SPATIO-TEMPORAL ANALYSIS OF ASTHMA HOSPITALIZATIONS AND ASSOCIATED FACTORS IN EASTERN TEXAS, 2005-2012

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ABSTRACT

The prevalence of asthma is increasing for both adult and children in eastern Texas. This study examines the spatial and temporal differences in asthma hospital discharge rates and its association with socioeconomic risk indicators, air pollutants (ozone and NO_2) and meteorological variables (temperature, wind speed, and wind direction to an extent). Socioeconomic risk indicators were subjected to principal component analysis to create socioeconomic deprivation index for each county. Annual and diurnal temporal distribution of ozone, NO_2, temperature and wind speed were analyzed to understand their characteristics during a wet year (2007) and a dry year (2011). Hotspot analysis and Cluster Outlier analysis of asthma hospitalization examined its association with aforementioned environmental variables at selected metro area in eastern Texas. Socioeconomic indicators were associated with asthma hospital discharge rate both at county and across census tracts in metro areas. Instances when ozone production doesn't coincide with the NOx and temperature in coastal cities, wind speed and wind direction may play a role. Ozone and NO_2 has an inverse relationship with adult and child asthma discharges. Temperature was the only environmental variable with significant association to children asthma discharge rate. Enough evidences exist to suggest high asthma hospital discharges in eastern Texas, but ozone is not a standalone risk factor. Further analysis of weather patterns and air pollutants is required to develop effective asthma action plan.

Chapter 1 - Introduction

Asthma is a chronic lung disease that causes inflammation and narrowing of the airways which can lead to wheezing, shortness of breath, and tightness of chest (NIH, 2014). There is large degree of consensus among scientists that chronic exposure to ambient concentration of air pollutants (tropospheric ozone and PM2.5) leads to negative health effects (Schwartz, 2004; Samet and Krewski, 2007; Perez et al., 2013). There are also suggestions that air pollutants contribute to moderate or severe asthma exacerbations and new onset of asthma in children and adults alike (Vardoulakis and Osborne, 2018; Orellano et al., 2017). Extensive studies suggest asthma incidence is occurring at higher frequencies (Brozek et al., 2015; Eder et al., 2006; Lundback et al., 2016). According to Centers for Disease Control and prevention (CDC), the incidence of asthma has grown to 1 in 14 people in 2009 compared to 1 in 12 people in 2001 (CDC, 2011). Chronic exposure to asthma agents can cause the situation to worsen leading to chronic obstructive pulmonary diseases (COPD), increased hospitalizations, significant medical costs and eventually resulting in death (Ko et al., 2007; Shima et al., 2002). Figure 1 shows the trend of lifetime and current asthma prevalence for children and adult during 2005 to 2014 based on Behavioral Risk factor Surveillance System in Texas.

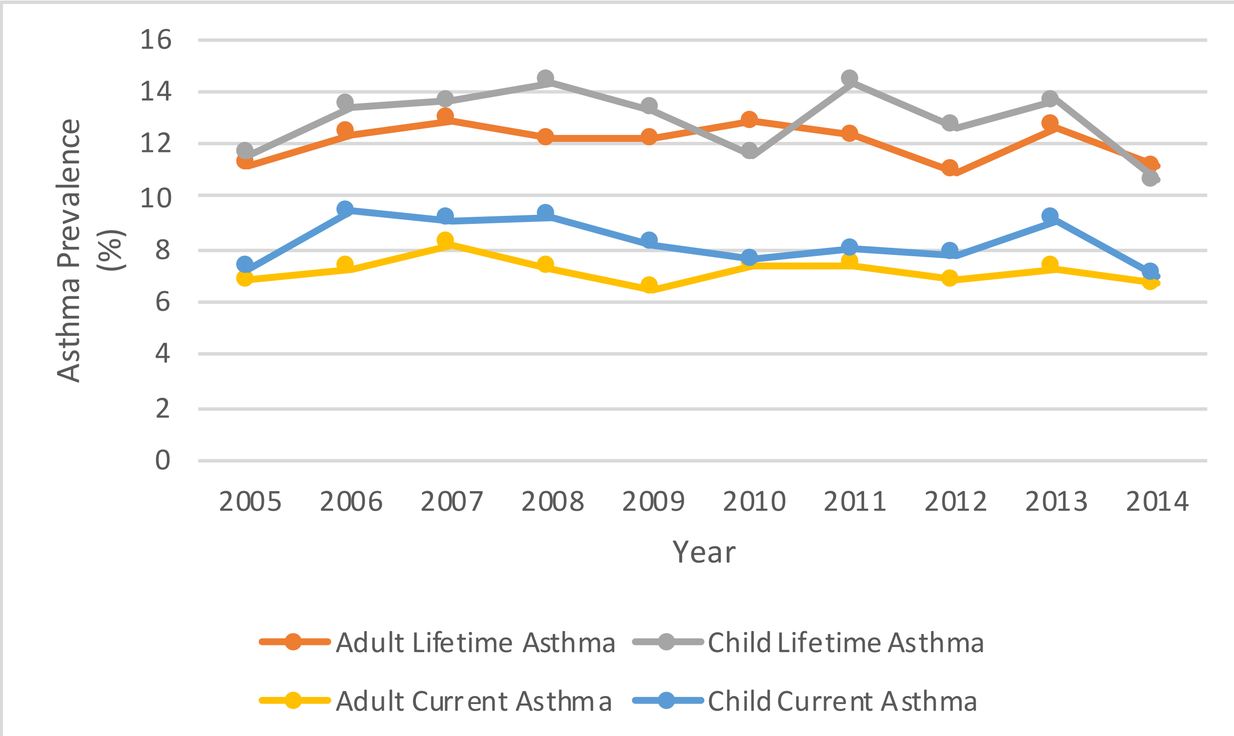


Figure 1: Lifetime and Current Asthma Prevalence for children and adults in Texas, 2005-2014

The prevalence and incidence rate of asthma has been increasing worldwide in recent decades. According to Global Initiative for Asthma (GINA), more than 300 million people are estimated to have asthma worldwide, whereas 100 million additional patients are estimated to have asthma by 2025 (Nunes et al., 2016). A National Health Interview Survey (NHIS) conducted in 2012 reports that about 40 million people suffer from lifetime asthma (13% of US population) and 26 million suffer from current asthma (8%) in the United States (CDC, 2019). Another research study conducted by Winer et al. (2012) showed that the overall asthma incidence in children up to 5 years old (23/1000 children per year) was 5 times higher compared to youths aged 12-17 years old (4.4/1000 per year). Notably, adult females had twice as much asthma incidence compared to adult males (4.9/1000 per year vs 2.8/1000 per year respectively).

Asthma is a huge public health issue, not only in United States, but also in Texas. The Asthma and Allergy Foundation of America (AAFA) has listed six metropolitan cities from Texas in the top 100 most challenging places to live with asthma in 2019 Asthma Capitals national rankings. Dallas is listed at #76, followed by Austin (#77), San Antonio (#94), El Paso (#95), Houston (#98) and McAllen (#99). The cities are ranked based on three health outcomes: prevalence, emergency room visits and mortality (AAFA, 2019). More than 1.4 million adults (7.3% Texans) and 617,000 children (9.1%) had asthma according to 2014 Asthma Burden Report, Texas DSHS (Wickerham, 2014). In Texas, current female adult asthma prevalence is almost twice as male adult asthma prevalence and current male child asthma prevalence is higher than female child asthma prevalence (Figure 2). The asthma prevalence for both genders reveals a decreasing trend.

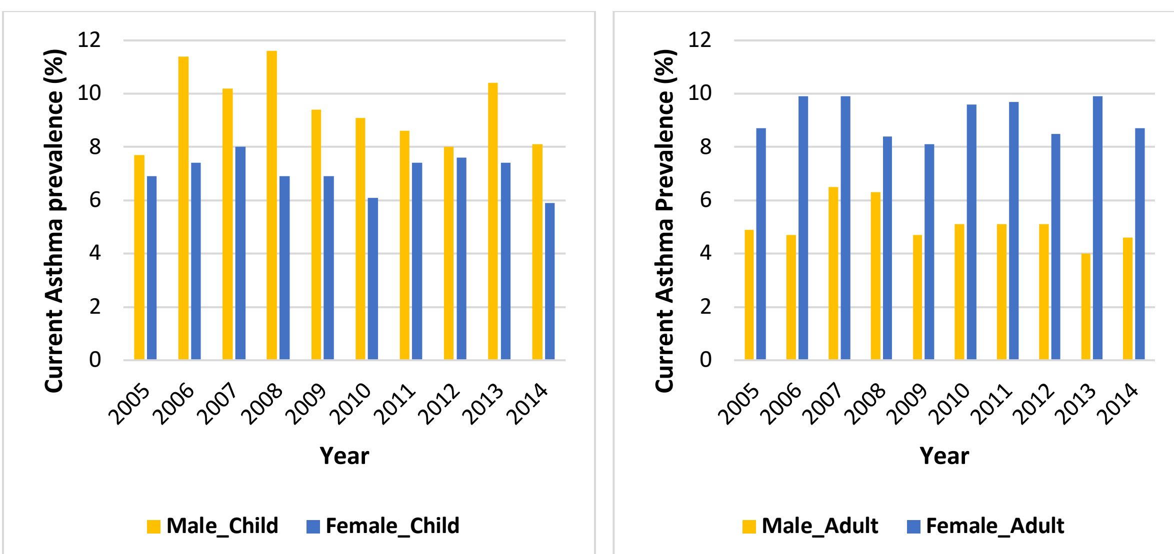


Figure 2: Current Asthma Prevalence for children and adults by gender in Texas, 2005-2014

Texas is the second most populous state in the U.S., with a population estimated to be close to 27,419,600 (8.67% of U.S. population) according to the 2017 American Community Survey, U.S. Bureau of Census estimates. Based on the estimates, approximately 42.87% of the population of Texas is White (not Hispanic or Latino), 38.93% is Hispanic or Latino and 11.99% is Black or African American. There are 254 counties in Texas, of which 191 are considered rural. However, only an estimated 11% of the population live in rural areas while most Texans live in urban areas. Major populations live in the Dallas-Fort Worth-Arlington metropolitan area followed by the Houston-The Woodlands-Sugarland, San Antonio, Austin, El Paso and Brownsville areas. Hispanic populations are highly concentrated in the South and West Texas (more than 25%), a contrast to lower concentration of Hispanics in Eastern and Central Texas, except the major urban areas. Along with this spatial distribution of population, there is also a noticeable spatial variation in poverty levels in Texas. Sixteen percent of people live below the poverty level in Texas, 4% higher than United States in general. More than 30% of the population lives in poverty in Brooks, Cameron, Hidalgo, Starr, Webb, Willacy and Zapata counties in South Texas and Hudspeth county near El Paso. Counties with the lowest population living in poverty are found in some counties with major urban areas. Disparities in asthma prevalence can be observed in Texas by gender, ethnicity and geographic regions of the state. Large parts of west Texas have low population density and many counties have no continuous air pollutant monitoring stations at all. In this study, eastern Texas is selected as the area of the study. Only the populous counties and metro areas was used for analytical purposes for this study.

Although there have been major advances in asthma diagnosis and treatment, people still die from asthma related issues in Texas (Wickerham, 2014). There were 1,429 asthma related deaths among all ages between 2006-2012. The age adjusted asthma mortality rate has decreased from 13.2 per 1 million people in 2002 to 8.4 per 1 million people in 2012. Females have significantly higher age adjusted mortality rate (10.6 per 1 million) compared to males (7.1 per 1 million). In terms of ethnicity, age adjusted mortality rate among blacks (19.7 per 1 million) is more than double as that of whites (8.8 per 1 million) and more than three times that of Hispanics (5.6 per 1 million). Although no cure for asthma is currently available, guidelines to ease and control exacerbations through proper management, education and avoidance of environmental triggers are typically given to patients. According to Nurmagambetov et al. (2018), the annual economic cost of asthma was 81.9 billion in U.S. during 2008-2013 – including medical costs and loss of work and school days. A combined more than 300 million dollars was spent in 2014 on asthma related care for children and adults aged 65+ years in Texas. According to the same report more than 90% of hospitalization were potentially preventable which means the hospitalization would likely have been prevented if an individual who was hospitalized had access to a primary care physician and had followed guidelines to control and self-manage asthma on a daily basis and in case of worsening symptoms. All in all, asthma burden has many direct, indirect and intangible costs which are difficult to estimate (Nunes et al., 2017). Direct asthma burden includes visit to emergency services, hospitalizations, medications and complementary treatments. Indirect asthma burden includes costs related to loss of school and workdays, and early mortality. Intangible asthma burden includes cost related to changes in quality of life.

Socioeconomic status has been used to assess health quality of life, disease prevalence and mortality in Europe (Dalstra et al., 2005; Mielck et al., 2014), America (Adler and Newman, 2002; Bravemen et al., 2010), Australia and New Zealand (Pathirana and Jackson, 2018). Although asthma is a multifactorial disorder and may be caused through combined action of history of atopy (a genetic tendency to develop allergic disease), social and environmental factors (Gong et al., 2014), many studies have examined the association of socioeconomic factors and asthma hospitalization (Thompsen, 2015). However, the relation of socioeconomic status to asthma have not been completely elucidated. Much research has associated high incidence of asthma with low socioeconomic status (Azeez et al., 2016; Basagaña et al., 2004; Chen et al., 2016, Gong et al., 2014). Few studies also suggest low levels of asthma in low socioeconomic status groups is related to the hygiene hypothesis (Kant, 2013), or no association at all (Hancox et al., 2004). The variations in results may be attributed to the type of study designs or what socioeconomic risk factors were selected.

Socioeconomic status is a measure that indicates the relative position of an individual or a community in its societal hierarchy (Karnevisto et al., 2011). Socioeconomic status can be measured by combining a comprehensive list of socioeconomic indicators that contribute to susceptibilities that may affect human health. There is no consensus on the risk indicators that are applicable in all settings. To date, studies have used a single indicator or a composite of few to analyze the association between socioeconomic status and asthma hospitalization (Chen et al., 2007; Eagan et al., 2004; Grant et al., 2000), but that is oversimplification of this issue. For a comprehensive understanding, indicators related to education, income, occupation, ethnicity and housing should be taken into consideration simultaneously at the individual and area levels (Singh and Siapush, 2002). In addition to this, previous studies have been focused on the national level (Zahran et al., 2018; Norback et al., 2018; Damgaard et al., 2015) or at the multi-cities level (Thakur et al., 2014; Fattore et al., 2015; O'Lenick et al., 2017). This is mostly because of limited data availability at a local level. However, epidemiological concerns of asthma at local level cannot be underestimated. Thus, there exists a need to tailor research to target the concerns of asthma in smaller communities in order to realize significant and real long-term benefits.

According to American Psychological Association (APA), the National committee in Vital Health and Statistics recommends the aforementioned approach to provide public with in-depth look to conceptualize and measure social class (Diemer at al., 2013).

Asthma has a heterogenous distribution and can differ from community to community. Because there is a lack of gold standard to measure socioeconomic status, a comprehensive approach has been adopted for this study. It is important to define and evaluate the use of socioeconomic indicators to properly estimate the socioeconomic differentials.

Education is one of the frequently used indicators in epidemiological studies. Education captures transition of an individual from childhood to adulthood and determines an individual's future employment and income (Galobardes et al., 2006). It may influence an individual's reception of health education messages. Previous studies concluded that individuals with low educational level had a high risk of developing asthma (Eagan et al., 2004) and had poor asthma control (Bulow et al., 2015). The known current asthma prevalence by educational attainment in Texas is shown in figure 3. Current asthma prevalence based on BRFSS follows an increasing trend for high school graduates but follows a decreasing trend for non-high school graduates, some college and college graduates during 2005 to 2015.

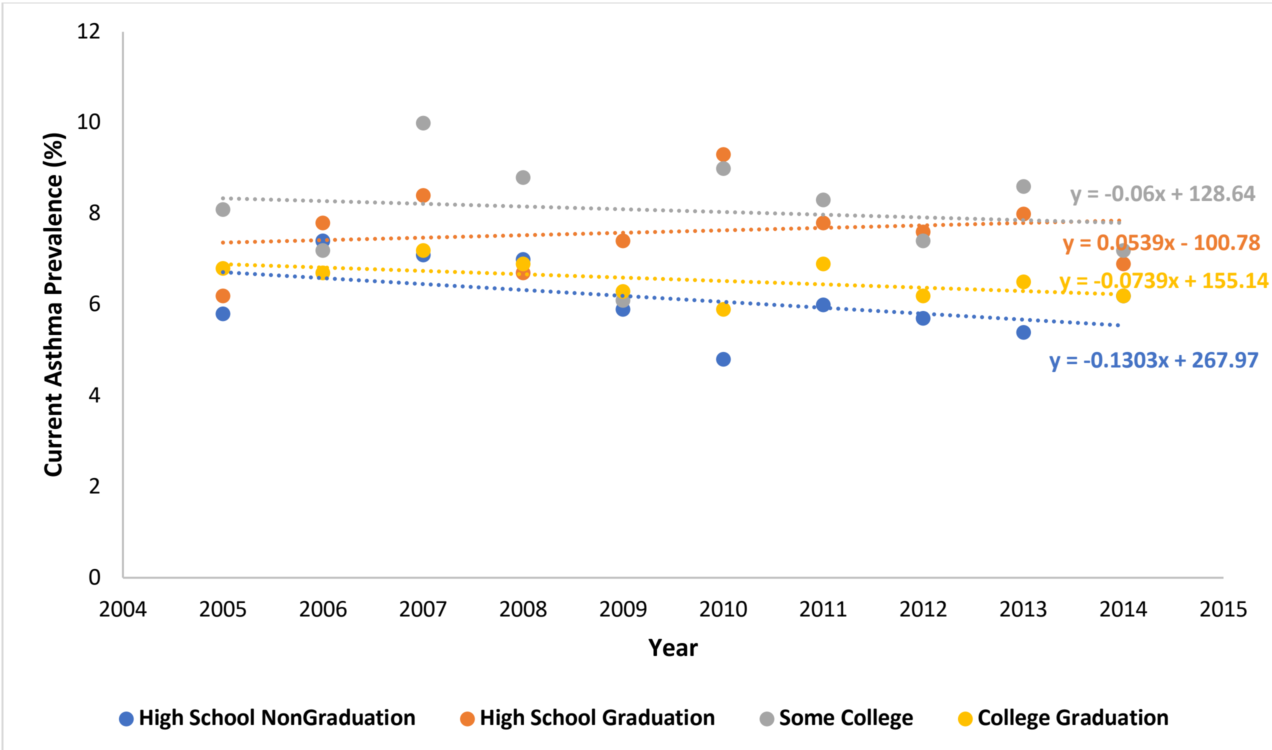


Figure 3: Current asthma prevalence as a function of educational attainment in Texas, 2005-2015

In addition to education, income is another important socioeconomic indicator. Income measures the material resources of a person and influences his/her quality of health through access to better quality food and shelter (Galobardes et al., 2006). According to the State of Nations Housing Report (2017), more than 70% of low-income households spent more than 50% on rent often having to forego other necessities, food and medical care. According to the same report, the number of poor households living in high poverty tracts in low density areas more than doubled in the Austin, Dallas-Fort Worth and Houston metropolitan statistical area (MSA). The known current asthma prevalence by income in Texas is shown in figure 4. Current asthma prevalence based on BRFSS follows an increasing trend for adults with an income between $25,000-$49,000 and follows a decreasing trend for other income ranges during 2005 to 2015.

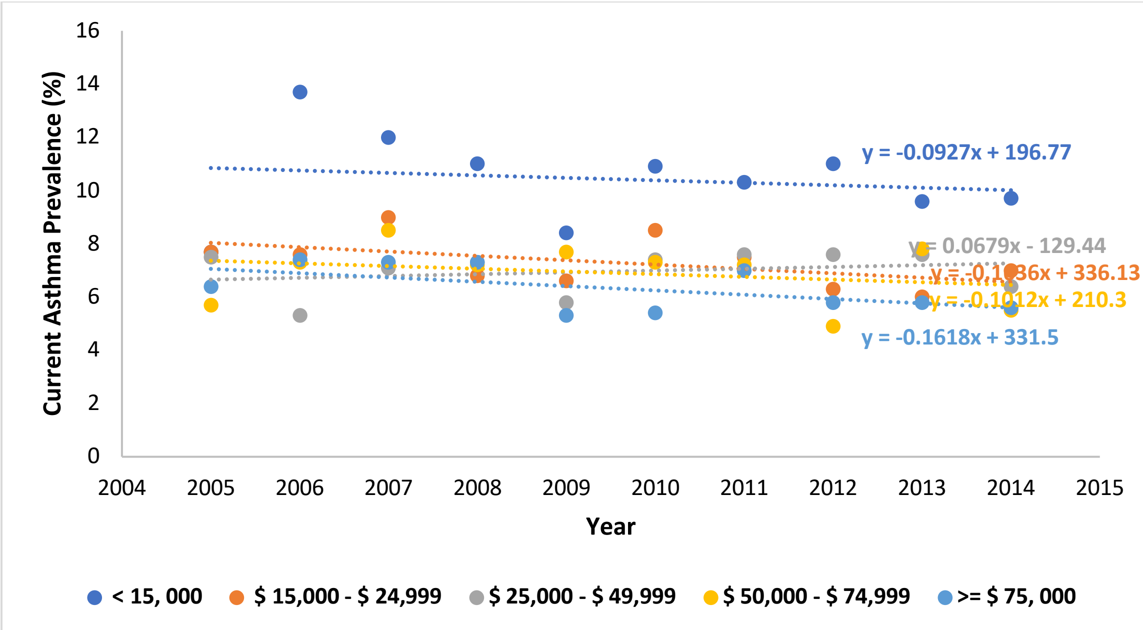


Figure 4: Current asthma prevalence as a function of income for adults in Texas, 2005-2015

Housing indicators reflects the material aspect of socioeconomic circumstances of a household or a person. Aspects of housing, such as, housing is of a poor quality or renter occupied, and there is limited access to household amenities (e.g. kitchen, plumbing, cars etc.), or if the household conditions are overcrowded, can lead to better understanding of the underlying aspects of socioeconomic structure. Studies show that people in renter-owned housing units have higher prevalence of asthma than owner occupied housing units, primarily because of the often-deteriorated conditions associated with renter occupied housing units in inner cities (Rosenbaum, 2008). It has been shown a significant positive association between deteriorated housing conditions and allergens which can lead to exacerbation of asthma (Rauh et al., 2008). Housing has played a significant role in segregating communities based on their income and race. According to Pew Social and Demographic Trends (2012), this has led to ethnic minorities living in high poverty tracts and the continuous deterioration of the housing conditions they live in. Of specific importance, it is recognized that as the conditions of housing deteriorate, the low quality of housing is related to increase in asthmatic conditions because of allergens, mold and dampness (Kanchongkittiphon et al., 2014; Kercsmar et al., 2006).

Maps across census tracts for selected metros were created and analyzed to gain an initial understanding of spatial distribution of child (under 5 years) and elderly population, poverty and income in eastern Texas. Aforementioned socioeconomic and demographic data across census tracts during 2006 to 2010 were acquired from US Bureau of Census for this exploratory analysis.

