34.26	44.53	43.48	39.49	35.70	38.83
N	19	19	19	19	19	19

Table: Descriptive statistics of summer average concentrations for ozone

4. Ozone 8-hours

Station	County	2010	2011	2012	2013	2014	2010-2014
C13	Tarrant	41.85	48.87	39.61	44.5	44.09	43.78
C17	Tarrant	46.4	56.95	42.88	45.49	43.26	47
C31	Collin	45.1	54.24	47.31	45.39	44.29	47.26
C52	Ellis	42.27	52.91	41.81	43.45	39.58	44
C56	Denton	42.94	54.27	45.76	48.42	45.79	47.43
C60	Dallas	43.16	50.28	41.64	43.74	41.94	44.15
C61	Tarrant	44.19	52.21	42.64	39.55	39.62	43.64
C63	Dallas	42.52	53.1	44.65	44.93	39.4	44.92
C69	Rockwall	43.55	52.06	44.9	45.34	42.81	45.73
C70	Tarrant	45.48	51.83	46.01	45.97	44.66	46.79
C71	Kaufman	43.65	52.34	44.06	43.71	40.33	44.82
C73	Hood	42.86	50.27	42.36	42.75	42.24	44.09
C75	Tarrant	46.12	49.84	42.01	43.33	41.55	44.57
C76	Parker	44.28	56.57	36.4365	44.36	42.31	45.91
C77	Johnson	43.57	52.6	43.26	44.17	43.64	45.45
C1006	Hunt	43.15	52	44.38	43.74	40.15	44.68
C1032	Denton	46.56	54.9	47.24	47.77	45.64	48.42
C1044	Ellis	41.8	52.48	42.68	41.52	39.45	43.59
C1051	Navarro	45.17	53.33	43.22	43.2	40.43	45.07

Table: CAMS Stations (Max 8hr Ozone /Summer 2010 - 2014)

	2010	2011	2012	2013	2014	2010 - 2014
Mean	43.93	52.69	43.31	44.28	42.17	45.33
Stdev	1.50	2.11	2.59	2.01	2.14	1.45
Median	43.57	52.48	43.22	44.17	42.24	44.92
Minimum	41.80	48.87	36.44	39.55	39.40	43.59
Maximum	46.56	56.95	47.31	48.42	45.79	48.42
N	19	19	19	19	19	19

Table: Descriptive statistics of maximum 8 hour concentrations for ozone

5. Temperature

Station	County	2010	2011	2012	2013	2014	2010-2014
C13	Tarrant	86.09	91.35	84.52	84.79	51.02	79.55
C17	Tarrant	85.22	90.23	84.53	83.89	82.2	85.21
C52	Ellis	84.97	90.06	84.24	83.58	81.86	84.94
C56	Denton	85.3	89.67	84.43	81.91	81.91	84.65
C60	Dallas	87.09	91.73	86.59	85.81	84.19	87.08
C61	Tarrant	85.26	89.98	84.72	83.87	82.19	85.2
C63	Dallas	85.93	89.91	84.99	84.02	82.35	85.44
C70	Tarrant	86.21	90.35	84.94	83.63	82.78	85.58
C71	Kaufman	84.1	89.28	83.01	83.89	80.8	84.21
C75	Tarrant	84.88	90.07	84.18	83.4	81.84	84.88
C1006	Hunt	84.73	88.35	82.98	82.05	80.42	83.7
C1044	Ellis	84.08	89.79	83.84	83.1	81.35	84.43
C1051	Navarro	84.04	88.37	83.55	83.41	81.35	84.15

Table: CAMS Stations (Temperature / Summer 2010 - 2014)

	2010	2011	2012	2013	2014	2010 - 2014
Mean	85.22	89.93	84.35	83.64	79.56	84.54
Stdev	0.92	0.96	0.94	1.01	8.63	1.72
Median	85.22	89.98	84.43	83.63	81.86	84.88
Minimum	84.04	88.35	82.98	81.91	51.02	79.55
Maximum	87.09	91.73	86.59	85.81	84.19	87.08
N	13	13	13	13	13	13

Table: Descriptive statistics of summer average concentrations for temperature

6. Wind Speed

Station	County	2010	2011	2012	2013	2014	2010-2014
C13	Tarrant	7.09	7.21	6.41	6.28	7.10	6.82
C17	Tarrant	7.25	7.48	6.62	6.44	7.25	7.01
C52	Ellis	9.88	11.11	9.10	8.93	9.84	9.77
C56	Denton	5.62	7.83	7.27	6.93	7.89	7.11
C60	Dallas	5.29	5.29	5.15	5.07	5.38	5.24
C61	Tarrant	7.29	8.05	7.11	6.65	7.65	7.35
C63	Dallas	5.54	5.61	5.36	5.17	5.63	5.46
C70	Tarrant	6.60	6.51	5.83	5.56	6.30	6.16
C71	Kaufman	5.80	5.44	5.02	4.96	5.24	5.29
C75	Tarrant	8.36	9.56	8.29	8.12	9.19	8.70
C1006	Hunt	4.95	4.47	4.13	3.99	4.35	4.38
C1044	Ellis	5.44	6.21	5.58	5.57	6.02	5.77
C1051	Navarro	8.00	8.67	7.72	7.72	8.23	8.07

Table: CAMS Stations (Wind Speed / Summer 2010 - 2014)

	2010	2011	2012	2013	2014	2010 - 2014
Mean	6.70	7.19	6.43	6.26	6.93	6.70
Stdev	1.45	1.88	1.43	1.41	1.62	1.53
Median	6.60	7.21	6.41	6.28	7.10	6.82
Minimum	4.95	4.47	4.13	3.99	4.35	4.38
Maximum	9.88	11.11	9.10	8.93	9.84	9.77
N	13	13	13	13	13	13

Table: Descriptive statistics of summer average concentrations for wind speed

II. Winter

1.Nitric Oxide

Station	County	2010-2011	2011-2012	2012-2013	2013-2014	2010-2014
C13	Tarrant	7.33	8.34	6.06	8.51	7.56
C17	Tarrant	2.63	2.81	1.68	2.94	2.51
C52	Ellis	2.10	3.22	1.85	2.38	2.39
C56	Denton	3.32	2.65	2.35	3.21	2.88
C60	Dallas	7.92	9.77	4.12	11.82	8.41
C61	Tarrant	4.60	5.52	4.11	4.22	4.61
C63	Dallas	4.51	6.08	3.82	5.60	5.00
C70	Tarrant	2.83	3.21	2.40	3.25	2.92
C71	Kaufman	0.92	1.14	0.80	0.85	0.93
C75	Tarrant	1.52	1.89	1.31	1.82	1.64
C1006	Hunt	1.40	1.88	1.00	1.27	1.39
C1044	Ellis	0.91	1.35	1.44	1.30	1.25
C1051	Navarro	1.01	1.29	0.45	0.86	0.90

Table: CAMS Stations (Nitric Oxide/ Winter 2010 - 2014)

	2010 - 2011	2011 - 2012	2012 - 2013	2013 - 2014	2010 - 2014
Mean	3.15	3.78	2.41	3.69	3.26
Stdev	2.34	2.80	1.65	3.25	2.46
Median	2.63	2.81	1.85	2.94	2.51
Minimum	0.91	1.14	0.45	0.85	0.90
Maximum	7.92	9.77	6.06	11.82	8.41
N	13	13	13	13	13

Table: Descriptive statistics of winter average concentrations for nitric oxide

2. Nitrogen Dioxide

Station	County	2010-2011	2011-2012	2012-2013	2013-2014	2010-2014
C13	Tarrant	13.33	12.12	11.76	10.73	11.99
C17	Tarrant	12.41	10.70	10.11	11.17	11.10
C52	Ellis	9.57	9.06	5.64	7.06	7.83
C56	Denton	9.26	5.88	8.48	8.74	8.09
C60	Dallas	15.97	14.57	14.43	15.49	15.12
C61	Tarrant	11.11	10.78	9.79	10.40	10.52
C63	Dallas	12.70	12.57	9.27	10.41	11.24
C70	Tarrant	10.53	9.65	9.61	9.31	9.77
C71	Kaufman	5.31	4.79	4.71	4.01	4.71
C75	Tarrant	9.39	8.20	7.68	7.20	8.12
C1006	Hunt	6.07	5.70	5.44	5.36	5.64
C1044	Ellis	6.13	6.45	6.44	5.88	6.23
C1051	Navarro	5.21	4.44	4.43	4.20	4.57

Table: CAMS Stations (Nitrogen Dioxide / Winter 2010 - 2014)

	2010 - 2011	2011 - 2012	2012 - 2013	2013 - 2014	2010 - 2014
Mean	9.77	8.84	8.29	8.46	8.84
Stdev	3.38	3.24	2.95	3.27	3.14
Median	9.57	9.06	8.48	8.74	8.12
Minimum	5.21	4.44	4.43	4.01	4.57
Maximum	15.97	14.57	14.43	15.49	15.12
N	13	13	13	13	13

Table: Descriptive statistics of winter average concentrations for nitrogen dioxide

3. Ozone

Station	County	2010-2011	2011-2012	2012-2013	2013-2014	2010-2014
C13	Tarrant	19.84	15.96	21.27	20.07	19.28
C17	Tarrant	23.42	20.05	23.08	20.94	21.87
C31	Collin	24.70	21.95	27.87	22.15	24.17
C52	Ellis	22.38	21.07	24.23	23.83	22.88
C56	Denton	21.03	19.97	22.88	21.68	21.39
C60	Dallas	19.31	16.55	20.73	18.93	18.88
C61	Tarrant	21.62	19.37	21.64	20.32	20.74
C63	Dallas	21.56	19.93	22.42	21.56	21.37
C69	Rockwall	26.47	23.13	26.12	24.73	25.11
C70	Tarrant	21.81	19.15	24.02	21.74	21.68
C71	Kaufman	27.04	23.24	27.37	25.68	25.83
C73	Hood	23.19	21.89	25.18	22.50	23.19
C75	Tarrant	23.05	19.74	23.33	21.89	22.00
C76	Parker	30.76	27.61	29.21	28.26	28.96
C77	Johnson	23.10	20.84	25.03	23.41	23.09
C1006	Hunt	25.01	21.49	24.57	24.16	23.81
C1032	Denton	25.55	21.92	25.48	24.49	24.36
C1044	Ellis	24.22	21.49	24.20	21.80	22.93
C1051	Navarro	27.53	23.59	26.57	24.50	25.55

Table: CAMS Stations (Ozone / Winter 2010 - 2014)

	2010 - 2011	2011 - 2012	2012 - 2013	2013 - 2014	2010 - 2014
Mean	23.77	21.00	24.48	22.77	23.00
Stdev	2.85	2.57	2.28	2.23	2.40
Median	23.19	21.07	24.23	22.15	22.93
Minimum	19.31	15.96	20.73	18.93	18.88
Maximum	30.76	27.61	29.21	28.26	28.96
N	19	19	19	19	19

Table: Descriptive statistics of winter average concentrations for ozone

Station	County	2010-2011	2011-2012	2012-2013	2013-2014	2010-2014
C13	Tarrant	41.63	44.17	40.12	45.94	42.96
C17	Tarrant	46.95	48.81	42.74	45.79	46.07
C31	Collin	44.80	48.91	45.48	46.95	46.53
C52	Ellis	43.62	44.49	41.82	45.36	43.82
C56	Denton	43.08	43.54	43.50	45.53	43.91
C60	Dallas	42.84	43.94	40.17	44.59	42.89
C61	Tarrant	44.95	46.99	40.18	41.24	43.34
C63	Dallas	40.81	46.43	42.09	44.44	43.44
C69	Rockwall	45.54	46.83	42.91	46.75	45.51
C70	Tarrant	43.38	48.11	42.94	45.71	45.03
C71	Kaufman	44.41	46.55	42.17	45.69	44.70
C73	Hood	45.34	48.16	42.48	45.85	45.46
C75	Tarrant	42.20	46.14	40.34	42.02	42.68
C76	Parker	48.69	44.26	37.76	46.64	44.34
C77	Johnson	44.56	42.19	38.43	46.40	42.90
C1006	Hunt	43.80	46.17	41.62	44.50	44.02
C1032	Denton	45.38	48.16	44.55	48.14	46.55
C1044	Ellis	43.37	44.61	39.93	44.57	43.12
C1051	Navarro	45.65	45.79	41.45	44.13	44.25