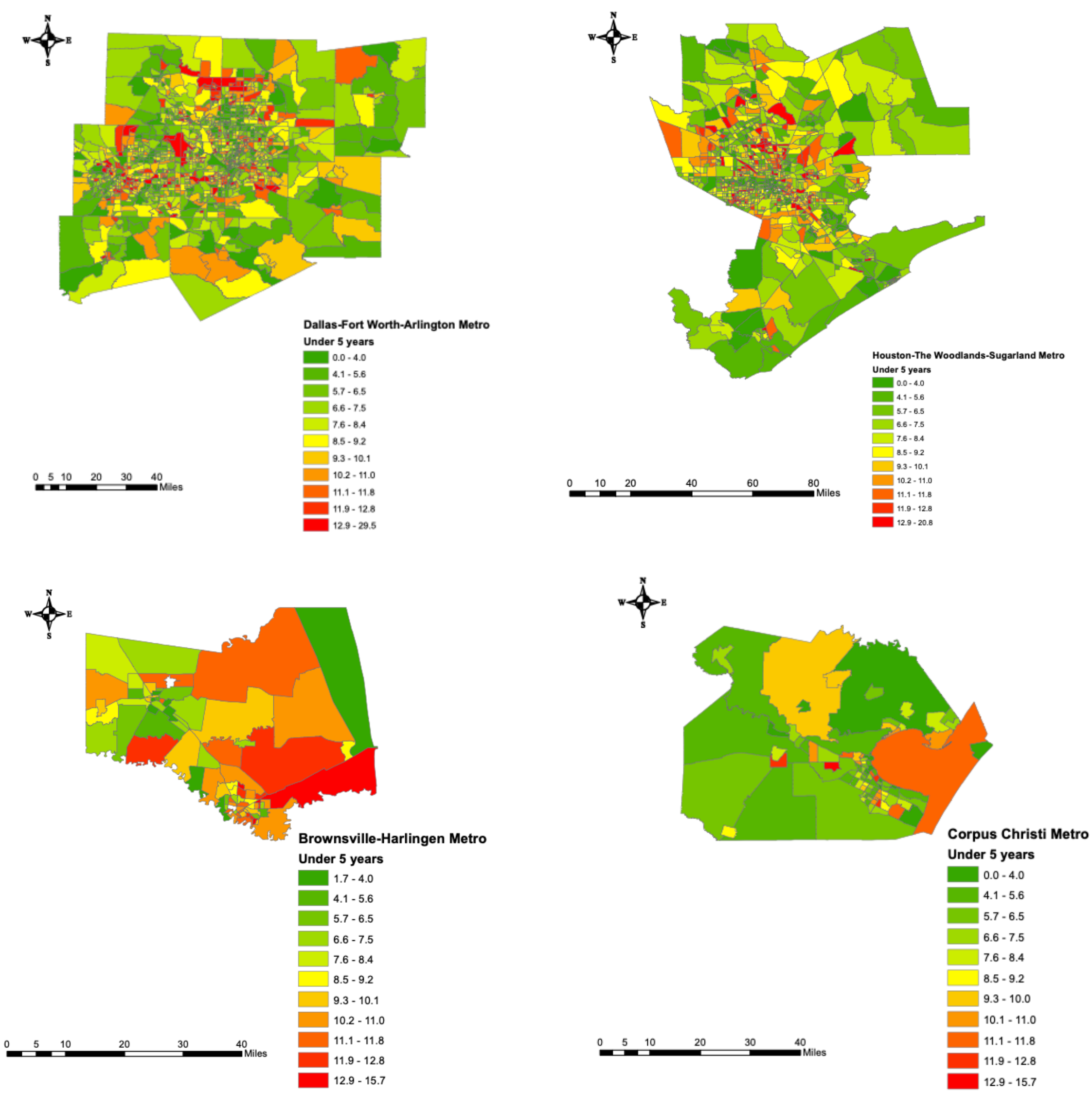


Figure 5: Percentage Children (under 5 years) across census tracts in selected eastern Texas metros, 2006-2010

Most children live in and around metropolitan areas in Texas (CPPP, 2015). Figure 5 shows the similar trends for metro areas in eastern Texas during 2006 to 2010.

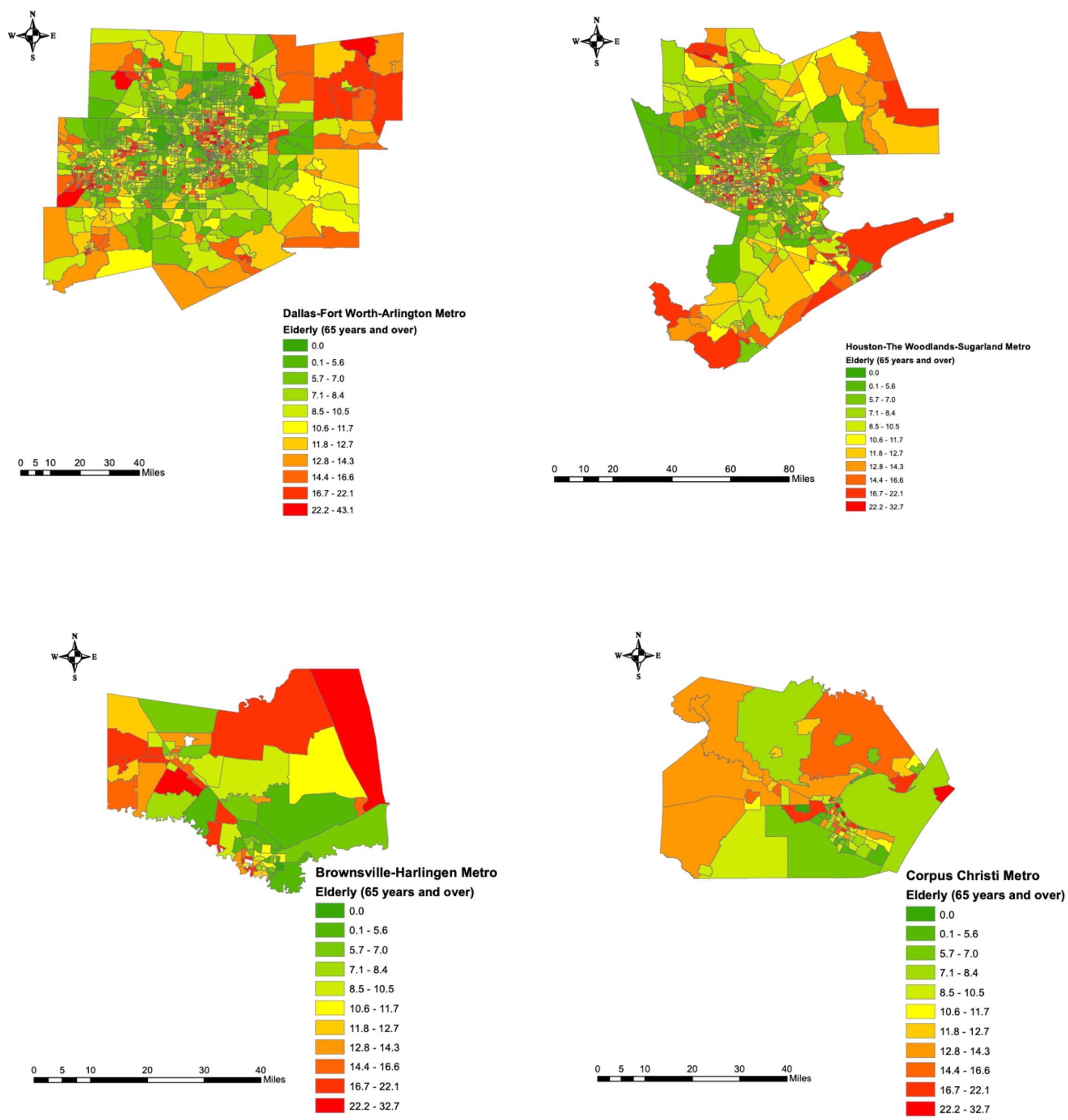


Figure 6: Percentage Elderly 65 (years and over) across census tracts in selected eastern Texas metros, 2006-2010

Among the metro areas shown above, Corpus Christi metro had highest elderly population (12%). Nearly 15% of Texans are 65 years and older as of 2019, and older population will make 1/5th of Texan population by 2040 according UT News (2019). Because elderly population have higher prevalence of diseases, they require careful monitoring.

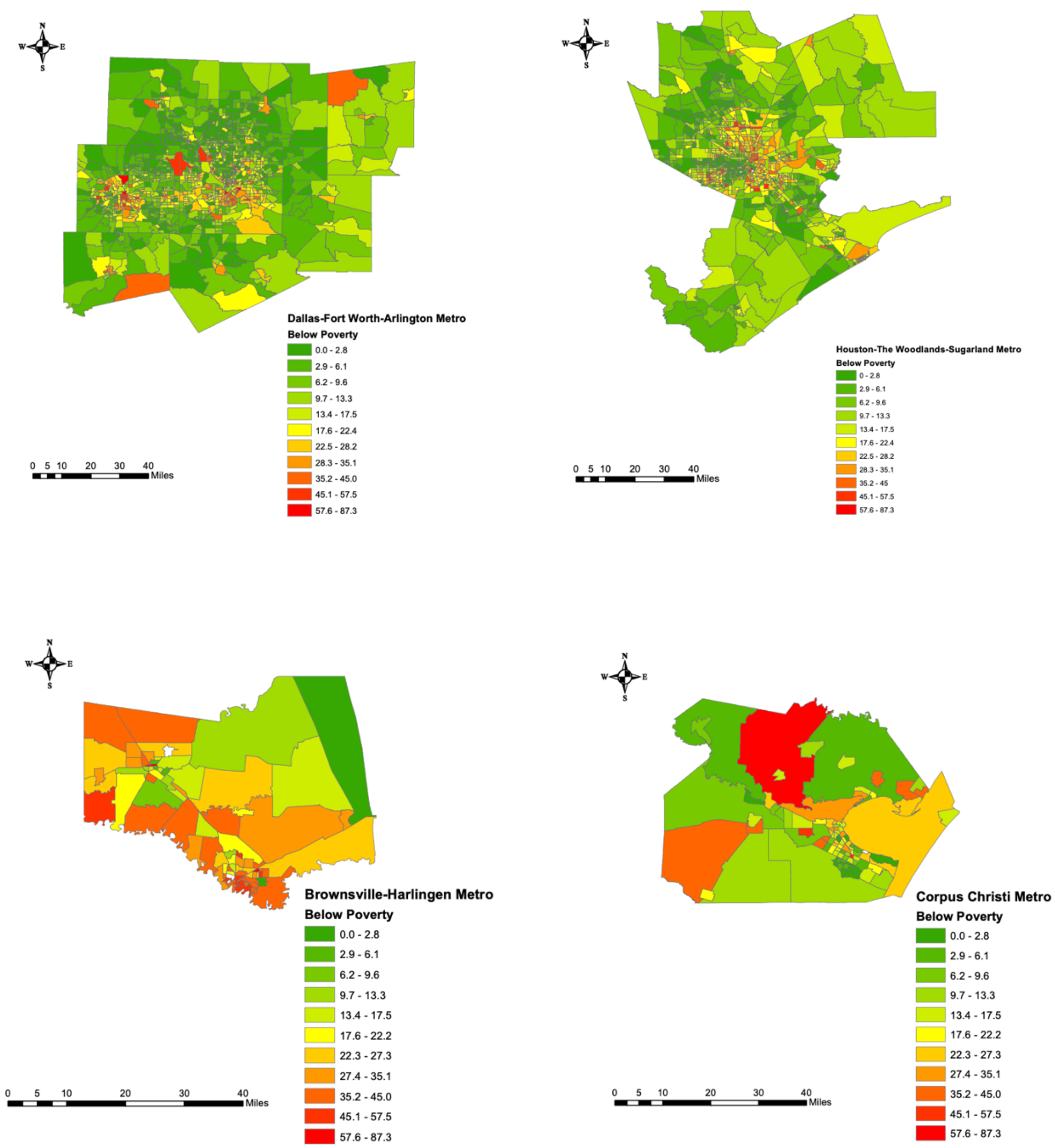


Figure 7: Percentage poverty across census tracts in selected eastern Texas metros, 2006-2010

Figure 7 shows the percentage of poverty across census tracts in selected eastern Texas metros during 2006 to 2010. Census Bureau uses income thresholds based on family size and family composition to determine percentage of families who live below poverty in United States (U.S. Census Bureau, 2019). According to an example, U.S. Census Bureau determines 2018 poverty threshold of $30,718 for a family with 2 children, 1 father, 1 mother and 1 grand-aunt based on the total family income. If the family income is below poverty threshold, the whole family is considered to live in poverty whereas if the family income is above poverty threshold, the family is considered to live in poverty. Brownsville-Harlingen was ranked as #2 poorest city in America based on 2011 U.S. Bureau Census data (Cohen, 2013). Almost 30% of people in Brownsville-Harlingen metro live under poverty. This statistic is evident in figure 7. Corpus Christi metro has a poverty rate of 14.85%. Hunt (14.4%), Dallas (14.3%) and Tarrant (10.4%) counties record high poverty rate in Dallas-Fort Worth-Arlington area. Houston-The Woodlands-Sugarland metro has higher poverty rate (9.3%) than Dallas-Fort Worth-Arlington metro (8.9%). Harris county has the highest poverty rate in Houston-The Woodlands-Sugarland metro. Poverty is prominent in inner cities and neighborhoods.

Many studies have provided evidence that air pollutants continue to be a growing problem in urban cities (Banta et al., 2005; Cohen et al. 2005; Hankey and Marshall, 2017) and increases in the concentrations of air pollutants have an adverse effect on a wide range of human health issues like: respiratory health, cardiovascular disease, reduction in lung function, asthma and death on rare occasions (Anderson et al., 2013; Gorai et al., 2014; Perez et al., 2013; Samet and Krewski, 2007). The impact of ambient air pollutants and meteorological conditions on health studies has been of ongoing concern because air pollutants have been associated with increased numbers of hospital admissions, emergency room visits and asthma symptoms (Simoni et al., 2015). According to recent studies cited by the Environmental Protection Agency (EPA), air pollutants can harm human health even at low concentrations (EPA, 2019). This has led to implementation of stricter standards for criteria pollutants like ozone, NO_2, particulate matters etc. because the existing standards are not adequate.

Ozone is a secondary pollutant and its production is favorable by availability of NO_2, temperature and the photochemical reactions. In the troposphere, Nitrogen dioxide is the main source of ozone. Nitrogen dioxide (NO_2) is photolyzed to yield atomic oxygen, which is quickly followed by the combination of atomic oxygen and its molecular form to form ozone. However, there is no net gain or loss of ground level ozone in the troposphere in this cycle because ozone quickly reacts with NO to produce molecular oxygen by

$$NO_2 + h\nu \rightarrow NO + O$$

$$O + O_2 + M \rightarrow O_3 + M$$

$$O_3 + NO \rightarrow NO_2 + O_2$$

However, precursors like carbon monoxide (CO), methane (CH_4), non-methane hydrocarbons (NMHC) undergo a series of complex photochemical reactions with volatile organic compounds (VOCs) and NOx (NO_2 and NO) to produce ozone under the presence of adequate heat and sunlight (Nevers, 2000; Elampari et al., 2010). Atomic oxygen combines with water vapor in the atmosphere to form hydroxyl radicals OH). Hydroxyl radicals are highly reactive oxidants that combine with most of the trace gases in the troposphere, mainly CO and CH_4, are its dominant sinks. Methane (CH_4) is oxidized to HO_2, which in turn converts NO to NO_2 leading to the formation of O_3 (Wallace and Hobbs, 2006) by

$$CH_4 + OH \rightarrow CH_3O + H_2O$$

$$CH_3O + O_2 + M \rightarrow CH_3O_2 + M$$

$$CH_3O_2 + NO \rightarrow CH_3O + NO_2$$

$$CH_3O + O_2 \rightarrow CH_2O + HO_2$$

$$HO_2 + NO \rightarrow OH + NO_2$$

$$NO_2 + hv \rightarrow NO + O \text{ (2x)}$$

$$O + O_2 + M \rightarrow O_3 + M \text{ (2x)}$$

The net result of this photochemistry was

$$CH_4 + 4O_2 + 2hv \rightarrow CH_2O + H_2O + 2O_3$$

In this photochemical process, OH, NO, CH_3O are regenerated and NO is converted to NO_2 without the loss of O_3. Hydroxide (OH), HO_2, NO and NO_2 are catalysts in this reaction. Increase in the concentration of NO may lead to increase in the concentration of NO_2, meaning there was a net gain of O_3 in the troposphere. Similar oxidations can also occur in presence of CO, NHMC and VOCs leading to ozone production (Wallace and Hobbs, 2006).

Figure 5 shows the typical variations of precursors and the yield of ozone during a day. Nitrogen oxides (NOx) and VOCs build up during the morning rush hour and ozone along with chemical species like aldehydes and peroxyacetyl nitrate (PAN, formed from oxidation of NO with acetyl radical combined with methyl radical) starts to peak around noon when the intensity of solar radiation increases. As the intensity of solar radiation and photochemical activity decrease after late afternoon or evening, the concentration of these chemical species starts to decrease. Various chemical species (O_3, CO, CH_4, aldehydes, hydrocarbons, PAN etc.) formed during this reaction in polluted air under strong sunlight and stable meteorological condition can create brown haze above cities, a phenomenon called photochemical smog (Wallace and Hobbs, 2006).

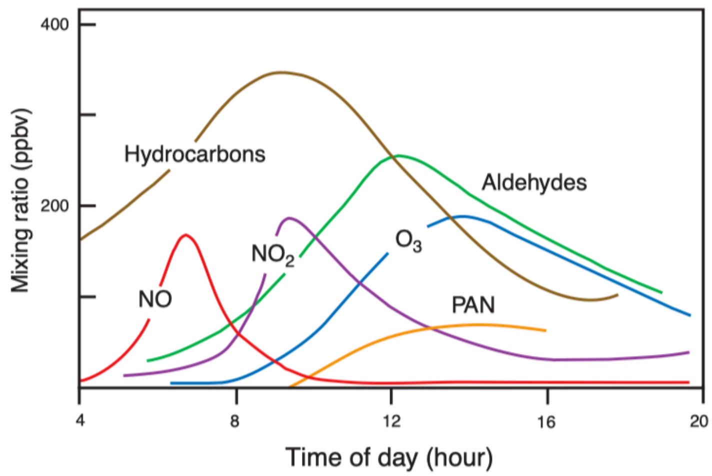


Figure 5: Typical variations during a day of some important pollutants in photochemical smog in Los Angeles. [Adapted from JM Wallace and PV Hobbs].

In addition to the distinct diurnal variation in ozone (Bieg et al., 2007), tropospheric ozone shows a marked seasonal variation exhibiting high ozone levels during the summer months and lower ozone levels during winter months (Noreen et al., 2018; Granados-Munoz and Leblanc, 2016; Khoder, 2009). Tropospheric ozone is typically concentrated in urban areas because of the high emission levels of precursor gases and it is enhanced by the urban heat island effect (Cardelino and Chameides, 1990; Stathopoulou et al., 2008). This is a phenomenon in which urban areas accumulate more heat compared to the rural areas resulting in high ambient air temperatures leading to more ozone formation (Mihalakakou et al., 2004). Because of high NOx concentrations in urban areas and consequently the accumulation of large concentrations of NO, ozone depletion is favored in urban areas. On the other hand, rural areas are dominated by availability of biogenic VOCs from plants and vegetation. Because of large concentration of VOCs, ozone production can be favored in rural area and is NOx limited (Paoletti et al., 2014). Ozone produced in urban areas can be transported downwind to rural areas as well. According to a study reported by Canada-USA Air Quality Committee (1999) in the eastern North America domain, there was elevated ozone concentration in areas with low wind speed (<3 m/s) because ozone accumulated near precursor emission concentration areas. The overall ozone concentration was lower at intermediate winds (3-6 m/s) and may be displaced as far as 500 km downwind. Ozone concentration in an area decreases considerably when wind speed is higher than 6 m/s due to dilution and ozone may be displaced as far as 1000 km downwind. According to Austin et al. (2014), the fate of ozone formation/removal is also dependent on the wind direction.

In this way, understanding not only the socioeconomic risk indicators, but the way air pollutant and meteorological parameters relate to spatio-temporal variation asthma hospitalization is important to undertake the asthma action plan.

Chapter 2 - Association Between Socioeconomic Factors and Asthma Hospitalization Discharge Rates for Children and Adults in eastern Texas

A main goal of this study is to understand the association between the socioeconomic indicators and the asthma hospitalization rates at the county level in Texas for children (0-17 years) and adults (18+ years) population. Significant socioeconomic indicators were used to create a multidimensional socioeconomic deprivation (SED) index at county and metropolitan statistical areas (at census tract level) in eastern Texas. Only the populous counties were investigated for metropolitan areas. The following hypothesis were tested: socioeconomic deprivation status is associated with asthma hospitalization rates for both children and adults.

Methods

Asthma hospitalization discharge rates were accessed from Texas Health Care Information Collection (THCIC) Inpatient Hospital Discharge dataset for Texas on a county-by-county basis for children and adults. Child and adult hospitalization rates include patients from 0-17 years and 18+ years respectively. Asthma diagnosis and disease coding were based on International Classification of Disease, 9th Revision, Clinical Modification (ICD-9-CM:493-493.99) (CDC, 2019). A new asthma diagnosis and disease coding has been developed (ICD-10-CM) starting 2015 which is not applicable to our data (NCHS, 2017). The data was obtained using a standardized questionnaire, Texas Behavioral Risk Factor Surveillance System (BRFSS) developed with collaboration between Centers for Disease Control and Prevention (CDC) and Texas Department of State Health Services (DSHS). The questionnaires that were used can be found in Texas DSHS website (https://www.dshs.texas.gov/chs/brfss/pages/questions.shtm).

Data for asthma hospitalizations are available for the period of 2005-2011. In the first, instance, asthma hospital discharges were aggregated for each county. Counties with hospitalizations below 12 patients were assigned no value. As a result, only 74 and 121 counties out of 254 counties had data for children and adults respectively in 2005. There was a total of 9,985 child hospital admissions and 16,043 adult hospital admissions in relation to asthma in Texas, in 2005. The total hospital discharges varied from county to county with lowest (12) recorded in Austin County, whereas highest (2091) recorded in Harris County in 2005. Only 73 and 116 counties out of 254 counties had data for children and adults respectively in 2010. There was a total of 9,280 child and 15,125 adult hospital admissions in 2011. The lowest hospital discharge (12) was recorded in Morris and Wise counties whereas the highest (3249) was recorded in Harris county in 2011. Crude hospitalization rate (total number of cases divided by total number of persons in population) was calculated per 10,000 residents for the purpose of analysis. THCIC collets data from most Texas hospitals. According to THCIC, there are 64 counties with no hospitals and hospitals in some counties are statutorily exempted from reporting which is presumably why there is limited data from west Texas as of 2011. Total hospital admission and discharge in relation to asthma can have been underestimated. The current analysis was restricted to eastern Texas to control for the effect of limited data. Emergency department visits that did not result in hospital admission were not included in the data, because of which the burden of less serious asthma episodes is not reflected in this data. Since an individual can be hospitalized more than once, there was no distinction between multiple hospitalizations for the same individual and the same diagnosis (Wickerham, 2014).

In addition, socio-economic indicators were extracted from the U.S. Census Bureau via American Community Survey (ACS). ACS provides data every year, but areas must meet a particular population threshold (65,000 +) to be published (U.S. Census Bureau, 2019). ACS also calculates 5-year estimates and have no population threshold. For Example: 2006-2010 ACS 5-year estimates data collected between January 1, 2006 and December 31, 2010. Since data has no population threshold, all areas are included, and the sample size is also very large. According to U.S. Census Bureau, ACS 5-year estimates is the most reliable data. Although, there is no consensus on what indicators contribute to socio-economic status of an area, Singh and Siapush (2002) suggest indicators should directly or indirectly reflect the normative value, social good or social welfare of an area. Some of the indicators are measured at individual levels (e.g. education, occupation, ethnicity) whereas others are measured at a scale of family or neighborhood (e.g. housing). Twenty-six socio-economic indicators that may be viewed as comprehensive approximation of living conditions and socioeconomic deprivation based on aforementioned research were considered to encompass the broad domains of education, income, employment, ethnicity, housing and transportation: a) percentage of families living in poverty, b) percentage of unemployed people, c) percentage of white collar occupation (management, sciences, arts etc.), d) percentage of people with education less than 9th grade, e) percentage of people with Bachelor's degree or higher, f) percentage of people with income less than $15,000, g) percentage of people living in overcrowding conditions (more than 1 person per room), h) percentage of people who are divorced, i) percentage of child population under 5 years, j) percentage of elderly population (65 years and over), k) percentage of black population, l) percentage of single mothers living with children under 18 years, m) percentage of people who are foreign born and not a U.S. citizen, n) percentage of ethnic minority living as a householder, o) percentage of house heating with gas, p) percentage of house heating with fuel, oil etc., q) percentage of house heating with wood, r) percentage of house built on 1969 or before, s) percentage of house with incomplete kitchen facilities, t) percentage of house with incomplete plumbing facilities, u) percentage of households with no vehicle, v) percentage of renter-occupied housing units, w) percentage of people using public transportation for work, x) percentage of people who speak language other than English, y) percentage of people who have no wage or salary income and z) percentage of people who use cash public assistance or Food Stamps/SNAPS. The aforementioned variables were selected based on their theoretical relevance and prior empirical research (Singh and Siapush, 2002).

Since socioeconomic indicators are based on ACS 5-year census data for this study, asthma hospitalization discharge rates were averaged across 5-year period (2006-2010) for consistency. A county-by-county socio-economic deprivation index was calculated based on corresponding socio-economic indicators by applying principal component analysis in SAS® on Demand for Academics: Studio software, Version 9 (SAS Institute 2019), the preferred approach for developing such indexes (Pampalon et al., 2009; Krieger et al., 2003). Because as many as 26 indicators factors could be related to SED index for a geographic area, Principal Component Analysis (PCA) helped to reduce the complex dimensionality of the intercorrelated quantitative datasets to effectively interpret data with minimal loss of information (Jolliffe and Cadima, 2016). The original set of socioeconomic indicators was reduced to smaller number of principal components that accounted for the variance in the observed indicators and are uncorrelated to each other. The first principal component accounts for the most variance. The succeeding components will account for the variance in the data set that was not considered in the preceding components. The ultimate goal is to retain minimum variables in each component that account for the maximum variance present in the 26 indicators.