Table: CAMS Stations (Ozone Max 8hrs / Winter 2010 - 2014)

	2010 - 2011	2011 - 2012	2012 - 2013	2013-2014	2010 - 2014
Mean	44.26	46.01	41.61	45.28	44.29
Stdev	1.86	1.94	1.96	1.64	1.26
Median	44.41	46.17	41.82	45.69	44.02
Minimum	40.81	42.19	37.76	41.24	42.68
Maximum	48.69	48.91	45.48	48.14	46.55
N	19	19	19	19	19

Table: Descriptive statistics of winter maximum 8-hour concentrations for ozone

4. Temperature

Station	County	2010-2011	2011-2012	2012-2013	2013-2014	2010-2014
C13	Tarrant	47.11	49.80	50.53	50.01	49.36
C17	Tarrant	46.31	49.14	49.77	43.94	47.29
C52	Ellis	47.45	50.14	50.93	45.21	48.43
C56	Denton	45.21	48.09	48.61	42.52	46.11
C60	Dallas	48.03	51.28	52.32	46.14	49.44
C61	Tarrant	47.00	49.94	50.55	44.57	48.01
C63	Dallas	47.00	50.24	50.86	44.80	48.22
C70	Tarrant	46.66	49.86	49.63	43.85	47.50
C71	Kaufman	46.73	50.25	50.62	44.69	48.07
C75	Tarrant	45.97	49.38	49.23	43.56	47.03
C1006	Hunt	45.22	48.59	48.55	42.92	46.32
C1051	Navarro	48.09	51.23	51.84	46.95	49.53

Table: CAMS Stations (Temperature / Winter 2010 - 2014)

	2010 - 2011	2011 - 2012	2012 - 2013	2013 - 2014	2010 - 2014
Mean	46.73	49.83	50.29	44.93	47.94
Stdev	0.94	0.94	1.17	2.03	1.15
Median	46.87	49.90	50.54	44.63	48.04
Minimum	45.21	48.09	48.55	42.52	46.11
Maximum	48.09	51.28	52.32	50.01	49.53
N	12	12	12	12	12

Table: Descriptive statistics of winter average concentrations for temperature

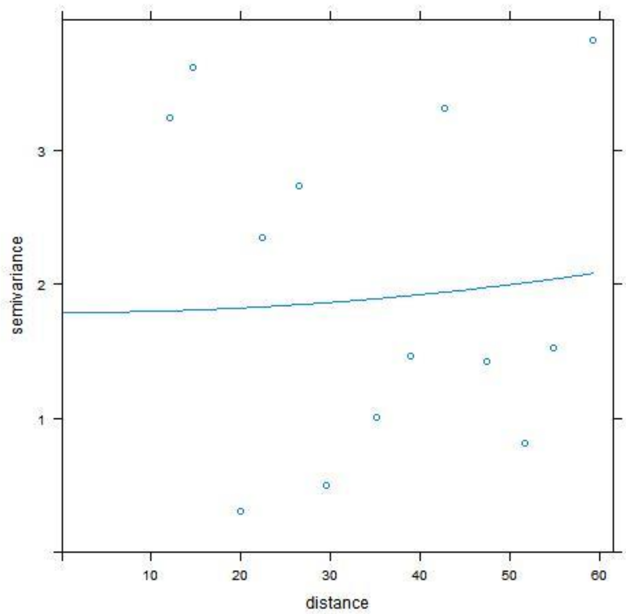
5. Wind Speed

Station	County	2010-2011	2011-2012	2012-2013	2013-2014	2010-2014
C13	Tarrant	8.31	8.13	8.39	8.21	8.26
C17	Tarrant	8.07	7.62	8.19	8.08	7.99
C56	Denton	8.11	7.60	8.29	7.82	7.95
C60	Dallas	5.96	5.70	6.18	5.62	5.86
C61	Tarrant	8.58	8.14	8.48	7.91	8.28
C63	Dallas	6.71	6.38	6.65	6.37	6.53
C70	Tarrant	6.93	6.55	6.76	6.52	6.69
C71	Kaufman	6.84	6.01	6.19	6.20	6.31
C75	Tarrant	9.58	9.45	9.75	9.71	9.62
C1006	Hunt	5.46	4.90	5.44	5.39	5.30
C1044	Ellis	7.99	7.59	7.64	8.14	7.84
C1051	Navarro	9.98	9.01	9.68	9.26	9.48

Table: CAMS Stations (Wind Speed / Winter 2010 - 2014)

	2010 - 2011	2011 - 2012	2012 - 2013	2013 - 2014	2010 - 2014
Mean	7.71	7.26	7.64	7.44	7.51
Stdev	1.37	1.37	1.40	1.39	1.37
Median	8.03	7.60	7.92	7.87	7.90
Minimum	5.46	4.90	5.44	5.39	5.30
Maximum	9.98	9.45	9.75	9.71	9.62
N	12	12	12	12	12

Table: Descriptive statistics of winter average concentrations for wind speed



(a)

(b)

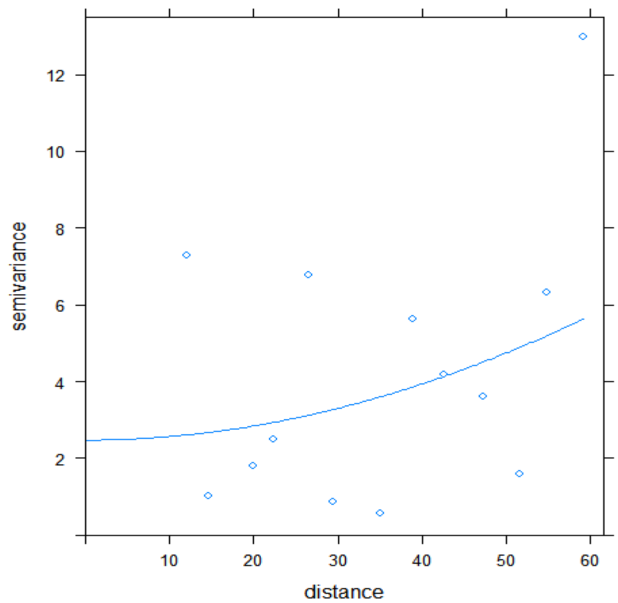
(c)

Figure (a-c)

a – Semivariogram

b – Spatial distribution of the variance of 5-year annual average nitric oxide concentration

c – Spatial distribution of the confidence interval of 5-year annual average nitric oxide concentratio



(a)

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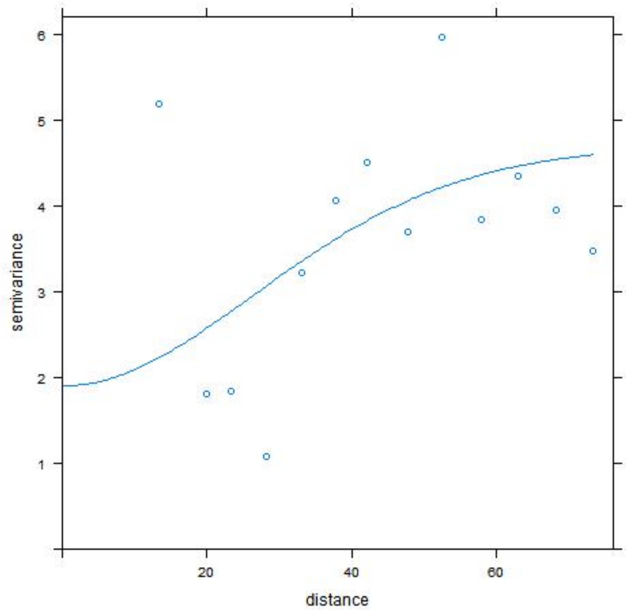
(c)

Figure (a-c)

a – Semivariogram

b – Spatial distribution of the variance of 5-year annual average nitrogen dioxide concentration

c – Spatial distribution of the confidence interval of 5-year annual average nitrogen dioxide concentration



(a)

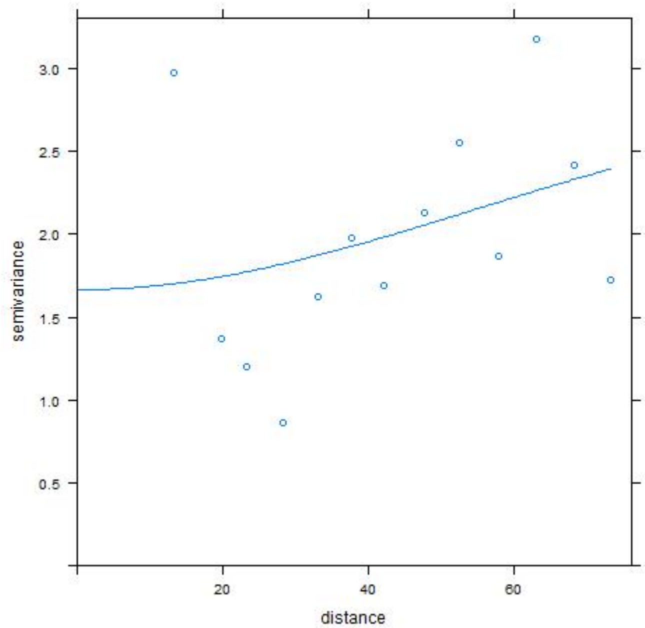
(b) **(c)**

Figure (a-c)

a – Semivariogram

b – Spatial distribution of the variance of 5-year annual average ozone concentration

c – Spatial distribution of the confidence interval of 5-year annual average ozone concentration



(a)

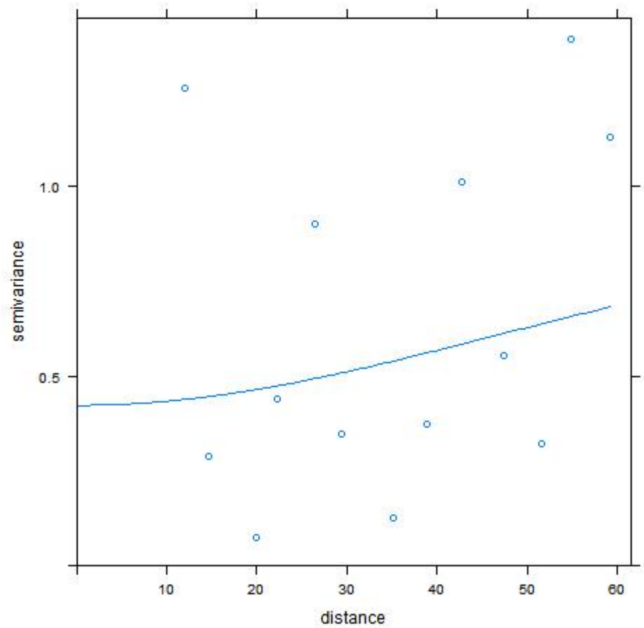
(b) **(c)**

Figure (a-c)

a – Semivariogram

b – Spatial distribution of the variance of 5-year annual 8-hour average ozone concentration

c – Spatial distribution of the confidence interval of 5-year annual 8-hour average ozone concentration



(a)

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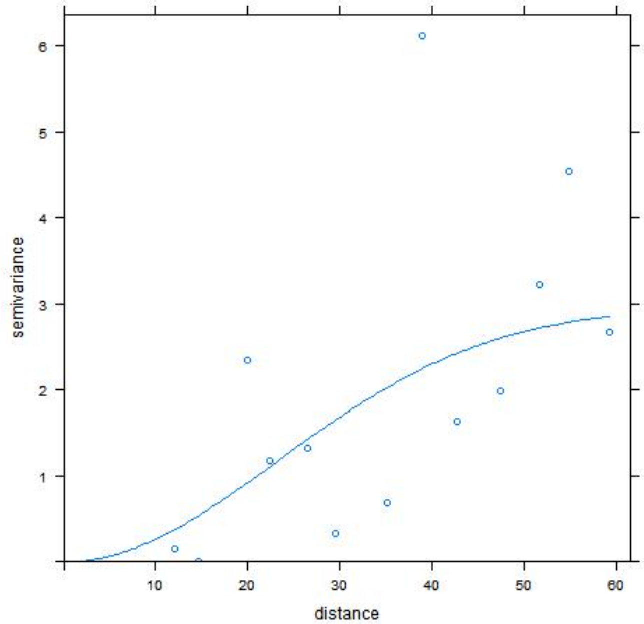
Figure (a-c)

a – Semivariogram

b – Spatial distribution of the variance of 5-year annual average temperature

c – Spatial distribution of the confidence interval of 5-year annual average temperature



(a)

(b)

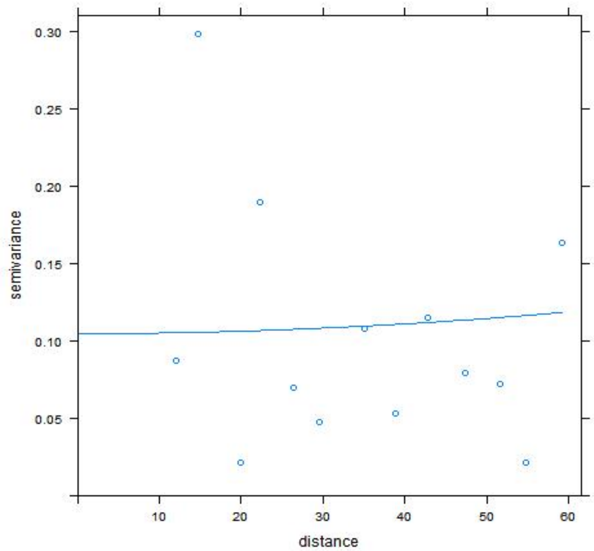
(c)

Figure (a-c)

a – Semivariogram

b – Spatial distribution of the variance of 5-year annual average wind speed

c – Spatial distribution of the confidence interval of 5-year annual average wind speed



(a)

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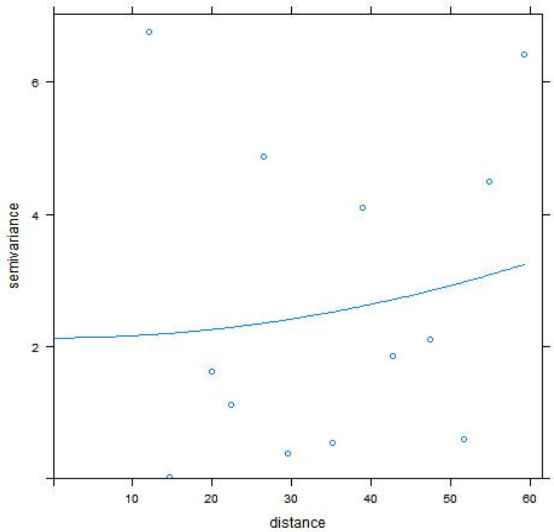
(c)

Figure (a-c)

a – Semivariogram

b – Spatial distribution of the variance of 5-year summer average nitric oxide concentration

c – Spatial distribution of the confidence interval of 5-year summer average nitric oxide concentration



(a)

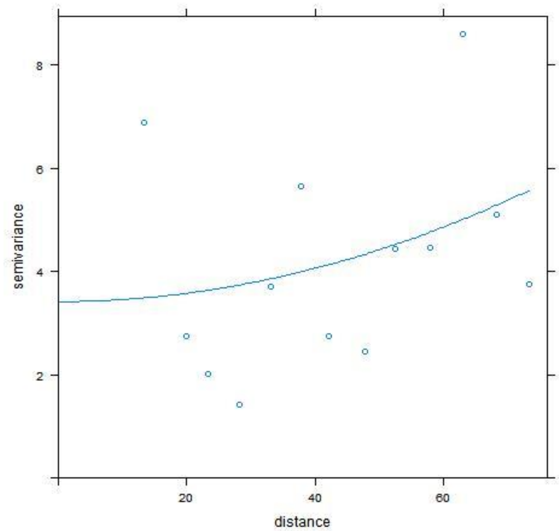
(b) **(c)**

Figure (a-c)

a – Semivariogram

b – Spatial distribution of the variance of 5-year summer average nitrogen dioxide concentration

c – Spatial distribution of the confidence interval of 5-year summer average nitrogen dioxide concentration



(a)

(b)

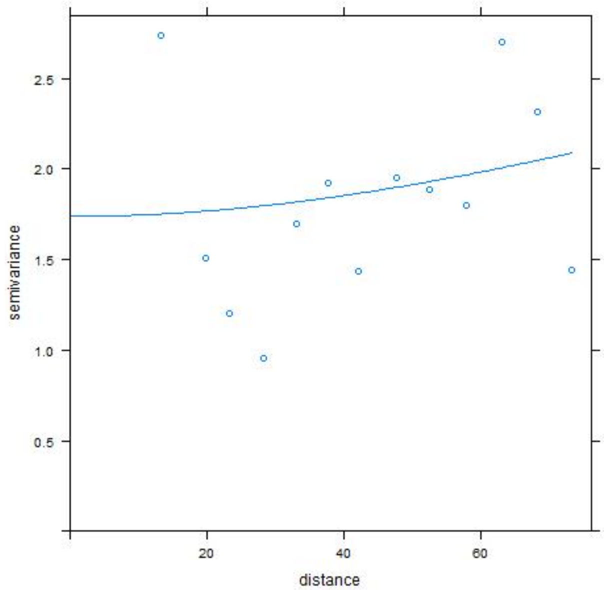
(c)

Figure (a-c)

a – Semivariogram

b – Spatial distribution of the variance of 5-year summer average ozone concentration

c – Spatial distribution of the confidence interval of 5-year summer average ozone concentration



(a)

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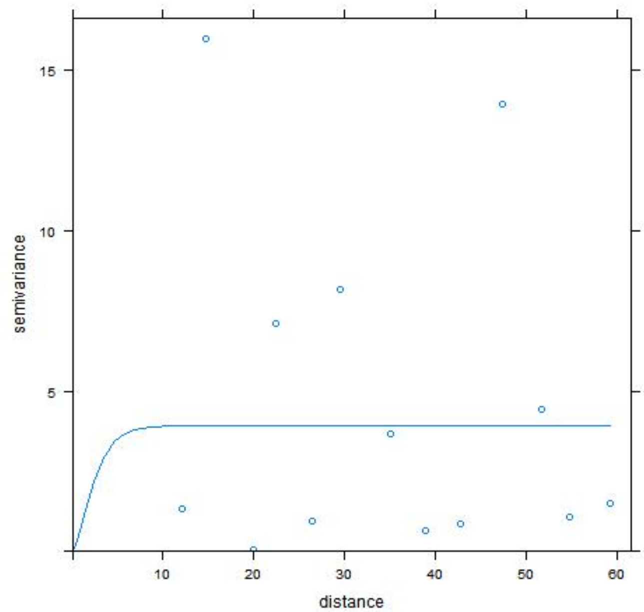
(c)

Figure (a-c)

a – Semivariogram

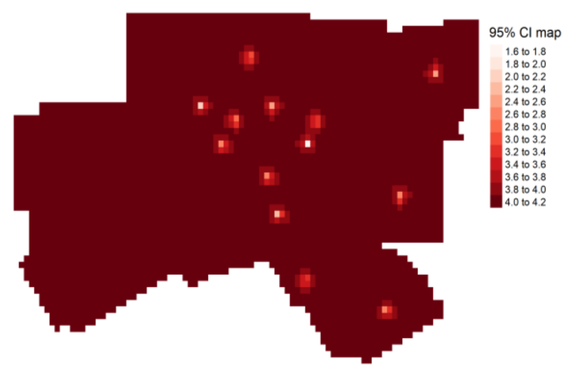
b – Spatial distribution of the variance of 5-year summer 8-hour average ozone concentration

c – Spatial distribution of the confidence interval of 5-year summer 8-hour average ozone concentratio



(a)

(b)



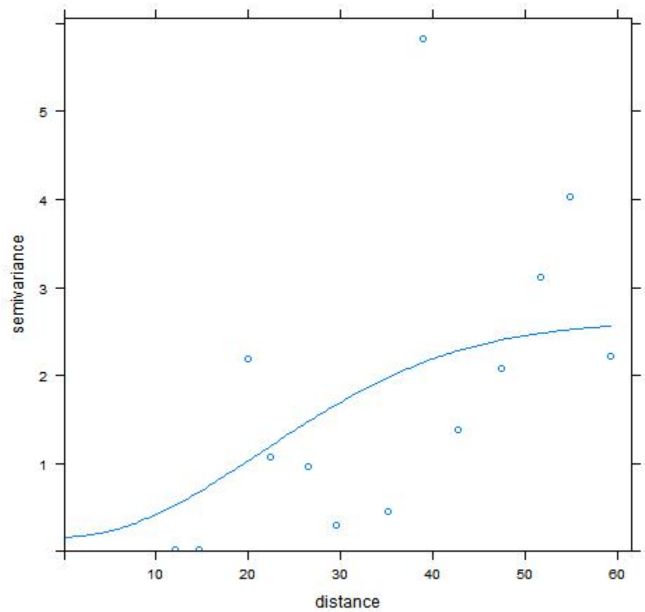
(c)

Figure (a-c)

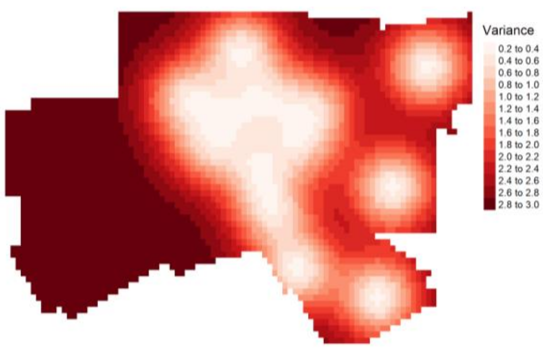
a – Semivariogram

b – Spatial distribution of the variance of 5-year summer average temperature

c – Spatial distribution of the confidence interval of 5-year summer average temperature



(a)



(b)

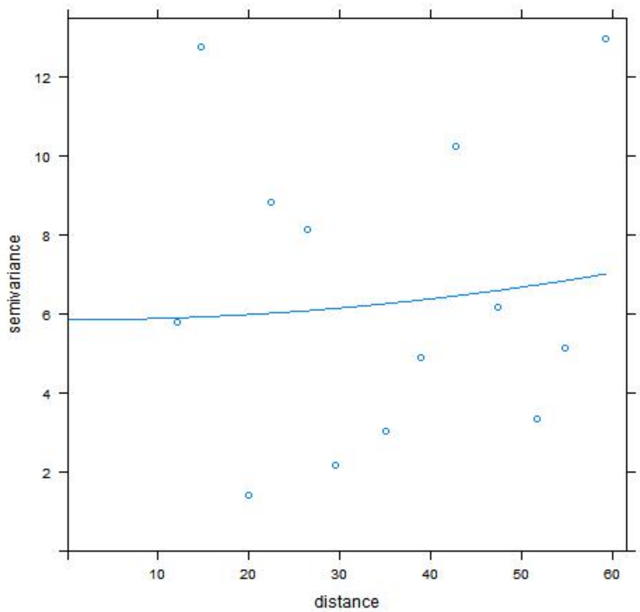
(c)

Figure (a-c)

a – Semivariogram

b – Spatial distribution of the variance of 5-year summer average wind speed

c – Spatial distribution of the confidence interval of 5-year summer average wind speed



(a)

(b)