Child and adult asthma hospitalization data was correlated with socio-economic indicators first. Only indicators significant to both categories were retained for the next stage of analysis. Once the significant indicators are subjected to principal component analysis, components with eigenvalue >1 are retained based on Kaiser Guttman criterion (Kaiser, 1960) or enough components are retained such that cumulative percentage of variance for components are greater than 70%. A varimax rotation can be applied to the dataset to improve interpretability. However, promax rotation will produce varimax rotation followed by a promax (oblique) rotation, which is preferred. Promax rotation returns a factor pattern matrix consisting of standardized regression coefficients. Kline (2002) and DiStefano et al. (2009) suggest a factor loading with standardized regression coefficient greater than 0.3 in absolute value to be significant and to be selected for further analysis. For each significant indicator retained, PCA produces a standardized weighted score to calculate a SED index. Higher indicator weights meant higher contribution to the socio-economic status and vice versa. Since asthma data was not available for census tract data, index construction was performed by applying PCA without correlating the socioeconomic variables with asthma data as attempted before in a Singh and Siapush (2002) study. To our knowledge, no previous study in eastern Texas has assessed combined association between child and adult asthma hospitalization discharge rate and socioeconomic risk indicators by creating a socioeconomic deprivation index.

Results

Correlation coefficients for crude asthma hospitalization discharge rate for both child and adult versus socioeconomic indicators were determined to examine preliminary associations and the significance of indicators for Texas in 2006-2010, the results of which are shown in Table 1.

Table 1: List of significant socioeconomic indicators and corresponding correlation coefficients and p-values

Socioeconomic Deprivation variables	Childhood asthma crude hospital discharge rate (per 10,000 residents)	Adult asthma crude hospital discharge rate (per 10,000 residents)
% Below poverty	0.27 ($p < 0.05$)	0.28 ($p < 0.05$)
% White collar occupation	-0.37 ($p < 0.001$)	-0.47 ($p < 0.001$)
% Bachelor’s degree or higher	-0.34 ($p < 0.05$)	-0.44 ($p < 0.001$)
% Income less than $15,000	0.42 ($p < 0.001$)	0.44 ($p < 0.001$)
% Under 5 years	-0.23 ($p < 0.05$)	-0.30 ($p < 0.05$)
% Elderly (65 years and over)	0.46 ($p < 0.001$)	0.51 ($p < 0.001$)
% Single mothers w/ children under 18 years	0.41($p < 0.001$)	0.37 ($p < 0.001$)
% Heating with wood	0.26 ($p < 0.05$)	0.35 ($p < 0.05$)
% House built 1969 or before	0.51 ($p < 0.001$)	0.40 ($p < 0.001$)
% No Vehicles	0.46 ($p < 0.001$)	0.34 ($p < 0.001$)
% No wage or salary income	0.50 ($p < 0.001$)	0.58 ($p < 0.001$)
% Cash public assistance or Food Stamps/SNAPS	0.30 ($p < 0.05$)	0.29 ($p < 0.05$)

Preliminary correlation analysis indicates that both child and adult asthma hospitalization discharge rates was significantly correlated to poverty, white collar occupation, bachelor’s degree or higher, income less than $15000, population under 5 years, elderly population, single mothers living with children under 18 years, house built on 1969 or before, households with no vehicle, people who have no wage or salary income, and people who get cash public assistance or food stamps/SNAPS. Bachelor’s degree or higher indicator was excluded because multicollinearity was observed between people with white collar population and people with bachelor’s degree or higher (r=0.91). Foreign Born, not a U.S. citizen was excluded as its impact to the SED index construct was not clear. This indicator may be underreported because it may involve non-reporting of illegal immigrants in the population. People using public transportation was also excluded because of its limited distribution range and also because public transport is biased to metropolitan areas. Only statistically significant socioeconomic indicators were selected for principal component analysis in order to reduce a set of correlated attributes to smaller set of uncorrelated attributes.

The output of principal component analysis involving the significant variables from preliminary analysis is provided in the Appendix. Based on Kaiser Guttman criterion, components with an eigenvalue greater than 1 were considered. Component 1 and component 2 have eigenvalues of 5.41 and 2.55 respectively which contributes to a cumulative proportion of 0.91 which is worthy of retention. After promax rotation is applied, PCA yields a factor pattern matrix with standardized regression coefficients. Indicators with standardized regression coefficients greater than 0.3 are considered significant and used to calculate the SED indices. According to factor 1 in factor pattern matrix, percentage of people living in poverty, with income less than $15000, households with no vehicle, people who have no wage or salary income and people who get cash public assistance or food stamps/SNAPS were considered significant. On the other hand, according to factor 2, percentage of people with white collar occupation, population under 5 years, elderly population, heating with wood and no wage or salary income were considered significant. No wage or salary income was significant in both components. Single mothers with children under 18 years and House built on 1969 or before were not significant in either factor. PCA also yields standardized regression scoring coefficients which represents the relative weight for each significant variable in the SED index construct, the results of which are shown in Table 2. SED index can be computed by summing the products of significant socioeconomic indicators census value with its optimal weight (O'Rourke and Hatcher, 2019).

Table 2: List of significant socioeconomic indicators with standardized scoring coefficients (relative weights) used for socioeconomic index construction

Socioeconomic Deprivation Index variables	Relative weights
% Below poverty	0.2296
% White collar occupation	-0.0638
% Income less than $15,000	0.2802
% Under 5 years	0.0059
% Elderly (65 years and over)	0.20149
% Heating with wood	0.0426
% No Vehicles	0.0526
% No wage or salary income	0.2309
% Cash public assistance or Food Stamps/SNAPS	0.1458

According to output in Table 2, percent of people below poverty, percent of people with income less than $15,000, percent of elderly population and percent of people with no wage or salary income contributed the most to the SED index whereas percentage of people with white collar occupation contributed the leastern.

SED index was calculated for each county in eastern Texas during 2006-2010 based on the significant socioeconomic indicators and its relative weights is shown in Table 3.

Table 3: Socioeconomic Deprivation Index values for counties in eastern Texas and corresponding crude asthma hospitalization discharge rates for both child and adult, 2006-2010

Geography	SED Index
Texas	13.2
Anderson	18.0
Angelina	16.9
Aransas	22.1
Archer	14.5
Atascosa	17.1
Austin	13.5
Bandera	19.4
Bastrop	12.5
Baylor	20.6
Bee	19.9
Bell	11.4
Bexar	14.0
Blanco	14.3
Bosque	17.7
Bowie	17.4
Brazoria	8.9
Brazos	14.8
Brewster	17.9
Brooks	34.4
Brown	19.7
Burleson	18.5
Burnet	16.5
Caldwell	16.7
Calhoun	17.6
Callahan	17.6
Cameron	25.5
Camp	19.7
Cass	23.1
Chambers	9.3
Cherokee	20.5
Clay	13.3
Coleman	27.6
Collin	4.2
Colorado	19.3
Comal	11.1
Comanche	24.1
Cooke	15.7

Coryell	11.7
Dallas	12.3
Delta	19.8
Denton	4.9
DeWitt	18.0
Duval	25.1
Easternland	23.3
Ellis	9.7
Erath	16.5
Falls	24.3
Fannin	17.4
Fayette	15.2
Fort Bend	5.0
Franklin	16.9
Freestone	16.9
Frio	20.9
Galveston	11.6
Gillespie	16.9
Goliad	17.3
Gonzales	18.3
Grayson	15.4
Gregg	15.9
Grimes	17.4
Guadalupe	10.6
Hamilton	19.0
Hardin	15.0
Harris	11.6
Harrison	16.8
Hays	9.7
Henderson	19.8
Hidalgo	25.3
Hill	18.5
Hood	14.8
Hopkins	17.2
Houston	24.9
Hunt	16.6
Jack	15.2
Jackson	15.2
Jasper	21.5
Jefferson	18.0
Jim Hogg	21.2
Jim Wells	20.8
Johnson	10.9
Karnes	20.5
Kaufman	10.6
Kendall	10.3
Kenedy	22.5
Kleberg	19.8
Lamar	19.4
Lamb	17.7
Lampasas	15.2
La Salle	25.4
Lavaca	17.8
Lee	13.9
Leon	20.6
Liberty	15.8
Limestone	16.6
Live Oak	17.7
Llano	22.3
McCulloch	22.4
McLennan	16.6
McMullen	18.1
Madison	19.7
Marion	27.5
Mason	22.9
Matagorda	18.6
Medina	15.5
Milam	20.1
Mills	18.7
Montague	18.9
Montgomery	9.0
Morris	22.4
Nacogdoches	19.2
Navarro	17.3
Newton	23.8
Nueces	16.4
Orange	17.1
Palo Pinto	17.1
Panola	16.9
Parker	11.0
Polk	24.7
Rains	16.5
Red River	20.6
Refugio	18.9
Robertson	21.4
Rockwall	6.0
Rusk	14.8
Sabine	27.2
San Augustine	31.5
San Jacinto	18.8
San Patricio	16.7
San Saba	23.4
Shackelford	14.3
Shelby	22.3
Smith	14.6
Somervell	14.3
Starr	30.6
Stephens	19.5
Tarrant	10.1
Throckmorton	21.8
Titus	15.5
Travis	9.5
Trinity	21.7
Tyler	21.0
Upshur	16.0
Van Zandt	18.0

Victoria	14.6
Walker	19.0
Waller	14.5
Washington	18.3
Webb	20.1
Wharton	16.9
Wichita	15.5
Wilbarger	20.9
Willacy	36.9
Williamson	6.2
Wilson	10.4
Wise	11.9
Wood	19.9
Young	19.1
Zapata	29.4

Filmer and Pritchett (2001) used arbitrary cut-off points to categorize households with various socioeconomic indices - lowest 40% households into 'poor', highest 20% as 'rich' and the rest and 'middle group' for better interpretability. This study will follow a model of classifying indices into quintiles, frequently used method in SED construction (Gwatkin et al., 2000; Howe et al., 2011; Tajik and Majdzadeh, 2014). Table 4 demonstrates the results of quintiles for SED indices in eastern Texas.

Table 4: Classification of socioeconomic deprivation indices by quintile in eastern Texas, 2006-2012

Site	Richest	Second	Third	Fourth	Poorest
Eastern Texas	0-13.9	14-16.6	16.7-18.3	18.9-20.6	20.7-36.9

Analysis for association between SED index and asthma hospitalization discharge rate was significant for both child ($r=0.47$, $p<0.001$) and adult ($r=0.51$, $p<0.001$) for eastern Texas during 2006-2010. The SED index for the state of Texas was 13.2 whereas the SED indices for the counties ranged from a minimum of 4.2 for Collin county and a maximum of 36.9 for Willacy county. Figure 9 represents the eastern Texas county-specific SED indices for 2006-2010.

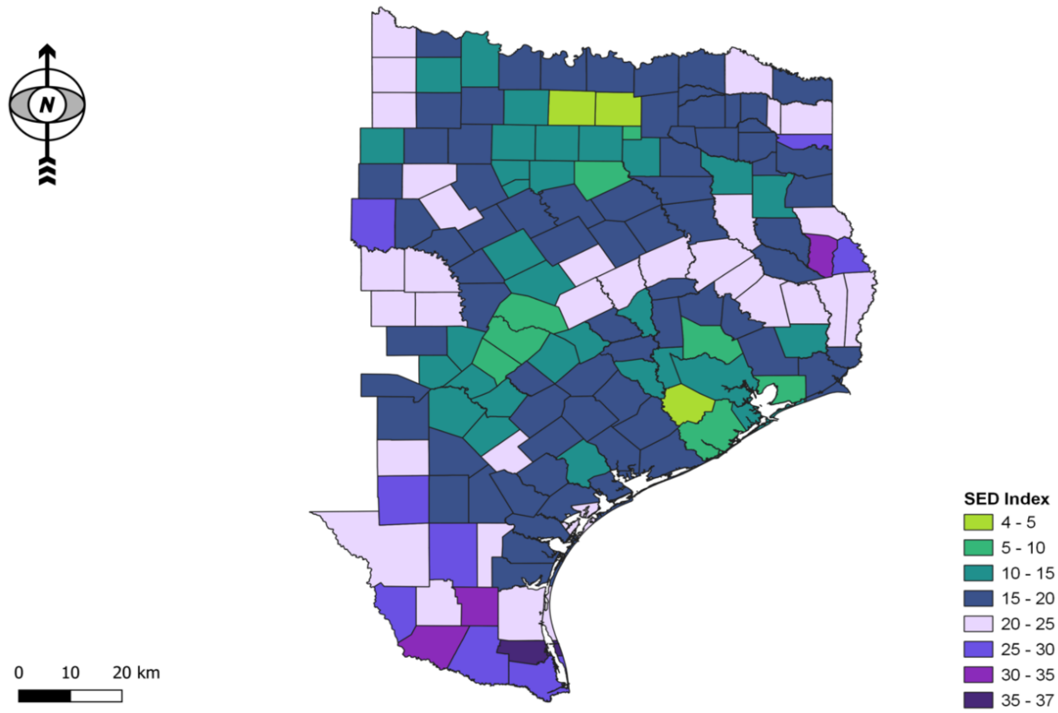


Figure 9: SED Indices by county area of residence in eastern Texas, 2006-2010

People living in South Texas were found to have consistently higher SED indices (25 and above). These counties have high percentages of people living in poverty, dependent on cash public assistance or food stamps/SNAPS and low white-collar occupation. Counties bordering Louisiana in eastern Texas also had high SED indices. Collin and Denton counties along with Fort Bend county had the lowest SED (4-5) indices in the entire eastern Texas. Collin and Denton counties have low percentage of population in poverty and high percentage of people with white-collar occupations. Most of the rural countries fell in the range of 15-20. The term Metropolitan and Non-metropolitan is interchangeably used as urban and rural in this study as designated by Health Professions Resource Center (DSHS).

To understand the variation of SED indices across a finer level, PCA was ran again for socioeconomic variables at the census tract level. Results by metropolitan statistical area is included below.

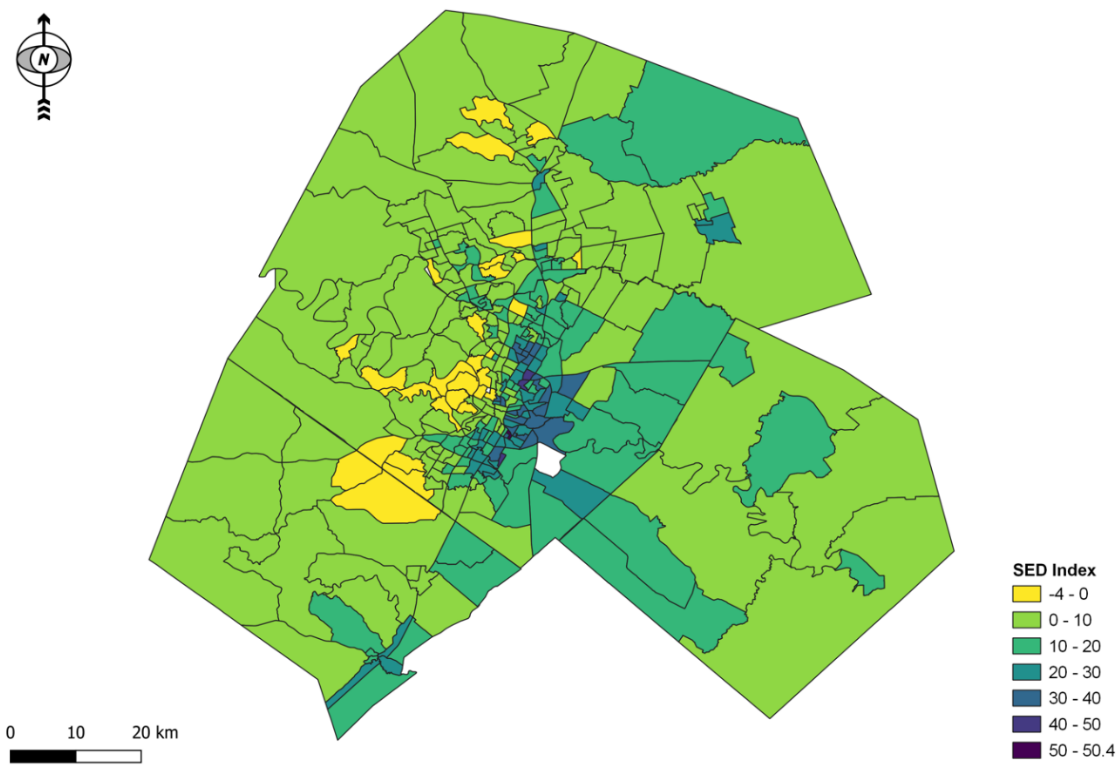


Figure 10: SED Indices by census tract area of residence in Austin-Round Rock Metropolitan Statistical Area, 2006-2010

Austin-Round Rock metro area includes Bastrop, Hays, Travis and Williamson counties. Census Tract 23.16 in Travis county had the maximum SED index of 50.4. Along with 59.3% of families in poverty, this census tract has almost 41% people with education under 9th grade and

99.4% of housing units are renter occupied. On the other hand, the minimum value of SED index was found to be -3.5 in census tract 17.51, also in Travis county. Eighty percent of people in this census tract have a white-collar occupation and 0% of families are in poverty and 0% of people are unemployed (within statistical error). Travis county had a wide distribution range of SED indices compared to other counties. The western side of Austin is the leastern deprived part of the metro (see figure 10).

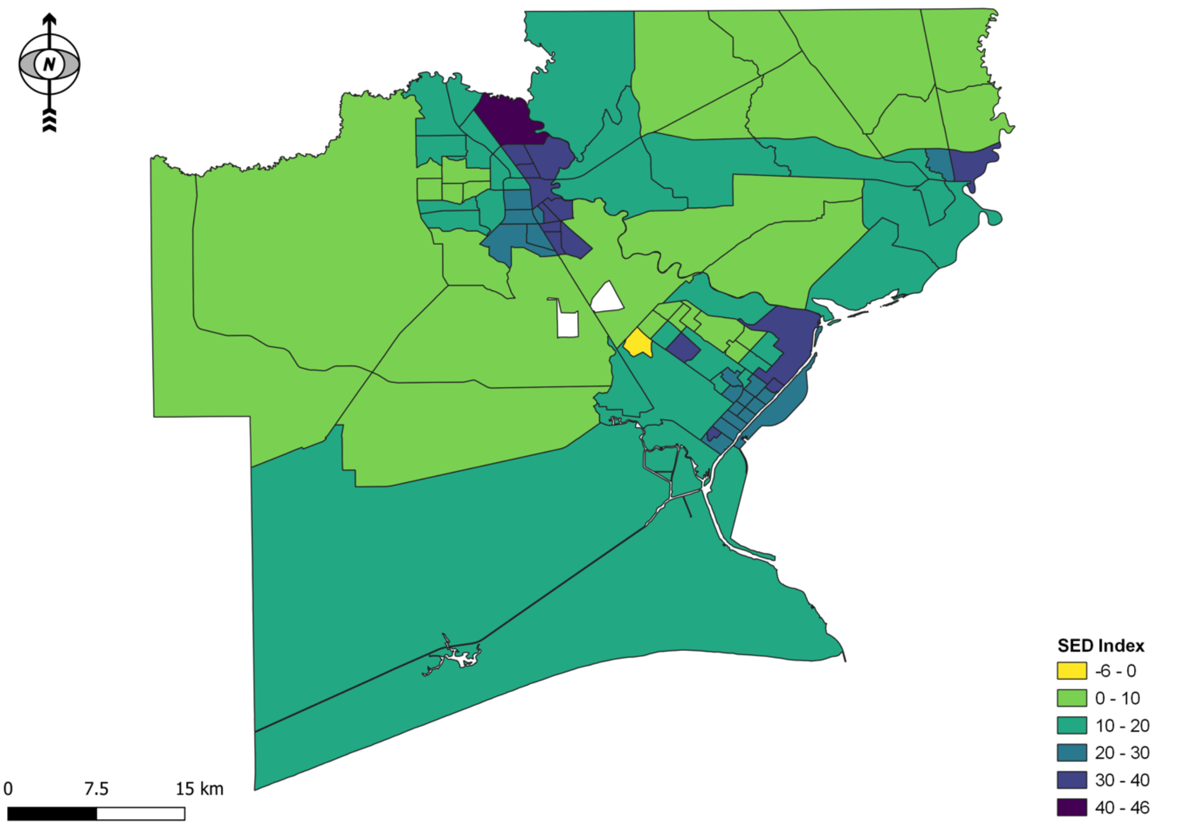


Figure 11: SED Indices by census tract area of residence in Beaumont-Port Arthur Metropolitan Statistical Area, 2006-2010

Beaumont-Port Arthur metro area includes Jefferson and Orange counties. The maximum value of SED index was found to be 27.6 in census tract 59 whereas the minimum value was found in -5.1 in census tract 9800. Both were found in Jefferson county. The highest SED index values were found around the vicinity of Beaumont and Port Arthur cities (see figure 11).

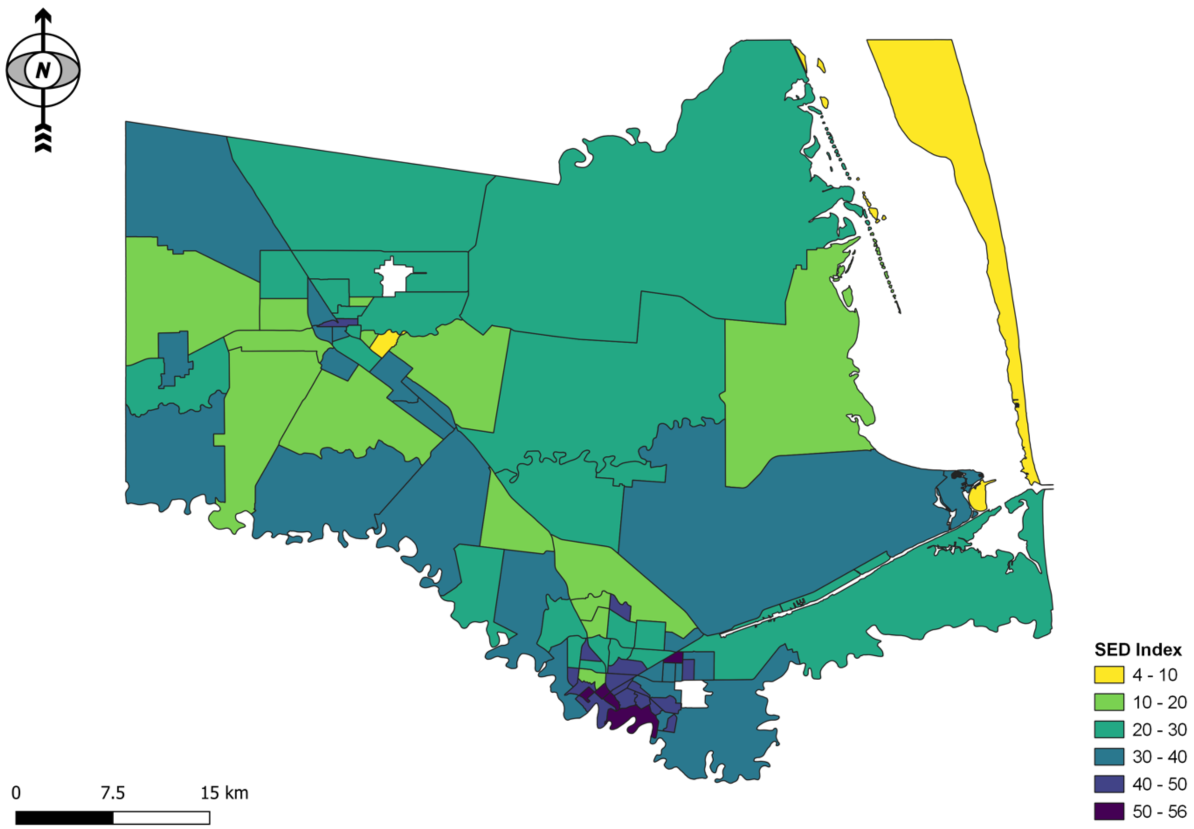


Figure 12: SED Indices by census tract area of residence in Brownsville-Harlingen Metropolitan Statistical Area, 2006-2010

Brownsville-Harlingen metro is within Cameron county. Twenty-five out of 85 census tracts in Cameron county has a SED index of 20 or higher. The highest SED indices were concentrated around principal cities like Brownsville, Harlingen, and along the south border of the metro area (see figure 12).