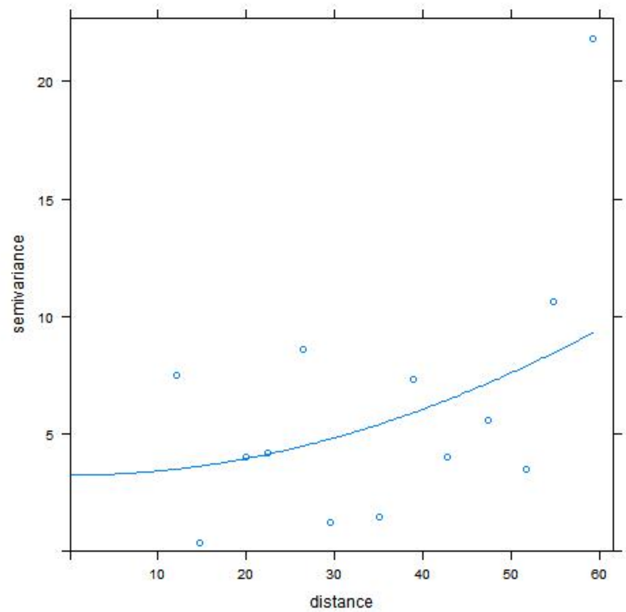
(c)

Figure (a-c)

a – Semivariogram

b – Spatial distribution of the variance of 5-year winter average nitric oxide

c – Spatial distribution of the confidence interval of 5-year winter average nitric oxide



(a)

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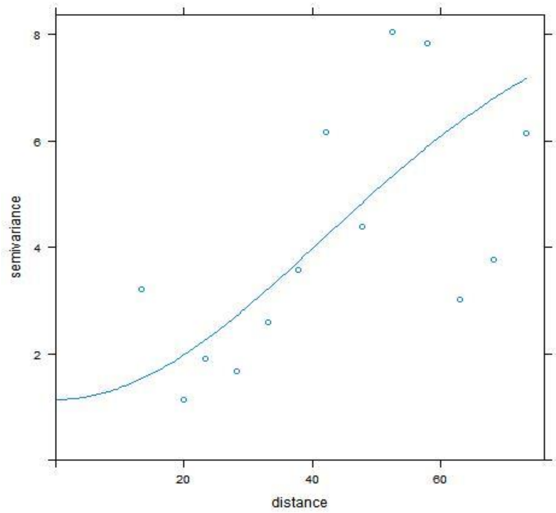
(c)

Figure (a-c)

a – Semivariogram

b – Spatial distribution of the variance of 5-year winter average nitrogen dioxide

c – Spatial distribution of the confidence interval of 5-year winter average nitrogen dioxid



(a)

(b)

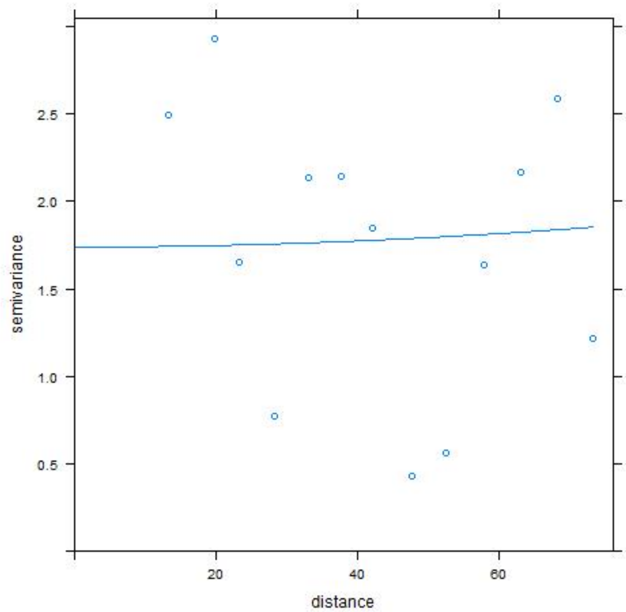
(c)

Figure (a-c)

a – Semivariogram

b – Spatial distribution of the variance of 5-year winter average ozone concentration

c – Spatial distribution of the confidence interval of 5-year winter average ozone concentration



(a)

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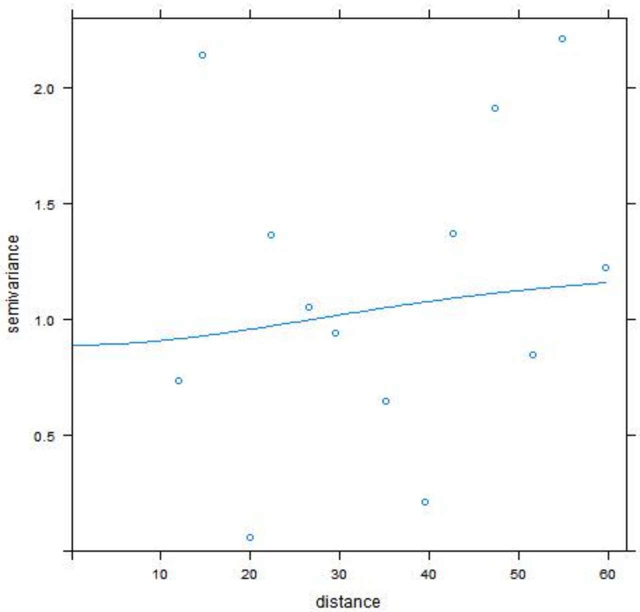
(c)

Figure (a-c)

a – Semivariogram

b – Spatial distribution of the variance of 5-year winter 8-hour average ozone concentration

c – Spatial distribution of the confidence interval of 5-year winter 8-hour average ozone concentratio



(a)

(b)

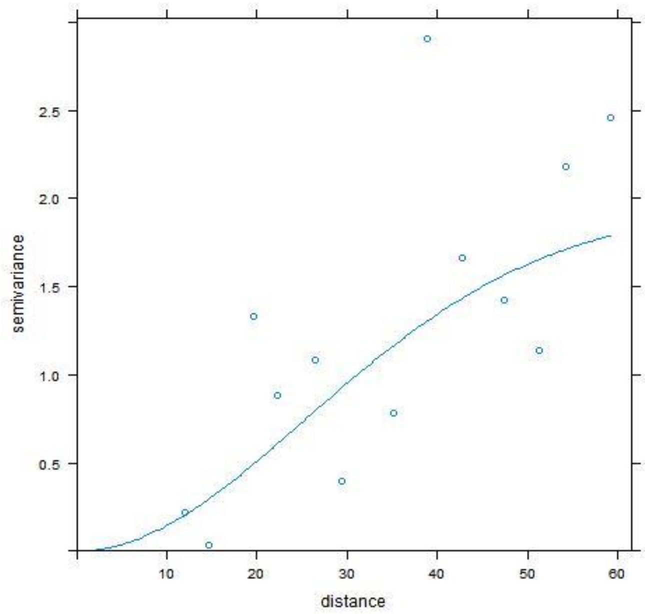
(c)

Figure (a-c)

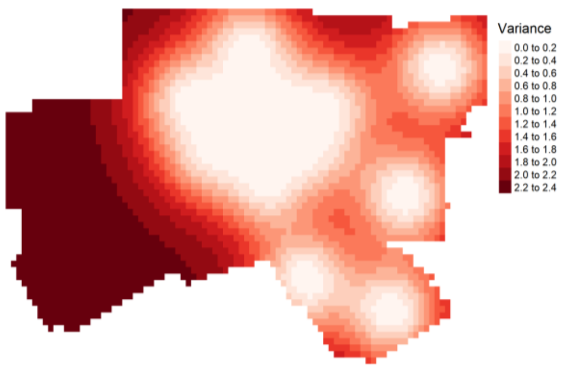
a – Semivariogram

b – Spatial distribution of the variance of 5-year winter average temperature

c – Spatial distribution of the confidence interval of 5-year winter average temperature



(a)



(b)

(c)

Figure (a-c)

a – Semivariogram

b – Spatial distribution of the variance of 5-year winter average wind speed

c – Spatial distribution of the confidence interval of 5-year winter average wind speed

Appendix B: Chapter 4

County	Tract	SED Index
Collin	Census Tract 316.24	24.8
Collin	Census Tract 316.30	9.1
Collin	Census Tract 316.23	9.8
Collin	Census Tract 316.25	7.5
Collin	Census Tract 317.08	12.8
Collin	Census Tract 315.05	8.4
Collin	Census Tract 315.04	7.1
Collin	Census Tract 315.06	23.3
Collin	Census Tract 320.08	12.8
Collin	Census Tract 318.05	10.3
Collin	Census Tract 320.12	22.8
Collin	Census Tract 305.20	9.5
Collin	Census Tract 305.21	7.4
Collin	Census Tract 305.24	6.3
Collin	Census Tract 305.19	5.8
Collin	Census Tract 316.21	11.4
Collin	Census Tract 317.04	13.6
Collin	Census Tract 316.47	6.4
Collin	Census Tract 316.53	9.1
Collin	Census Tract 316.49	9.4
Collin	Census Tract 316.43	13.4
Collin	Census Tract 316.32	12.3
Collin	Census Tract 305.30	8.6
Collin	Census Tract 305.15	9.2
Collin	Census Tract 304.04	10.0
Collin	Census Tract 303.01	6.9
Collin	Census Tract 305.27	7.3
Collin	Census Tract 316.22	8.6
Collin	Census Tract 309	29.5
Collin	Census Tract 306.01	7.7
Collin	Census Tract 311	17.1
Collin	Census Tract 305.28	8.2
Collin	Census Tract 318.06	16.4
Collin	Census Tract 317.19	11.0
Collin	Census Tract 317.20	37.1
Collin	Census Tract 317.18	9.9
Collin	Census Tract 317.15	8.0

Collin	Census Tract 317.16	13.0
Collin	Census Tract 317.13	18.3
Collin	Census Tract 317.14	21.9
Collin	Census Tract 317.12	17.0
Collin	Census Tract 316.63	6.7
Collin	Census Tract 316.64	4.7
Collin	Census Tract 318.07	12.1
Collin	Census Tract 316.55	14.4
Collin	Census Tract 316.54	7.3
Collin	Census Tract 314.09	11.2
Collin	Census Tract 320.13	22.2
Collin	Census Tract 314.05	5.4
Collin	Census Tract 315.08	15.6
Collin	Census Tract 314.10	8.3
Collin	Census Tract 320.11	8.9
Collin	Census Tract 313.17	7.4
Collin	Census Tract 313.15	12.2
Collin	Census Tract 313.09	9.5
Collin	Census Tract 313.08	10.0
Collin	Census Tract 313.10	9.2
Collin	Census Tract 312.02	11.9
Collin	Census Tract 305.14	5.7
Collin	Census Tract 314.08	10.2
Collin	Census Tract 313.14	9.2
Collin	Census Tract 305.12	5.0
Collin	Census Tract 316.61	6.2
Collin	Census Tract 305.05	9.6
Collin	Census Tract 316.56	6.4
Collin	Census Tract 316.58	14.7
Collin	Census Tract 316.60	10.9
Collin	Census Tract 316.57	13.6
Collin	Census Tract 317.11	9.4
Collin	Census Tract 305.09	6.6
Collin	Census Tract 305.07	4.2
Collin	Census Tract 305.08	9.7
Collin	Census Tract 305.10	8.7
Collin	Census Tract 320.10	22.8
Collin	Census Tract 313.16	6.8

Collin	Census Tract 313.13	6.4
Collin	Census Tract 314.11	6.9
Collin	Census Tract 313.12	5.9
Collin	Census Tract 305.22	6.0
Collin	Census Tract 305.11	7.1
Collin	Census Tract 305.23	9.8
Collin	Census Tract 305.16	15.3
Collin	Census Tract 305.26	7.2
Collin	Census Tract 305.25	7.5
Collin	Census Tract 305.29	5.2
Collin	Census Tract 305.31	6.7
Collin	Census Tract 305.17	8.5
Collin	Census Tract 306.05	7.7
Collin	Census Tract 307.01	30.8
Collin	Census Tract 306.03	13.4
Collin	Census Tract 308.02	26.4
Collin	Census Tract 307.02	21.3
Collin	Census Tract 308.01	16.5
Collin	Census Tract 314.06	8.9
Collin	Census Tract 314.07	6.3
Collin	Census Tract 303.04	16.9
Collin	Census Tract 303.03	7.6
Collin	Census Tract 303.02	7.4
Collin	Census Tract 303.05	13.7
Collin	Census Tract 302.02	8.7
Collin	Census Tract 306.04	5.4
Collin	Census Tract 312.01	12.7
Collin	Census Tract 302.03	12.2
Collin	Census Tract 310.04	18.7
Collin	Census Tract 320.09	8.3
Collin	Census Tract 317.09	12.8
Collin	Census Tract 317.06	6.3
Collin	Census Tract 316.52	7.6
Collin	Census Tract 316.45	5.3
Collin	Census Tract 316.48	10.5
Collin	Census Tract 316.40	12.9
Collin	Census Tract 316.41	6.8
Collin	Census Tract 316.39	10.2

Collin	Census Tract 316.38	5.5
Collin	Census Tract 304.03	14.2
Collin	Census Tract 304.08	18.6
Collin	Census Tract 316.37	6.2
Collin	Census Tract 316.33	8.2
Collin	Census Tract 310.01	19.5
Collin	Census Tract 318.04	20.5
Collin	Census Tract 320.04	21.4
Collin	Census Tract 320.03	29.3
Collin	Census Tract 319	32.6
Collin	Census Tract 305.13	9.4
Collin	Census Tract 305.18	4.0
Collin	Census Tract 316.59	13.5
Collin	Census Tract 302.01	9.6
Collin	Census Tract 310.03	21.0
Collin	Census Tract 315.07	9.3
Collin	Census Tract 313.11	8.4
Collin	Census Tract 317.17	19.5
Collin	Census Tract 318.02	12.0
Collin	Census Tract 316.46	8.7
Collin	Census Tract 316.42	5.8
Collin	Census Tract 316.34	18.8
Collin	Census Tract 316.36	10.6
Collin	Census Tract 316.35	16.3
Collin	Census Tract 305.04	14.6
Collin	Census Tract 304.06	17.9
Collin	Census Tract 304.05	9.7
Collin	Census Tract 304.07	7.0
Collin	Census Tract 316.62	8.7
Collin	Census Tract 305.06	7.7
Collin	Census Tract 316.31	16.2
Collin	Census Tract 316.13	5.5
Collin	Census Tract 316.12	8.9
Collin	Census Tract 316.11	13.6
Collin	Census Tract 316.29	18.4
Collin	Census Tract 316.26	8.4
Collin	Census Tract 316.28	9.9
Collin	Census Tract 316.27	11.1

Dallas	Census Tract 141.33	24.0
Dallas	Census Tract 141.34	7.6
Dallas	Census Tract 141.35	8.7
Dallas	Census Tract 141.31	14.7
Dallas	Census Tract 141.32	17.7
Dallas	Census Tract 185.05	29.3
Dallas	Census Tract 136.25	31.6
Dallas	Census Tract 107.04	35.7
Dallas	Census Tract 108.01	30.2
Dallas	Census Tract 108.03	17.1
Dallas	Census Tract 109.02	30.4
Dallas	Census Tract 110.01	21.4
Dallas	Census Tract 110.02	21.4
Dallas	Census Tract 111.01	14.8
Dallas	Census Tract 111.03	31.0
Dallas	Census Tract 111.04	28.9
Dallas	Census Tract 166.15	18.3
Dallas	Census Tract 166.16	15.8
Dallas	Census Tract 166.17	9.0
Dallas	Census Tract 166.18	20.5
Dallas	Census Tract 166.19	23.4
Dallas	Census Tract 166.20	11.8
Dallas	Census Tract 192.02	29.7
Dallas	Census Tract 192.03	10.7
Dallas	Census Tract 192.04	23.4
Dallas	Census Tract 181.22	9.9
Dallas	Census Tract 179	22.6
Dallas	Census Tract 178.06	26.9
Dallas	Census Tract 178.05	19.0
Dallas	Census Tract 130.09	20.4
Dallas	Census Tract 130.08	14.5
Dallas	Census Tract 136.23	25.1
Dallas	Census Tract 136.21	24.7
Dallas	Census Tract 136.22	21.5
Dallas	Census Tract 130.10	34.2
Dallas	Census Tract 126.04	30.2
Dallas	Census Tract 176.05	33.3
Dallas	Census Tract 176.06	25.7

Dallas	Census Tract 109.04	32.9
Dallas	Census Tract 111.05	44.6
Dallas	Census Tract 131.01	6.2
Dallas	Census Tract 131.02	8.5
Dallas	Census Tract 132	12.7
Dallas	Census Tract 133	6.0
Dallas	Census Tract 134	5.4
Dallas	Census Tract 135	4.7
Dallas	Census Tract 136.05	8.9
Dallas	Census Tract 192.08	40.6
Dallas	Census Tract 193.01	5.3
Dallas	Census Tract 193.02	7.3
Dallas	Census Tract 194	11.4
Dallas	Census Tract 195.01	6.2
Dallas	Census Tract 195.02	8.0
Dallas	Census Tract 196	7.7
Dallas	Census Tract 197	8.1
Dallas	Census Tract 130.07	17.3
Dallas	Census Tract 130.05	9.8
Dallas	Census Tract 130.04	8.1
Dallas	Census Tract 129	13.4
Dallas	Census Tract 128	15.1
Dallas	Census Tract 127.02	26.9
Dallas	Census Tract 159	32.4
Dallas	Census Tract 165.21	23.5
Dallas	Census Tract 164.13	8.3
Dallas	Census Tract 164.12	7.9
Dallas	Census Tract 141.37	9.2
Dallas	Census Tract 136.06	19.6
Dallas	Census Tract 136.07	13.5
Dallas	Census Tract 136.08	4.6
Dallas	Census Tract 136.09	21.0
Dallas	Census Tract 136.10	20.6
Dallas	Census Tract 136.11	8.8
Dallas	Census Tract 136.15	34.3
Dallas	Census Tract 198	8.4
Dallas	Census Tract 199	30.7
Dallas	Census Tract 56	37.3

Dallas	Census Tract 115	44.4
Dallas	Census Tract 178.13	19.1
Dallas	Census Tract 122.09	23.1
Dallas	Census Tract 22	18.9
Dallas	Census Tract 91.03	29.0
Dallas	Census Tract 91.05	33.8
Dallas	Census Tract 181.20	15.2
Dallas	Census Tract 126.01	31.6
Dallas	Census Tract 125	28.1
Dallas	Census Tract 124	11.4
Dallas	Census Tract 123.02	46.8
Dallas	Census Tract 122.06	16.9
Dallas	Census Tract 78.19	38.0
Dallas	Census Tract 143.12	12.1
Dallas	Census Tract 142.05	6.9
Dallas	Census Tract 137.27	13.3
Dallas	Census Tract 138.05	24.6
Dallas	Census Tract 138.06	12.3
Dallas	Census Tract 79.09	15.1
Dallas	Census Tract 136.16	18.3
Dallas	Census Tract 136.17	14.4
Dallas	Census Tract 136.18	9.0
Dallas	Census Tract 136.19	7.7
Dallas	Census Tract 137.11	30.0
Dallas	Census Tract 137.12	18.9
Dallas	Census Tract 137.13	44.5
Dallas	Census Tract 168.04	14.9
Dallas	Census Tract 167.04	23.2
Dallas	Census Tract 167.05	21.0
Dallas	Census Tract 167.01	23.7
Dallas	Census Tract 114.01	42.9
Dallas	Census Tract 113	22.5
Dallas	Census Tract 112	22.4
Dallas	Census Tract 122.04	24.5
Dallas	Census Tract 122.11	38.5
Dallas	Census Tract 122.07	32.7
Dallas	Census Tract 122.08	52.7
Dallas	Census Tract 121	32.4

Dallas	Census Tract 120	33.8
Dallas	Census Tract 79.10	16.3
Dallas	Census Tract 78.25	29.5
Dallas	Census Tract 78.24	7.6
Dallas	Census Tract 78.26	20.6
Dallas	Census Tract 78.27	29.0
Dallas	Census Tract 130.11	38.1
Dallas	Census Tract 185.06	35.8
Dallas	Census Tract 137.14	24.9
Dallas	Census Tract 137.15	15.9
Dallas	Census Tract 137.16	16.7
Dallas	Census Tract 137.17	26.0
Dallas	Census Tract 137.18	30.7
Dallas	Census Tract 137.19	15.4
Dallas	Census Tract 137.20	18.9
Dallas	Census Tract 137.21	10.0
Dallas	Census Tract 89	45.8
Dallas	Census Tract 88.02	41.4
Dallas	Census Tract 88.01	33.6
Dallas	Census Tract 87.05	26.0
Dallas	Census Tract 87.04	41.3
Dallas	Census Tract 87.03	34.2
Dallas	Census Tract 87.01	49.4
Dallas	Census Tract 173.04	10.3
Dallas	Census Tract 117.01	26.7
Dallas	Census Tract 116.01	35.8
Dallas	Census Tract 116.02	28.5
Dallas	Census Tract 93.04	55.9
Dallas	Census Tract 93.03	33.0
Dallas	Census Tract 93.01	31.8
Dallas	Census Tract 92.02	34.1
Dallas	Census Tract 92.01	29.6
Dallas	Census Tract 171.02	26.0
Dallas	Census Tract 91.04	36.0
Dallas	Census Tract 78.21	36.8
Dallas	Census Tract 79.12	11.9
Dallas	Census Tract 78.22	14.9
Dallas	Census Tract 78.23	47.7

Dallas	Census Tract 190.40	12.9
Dallas	Census Tract 190.41	10.6
Dallas	Census Tract 137.22	15.6
Dallas	Census Tract 137.25	20.8
Dallas	Census Tract 138.03	8.0
Dallas	Census Tract 138.04	13.1
Dallas	Census Tract 139.01	20.3
Dallas	Census Tract 139.02	21.2
Dallas	Census Tract 140.01	17.6
Dallas	Census Tract 141.03	32.4
Dallas	Census Tract 86.04	52.3
Dallas	Census Tract 59.02	35.8
Dallas	Census Tract 59.01	27.1
Dallas	Census Tract 57	37.8
Dallas	Census Tract 55	34.7
Dallas	Census Tract 54	41.1
Dallas	Census Tract 49	39.3
Dallas	Census Tract 91.01	34.1
Dallas	Census Tract 85	31.2
Dallas	Census Tract 84	29.5
Dallas	Census Tract 82	20.2
Dallas	Census Tract 81	9.1
Dallas	Census Tract 80	6.9
Dallas	Census Tract 131.04	11.5
Dallas	Census Tract 131.05	27.7
Dallas	Census Tract 64.01	22.6
Dallas	Census Tract 141.30	12.9
Dallas	Census Tract 141.38	12.0
Dallas	Census Tract 142.06	11.8
Dallas	Census Tract 165.20	29.3
Dallas	Census Tract 108.05	35.9
Dallas	Census Tract 108.04	42.5
Dallas	Census Tract 64.02	29.2
Dallas	Census Tract 136.20	11.6
Dallas	Census Tract 136.24	16.4
Dallas	Census Tract 141.13	16.5
Dallas	Census Tract 141.14	27.5
Dallas	Census Tract 141.15	17.1