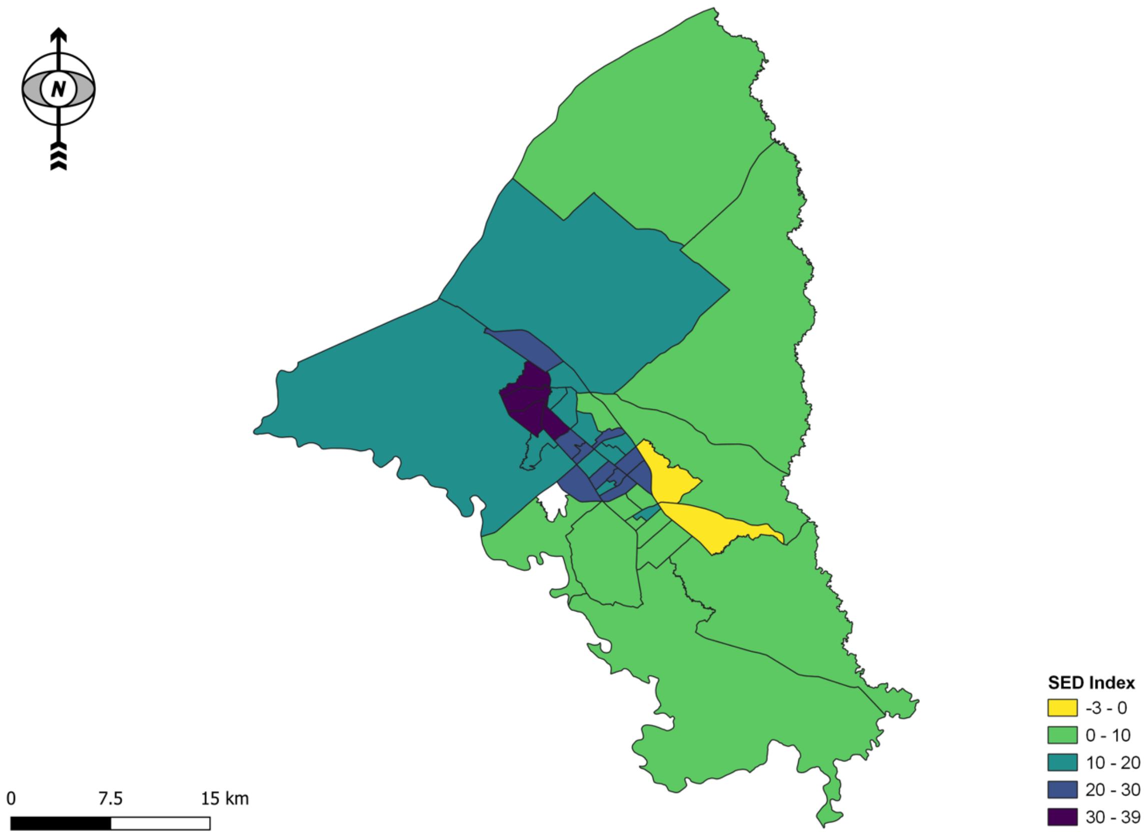


Figure 13: SED Indices by census tract area of residence in Bryan-College Station Metropolitan Statistical Area, 2006-2010

Bryan-College Station metro area is within Brazos county. Fourteen out of 41 census tracts in Brazos have SED indices 20 or higher. These census tracts are represented by a very high percentage of renter-occupied housing units, high percentage of black persons and large percentage of people living in poverty. Census tract 20.09 which includes College Station has a SED index of -2.5. Low SED index census tracts were represented by low percentage of single mothers living with children under 18 years. Census tracts with high SED indices are on the west side of College Station (see figure 13).

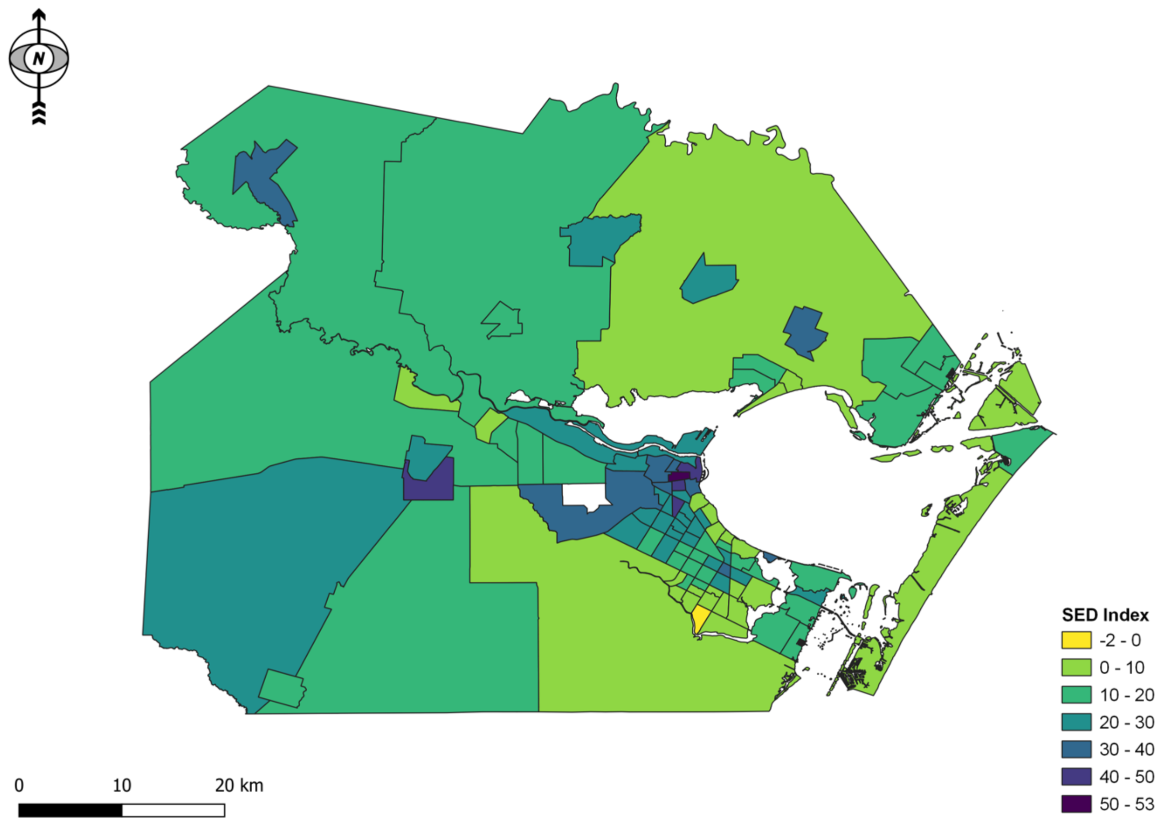


Figure 14: SED Indices by census tract area of residence in Corpus Christi Metropolitan Statistical Area, 2006-2010

Corpus Christi metro area includes Nueces and San Patricio counties. Nueces is south of Corpus Christi bay whereas San Patricio is north of the bay. The census tracts with high SED indices in Corpus Christi metro area are on the west side of Corpus Christi Bay along Highway 37 in Nueces county. Thirty six out of 80 census tracts have an SED index of 20 or higher. These census tracts are noted for a high percentage of people who speak a language other than English, high renter-occupied housing units and high poverty levels. Twelve counties have SED index 40 or higher (see figure 14).

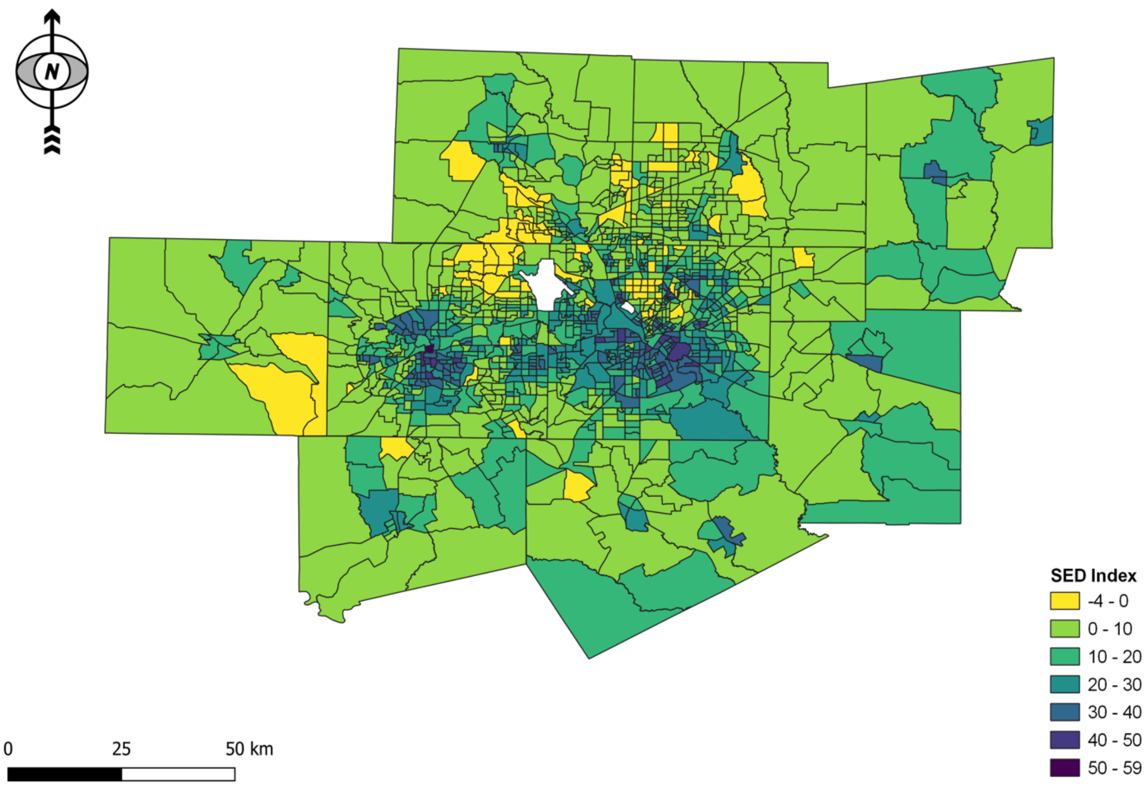


Figure 15: SED Indices by census tract area of residence in Dallas-Fort Worth-Arlington Metropolitan Statistical Area, 2006-2010

Dallas-Fort Worth Arlington Metro area consists of two metropolitan divisions: Fort Worth-Arlington and Dallas-Irving-Plano metropolitan divisions. Fort Worth-Arlington includes Hood, Johnson, Parker, Somervell, Tarrant and Wise counties whereas Dallas-Irving-Plano metro division includes Collin, Dallas, Denton, Kaufman and Rockwall counties. Census tracts in Collin and Denton counties have very low SED indices. This is mostly because of low percentage of people living in poverty and a high percentage of people with white collar occupations. Six out of 151 census tracts have SED index of 20 or higher in Collin county whereas 11 out of 137 census tracts in Denton have SED of 20 or higher. On the other hand, Dallas county has a wide distribution range of SED indices across its census tracts. Almost half (228) of 527 census tracts in Dallas county had a SED index of 20 or higher. Twenty-four census tracts had a SED index of 40 or higher. Census tracts with high SED indices were represented by high percentage of black persons, high percentage of single mothers living with children under 18 years, high percentage of people speaking a language other than English, high percentage of renter-occupied housing units, high percentage of people living in poverty and large percentage of people using cash public assistance or food stamps/SNAPS. Tarrant county has a wide distribution range of SED indices like Dallas county and the risk indicators that influenced the SED index construct had a common theme. Ninety-seven out of 356 census tracts had a SED index of 20 or higher and 159 census tracts had a SED index of lower than 10. In contrast, 144 census tracts in Dallas county had a SED index of 10 or lower. These census tracts were represented by persons employed in management, arts, sciences etc. (white-collar occupation), less people living in overcrowded conditions, low percentage of people living in poverty. Census tracts in Johnson, Parker, Rockwall, Somervell and Wise counties had low SED index. Counties in urban locations had high SED index compared to location in the outskirts of the metropolitan area (see figure 15).

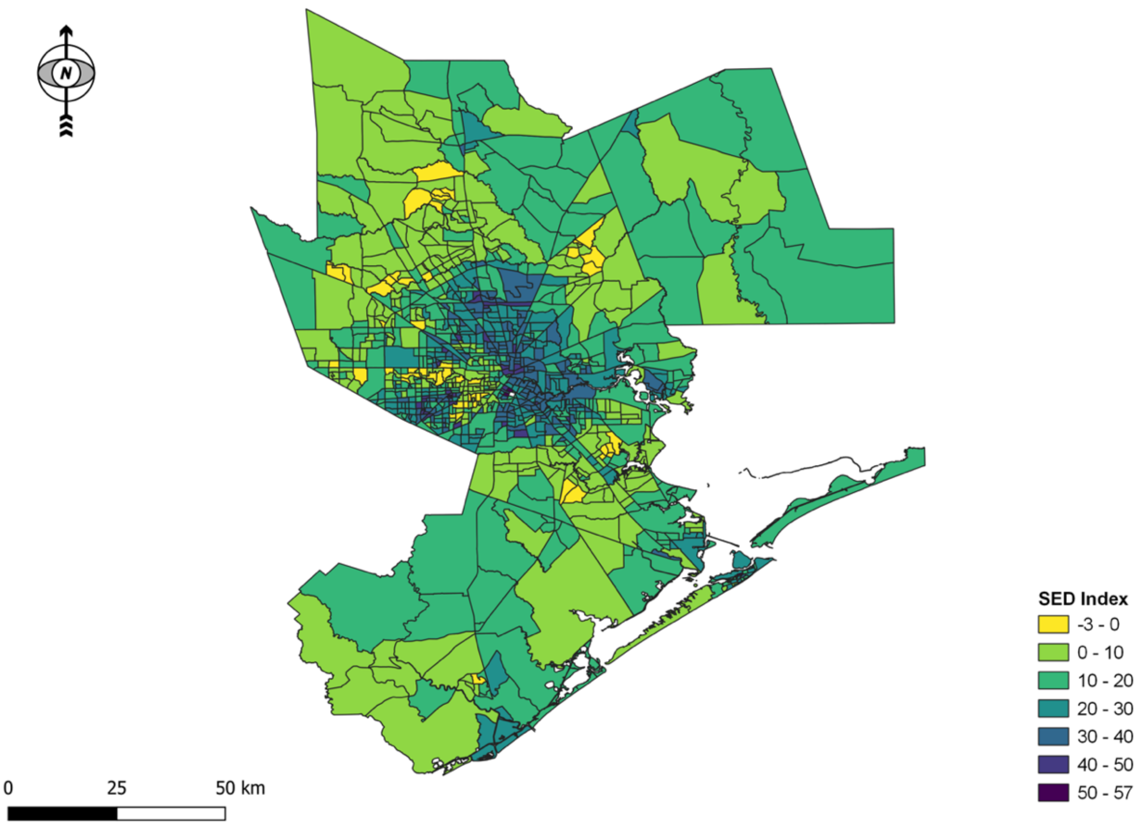


Figure 16: SED Indices by census tract area of residence in Houston-The Woodlands-Sugarland Metropolitan Statistical Area, 2006-2010

Houston-The Woodlands-Sugarland metro area within Brazoria, Fort Bend, Galveston, Harris, Liberty and Montgomery counties. Census tracts in Brazoria, Fort Bend, Liberty and Montgomery are represented by low SED indices. Only 3 out of 50 census tracts in Brazoria, 7 out of 75 census tracts in Fort Bend, 1 out of 14 census tracts in Liberty and 3 out of 59 census tracts in Montgomery have a SED index of 20 or higher. Seventeen out of 66 census tracts in Galveston county have a SED index of 20 or higher which was characterized by people in poverty, single mothers with children living under 18 years and renter-occupied housing units. The maximum value of SED index was found to be in Houston-The Woodlands-Sugarland metro area was 56.5 in Galveston county. Houston-The Woodlands-Sugarland had a lot of socioeconomically deprived census tracts in Harris county. Out of 785 census tracts in Harris county, 348 counties have SED index of 20 or higher and 38 census tracts had SED index of 40 or higher. Higher SED indices were represented by high percentage of people living in poverty, high percentage of black population, high percentage of single mothers with children under 18 years, high percentage of people who speak a language other than English, high percentage of renter-occupied housing units, and high percentage of people with cash public assistance and food stamps/SNAPS. The population with highest SED index seems to be confined to the downtown area of Houston (see figure 16).

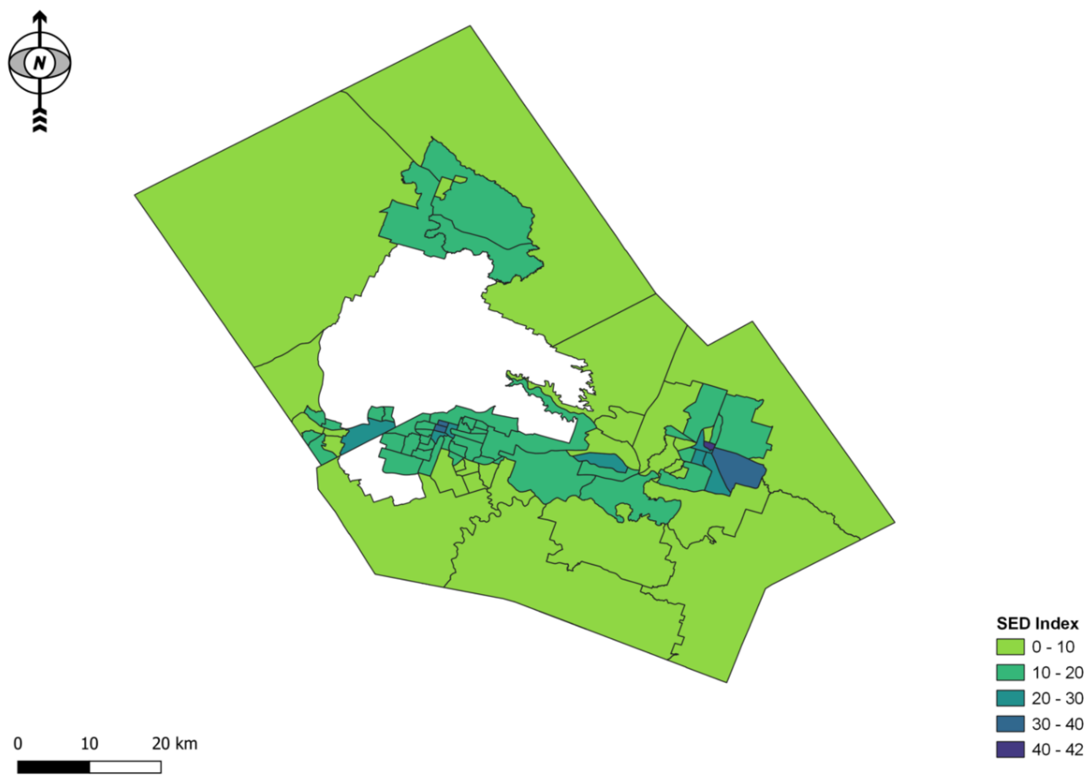


Figure 17: SED Indices by census tract area of residence in Killen-Temple-Fort Hood Metropolitan Statistical Area, 2006-2010

Killen-Temple-Fort Hood metro area is within Bell, Coryell and Lampasas counties. High SED indices occur around the principal cities Killen and Temple (both in Bell county) which is represented by high percentage of black population, single mothers living with children under 18 years and renter-occupied housing units. Only 12 out of 84 census tracts in the metro area have a SED index of 20 or higher (see figure 17).

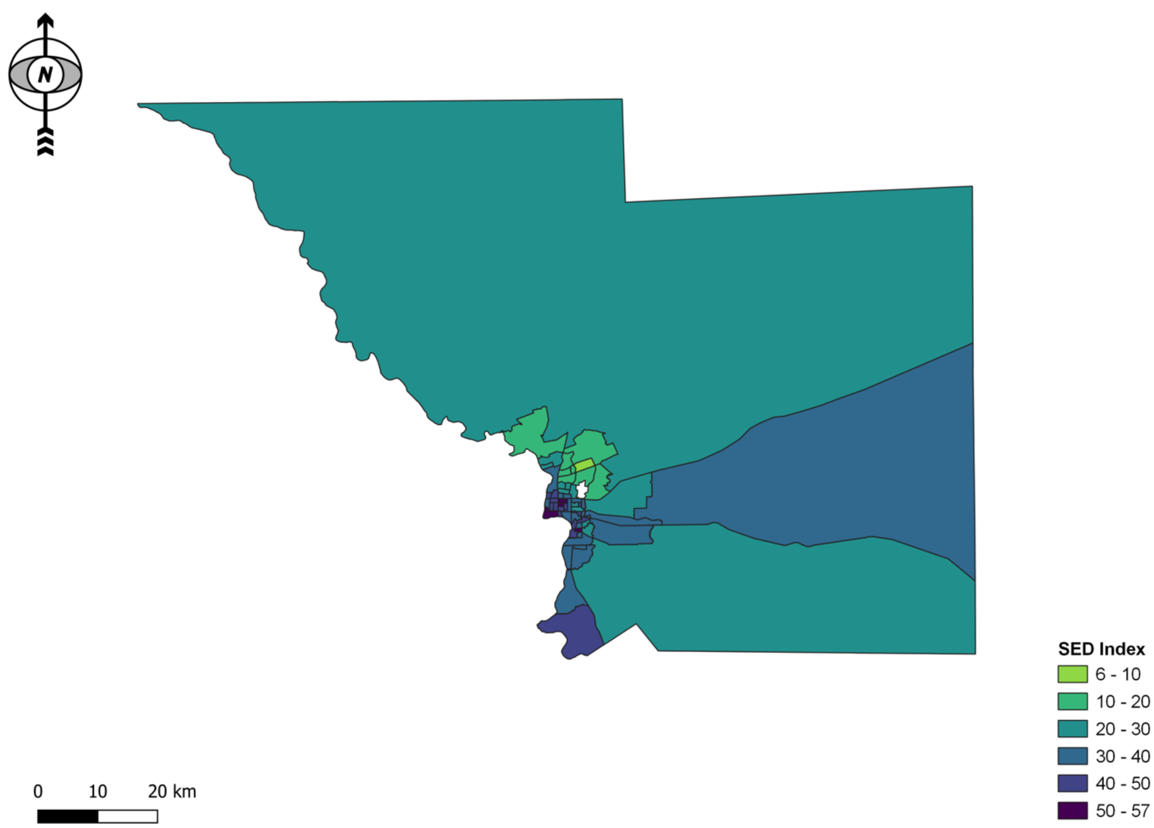


Figure 18: SED Indices by census tract area of residence in Laredo Metropolitan Statistical Area, 2006-2010

The Laredo metro area is within Webb county in the south Texas. Tracts with high SED indices are concentrated around Laredo city. Close to 85% (51 out of 60) of the census tracts in Laredo MSA have SED index 20 or higher. Seventeen tracts have an SED index higher than 40.

The maximum value for an SED index was found to be 57. High SED indices are represented by high percentage of people living in poverty, single mom living with a children under 18 years, speaking a language other than English, renter-occupied housing units and receiving cash public assistance or food stamps/SNAPS (see figure 18).