Dallas	Census Tract 141.16	19.3
Dallas	Census Tract 141.19	8.1
Dallas	Census Tract 141.20	7.7
Dallas	Census Tract 141.21	13.4
Dallas	Census Tract 141.23	6.2
Dallas	Census Tract 141.24	7.0
Dallas	Census Tract 48	39.6
Dallas	Census Tract 41	45.2
Dallas	Census Tract 170.03	21.0
Dallas	Census Tract 169.03	26.5
Dallas	Census Tract 169.02	22.1
Dallas	Census Tract 168.02	14.4
Dallas	Census Tract 167.03	24.9
Dallas	Census Tract 173.05	13.7
Dallas	Census Tract 79.03	9.5
Dallas	Census Tract 79.02	13.3
Dallas	Census Tract 127.01	35.7
Dallas	Census Tract 78.18	37.8
Dallas	Census Tract 78.11	36.0
Dallas	Census Tract 78.10	17.2
Dallas	Census Tract 136.26	22.7
Dallas	Census Tract 17.04	8.4
Dallas	Census Tract 6.05	15.7
Dallas	Census Tract 4.06	25.2
Dallas	Census Tract 6.06	7.5
Dallas	Census Tract 79.14	19.8
Dallas	Census Tract 4.01	31.9
Dallas	Census Tract 4.04	20.0
Dallas	Census Tract 4.05	35.3
Dallas	Census Tract 141.26	9.5
Dallas	Census Tract 142.03	22.7
Dallas	Census Tract 142.04	31.4
Dallas	Census Tract 143.02	19.0
Dallas	Census Tract 143.06	22.6
Dallas	Census Tract 143.07	11.4
Dallas	Census Tract 181.23	13.2
Dallas	Census Tract 90	37.7
Dallas	Census Tract 192.11	16.4

Dallas	Census Tract 192.10	6.3
Dallas	Census Tract 192.06	20.9
Dallas	Census Tract 191	15.5
Dallas	Census Tract 190.23	7.9
Dallas	Census Tract 190.37	12.4
Dallas	Census Tract 180.02	24.4
Dallas	Census Tract 78.09	21.7
Dallas	Census Tract 78.15	51.8
Dallas	Census Tract 78.12	4.6
Dallas	Census Tract 78.05	16.4
Dallas	Census Tract 40	36.8
Dallas	Census Tract 5	25.2
Dallas	Census Tract 6.01	31.2
Dallas	Census Tract 6.03	11.0
Dallas	Census Tract 7.01	12.0
Dallas	Census Tract 7.02	12.9
Dallas	Census Tract 17.01	13.2
Dallas	Census Tract 18	10.4
Dallas	Census Tract 19	16.6
Dallas	Census Tract 20	32.8
Dallas	Census Tract 143.08	36.4
Dallas	Census Tract 143.09	38.3
Dallas	Census Tract 143.10	23.3
Dallas	Census Tract 144.03	22.9
Dallas	Census Tract 144.05	21.5
Dallas	Census Tract 144.06	25.5
Dallas	Census Tract 144.07	24.5
Dallas	Census Tract 178.11	14.3
Dallas	Census Tract 180.01	22.0
Dallas	Census Tract 178.12	14.9
Dallas	Census Tract 178.07	21.8
Dallas	Census Tract 178.04	24.9
Dallas	Census Tract 177.04	25.2
Dallas	Census Tract 176.02	20.3
Dallas	Census Tract 176.04	23.4
Dallas	Census Tract 39.02	43.8
Dallas	Census Tract 39.01	50.9
Dallas	Census Tract 38	42.4

Dallas	Census Tract 37	37.7
Dallas	Census Tract 34	39.9
Dallas	Census Tract 123.01	33.6
Dallas	Census Tract 27.02	44.3
Dallas	Census Tract 27.01	58.0
Dallas	Census Tract 122.10	38.3
Dallas	Census Tract 21	25.1
Dallas	Census Tract 31.01	14.9
Dallas	Census Tract 42.01	24.6
Dallas	Census Tract 42.02	31.0
Dallas	Census Tract 43	29.1
Dallas	Census Tract 44	12.1
Dallas	Census Tract 45	24.7
Dallas	Census Tract 144.08	19.7
Dallas	Census Tract 145.01	15.3
Dallas	Census Tract 145.02	29.7
Dallas	Census Tract 146.01	21.3
Dallas	Census Tract 146.02	30.1
Dallas	Census Tract 146.03	30.1
Dallas	Census Tract 147.01	38.1
Dallas	Census Tract 147.02	37.2
Dallas	Census Tract 147.03	20.6
Dallas	Census Tract 149.01	31.2
Dallas	Census Tract 149.02	29.3
Dallas	Census Tract 175	18.8
Dallas	Census Tract 174	19.6
Dallas	Census Tract 168.03	17.6
Dallas	Census Tract 190.24	16.6
Dallas	Census Tract 190.21	24.2
Dallas	Census Tract 190.20	18.0
Dallas	Census Tract 190.33	29.9
Dallas	Census Tract 190.32	24.9
Dallas	Census Tract 190.34	26.4
Dallas	Census Tract 190.14	35.8
Dallas	Census Tract 24	29.3
Dallas	Census Tract 117.02	31.4
Dallas	Census Tract 16	31.1
Dallas	Census Tract 15.04	36.1

Dallas	Census Tract 15.03	50.0
Dallas	Census Tract 15.02	34.3
Dallas	Census Tract 14	31.6
Dallas	Census Tract 13.02	25.8
Dallas	Census Tract 13.01	17.9
Dallas	Census Tract 12.02	22.2
Dallas	Census Tract 12.04	35.4
Dallas	Census Tract 141.27	11.2
Dallas	Census Tract 207	8.9
Dallas	Census Tract 185.01	26.6
Dallas	Census Tract 200	7.8
Dallas	Census Tract 202	37.6
Dallas	Census Tract 201	24.5
Dallas	Census Tract 206	6.0
Dallas	Census Tract 46	18.6
Dallas	Census Tract 47	39.0
Dallas	Census Tract 50	34.1
Dallas	Census Tract 51	32.4
Dallas	Census Tract 52	25.6
Dallas	Census Tract 53	28.4
Dallas	Census Tract 60.01	41.3
Dallas	Census Tract 60.02	41.1
Dallas	Census Tract 61	29.7
Dallas	Census Tract 62	31.4
Dallas	Census Tract 150	34.2
Dallas	Census Tract 151	25.1
Dallas	Census Tract 152.02	37.9
Dallas	Census Tract 152.04	18.7
Dallas	Census Tract 152.05	32.9
Dallas	Census Tract 152.06	17.8
Dallas	Census Tract 153.03	29.1
Dallas	Census Tract 153.04	22.8
Dallas	Census Tract 190.13	51.1
Dallas	Census Tract 12.03	18.5
Dallas	Census Tract 190.31	10.0
Dallas	Census Tract 190.29	20.2
Dallas	Census Tract 190.28	17.0
Dallas	Census Tract 190.26	14.0

Dallas	Census Tract 190.27	16.2
Dallas	Census Tract 190.04	18.9
Dallas	Census Tract 11.02	8.6
Dallas	Census Tract 8	29.4
Dallas	Census Tract 11.01	19.8
Dallas	Census Tract 10.02	13.6
Dallas	Census Tract 10.01	11.1
Dallas	Census Tract 78.04	22.6
Dallas	Census Tract 9	36.3
Dallas	Census Tract 3	8.7
Dallas	Census Tract 2.02	11.7
Dallas	Census Tract 2.01	10.8
Dallas	Census Tract 205	52.7
Dallas	Census Tract 203	40.8
Dallas	Census Tract 204	22.1
Dallas	Census Tract 192.12	54.6
Dallas	Census Tract 109.03	30.0
Dallas	Census Tract 126.03	20.8
Dallas	Census Tract 78.20	48.9
Dallas	Census Tract 79.11	15.9
Dallas	Census Tract 63.01	24.8
Dallas	Census Tract 63.02	22.5
Dallas	Census Tract 65.01	26.6
Dallas	Census Tract 65.02	26.7
Dallas	Census Tract 67	31.6
Dallas	Census Tract 68	35.3
Dallas	Census Tract 69	44.8
Dallas	Census Tract 71.01	9.0
Dallas	Census Tract 153.05	22.6
Dallas	Census Tract 153.06	16.1
Dallas	Census Tract 154.01	13.8
Dallas	Census Tract 154.03	28.2
Dallas	Census Tract 154.04	40.0
Dallas	Census Tract 155	30.5
Dallas	Census Tract 156	26.4
Dallas	Census Tract 189	27.0
Dallas	Census Tract 188.02	21.2
Dallas	Census Tract 188.01	29.1

Dallas	Census Tract 187	27.8
Dallas	Census Tract 186	23.2
Dallas	Census Tract 184.03	22.4
Dallas	Census Tract 184.02	16.2
Dallas	Census Tract 184.01	29.5
Dallas	Census Tract 1	10.0
Dallas	Census Tract 177.03	34.3
Dallas	Census Tract 172.01	36.1
Dallas	Census Tract 178.14	15.2
Dallas	Census Tract 119	27.2
Dallas	Census Tract 118	31.4
Dallas	Census Tract 25	33.8
Dallas	Census Tract 181.35	15.6
Dallas	Census Tract 166.22	16.0
Dallas	Census Tract 166.24	10.9
Dallas	Census Tract 137.26	16.3
Dallas	Census Tract 192.13	45.9
Dallas	Census Tract 190.38	16.7
Dallas	Census Tract 190.39	17.0
Dallas	Census Tract 71.02	22.8
Dallas	Census Tract 72.01	37.3
Dallas	Census Tract 72.02	41.2
Dallas	Census Tract 73.01	6.4
Dallas	Census Tract 73.02	17.8
Dallas	Census Tract 76.01	6.5
Dallas	Census Tract 76.04	7.4
Dallas	Census Tract 76.05	8.0
Dallas	Census Tract 77	7.1
Dallas	Census Tract 157	24.7
Dallas	Census Tract 158	30.5
Dallas	Census Tract 160.01	25.1
Dallas	Census Tract 160.02	35.2
Dallas	Census Tract 161	29.9
Dallas	Census Tract 162.01	29.7
Dallas	Census Tract 162.02	27.6
Dallas	Census Tract 183	21.5
Dallas	Census Tract 182.06	28.6
Dallas	Census Tract 182.04	29.7

Dallas	Census Tract 182.05	26.6
Dallas	Census Tract 181.32	16.7
Dallas	Census Tract 181.30	23.2
Dallas	Census Tract 181.29	11.1
Dallas	Census Tract 181.27	20.4
Dallas	Census Tract 190.25	8.4
Dallas	Census Tract 181.26	14.8
Dallas	Census Tract 181.24	7.1
Dallas	Census Tract 181.04	8.2
Dallas	Census Tract 178.08	12.0
Dallas	Census Tract 177.02	19.6
Dallas	Census Tract 173.06	20.3
Dallas	Census Tract 173.03	14.9
Dallas	Census Tract 190.42	11.8
Dallas	Census Tract 190.43	6.9
Dallas	Census Tract 181.40	11.4
Dallas	Census Tract 181.34	9.4
Dallas	Census Tract 181.39	14.9
Dallas	Census Tract 181.38	21.7
Dallas	Census Tract 181.37	14.9
Dallas	Census Tract 181.33	12.6
Dallas	Census Tract 181.36	8.4
Dallas	Census Tract 78.01	8.2
Dallas	Census Tract 79.06	8.8
Dallas	Census Tract 94.01	20.1
Dallas	Census Tract 94.02	8.3
Dallas	Census Tract 95	9.1
Dallas	Census Tract 96.03	9.2
Dallas	Census Tract 96.04	18.5
Dallas	Census Tract 96.05	23.1
Dallas	Census Tract 96.07	12.7
Dallas	Census Tract 163.01	21.3
Dallas	Census Tract 163.02	27.6
Dallas	Census Tract 164.01	15.8
Dallas	Census Tract 164.06	22.6
Dallas	Census Tract 164.07	26.5
Dallas	Census Tract 164.08	15.9
Dallas	Census Tract 164.09	11.3