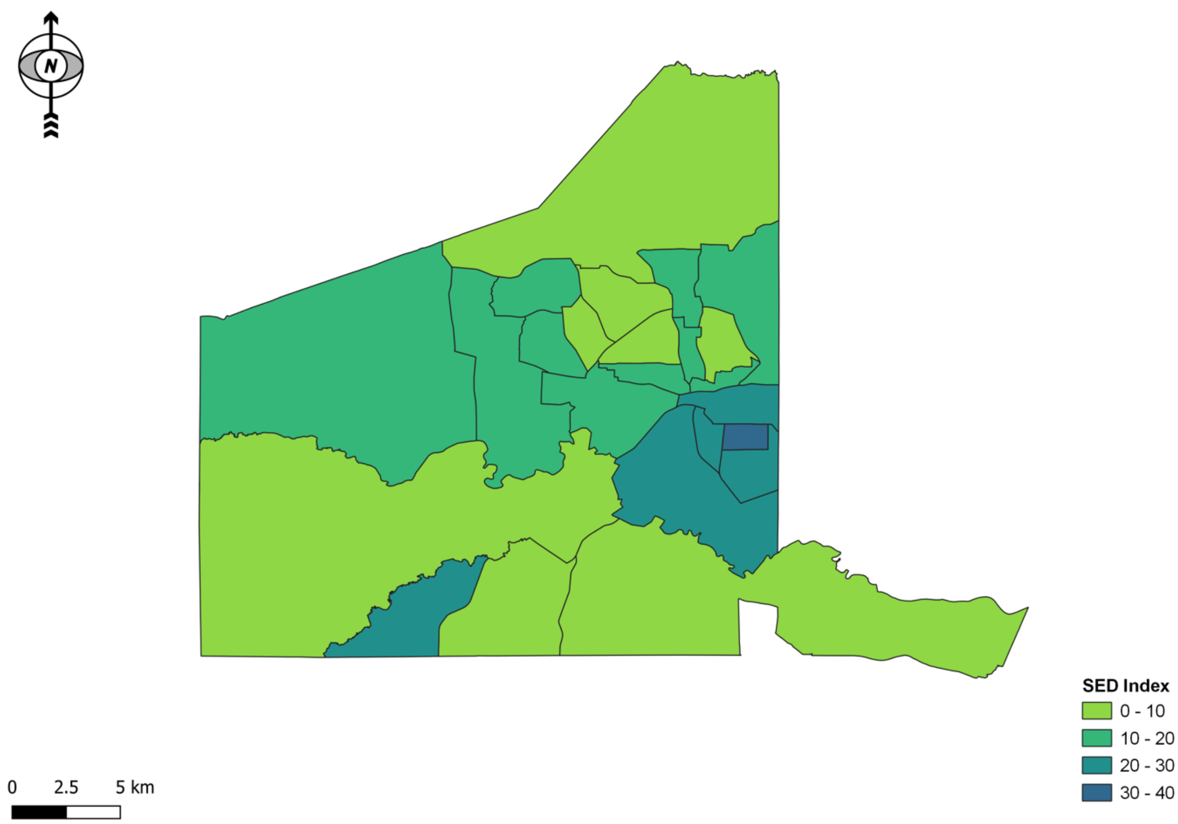


Figure 19: SED Indices by census tract area of residence in Longview Metropolitan Statistical Area, 2006-2010

Longview metro area is encompassed by Gregg county. Six out of 24 tracts in Gregg county have a SED index of 20 or higher. The maximum value of SED index was found to be 37.3. High SED indices were represented by a high percentage of population living in poverty, a significant black population, single mothers living with children under 18 years, renter-occupied housing units and people receiving cash public assistance or food stamps/SNAPS (see figure 19).

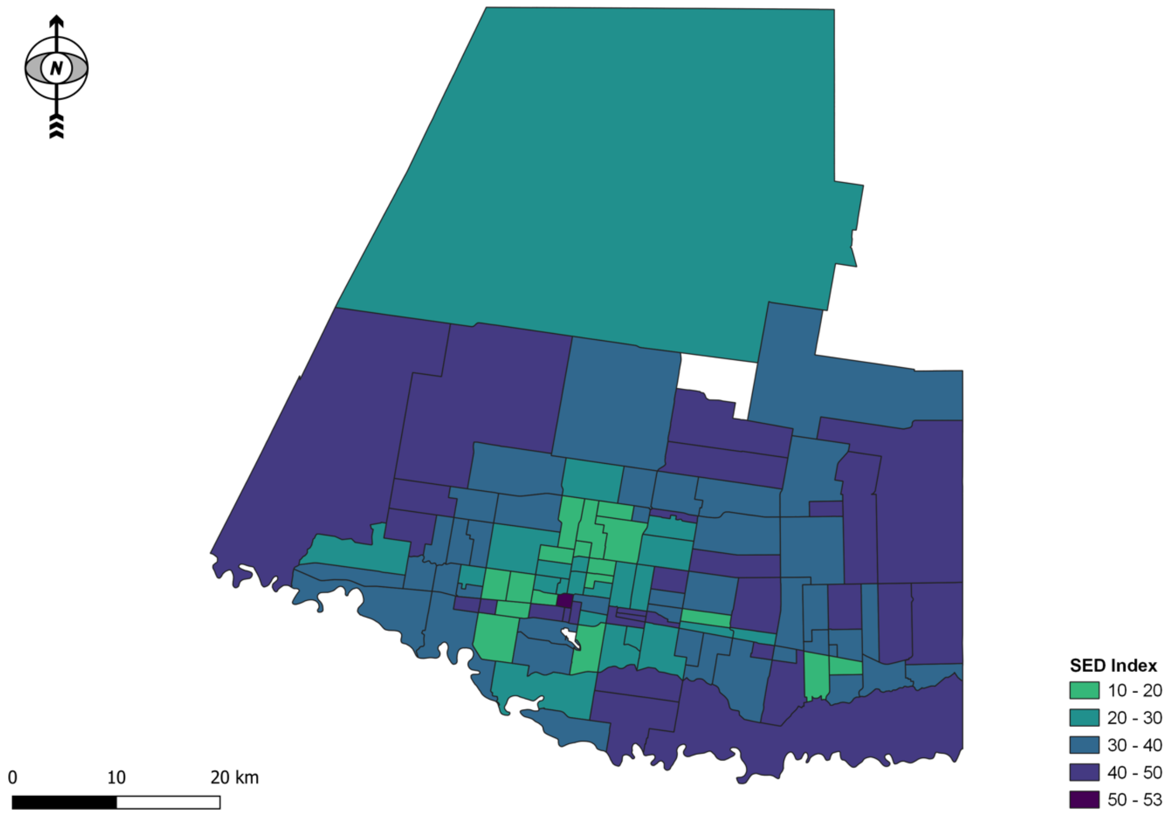


Figure 20: SED Indices by census tract area of residence in McAllen-Edinburg-Mission Metropolitan Statistical Area, 2006-2010

McAllen-Edinburg-Mission metro area is within Hidalgo county. High SED index are represented in the south part of the county with high percentage of population speaking a language other than English, people living in poverty, single mothers with children living under 18 years, renter-occupied housing units and people receiving cash public assistance or food stamps/SNAPS. Close to 85% (94 out of 111) census tracts have a SED index of 20 or higher, and 31 census tracts in Hidalgo county have a SED index of 40 or higher. The maximum value of SED index was found to be 52.9 (see figure 20).

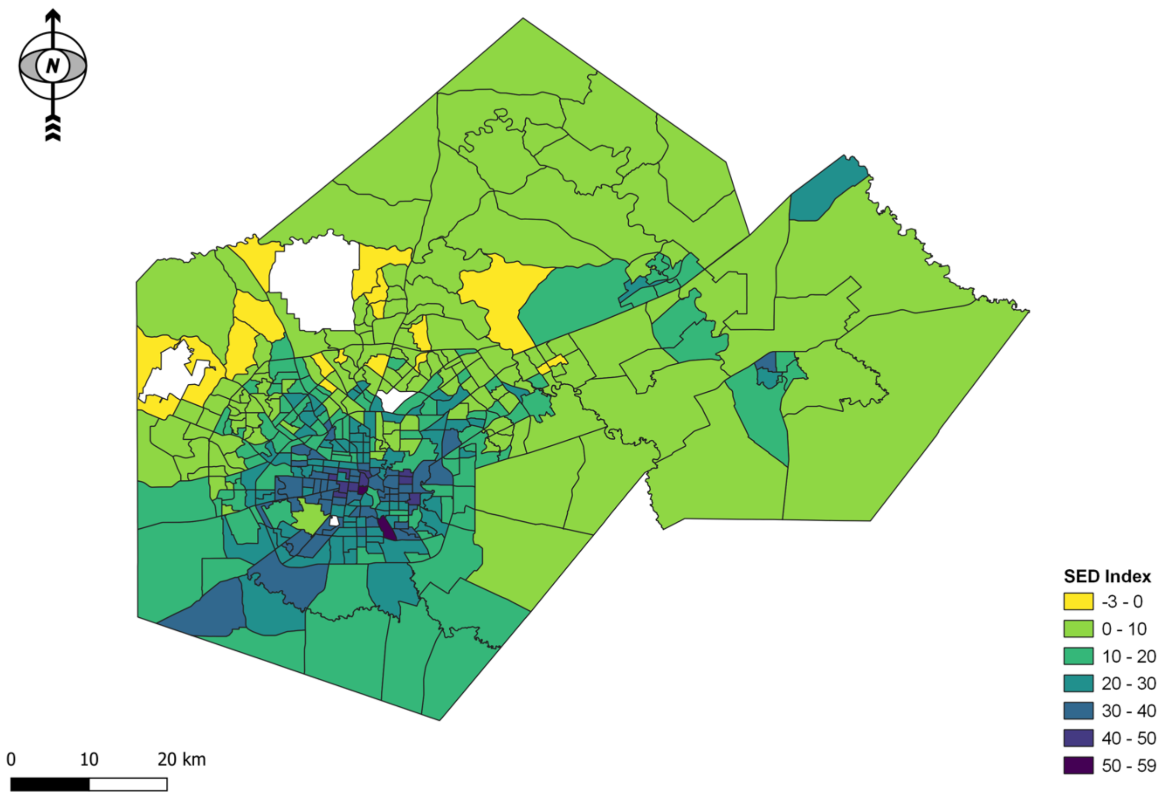


Figure 21: SED Indices by census tract area of residence in San Antonio-New Braunfels Metropolitan Statistical Area, 2006-2010

San Antonio-New Braunfels metro area is within Bexar, Comal and Guadalupe counties. High SED indices are found around the San Antonio downtown area whereas census tracts in Comal and Guadalupe counties have low SED indices. The maximum value of SED index was found to be 59 for census tract 1105. Almost 40% (145 out of 362) of the census tracts in Bexar county have an SED index of 20 or higher. Thirteen census tracts have an SED index of 40 or higher. High SED indices in this metro area are represented by a high percentage of single mothers living with children under 18 years, renter-occupied housing units, people living in poverty and households with no vehicle (see figure 21).

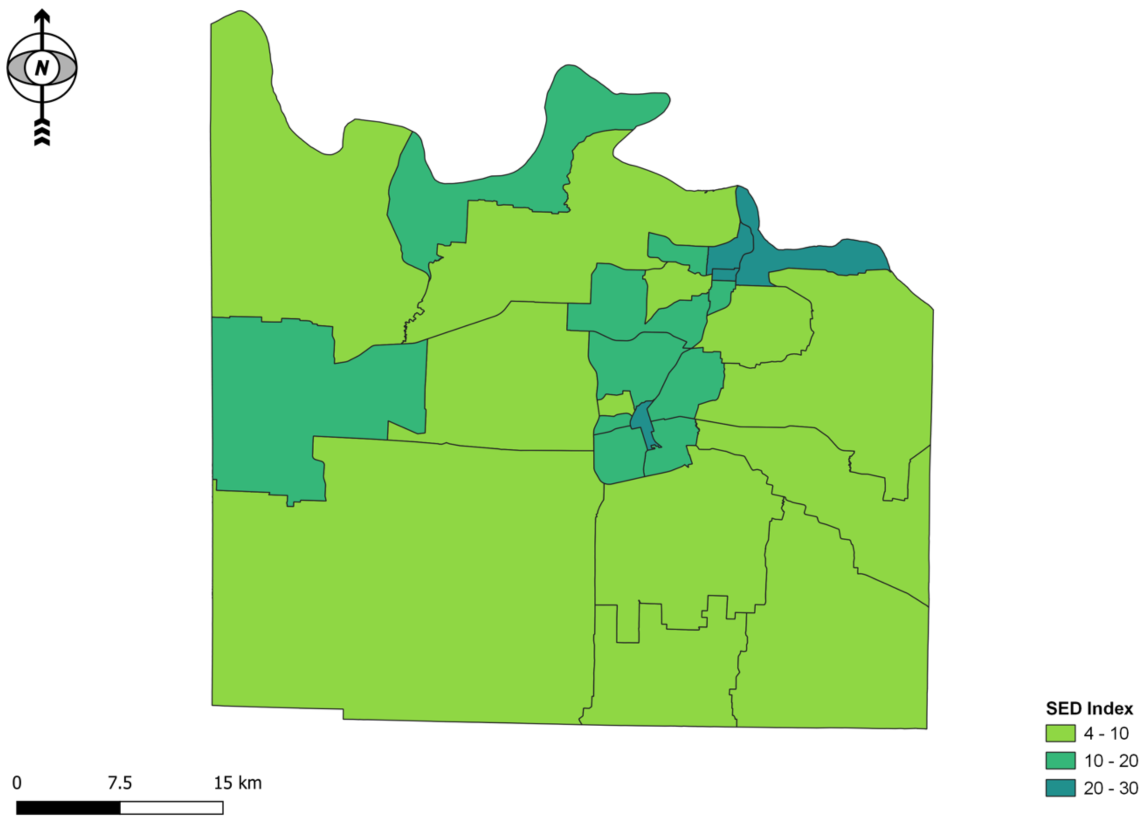


Figure 22: SED Indices by census tract area of residence in Sherman-Denison Metropolitan Statistical Area, 2006-2010

Sherman-Denison metro area is within Grayson county. The SED index was high in the principal cities of Denison and Sherman. The maximum value of SED index was found to be 30 represented by high percentage of black population, renter-occupied housing units and people living in poverty. Only 4 out of 26 census tracts had a SED index of 20 or higher (see figure 22).

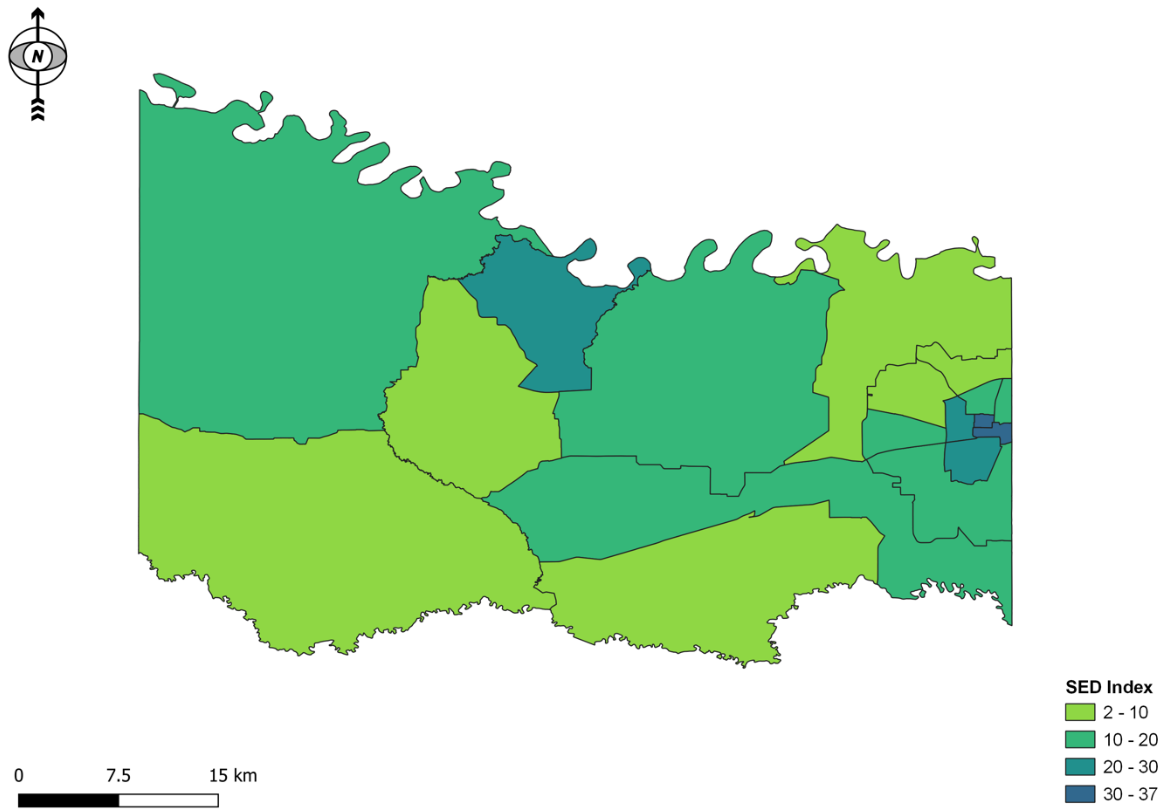


Figure 23: SED Indices by census tract area of residence in Texarkana Metropolitan Statistical Area, 2006-2010

Texarkana metro area is in Bowie county. The maximum value of SED index was found to be 37 for tract 105. High SED index in Grayson county was represented by high percentage of black population, single mothers living with children under 18 years, renter-occupied housing units and people living in poverty. Only 4 out of 18 census tracts had a SED index of 20 or higher (see figure 23).

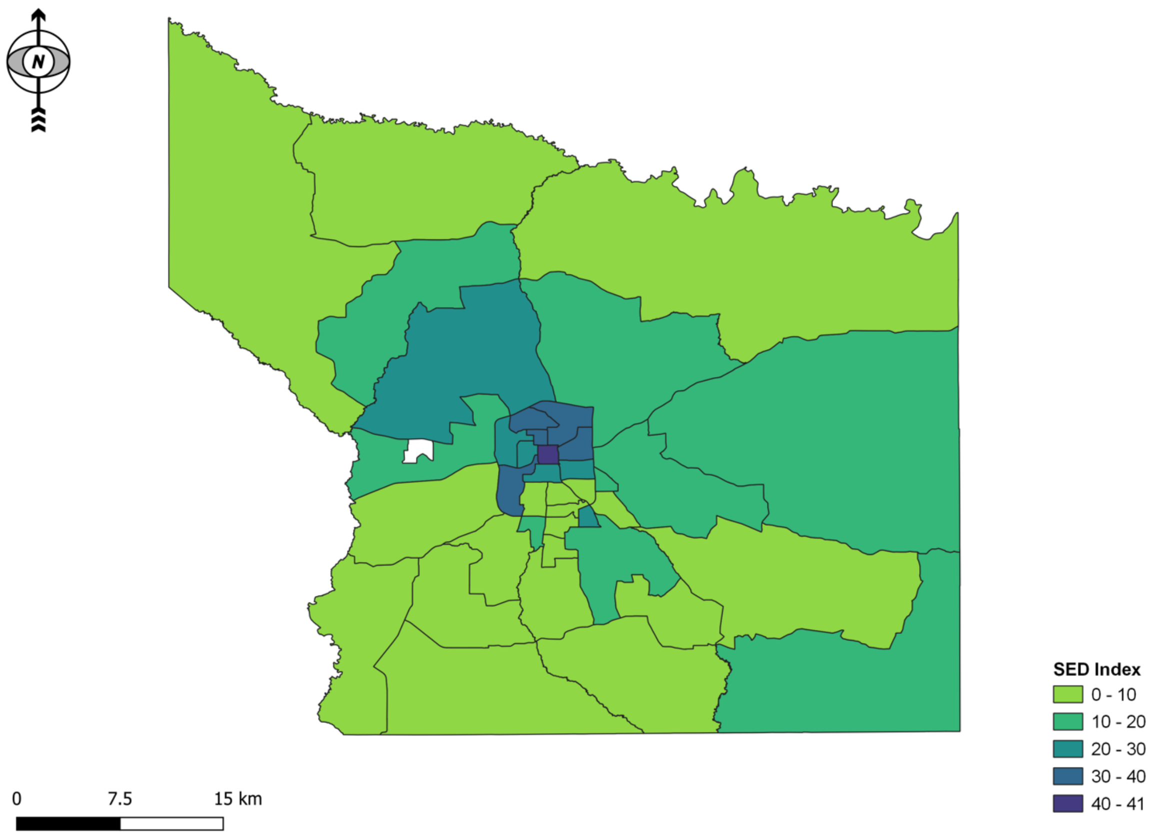


Figure 24: SED Indices by census tract area of residence in Tyler Metropolitan Statistical Area, 2006-2010

Tyler metro area is in Smith county. Here the highest SED index was found in the principal city of Tyler represented by a high percentage of black population, single mothers living with children under 18 years, renter-occupied housing units, people living in poverty and people receiving cash public assistance or food stamps/SNAPS. The maximum value for the SED index was found to be 41.4 for tract 5. Twelve out of 40 census tracts had an SED index of 20 or higher (see figure 24).

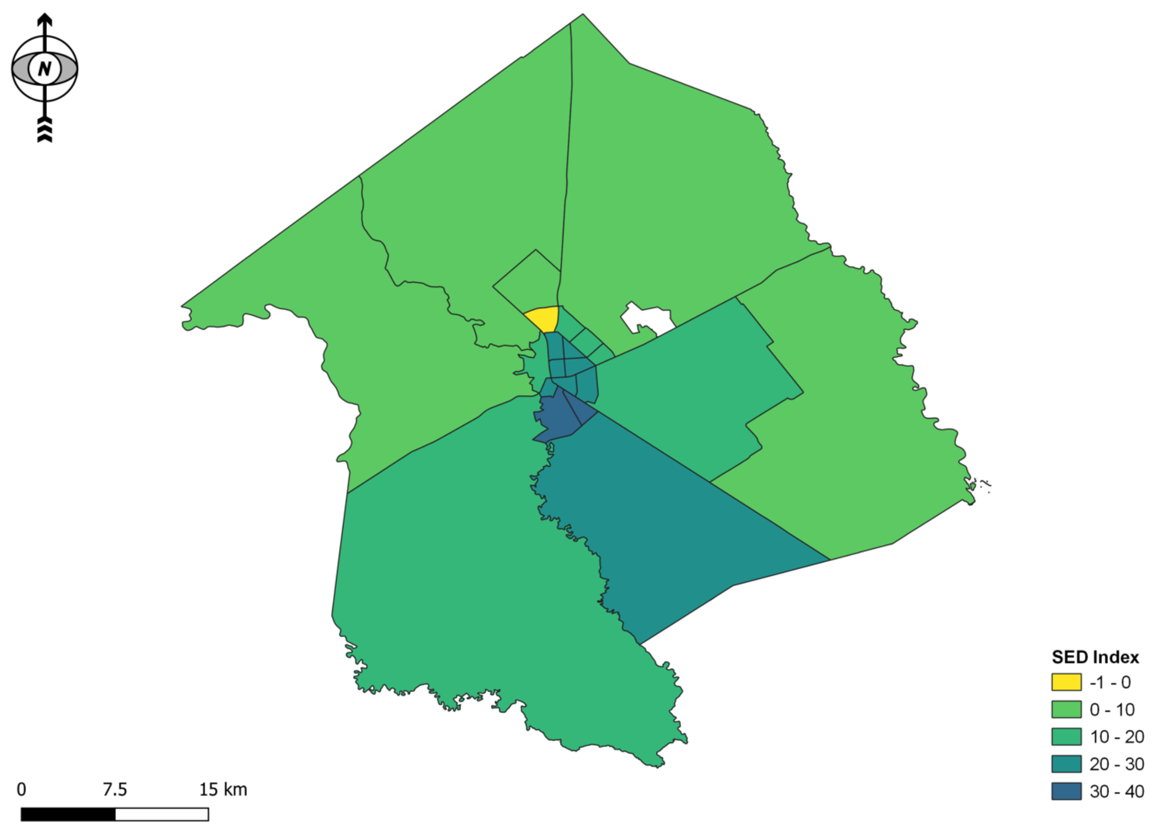


Figure 25: SED Indices by census tract area of residence in Victoria Metropolitan Statistical Area, 2006-2010

Victoria metro area is in Victoria county. The highest SED index was found in the principal city of Victoria represented by high percentage single mothers living with children under 18 years, people living in renter-occupied housing units, people speaking a language other than English, people living in poverty and people receiving cash public assistance or food stamps/SNAPS. The maximum value for the SED index was found to be 39.9 for tract 3.01. Almost half (10 out of 22) census tracts had an SED index of 20 or higher in Victoria county (see figure 25).