Dallas	Census Tract 164.10	10.1
Dallas	Census Tract 164.11	11.5
Dallas	Census Tract 181.11	28.8
Dallas	Census Tract 181.21	19.4
Dallas	Census Tract 182.03	19.7
Dallas	Census Tract 181.05	25.6
Dallas	Census Tract 192.05	5.2
Dallas	Census Tract 190.19	32.4
Dallas	Census Tract 173.01	20.8
Dallas	Census Tract 172.02	25.6
Dallas	Census Tract 171.01	23.9
Dallas	Census Tract 170.04	30.4
Dallas	Census Tract 170.01	20.4
Dallas	Census Tract 86.03	42.7
Dallas	Census Tract 181.41	25.7
Dallas	Census Tract 181.42	13.4
Dallas	Census Tract 79.13	15.8
Dallas	Census Tract 166.23	14.8
Dallas	Census Tract 166.21	21.7
Dallas	Census Tract 166.26	23.7
Dallas	Census Tract 166.25	14.2
Dallas	Census Tract 96.08	17.0
Dallas	Census Tract 96.09	5.7
Dallas	Census Tract 96.10	44.9
Dallas	Census Tract 96.11	17.8
Dallas	Census Tract 97.01	25.1
Dallas	Census Tract 97.02	10.8
Dallas	Census Tract 98.02	34.3
Dallas	Census Tract 98.03	22.7
Dallas	Census Tract 98.04	45.3
Dallas	Census Tract 99	24.0
Dallas	Census Tract 100	27.5
Dallas	Census Tract 101.01	40.4
Dallas	Census Tract 165.02	19.7
Dallas	Census Tract 165.09	14.6
Dallas	Census Tract 165.10	15.3
Dallas	Census Tract 165.11	20.7
Dallas	Census Tract 165.13	10.6

Dallas	Census Tract 165.14	9.9
Dallas	Census Tract 165.16	22.6
Dallas	Census Tract 165.17	18.3
Dallas	Census Tract 190.18	26.8
Dallas	Census Tract 190.36	6.9
Dallas	Census Tract 190.35	34.2
Dallas	Census Tract 190.16	34.8
Dallas	Census Tract 185.03	36.9
Dallas	Census Tract 181.18	12.5
Dallas	Census Tract 181.28	19.4
Dallas	Census Tract 181.10	11.7
Dallas	Census Tract 165.23	6.5
Dallas	Census Tract 165.22	17.4
Dallas	Census Tract 143.11	12.1
Dallas	Census Tract 141.29	9.2
Dallas	Census Tract 141.28	12.5
Dallas	Census Tract 141.36	14.6
Dallas	Census Tract 101.02	26.6
Dallas	Census Tract 105	27.8
Dallas	Census Tract 106.01	26.6
Dallas	Census Tract 106.02	35.3
Dallas	Census Tract 107.01	31.4
Dallas	Census Tract 107.03	30.1
Dallas	Census Tract 165.18	17.1
Dallas	Census Tract 165.19	12.5
Dallas	Census Tract 166.05	38.2
Dallas	Census Tract 166.06	15.5
Dallas	Census Tract 166.07	34.5
Dallas	Census Tract 166.10	23.1
Dallas	Census Tract 166.11	20.3
Dallas	Census Tract 166.12	7.3
Denton	Census Tract 216.27	11.8
Denton	Census Tract 216.26	8.5
Denton	Census Tract 201.05	11.0
Denton	Census Tract 201.13	10.7
Denton	Census Tract 201.08	5.6
Denton	Census Tract 201.04	10.4
Denton	Census Tract 201.10	5.8

Denton	Census Tract 201.11	6.9
Denton	Census Tract 201.09	4.0
Denton	Census Tract 217.53	5.1
Denton	Census Tract 214.03	10.9
Denton	Census Tract 206.02	20.9
Denton	Census Tract 211	34.0
Denton	Census Tract 216.11	13.6
Denton	Census Tract 217.27	7.6
Denton	Census Tract 217.42	13.3
Denton	Census Tract 217.24	4.8
Denton	Census Tract 217.43	14.8
Denton	Census Tract 216.37	25.2
Denton	Census Tract 216.38	14.6
Denton	Census Tract 216.34	24.0
Denton	Census Tract 216.35	22.0
Denton	Census Tract 216.32	12.7
Denton	Census Tract 216.28	11.0
Denton	Census Tract 216.33	10.9
Denton	Census Tract 216.30	14.3
Denton	Census Tract 216.31	6.9
Denton	Census Tract 217.39	28.9
Denton	Census Tract 217.40	15.4
Denton	Census Tract 217.41	19.1
Denton	Census Tract 217.30	6.2
Denton	Census Tract 217.23	11.3
Denton	Census Tract 215.24	8.5
Denton	Census Tract 215.23	14.1
Denton	Census Tract 215.21	13.5
Denton	Census Tract 216.21	8.9
Denton	Census Tract 216.29	7.6
Denton	Census Tract 216.22	11.4
Denton	Census Tract 216.20	17.7
Denton	Census Tract 215.19	13.7
Denton	Census Tract 215.18	6.8
Denton	Census Tract 216.25	6.9
Denton	Census Tract 216.23	15.2
Denton	Census Tract 215.16	11.0
Denton	Census Tract 217.20	4.8

Denton	Census Tract 217.21	8.3
Denton	Census Tract 217.15	8.8
Denton	Census Tract 217.17	9.3
Denton	Census Tract 215.14	5.0
Denton	Census Tract 216.19	23.9
Denton	Census Tract 216.24	14.4
Denton	Census Tract 217.16	16.0
Denton	Census Tract 217.44	24.8
Denton	Census Tract 217.45	19.0
Denton	Census Tract 215.17	9.9
Denton	Census Tract 215.13	6.3
Denton	Census Tract 216.18	23.7
Denton	Census Tract 213.03	13.3
Denton	Census Tract 218	7.3
Denton	Census Tract 215.26	5.4
Denton	Census Tract 215.12	5.4
Denton	Census Tract 214.08	11.6
Denton	Census Tract 212.02	28.0
Denton	Census Tract 213.05	13.2
Denton	Census Tract 217.50	5.6
Denton	Census Tract 217.47	9.7
Denton	Census Tract 217.19	5.8
Denton	Census Tract 216.36	17.0
Denton	Census Tract 215.20	14.9
Denton	Census Tract 217.52	5.3
Denton	Census Tract 217.51	6.5
Denton	Census Tract 217.49	6.1
Denton	Census Tract 217.48	5.8
Denton	Census Tract 217.22	10.6
Denton	Census Tract 203.06	12.7
Denton	Census Tract 203.07	7.4
Denton	Census Tract 217.46	7.8
Denton	Census Tract 217.18	5.8
Denton	Census Tract 213.04	15.1
Denton	Census Tract 203.08	6.8
Denton	Census Tract 203.09	13.1
Denton	Census Tract 205.05	7.8
Denton	Census Tract 205.04	23.7

Denton	Census Tract 214.04	7.6
Denton	Census Tract 205.06	10.6
Denton	Census Tract 214.09	12.3
Denton	Census Tract 201.14	19.6
Denton	Census Tract 215.27	7.4
Denton	Census Tract 215.15	8.5
Denton	Census Tract 217.25	5.5
Denton	Census Tract 203.10	7.4
Denton	Census Tract 214.07	17.1
Denton	Census Tract 212.01	31.3
Denton	Census Tract 214.06	5.9
Denton	Census Tract 205.03	26.4
Denton	Census Tract 201.12	7.4
Denton	Census Tract 215.22	10.6
Denton	Census Tract 215.25	5.3
Denton	Census Tract 219	5.0
Denton	Census Tract 214.05	17.5
Denton	Census Tract 201.15	14.3
Denton	Census Tract 201.07	10.1
Denton	Census Tract 202.05	12.3
Denton	Census Tract 201.06	8.7
Denton	Census Tract 201.03	12.0
Denton	Census Tract 202.04	10.8
Denton	Census Tract 216.16	20.3
Denton	Census Tract 216.12	11.2
Denton	Census Tract 217.26	7.3
Denton	Census Tract 217.29	7.4
Denton	Census Tract 217.31	7.6
Denton	Census Tract 217.32	13.4
Denton	Census Tract 217.34	24.3
Denton	Census Tract 217.33	21.4
Denton	Census Tract 213.01	30.4
Denton	Census Tract 216.15	12.0
Denton	Census Tract 215.02	23.3
Denton	Census Tract 216.14	12.8
Denton	Census Tract 209	37.0
Denton	Census Tract 203.05	5.7
Denton	Census Tract 216.13	23.6

Denton	Census Tract 208	25.3
Denton	Census Tract 210	28.2
Denton	Census Tract 217.35	13.9
Denton	Census Tract 217.36	8.8
Denton	Census Tract 217.38	11.3
Denton	Census Tract 217.37	14.0
Denton	Census Tract 217.28	24.1
Denton	Census Tract 202.03	13.5
Denton	Census Tract 204.03	23.8
Denton	Census Tract 203.03	8.6
Denton	Census Tract 207	33.3
Denton	Census Tract 204.02	11.9
Denton	Census Tract 202.02	9.8
Denton	Census Tract 206.01	34.0
Denton	Census Tract 204.01	16.4
Denton	Census Tract 215.05	11.0
Ellis	Census Tract 602.09	8.2
Ellis	Census Tract 602.10	11.4
Ellis	Census Tract 602.12	9.2
Ellis	Census Tract 602.08	7.2
Ellis	Census Tract 607.01	11.3
Ellis	Census Tract 608.03	19.9
Ellis	Census Tract 608.02	12.7
Ellis	Census Tract 607.03	15.0
Ellis	Census Tract 602.14	9.1
Ellis	Census Tract 607.02	18.0
Ellis	Census Tract 608.01	5.4
Ellis	Census Tract 602.11	10.5
Ellis	Census Tract 602.13	11.2
Ellis	Census Tract 606	18.1
Ellis	Census Tract 603	17.8
Ellis	Census Tract 612	18.4
Ellis	Census Tract 611	19.9
Ellis	Census Tract 605	22.9
Ellis	Census Tract 604	33.7
Ellis	Census Tract 602.07	14.9
Ellis	Census Tract 602.06	20.5
Ellis	Census Tract 609	10.8

Ellis	Census Tract 610	17.2
Ellis	Census Tract 601.02	19.4
Ellis	Census Tract 602.04	9.9
Ellis	Census Tract 617	15.7
Ellis	Census Tract 616	30.8
Ellis	Census Tract 615	35.4
Ellis	Census Tract 614	13.9
Ellis	Census Tract 613	21.4
Ellis	Census Tract 601.01	17.4
Erath	Census Tract 9502.01	26.4
Erath	Census Tract 9502.02	16.8
Erath	Census Tract 9504	23.6
Erath	Census Tract 9506	29.2
Erath	Census Tract 9507	17.6
Erath	Census Tract 9501	11.1
Erath	Census Tract 9505	23.3
Erath	Census Tract 9503	23.9
Hood	Census Tract 1602.10	7.6
Hood	Census Tract 1602.09	10.2
Hood	Census Tract 1603.01	13.3
Hood	Census Tract 1602.08	28.1
Hood	Census Tract 1603.02	17.2
Hood	Census Tract 1602.06	12.9
Hood	Census Tract 1602.05	18.1
Hood	Census Tract 1602.07	11.6
Hood	Census Tract 1602.04	10.9
Hood	Census Tract 1601	19.8
Hunt	Census Tract 9615.01	12.2
Hunt	Census Tract 9615.02	17.3
Hunt	Census Tract 9615.03	17.4
Hunt	Census Tract 9612	9.2
Hunt	Census Tract 9611	11.0
Hunt	Census Tract 9610	29.9
Hunt	Census Tract 9608	39.8
Hunt	Census Tract 9604	16.7
Hunt	Census Tract 9606	33.4
Hunt	Census Tract 9605	36.5
Hunt	Census Tract 9601	20.8