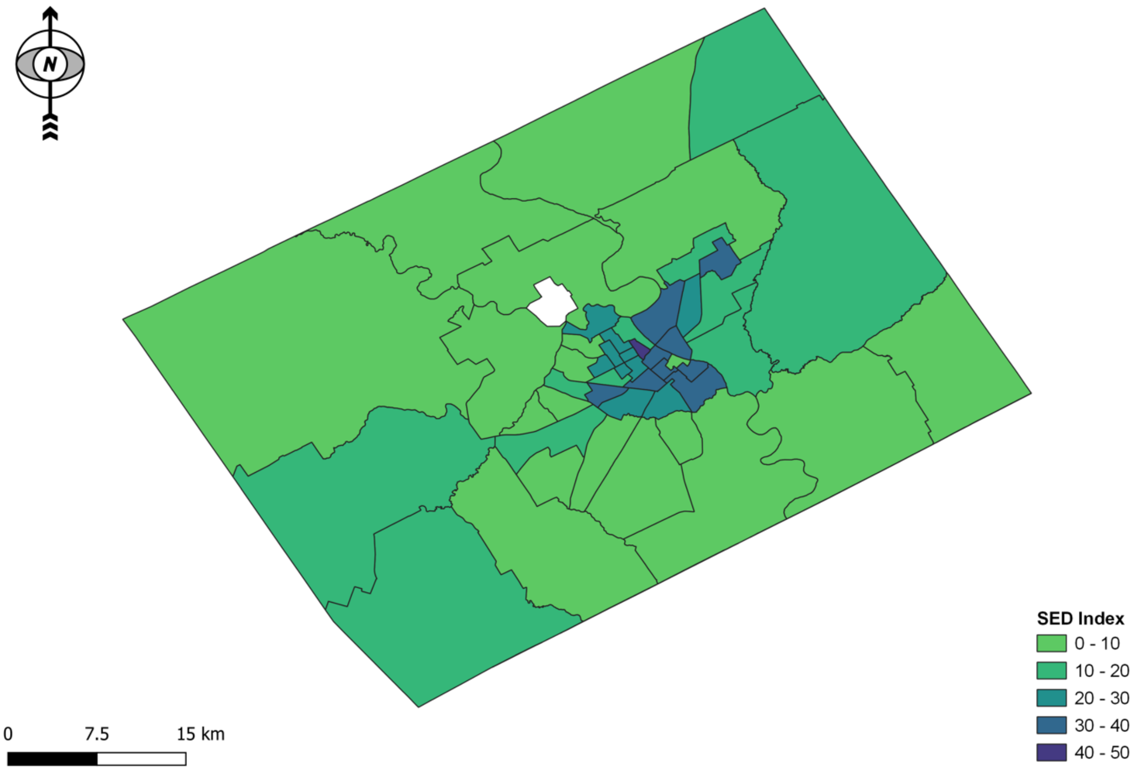


Figure 26: SED Indices by census tract area of residence in Waco Metropolitan Statistical Area, 2006-2010

Waco metro area is in McLennan county. The highest SED index was found in the city of Waco represented by a high percentage of people with education under 9th grade, single mothers living with children under 18 years, black population, people living in renter-occupied housing units, people speaking a language other than English, people living in poverty and people receiving cash public assistance or food stamps/SNAPS. The maximum SED index was found to be 45.3 for tract 12. A total of 20 out of 50 census tracts had an SED index of 20 or higher in McLennan county (see figure 26).

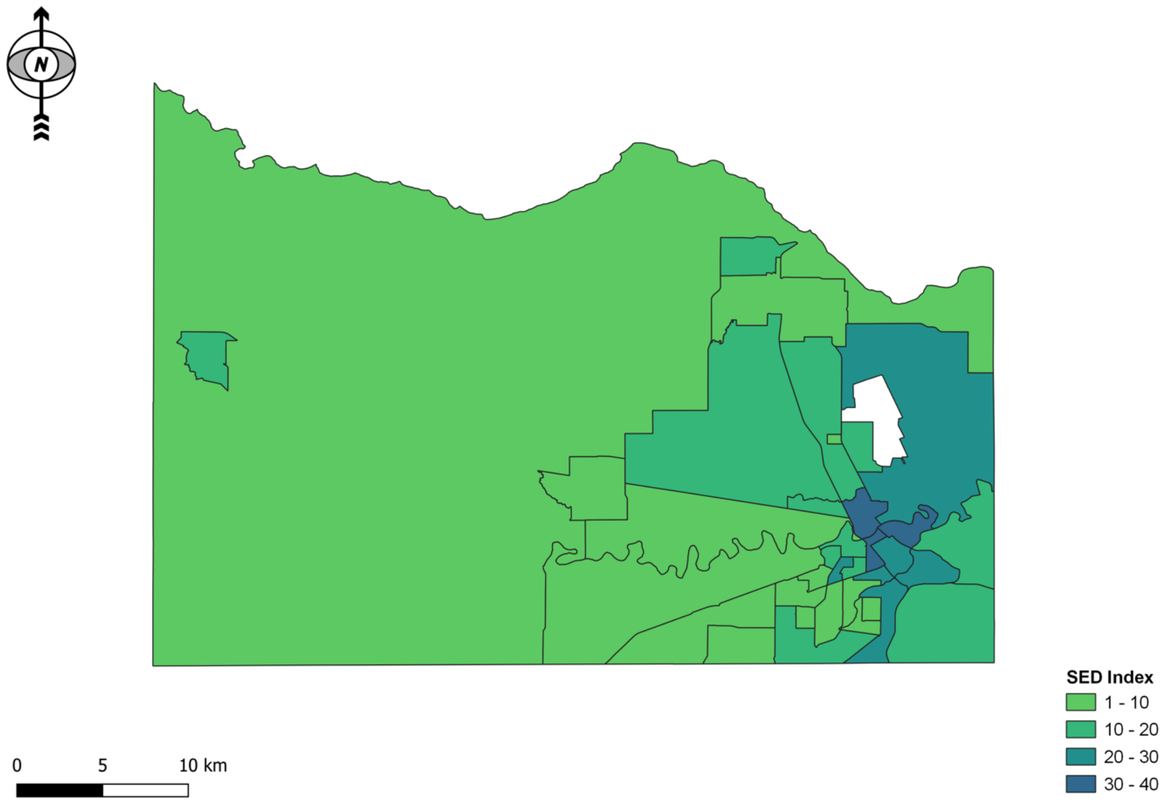


Figure 27: SED Indices by census tract area of residence in Wichita Falls Metropolitan Statistical Area, 2006-2010

Wichita Falls metro area is in Wichita county. The highest SED index was found in the city of Wichita Falls represented by high percentage single mothers living with children under 18 years, people living in renter-occupied housing units and people living in poverty. The maximum value of the SED index was found to be 39.7 for tract 102. A total of 9 out of 36 census tracts had an SED index of 20 or higher in Wichita county (see figure 27).

Discussion

The study explains the process of SED index construction using both child and adult asthma hospitalization discharge rate and a comprehensive list of socioeconomic risk indicators comprising domains of education, income, employment, ethnicity, housing and transportation in eastern Texas, 2006-2010. The output of relative weights of significant variable used for SED index construction in this study are listed in Table 2. A positive variable is associated with higher SED index whereas a negative number is associated with lower SED index. For example, the relative weight for percentage of people living in poverty is positive (0.2296) meaning a household with families living in poverty was ranked higher in SED status whereas the relative weight for percentage of people with white collar occupation is negative (-0.0638) meaning people with white collar occupations was ranked lower in SED status. The significant socioeconomic indicators that may have impacted the asthma hospitalizations for children and adult for eastern Texas in 2006-2010 are percentage of families living in poverty, percentage of people with white collar occupation (management, arts, sciences etc.), percentage of people who have an income of less than $15,000, percentage of children in the population under 5 years, percentage of elderly population (65 years and over), percentage of people who use wood for heating purposes, percentage of family households with no vehicles, percentage of people who have no salary or wage income and percentage of people who receive cash public assistance or Food Stamps/SNAPS. The hypothesis that socioeconomic deprivation status is associated with asthma hospitalization rates for both children and adults in eastern Texas is accepted.

The results of this study are consistent with studies conducted previously. A study done by Anderson and colleagues (2016) found that asthma is associated with poverty in Texas. Collin and Denton counties have lowest poverty rates whereas Cameron, Hidalgo, Willacy, Starr, Zapata have highest levels of poverty in Texas. Occupational triggers like smoke, inorganic dusts and low molecular weight category highly reactive agents are known to be responsible for severe exacerbation of asthma (Henneberger et al., 2015). A study conducted by Alexopoulos and Burdorf (2001) in Netherlands among blue collar and white-collar workers concluded that blue collar works had a more often and more prolonged absences due to respiratory disorders. The high prevalence of smoking among blue collar workers also contributed to this according to the same study. The burden of asthma is also high in low income families (Louisias and Phipatanaakul, 2017). Cardet et al. (2018) found that low income was a risk factor in failures of asthma treatment and exacerbations. A study done by Florida and Mellandar (2015) ranks four Texas metros (#1 Austin-Round Rock, #3 San Antonio-New Braunfels, #4 Houston-Sugarland-The Woodlands and #7 Dallas-Fort Worth-Arlington) in the top 10 metro areas with high levels of economic segregation when wealth, occupation and education were used as risk indicators to create an index. Higher asthma incidence in children (especially under 5 years) and elderly population (65 years and over) has been widely documented (Basagaña et al., 2004; Hedlund et al., 2007; Washington et al. 2018). Spahn (2008) investigated clinical progression of asthma in children and adults. This study pointed to asthma's potential to be dormant and relapse in mid adult life having originated in childhood. An estimated population of 4.8 million people in U.S. (Noonan et al. 2015) use wood stoves for heating purposes and although this is a very small population, residential heating with wood leads to exposure to particulate matter and endotoxins. There have not been a lot of studies that have found any association between heating with wood and asthma (Belanger and Triche, 2008). However, it is important to note that use of wood for heating purposes can be a marker of poverty and of substandard housing, and this might confound any association with asthma. Annual income includes all income from wages or salary, so having income less than $15,000 is a common indication of having no/low wages or salary and a high SED index. Most of the families receiving cash public assistance of food stamps/SNAPS are also low wage working families. According to Heflin et al. (2018), SNAP reaches 9.8 million households with children, 24% of them with children under 18 years of age. In the same study conducted in Missouri, there was evidence for asthma related emergency room visits for families using SNAP. This peaked at the first of the month when the rent and bills are due and can leave families undecided as to whether they should go to hospital. It is possible that households with low SNAP benefits suffer in this case. Being economically disadvantaged leads to stress, depression and anxiety. Recent studies (Chen and Miller, 2018; Marshall and Agarwal, 2000) have demonstrated that psychological stress amplifies the immune response to asthma triggers and favors inflammatory characteristics of asthma and allergic diseases (Chen and Miller, 2007).

It is important to consider that the method used in this study is not a process set in stone. Although as many as 26 risk indicators were used to construct the 2006-2010 SED index in eastern Texas, there are still many more indicators that could have been considered. Indicators like indoor allergens, cigarette smokers, access to healthcare, psychological stressors etc. can be added for future studies to name a few. But such information is not as readily available as that provided by the U.S. Bureau of Census. So all things considered, this was an adequate representation of the aspects of life that measure relative position of an individual or a community in its societal hierarchy. The indexes that are calculated in this study are not pure in a sense that only variables correlated with the child and adult asthma hospitalization discharge rate was used to create the deprivation index at county level. The results of principal component analysis depend on the nature of the variables chosen and the relationship between the variables that are considered (Vyas and Kuramanayake, 2006).

In addition to hospital visits, admission to emergency rooms and use of medications, asthma also burdens society in terms of economic cost (Bahadori et al., 2009). Patients with markers of asthma contributed up to $4,423 or more in expenditures compared to a patient without asthma (Sullivan et al., 2014). According to Nunes et al. (2017), asthma costs have probably exceeded the combined burden of Tuberculosis and HIV/AIDS. This has also led to decreased productivity among people with asthma because of absences from work, missed school days for children, permanent disability and premature death. Asthma related burden could also be intangible (e.g. decrease in quality of life, activity limitations, increase in pain or suffering).

Although this study does not provide any causal evidence, the methods and analysis proposed in this study have a good descriptive ability to identify the risk indicators that impact asthma hospitalization for children and adults in eastern Texas. It informs on the different risk indicators that can exacerbate or create an onset of asthma among people in different metropolitan areas of eastern Texas. Several asthma action plan guidelines have been created and implemented to achieve better diagnosis and treatment strategies at national and regional in the last decade. A comprehensive asthma action plan would best be implemented at a local level to achieve cost-effective outcomes, and significant and real long-term benefits.

Chapter 3 – Spatio-temporal Variation of Air Pollutants, Meteorological Parameters and Identification of Association with Asthma Hospital Discharge Rates in eastern Texas

Asthma is a heterogenous chronic pulmonary disease that causes recurring episodes of wheezing (a whistling sound made when breathing), tightness of chest, shortness of breath and coughing (Skarkova et al., 2015). People with asthma have constricted airways in response to various stimuli. The importance of asthma triggers varies from person to person, but few examples include: airborne allergens (e.g., pollen, animal dander, molds, cockroaches, dust mites etc.), air pollutants, breathing cold air, respiratory infections such as rhinovirus, emotional stress, preservatives and sulfites in foods and drinks, etc. As an asthmatic individual inhales air, stimuli can inflame and damage the airways causing muscles in the airways to constrict (bronchoconstriction), trapping air in the alveoli that can lead to wheezing, tightness of chest, shortness of breath and coughing. Swelling worsens the situation making the airways even narrower. As airways constrict, cells in the airways make more mucus than usual than will further narrow airways. Although the constriction of airways can be temporary and reversible, chronic exposure to stimuli may cause (lower) airway remodeling and incur permanent structural damage leading to diminished lung function over time (National Heart, Lung and Blood Institute, 2013; EPA 2019).

Asthma is influenced by multiple factors that include environment, infections, diet and genetics. Environmental exposure can occur both indoors and outdoors (Diette et al., 2008). According to EPA (2001) an average American spends 93% of life indoors. Indoor environment contains pollutants like ozone (penetrating from outdoors), particulate matter (from cooking, cleaning particles that sneak from outdoors), nitrogen dioxide (from gas stoves, fireplaces) and allergens from animal dander, molds, cockroaches, dust mites. Asthma can also be triggered by secondhand smoke. Along with ozone, particulate matter and nitrogen dioxide, the EPA (2019) has identified sulfur dioxide (from burning of fossil fuels, smelting of mineral ores), carbon monoxide (from the incomplete combustion of fossil fuels and from vehicles) and lead (from waste incinerators and smelters), collectively known as criteria pollutants that have an effect on public health. In addition to criteria pollutants, outdoor allergens also include pollen which is high in concentration (with some exceptions) during warmer seasons and low during cooler seasons. Viral respiratory tract infections include rhinovirus, respiratory syncytial virus, para influenza, metapneumovirus, coronavirus and other viruses (Busse et al., 2010). Heymann and colleagues (2004) found consistent findings that viral infections increase asthma complications in synergy with allergens both in children and adults. Foods with additives and chemicals prevalent in western diet can act as triggers for asthma through proinflammatory reactions (Brigham et al., 2015). Kearney (2010) reported that processed food is a potential factor to asthma burden. Studies of family history and twins (Willemsen et al., 2008), and familial aggregation and segregation studies have shown that there is a convincing relationship between genetics and asthma (Bijanzadeh et al., 2011). The relationship between risk of developing asthma is higher when both genetics and environmental factors are involved (Yeatts et al., 2006).

The studies on asthma and air pollutants has raised important questions on what factors are responsible for asthma hospitalizations. Annual and diurnal temporal distribution of pollutants and meteorological data was analyzed to explain the movement history of these variables in time. Analysis was conducted for 2007 and 2011 to see the distinction of air pollutants and meteorological parameters during a wet year (2007) and a dry year (2011). In this study, the relationships between air pollutants, meteorological parameters and asthma hospital discharge rates were explored using GIS along with their correlation analysis specifically for eastern Texas from 2005-2011. The idea was to identify geographic clusters of hotspots and cold spots of the aforementioned parameters which might allow us to make better decisions to tackle the issue of asthma hospitalizations and air pollution at a local level. The following hypothesis were tested: air pollutants like ozone, NO_2 and meteorological parameters like temperature and wind speed are associated with asthma hospitalization rates in both children and adults.

Methods

Asthma hospitalization discharge rates were accessed from Texas Health Care Information Collection (THCIC) Inpatient Hospital Discharge dataset for Texas on a county-by-county basis and for children and adults as in previous chapter. Asthma data was available for 159 counties. In addition, air pollutant and meteorological data was taken from Texas Commission on Environment Quality (TCEQ) website from 2005 to 2012. TCEQ maintains a 24-hour continuous air monitoring stations (CAMS) that measure various air pollutants – ozone and NO_2 were used for this study. Temperature and wind speed were considered for meteorological parameters. The hourly data of atmospheric pollutants and meteorological data were used to determine yearly averages for the time period 2005 to 2012. Ozone, temperature, NO_2 and windspeed data were collected from ninety-three, one hundred seventeen, forty-five and one hundred fourteen stations respectively. Figure 28 shows the spatial locations of the active CAMS from 2005-2012 in eastern Texas. The description of the CAMS network including region, number, site name, latitude and longitude in included in the appendix. Air pollutants and meteorological was not available for all counties in eastern Texas.

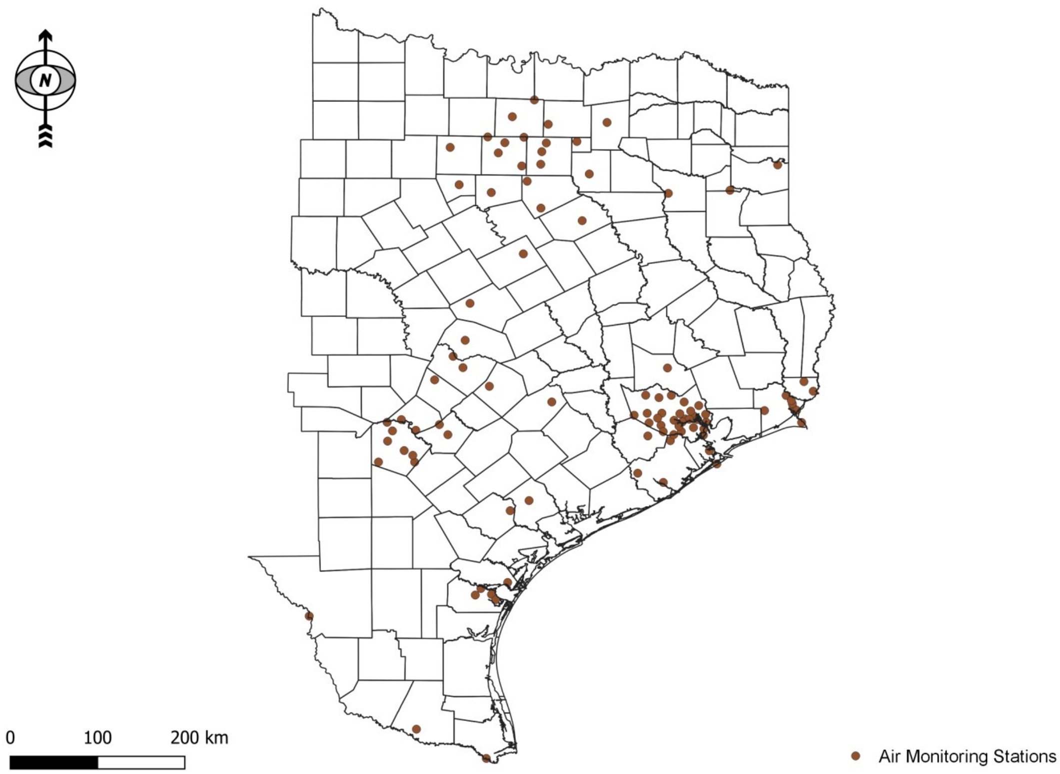


Figure 28: Active Continuous Air Monitoring Stations (CAMS) in eastern Texas, 2005-2012

Missing data was a common occurrence for these parameters because of equipment failure at CAMS sites. Ignoring missing data may skew the data and impact the power of the analysis. As noted in Hardt et al. (2013), substituting missing data leads to better results than no substitution at all. To our knowledge, no previous study in eastern Texas has used this method to substitute missing data. Use of mean as a substitute for missing data may work on dataset missing less than 5% data, but according to Kang (2013), this method adds no information and leads to underestimation of errors. Multiple Imputation Chained Equation (MICE), a superior method recommended in many studies (Raghunathan et al., 2001; Van Buuren, 2007) was used to substitute missing data using MICE function in R. Multiple predictions are made for each missing value using predictive mean matching where a missing value is randomly filled from observed values such that the regression-predicted value of observed value is closest to regression-predicted value for missing value.

Yearly trends of ozone, NO_2, temperature, wind speed and asthma discharge rate were examined for time series analysis using data from 2005 to 2012 at metropolitan statistical area level. If a county had multiple continuous air monitoring stations, the value was averaged for a particular year. For example: Harris county in Houston-The Woodlands-Sugarland metro area has 29 stations that measure ozone concentrations at various locations in the county. These ozone concentration values at various locations was averaged to calculate a single value of ozone concentration for Harris county in 2005. Similarly, the process was repeated for other counties in Houston-The Woodlands-Sugarland metro area for 2005. In the end, the values for all populous counties in Houston-The Woodlands-Sugarland metro area were averaged to get one value of ozone concentration for 2005. The process was repeated for 2006 to 2012. This process yielded a set of sequential numeric data items taken at yearly intervals for various metro areas in Texas. In addition to this, a CAMS site was selected from each metro area and analyzed in detail for 2007 and 2011.

Wind rose diagrams for a site in Dallas, Houston, San Antonio and Corpus Christi were drawn to understand how wind behaves across eastern Texas. The relationship of ozone to wind speed and wind direction is validated using wind roses. Wind rose diagrams are generated by using hourly observed wind speed and wind direction data. Wind rose diagram uses Beaufort scale to categorize wind speed (NWS, 2019). Windspeed with 0 miles per hour (mph) is considered as a calm wind. Wind speed greater than 8 mph was analyzed for this study because 8 mph designates a gentle breeze and it is expected that air pollutants at this speed would be significantly dispersed away from the original location. Wind rose diagrams are generated via MRCC's cli-Mate tools (MRCC, 2019). Wind rose diagram present as a circular map consisting of spokes with the length of each spoke representing how often wind blows from that direction. In an example of a wind rose diagram given below shows that the westerly wind is prevalent at this location and wind blows 30% of time from west. The different colors on that spoke provide information on the speed of the wind from specified direction. Based on the figure below, it can be assumed that wind flows from the west at a speed of 1-4 knots, and blows about 4% of the time. Winds at 4-7 knots occur about approximately 18% of the time followed by winds with speeds at 7-11 knots which occurs about 7% of the time.

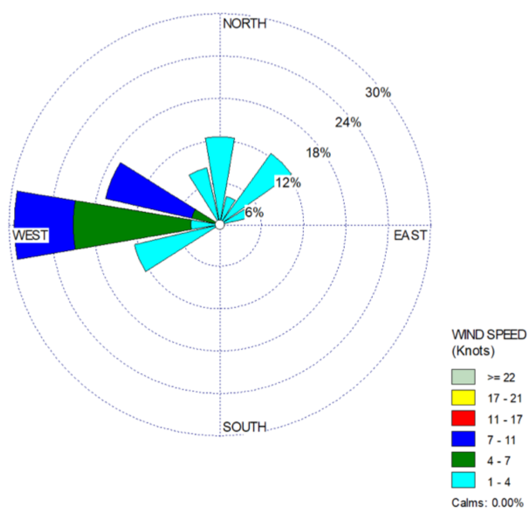


Figure 29: A wind rose diagram (Adapted from EPA, 2019)

The annual exposure levels for asthma, ambient air pollutants and meteorological parameters were linked by kriging, a geostatistical method in ArcGIS Version 10.5 (ESRI, 2001) to identify any association. In this analysis, first the latitude and longitude of the CAMS (which were obtained from TCEQ website) were fed into ArcGIS. This was followed by supplying the CAMS (point data in ArcGIS) with the yearly pollutant data (for ozone and NO_2) and meteorological data (for temperature and windspeed) averaged from 2005-2012. Interpolation can be used to transform a field data into a continuous surface based on measured values, and underlying mathematical formula or statistical models (ESRI, 2008). The most commonly used process in the air pollution field is known as Ordinary Kriging (Jarett et al., 2004), which was used here to estimate a spatially appropriate smooth surface of air pollutants and meteorological data based on the irregularly spaced data points. Centroid values were extracted for each county based on the spatially interpolated raster images. Spatial interpolated raster images were imported into GIS and overlaid with the eastern Texas county shapefiles. The predicted concentrations for ozone, NO_2, temperature and wind speed for each county in eastern Texas for 2005-2012 was generated using this method. It is assumed that spatial variation is homogenous over the domain and depends only on distance between two sites. The variables at unmeasured location were estimated using observed values at nearer locations. Over a finite geographical distribution called a neighborhood, points are assumed to be spatially correlated and the degree of spatial correlation decreases with increasing distance (Tyagi and Singh, 2013; Chopra and Holgate, 2005). Kriging uses a tool known as a semivariogram for making predictions. The accuracy of the spatial relationship between measured points were examined by measuring a fundamental statistical parameter called sum of squared error (SSER). SSER close to 0 indicates the model has a small error and the model fit is useful for prediction [Kutner et al., 2005]. For asthma hospital discharge rate, each county was treated as a point shape file and the value assigned to the centroid of county. Similarly, Ordinary Kriging (OK) was used to estimate a spatially appropriate smooth surface of asthma hospital discharge rate in eastern Texas. Centroid position for the asthma discharge rate is the same as the centroid positions of predicted pollutant and meteorological values for each county. Pairwise correlation coefficients were calculated to assess the strength of associations between the asthma hospital discharge rates and corresponding pollutant levels as well as meteorological data in eastern Texas for 2005-2012. Normality was checked for the spatially extrapolated data and transformed if necessary. Pairwise correlation coefficients greater than 0.3 displays non-trivial relationship between variables (Lorden et al., 2011).

Hotspot and cluster outlier analysis was performed on the asthma discharge rate to analyze the spatio-temporal prevalence of asthma using spatial statistical mapping in ArcGIS (ESRI, 2019). Spatial autocorrelation was assessed for the both adult and child discharge rates first. This process yielded 5 values: Moran's Index (I), Estimated Index, Variation, Z-score and p-value. Moran's Index was used along with z-score and p-value to assess spatial pattern and levels of asthma discharge rate clustering at various locations (Tsai et al., 2009). If Moran's index is close to 1, it means a cluster exists, whereas if a Moran's index is close to 0 it means dispersion exists (Sanchez-Martin et al., 2019). Positive z-score and a low p-value indicates a cluster of high asthma discharges (hotspot). Hotspots of asthma hospital discharge rates for adults and children were then calculated using the Getis-Ord Gi* function. According to Prasannakumar et al., (2011), Getis-Ord Gi* function yields a spatial cluster of hotspots (high value of asthma discharge rates) and cold spots (low values of asthma discharge rates). Hotspot analysis generates hotspots and coldspots (two groups) at three different confidence intervals (90%, 95%, (99%). Fixed Distance Band is chosen as selecting a distance method. Euclidean distance is used as a calculation method of distance (ESRI, 2019). Cluster Outlier Analysis was calculated using the Anselin Local Moran function. The concept is relatively similar to Getis-Ord Gi* function in hotspot analysis. Cluster Outlier analysis groups values into four groups, which will be discussed later. Hotspot analysis and Cluster Outlier analysis have been used in many epidemiology studies to assess spatial anomalies (Sanchez-Martin et al., 2019; Stopka et al., 2014; Tsai et al., 2009).

Results

The yearly descriptive statics of ozone, NO_2, temperature, wind speed and both child and adult asthma hospital discharge rates for eastern Texas are shown below in Table 1. The maximum yearly concentration for ozone was 28.7 ppb in 2011, whereas the minimum yearly concentration of ozone was 25.8 ppb in 2007 in eastern Texas. While the summer of 2007 was the wettest summer on record, 2011 was a very dry year overall (Hanna, 2014; Nielsen-Gammon, 2011). The maximum yearly NO_2 concentration was observed in 2005 (8.6 ppb) whereas the minimum yearly NO_2 concentration was observed in 2009 (6.8 ppb). The maximum value of annual average temperature was 70.7 °F in 2011 whereas the minimum value of annual average temperature was 68.8 °F in 2007 consistent to ozone maximum and minimum. Wind speed was found to be maximum in 2011 (7.8 m/s) whereas the minimum wind speed was found to be in 2005 (6.8 m/s). Adult asthma discharge rate was found to be high in 2005 (12.7 per 10,000 residents) compared to a low in 2011 (9.1 per 10,000 residents) whereas child asthma discharge rate was found to be high in 2006 (22.0 per 10,000 residents) compared to la ow in 2011 (15.8 per 10,000 residents). Asthma discharge rate is following a downward trend for both adults and children along with NO_2 concentration. On the other hand, ozone, temperature and wind speed is following an upward trend.

Table 5: Yearly pollutant, meteorological parameters and asthma discharge rate in eastern Texas, 2005-2011

	Eastern Texas						
Variables	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
Ozone (ppb)	28.2	28.2	25.8	26.9	26.5	27.2	28.7
NO2 (ppb)	8.6	8.2	8.2	7.4	6.8	7.1	6.9
Temperature (°F)	69.2	70.3	68.8	69.2	69.4	68.7	70.7
Wind Speed (m/s)	6.8	7.2	6.7	7.5	7.4	7.1	7.8
Adult Asthma Discharge Rate (per 10,000 residents)	12.7	11.3	11.7	11.6	11.6	11.3	9.1
Crude Child Discharge Rate (per 10,000 residents)	20.2	22.0	21.5	18.7	20.8	17.3	15.8

Table 6 summarizes the total number of quarterly asthma discharges and percentage of quarterly asthma discharges in Texas during 2011. There were 25,226 total discharges. Quarter 1 includes hospital discharges from January through March. Quarter 2 includes hospital discharges from April through June. Quarter 3 includes hospital discharges from July through September and Quarter 4 includes hospital discharges from October through December. Analysis of total discharges revealed that more patients were discharged in quarter 1 (January-March) and the leastern patients were discharged in quarter 3 (July-September).

Table 6: Total asthma discharges in Texas by quarter, 2011

	Total Asthma Discharges	Percentage of discharges (%)
Quarter 1	8373	33.2%
Quarter 2	5596	22.2%
Quarter 3	4663	18.5%
Quarter 4	6594	26.1%

Figure 30 shows the quarterly asthma hospital discharge rate for all ages in selected counties in Texas during 2011. The total asthma discharge rate was higher during the first quarter of 2011. The average asthma discharge rate for all ages was 3.8, 2.6, 2.0 and 2.8 per 10,000 residents during Quarter 1, Quarter 2, Quarter 3 and Quarter 4 respectively.

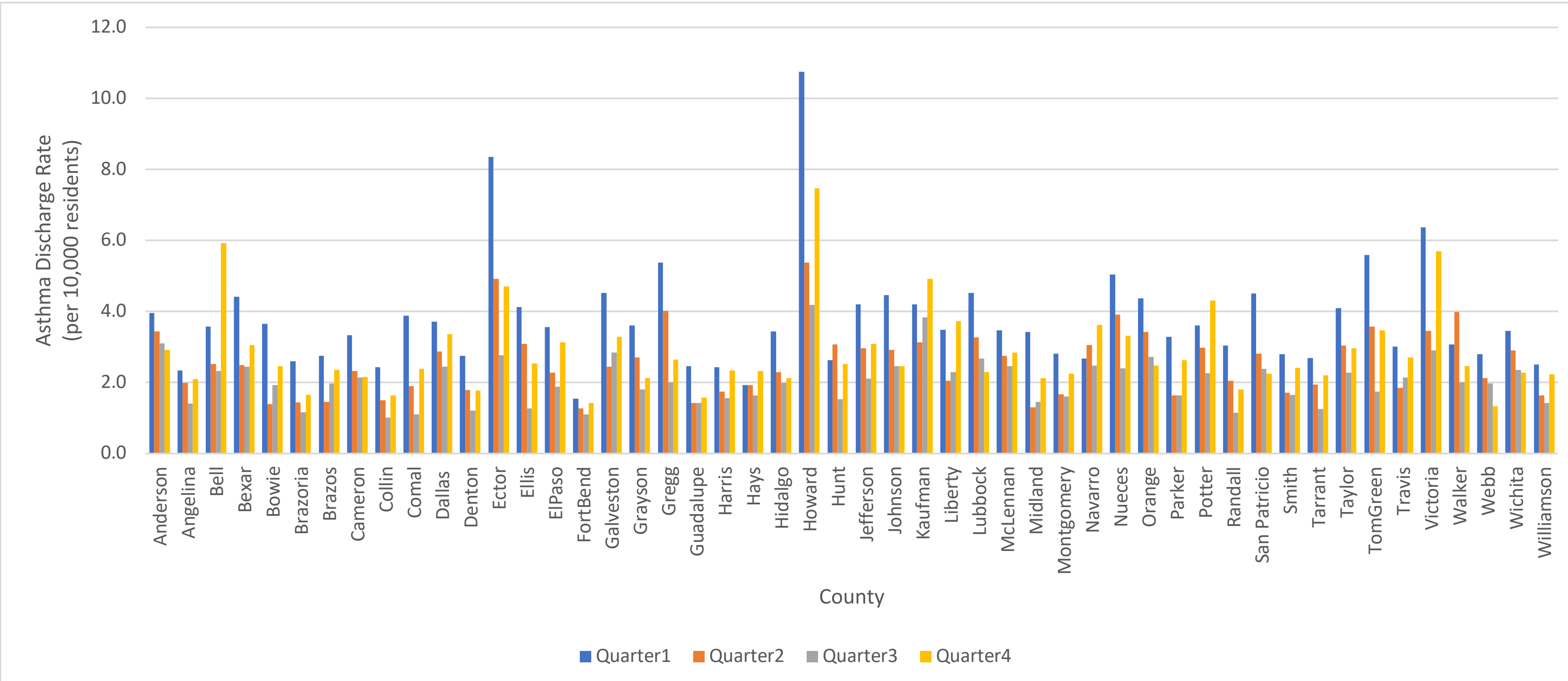


Figure 30: Quarterly trend in the rate of asthma discharge rate per 10,000 residents for all ages in selected counties of eastern Texas, 2011

Yearly variations in ozone, NO_2, temperature and wind speed are discussed next for the most populous metro cities in eastern Texas. Over this period, Dallas-Fort Worth-Arlington, Tyler metro area have ozone concentration consistently over 29 ppb as shown in figure 31. Ozone concentration increased over time in Corpus Christi from 2005 to 2012. Ozone in South Texas (Brownsville-Harlingen, Laredo, McAllen-Edinburgh-Mission metro areas) range from 21 ppb to 27 ppb. Ozone in Brownsville-Harlingen metro area is slightly higher than Laredo and McAllen-Edinburgh-Mission metro area. Ozone concentration has no change over time in Houston-The Woodlands-Sugarland and San Antonio-Braunfels metro area ranging from 24 to 29 ppb. Ozone is consistently high in 2011 in all metro areas.

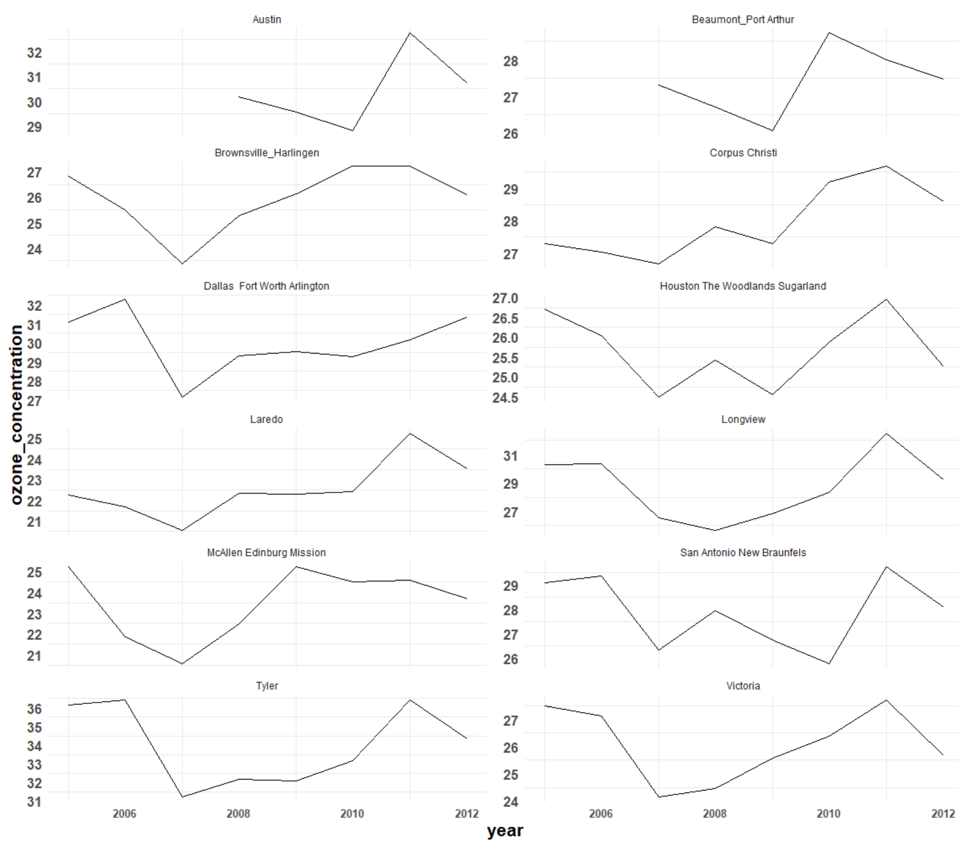


Figure 31: Yearly averaged ozone concentration (ppb) for metro cities in eastern Texas, 2005-2012

Nitrogen dioxide (NO_2) clearly shows a marked downward trend for all metro areas except San Antonio- Braunfels metro area as shown in figure 32. Beaumont-Port Arthur metro shows the largest change (28% decrease from 6.25 ppb to 4.5 ppb) followed by Longview and Tyler metros (both 24% decrease) closely followed by Houston-The Woodlands-Sugarland metro (23% decrease). Austin-Round Rock metro shows a decrease of NO_2 by 19% whereas Dallas-Fort Worth-Arlington shows the leastern decrease (16%).

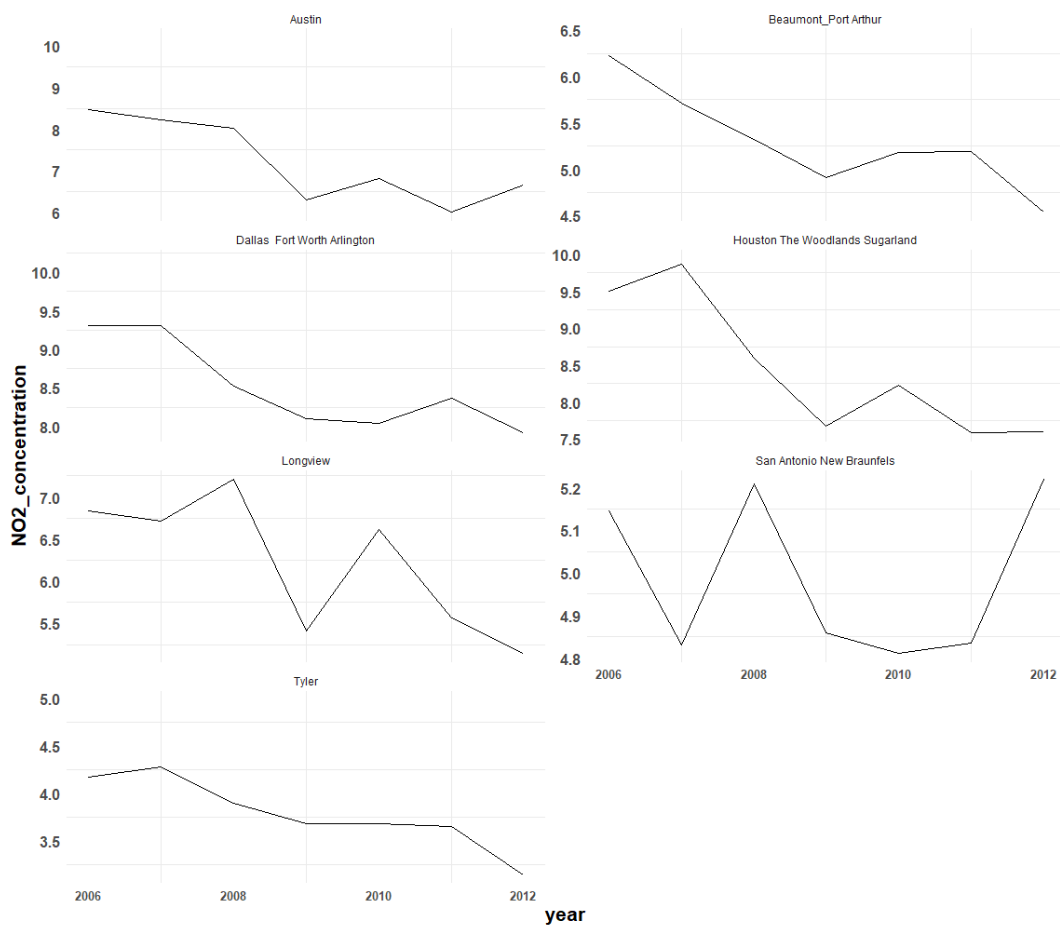


Figure 32: Yearly averaged NO_2 concentration (ppb) for metro cities in eastern Texas, 2005-2012

Temperature show an upwards trend in most of the metro areas in eastern Texas. Metros in South Texas (Brownsville-Harlingen, Laredo and McAllen-Edinburg-Mission) exhibited the highest yearly temperature with a maximum of a little over 76 °F followed by Corpus Christi (ranging from 72 °F to 75 °F), Victoria (maximum of 73 °F) and Houston-The Woodlands-Sugarland (ranging between 71°F and 72 °F). Figure 30 details the temperature variation for the metro areas during 2005-2012.

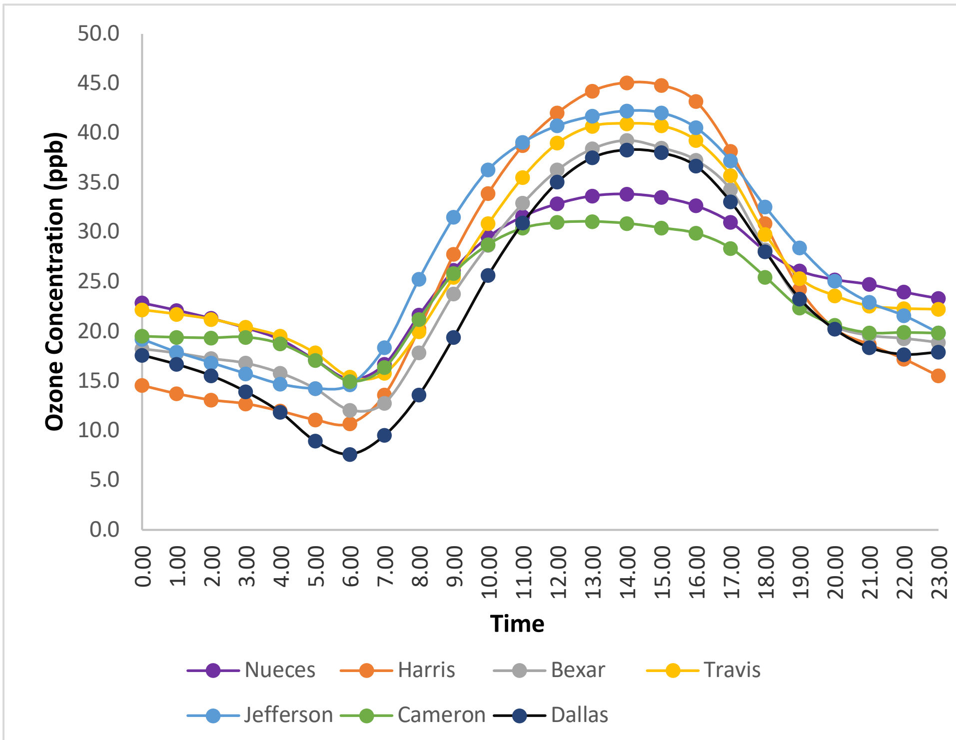
Figure 33: Yearly averaged temperature (°F) for metro cities in eastern Texas, 2005-2012

As shown in figure 34, Corpus Christi showed the highest yearly mean wind speed (9 m/s), clearly the windiest among the metros in eastern Texas followed by metros in South Texas.

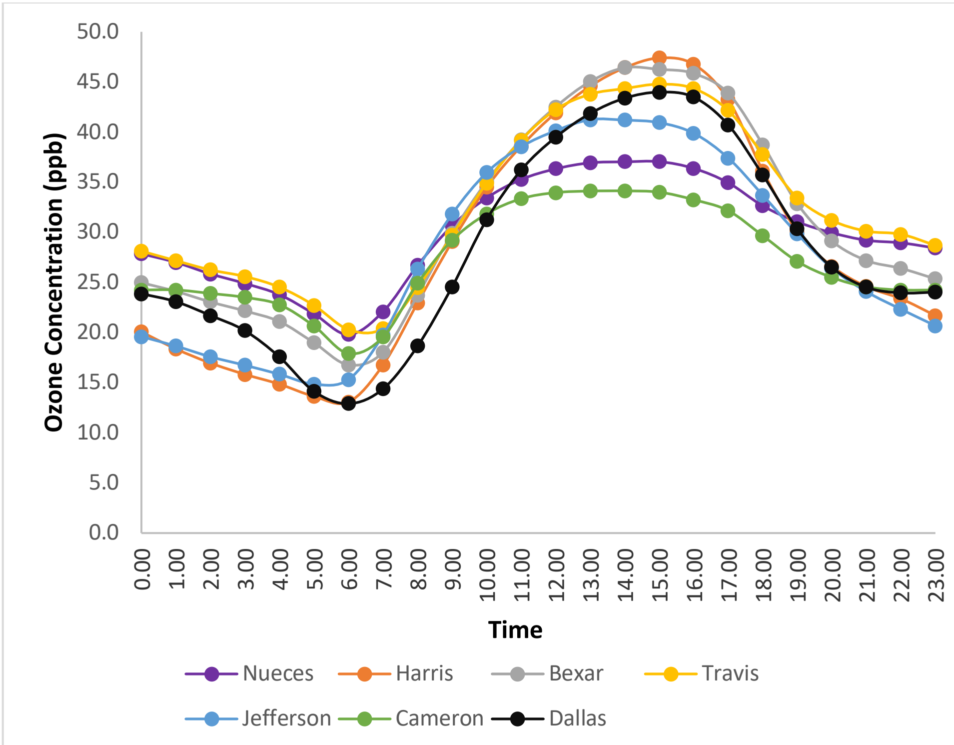
Wind speed fairly trend upwards in most metros. Wind speed was consistently high in 2011 in all metro areas.

Figure 34: Yearly averaged wind speed (m/s) for metro cities in eastern Texas, 2005-2012

Figure 35a and 35b shows the diurnal variation of ozone in selected counties in eastern Texas for 2007 and 2011. 2007 was a wet year while 2011 was a dry year in Texas. Noteworthy here, was that ozone concentrations during 2011 were higher than 2007. The highest concentration of ozone was found around 2 to 4 pm in the afternoon, after which the concentration of ozone decreased. The lowest ozone concentration was found around 6 am in the morning. Harris county in Houston exhibited highest ozone concentration both in 2007 and 2011 whereas Cameron county in South Texas followed closely by Nueces in Corpus Christi exhibited the lowest ozone concentrations. Although Harris county exhibited the highest ozone concentration during the day, it showed lowest concentration at night. Conversely, Nueces exhibited highest ozone concentration at night although it showed lowest concentration at day.