Hunt	Census Tract 9603	18.1
Hunt	Census Tract 9614	13.9
Hunt	Census Tract 9602	20.9
Hunt	Census Tract 9617	20.8
Hunt	Census Tract 9616	30.5
Hunt	Census Tract 9607	14.9
Hunt	Census Tract 9609	34.2
Hunt	Census Tract 9613	20.3
Johnson	Census Tract 1302.04	12.7
Johnson	Census Tract 1305	12.6
Johnson	Census Tract 1301	13.3
Johnson	Census Tract 1302.05	16.5
Johnson	Census Tract 1311	17.9
Johnson	Census Tract 1307	19.1
Johnson	Census Tract 1310	12.0
Johnson	Census Tract 1309	34.3
Johnson	Census Tract 1308	36.2
Johnson	Census Tract 1304.05	10.0
Johnson	Census Tract 1303.02	27.4
Johnson	Census Tract 1302.08	13.9
Johnson	Census Tract 1302.07	7.3
Johnson	Census Tract 1304.09	12.1
Johnson	Census Tract 1304.08	18.1
Johnson	Census Tract 1304.10	22.0
Johnson	Census Tract 1304.06	9.4
Johnson	Census Tract 1304.07	23.6
Johnson	Census Tract 1302.14	14.5
Johnson	Census Tract 1306.01	15.9
Johnson	Census Tract 1303.03	25.4
Johnson	Census Tract 1302.11	17.8
Johnson	Census Tract 1302.15	6.5
Johnson	Census Tract 1303.04	24.2
Johnson	Census Tract 1302.10	9.2
Johnson	Census Tract 1302.12	19.5
Johnson	Census Tract 1306.02	13.5
Johnson	Census Tract 1302.13	14.7
Kaufman	Census Tract 507.03	24.0
Kaufman	Census Tract 502.04	12.2

Kaufman	Census Tract 502.05	10.7
Kaufman	Census Tract 512.01	28.5
Kaufman	Census Tract 512.02	13.3
Kaufman	Census Tract 507.04	22.1
Kaufman	Census Tract 502.03	6.7
Kaufman	Census Tract 502.06	10.8
Kaufman	Census Tract 510	33.5
Kaufman	Census Tract 503	25.8
Kaufman	Census Tract 506	15.0
Kaufman	Census Tract 508	13.2
Kaufman	Census Tract 504	22.5
Kaufman	Census Tract 511	21.5
Kaufman	Census Tract 505	28.8
Kaufman	Census Tract 513	20.3
Kaufman	Census Tract 502.01	12.7
Kaufman	Census Tract 507.01	13.6
Navarro	Census Tract 9701	25.7
Navarro	Census Tract 9706	19.2
Navarro	Census Tract 9710	24.6
Navarro	Census Tract 9708	27.2
Navarro	Census Tract 9705	24.7
Navarro	Census Tract 9709	28.8
Navarro	Census Tract 9707	26.1
Navarro	Census Tract 9703	20.5
Navarro	Census Tract 9702	21.2
Navarro	Census Tract 9704	17.8
Palo Pinto	Census Tract 2	15.9
Palo Pinto	Census Tract 3	11.5
Palo Pinto	Census Tract 8	30.3
Palo Pinto	Census Tract 9	35.4
Palo Pinto	Census Tract 7	19.9
Palo Pinto	Census Tract 6	26.0
Palo Pinto	Census Tract 5	25.0
Palo Pinto	Census Tract 4	12.7
Palo Pinto	Census Tract 1	18.1
Parker	Census Tract 1401.01	21.0
Parker	Census Tract 1404.08	14.0
Parker	Census Tract 1407.05	14.4

Parker	Census Tract 1407.03	11.3
Parker	Census Tract 1407.04	8.8
Parker	Census Tract 1407.06	6.7
Parker	Census Tract 1404.09	25.9
Parker	Census Tract 1404.10	17.3
Parker	Census Tract 1405.01	9.3
Parker	Census Tract 1401.02	23.6
Parker	Census Tract 1404.11	18.6
Parker	Census Tract 1405.02	13.2
Parker	Census Tract 1404.03	16.9
Parker	Census Tract 1404.07	9.3
Parker	Census Tract 1402	12.9
Parker	Census Tract 1406.02	16.2
Parker	Census Tract 1403	15.3
Parker	Census Tract 1406.01	9.5
Parker	Census Tract 1404.05	13.5
Rockwall	Census Tract 404.01	17.2
Rockwall	Census Tract 405.05	8.6
Rockwall	Census Tract 405.03	20.1
Rockwall	Census Tract 405.06	6.7
Rockwall	Census Tract 401.01	6.9
Rockwall	Census Tract 405.04	7.1
Rockwall	Census Tract 404.02	9.7
Rockwall	Census Tract 401.02	9.1
Rockwall	Census Tract 403.02	11.5
Rockwall	Census Tract 403.01	12.8
Rockwall	Census Tract 402	8.9
Somervell	Census Tract 2	14.9
Somervell	Census Tract 1	16.1
Tarrant	Census Tract 1050.07	14.7
Tarrant	Census Tract 1139.26	10.2
Tarrant	Census Tract 1050.08	13.1
Tarrant	Census Tract 1140.08	12.3
Tarrant	Census Tract 1059.02	46.1
Tarrant	Census Tract 1047.02	36.6
Tarrant	Census Tract 1048.03	42.8
Tarrant	Census Tract 1111.04	19.9
Tarrant	Census Tract 1102.02	19.9

Tarrant	Census Tract 1102.03	14.9
Tarrant	Census Tract 1102.04	13.2
Tarrant	Census Tract 1103.01	33.3
Tarrant	Census Tract 1103.02	34.1
Tarrant	Census Tract 1104.01	12.8
Tarrant	Census Tract 1104.02	30.8
Tarrant	Census Tract 1105	20.6
Tarrant	Census Tract 1134.04	13.5
Tarrant	Census Tract 1134.05	19.2
Tarrant	Census Tract 1134.07	37.4
Tarrant	Census Tract 1134.08	16.0
Tarrant	Census Tract 1113.06	18.6
Tarrant	Census Tract 1112.02	28.7
Tarrant	Census Tract 1036.01	52.6
Tarrant	Census Tract 1036.02	25.3
Tarrant	Census Tract 1216.05	13.1
Tarrant	Census Tract 1216.06	11.6
Tarrant	Census Tract 1216.08	10.4
Tarrant	Census Tract 1216.09	6.9
Tarrant	Census Tract 1216.10	9.6
Tarrant	Census Tract 1216.11	13.8
Tarrant	Census Tract 1217.02	29.4
Tarrant	Census Tract 1217.03	40.6
Tarrant	Census Tract 1135.20	11.2
Tarrant	Census Tract 1135.19	9.1
Tarrant	Census Tract 1132.21	9.7
Tarrant	Census Tract 1132.20	23.5
Tarrant	Census Tract 1139.23	10.7
Tarrant	Census Tract 1139.25	15.1
Tarrant	Census Tract 1139.24	15.3
Tarrant	Census Tract 1131.02	18.2
Tarrant	Census Tract 1131.04	22.0
Tarrant	Census Tract 1131.07	7.2
Tarrant	Census Tract 1131.08	11.1
Tarrant	Census Tract 1131.10	25.4
Tarrant	Census Tract 1131.11	39.7
Tarrant	Census Tract 1037.01	39.7
Tarrant	Census Tract 1037.02	38.0

Tarrant	Census Tract 1046.01	29.8
Tarrant	Census Tract 1046.02	48.2
Tarrant	Census Tract 1046.03	35.4
Tarrant	Census Tract 1046.05	34.6
Tarrant	Census Tract 1060.01	19.0
Tarrant	Census Tract 1217.04	33.0
Tarrant	Census Tract 1221	30.6
Tarrant	Census Tract 1222	39.3
Tarrant	Census Tract 1223	34.0
Tarrant	Census Tract 1224	30.4
Tarrant	Census Tract 1227	27.7
Tarrant	Census Tract 1229	31.4
Tarrant	Census Tract 1115.29	6.5
Tarrant	Census Tract 1139.19	9.4
Tarrant	Census Tract 1048.04	40.3
Tarrant	Census Tract 1139.27	8.3
Tarrant	Census Tract 1139.29	4.3
Tarrant	Census Tract 1139.28	5.0
Tarrant	Census Tract 1108.07	19.3
Tarrant	Census Tract 1108.08	7.6
Tarrant	Census Tract 1026.01	25.4
Tarrant	Census Tract 1131.12	29.4
Tarrant	Census Tract 1132.06	15.2
Tarrant	Census Tract 1132.07	7.0
Tarrant	Census Tract 1132.10	7.6
Tarrant	Census Tract 1132.12	10.6
Tarrant	Census Tract 1132.13	17.6
Tarrant	Census Tract 1132.14	11.3
Tarrant	Census Tract 1060.02	24.8
Tarrant	Census Tract 1060.04	27.2
Tarrant	Census Tract 1061.01	23.5
Tarrant	Census Tract 1061.02	34.8
Tarrant	Census Tract 1062.01	35.1
Tarrant	Census Tract 1062.02	38.8
Tarrant	Census Tract 1063	38.5
Tarrant	Census Tract 1115.45	10.1
Tarrant	Census Tract 1115.13	11.7
Tarrant	Census Tract 1115.36	24.7

Tarrant	Census Tract 1115.37	13.6
Tarrant	Census Tract 1115.38	14.8
Tarrant	Census Tract 1115.39	13.4
Tarrant	Census Tract 1130.01	8.8
Tarrant	Census Tract 1130.02	24.1
Tarrant	Census Tract 1026.02	22.9
Tarrant	Census Tract 1139.21	9.2
Tarrant	Census Tract 1138.15	5.6
Tarrant	Census Tract 1138.16	6.1
Tarrant	Census Tract 1138.12	7.9
Tarrant	Census Tract 1138.13	5.3
Tarrant	Census Tract 1111.03	27.6
Tarrant	Census Tract 1141.03	6.2
Tarrant	Census Tract 1141.04	6.2
Tarrant	Census Tract 1132.15	12.3
Tarrant	Census Tract 1132.16	20.5
Tarrant	Census Tract 1132.17	13.0
Tarrant	Census Tract 1132.18	5.8
Tarrant	Census Tract 1133.01	14.1
Tarrant	Census Tract 1133.02	22.8
Tarrant	Census Tract 1134.03	10.7
Tarrant	Census Tract 1064	33.7
Tarrant	Census Tract 1110.05	28.7
Tarrant	Census Tract 1111.02	26.3
Tarrant	Census Tract 1110.13	12.6
Tarrant	Census Tract 1057.03	21.6
Tarrant	Census Tract 1110.03	11.7
Tarrant	Census Tract 1058	22.1
Tarrant	Census Tract 1114.04	14.6
Tarrant	Census Tract 1114.05	21.4
Tarrant	Census Tract 1115.32	10.8
Tarrant	Census Tract 1113.04	8.2
Tarrant	Census Tract 1115.06	17.4
Tarrant	Census Tract 1115.26	21.2
Tarrant	Census Tract 1142.06	12.2
Tarrant	Census Tract 1108.06	6.9
Tarrant	Census Tract 1142.07	10.4
Tarrant	Census Tract 1106	12.2

Tarrant	Census Tract 1001.01	25.5
Tarrant	Census Tract 1001.02	26.0
Tarrant	Census Tract 1002.01	34.1
Tarrant	Census Tract 1045.03	34.1
Tarrant	Census Tract 1045.02	38.5
Tarrant	Census Tract 1048.02	35.2
Tarrant	Census Tract 1057.01	18.2
Tarrant	Census Tract 1043	20.8
Tarrant	Census Tract 1042.02	16.6
Tarrant	Census Tract 1041	20.7
Tarrant	Census Tract 1110.08	14.6
Tarrant	Census Tract 1225	13.2
Tarrant	Census Tract 1226	16.3
Tarrant	Census Tract 1113.01	14.4
Tarrant	Census Tract 1002.02	29.9
Tarrant	Census Tract 1003	37.0
Tarrant	Census Tract 1004	30.6
Tarrant	Census Tract 1005.01	30.5
Tarrant	Census Tract 1005.02	35.4
Tarrant	Census Tract 1006.01	19.2
Tarrant	Census Tract 1006.02	18.9
Tarrant	Census Tract 1007	32.7
Tarrant	Census Tract 1055.11	19.9
Tarrant	Census Tract 1055.12	10.5
Tarrant	Census Tract 1055.08	15.9
Tarrant	Census Tract 1056	16.8
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Wise	Census Tract 1501.01	12.8

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