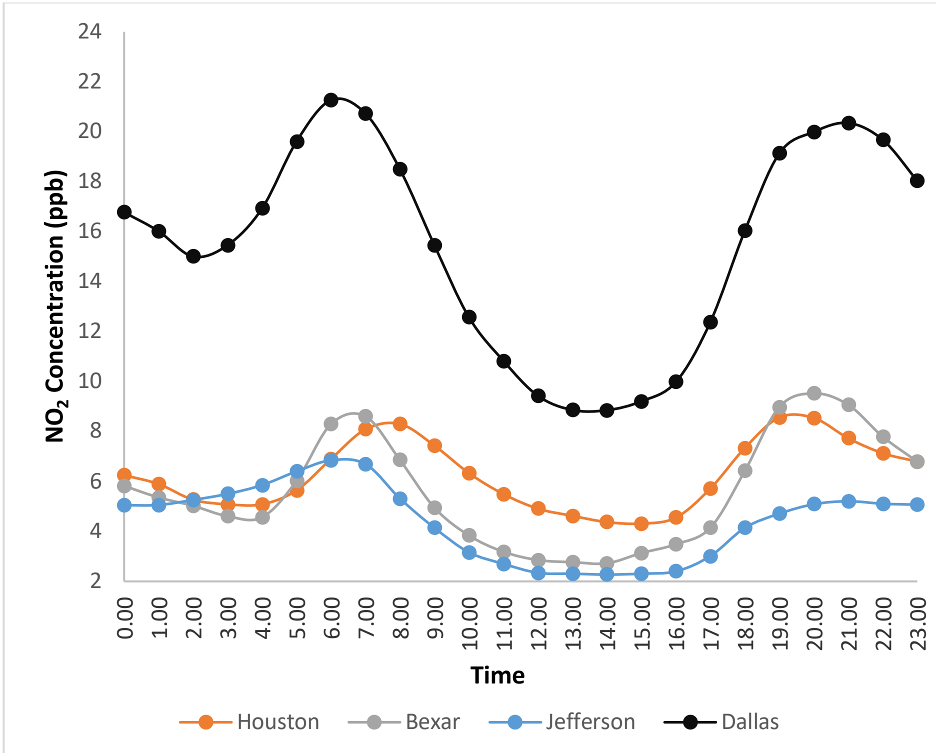
(a)



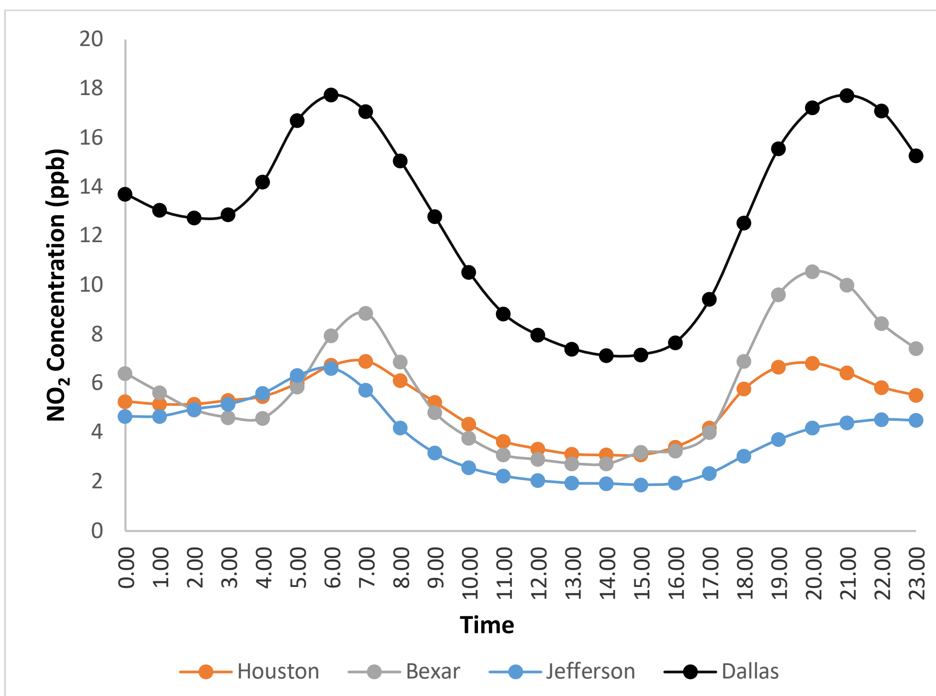
(b)

Figure 35: Diurnal ozone variation for selected counties in eastern Texas a) 2007; b) 2011

Figure 36a and 36b shows the double peak diurnal variation of NO_2 in selected counties in eastern Texas for 2007 and 2011. Data for Nueces, Cameron and Travis counties were not available. NO_2 concentration was higher in 2007 compared to 2011. The highest concentration of NO_2 was found around 5 to 8 am during the morning, after which the concentration of ozone decreased only to increase again around 7 pm at night. Noteworthy here, was that NO_2 shows an almost opposite diurnal pattern to ozone (NO_2 is high in the morning and evenings when ozone is at its lowest). Dallas has the highest NO_2 concentration, three-times the NO_2 concentration compared to other counties in the morning and two-times at night. Jefferson county has the lowest NO_2 concentrations.



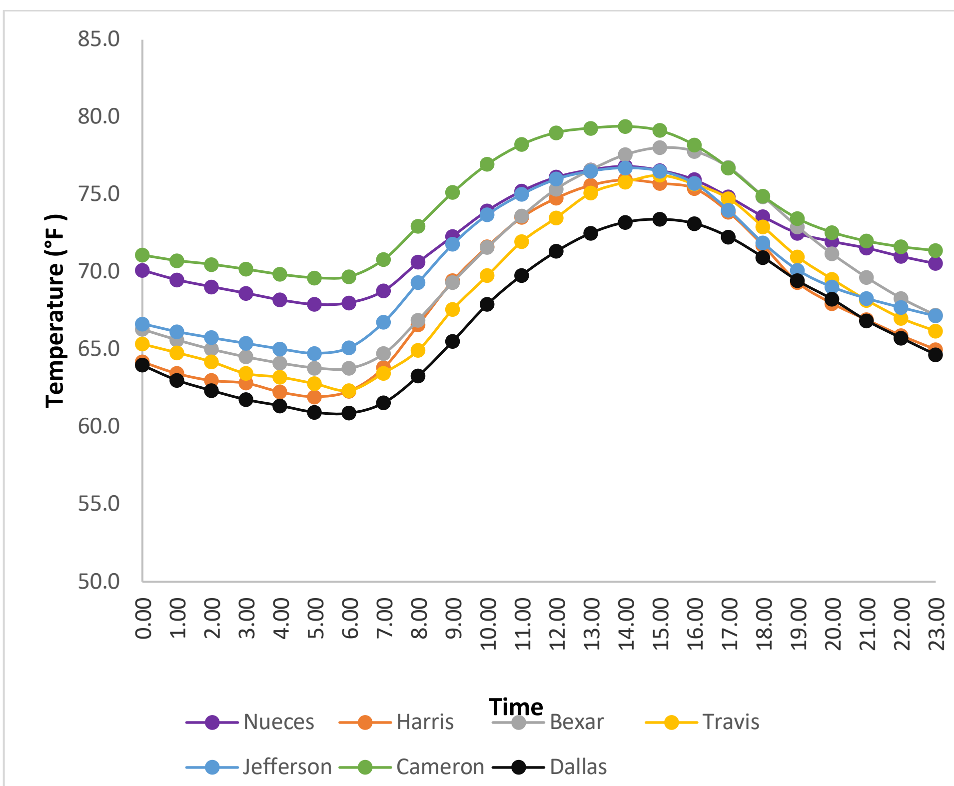
(a)



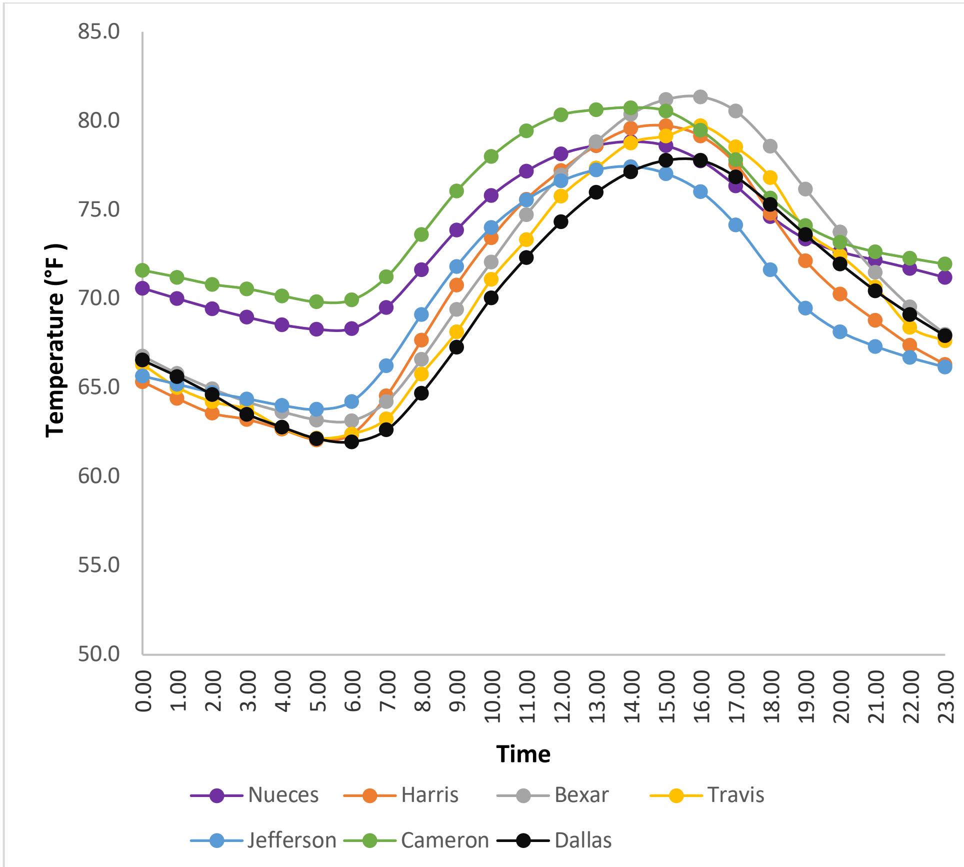
(b)

Figure 36: Diurnal NO_2 variation for selected counties in eastern Texas a) 2007; b) 2011

Temperature also shows a definite diurnal variation. Temperature begin to rise after sunrise, 6-8 am, and attains its maximum level around 2-4 pm. Cameron and Nueces had the higher temperatures compared to other counties in 2007 (10% higher at 0:00 am and 7% higher at 2 pm). Noteworthy here, was that Cameron, Jefferson, Harris and Nueces attain maximum temperature quicker (around 2 pm) than Bexar, Dallas and Travis counties (around 3 pm). Cameron, Jefferson and Nueces plateau at maximum temperature longer than Bexar, Dallas, Harris and Travis counties. This was consistently the case in both 2007 and 2011. Although Bexar, Dallas, Harris and Travis counties have significantly lower temperatures in the morning, they daily gained traction to arrive at similar maximum temperature levels as Cameron, Jefferson and Nueces in 2011 which is not the case in 2007. Cameron attained a high temperature of 79.4 °F in 2007 compared to 80.8 °F (a difference of 1.4 °F) in 2011. This pattern is similar in all counties confirming the hotter conditions in 2011 (see figure 37a and 37b).



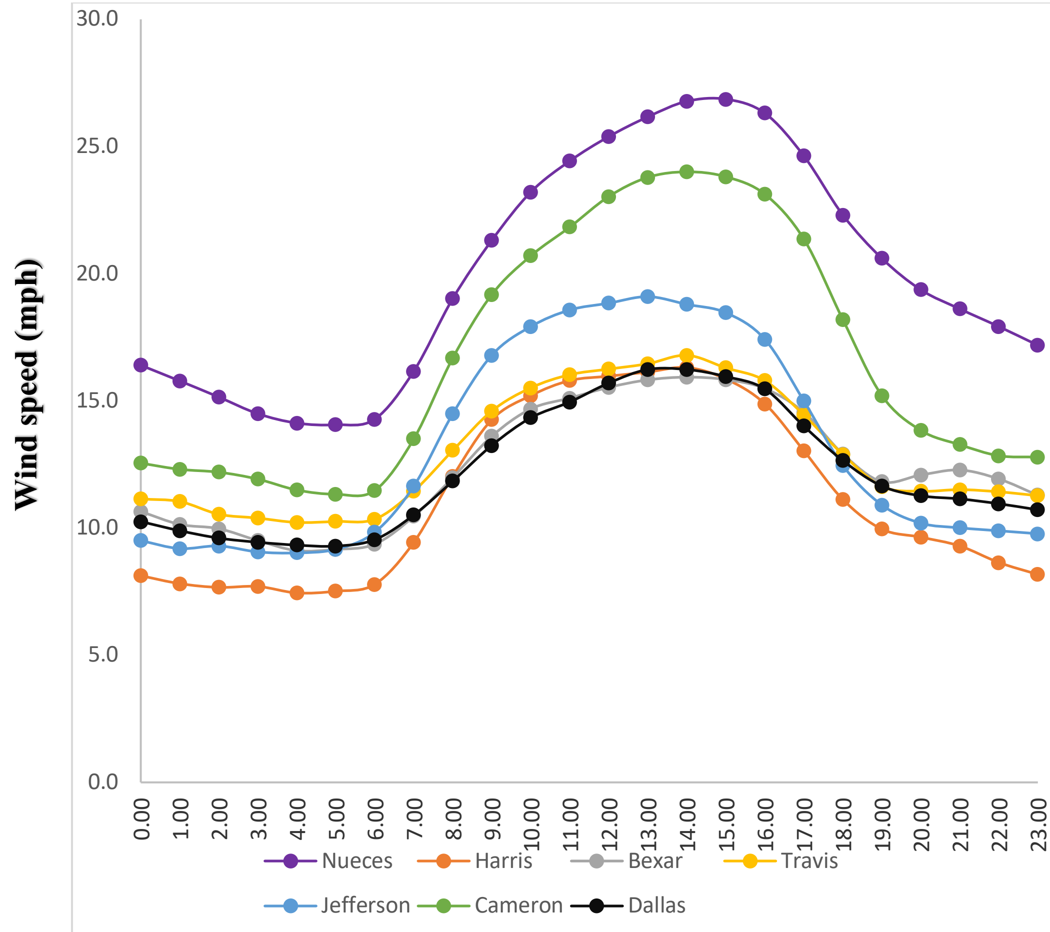
a



(b)

Figure 37: Diurnal temperature variation for selected counties in eastern Texas a) 2007; b) 2011

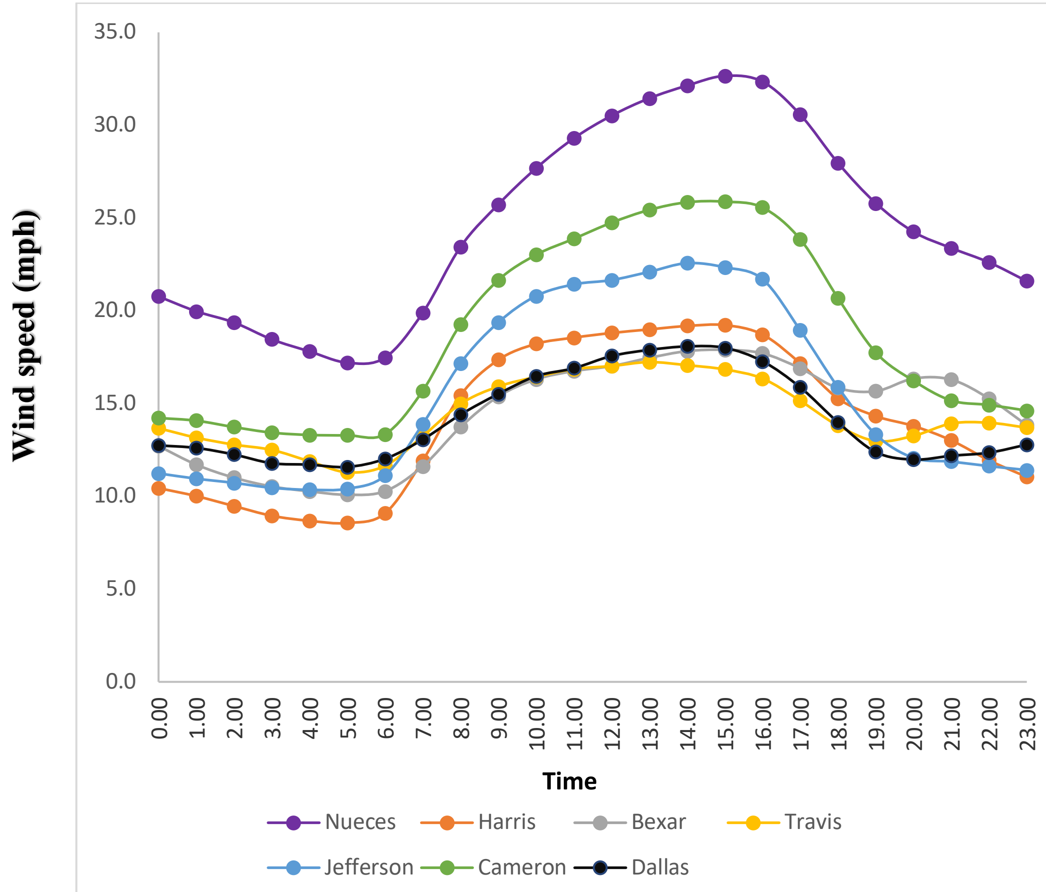
Figure 38a shows the diurnal variation of mean wind speed in selected counties in eastern Texas in 2007. Wind speed begins to rise after sunrise, 6 am, and attains its maximum level around 2-3 pm. Nueces shows a maximal wind speed in of 26.9 mph in 2007, followed by Cameron (24 mph), Jefferson (18.8 mph), Travis (16.8 mph), Harris (16.3 mph), Dallas (16.2 mph) and Bexar (15.9 mph). Nueces has 11% higher wind speed than Cameron and 39% higher wind speed than Bexar at each of their maximal levels.



(a)

Figure 38a: Diurnal wind speed variation for selected counties in eastern Texas, 2007

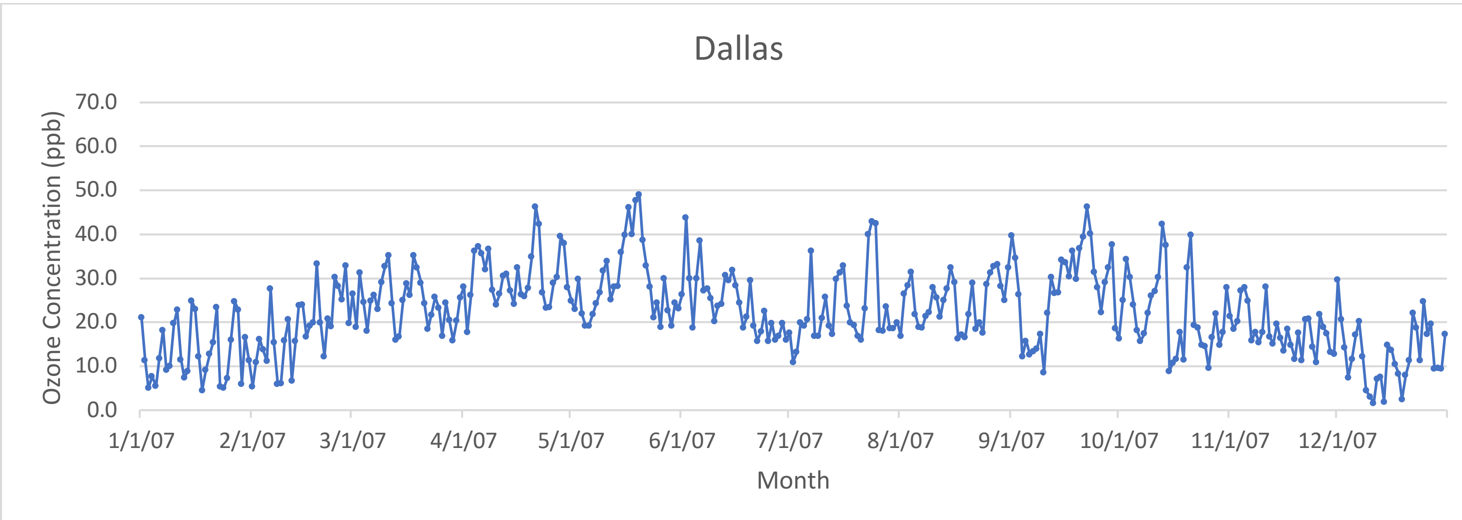
Figure 38b shows the diurnal variation of mean wind speed in selected counties in eastern Texas in 2011. Wind speed begins to rise after sunrise, 6 am, and attains its maximum level around 2-3 pm. Wind speed Nueces shows a maximal wind speed in of 32.7 mph in 2007, followed by Cameron (25.9 mph), Jefferson (22.6 mph), Harris (19.2 mph), Dallas (18.1 mph), Bexar (17.9 mph) and Travis (17.1 mph). Nueces has 21% higher wind speed than Cameron and 48% higher wind speed than Bear at each of their maximal levels. This is a greater difference compared to 2007. Compared among themselves, wind speed for Nueces in 2011 increased by 22% whereas wind speed for Jefferson, Harris, Bexar, Dallas, and Travis increased by 20%, 18%, 13%, 11%, 8% and 2% respectively compared to 2007.



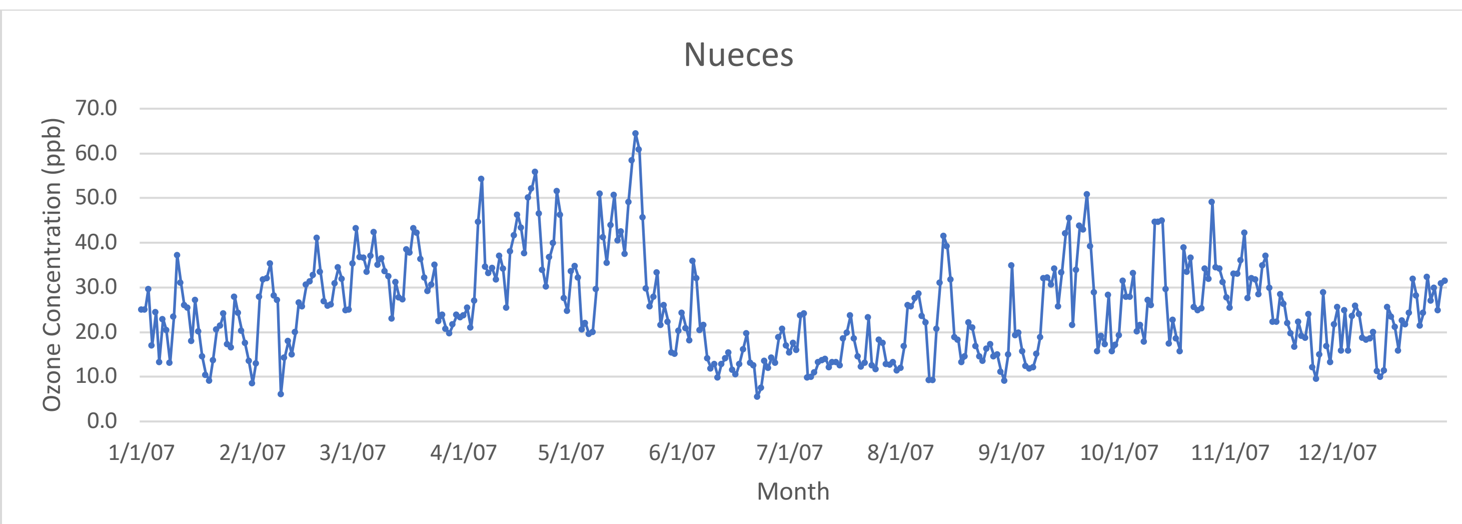
(b)

Figure 38b: Diurnal wind speed variation for selected counties in eastern Texas, 2011

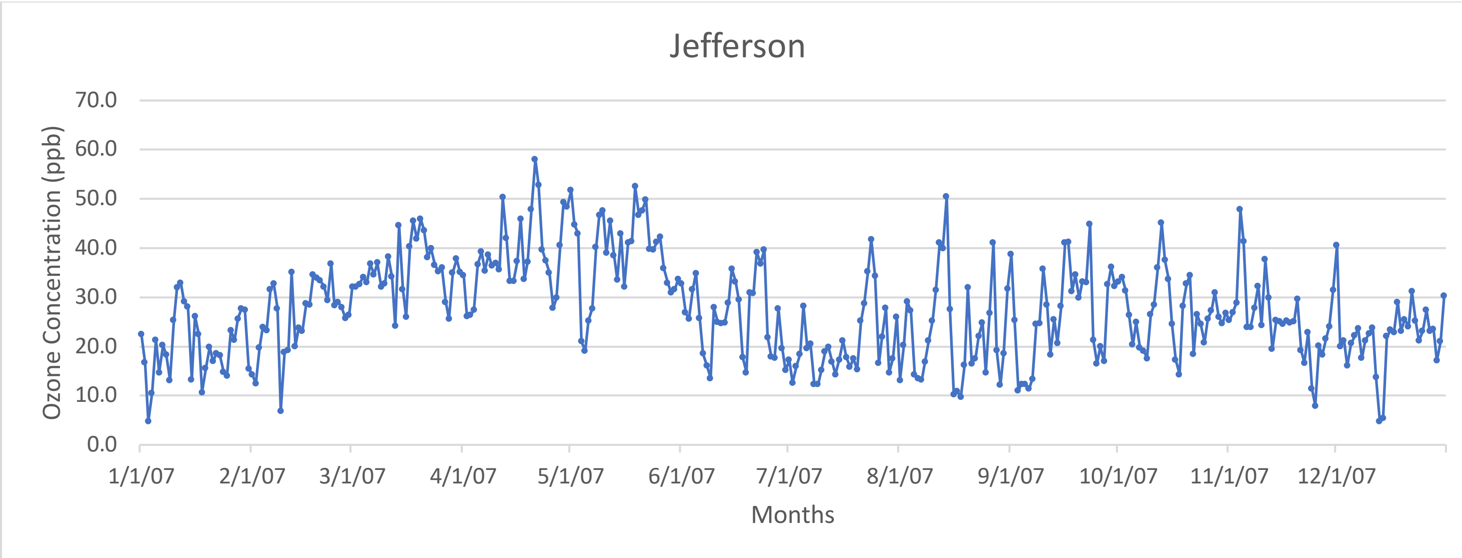
Annual variation of ozone in eastern Texas for 2007 (figure 39 a-g) and 2012 (figure 39 h-n) for selected counties is discussed next. Each point represents the average concentration for each day.



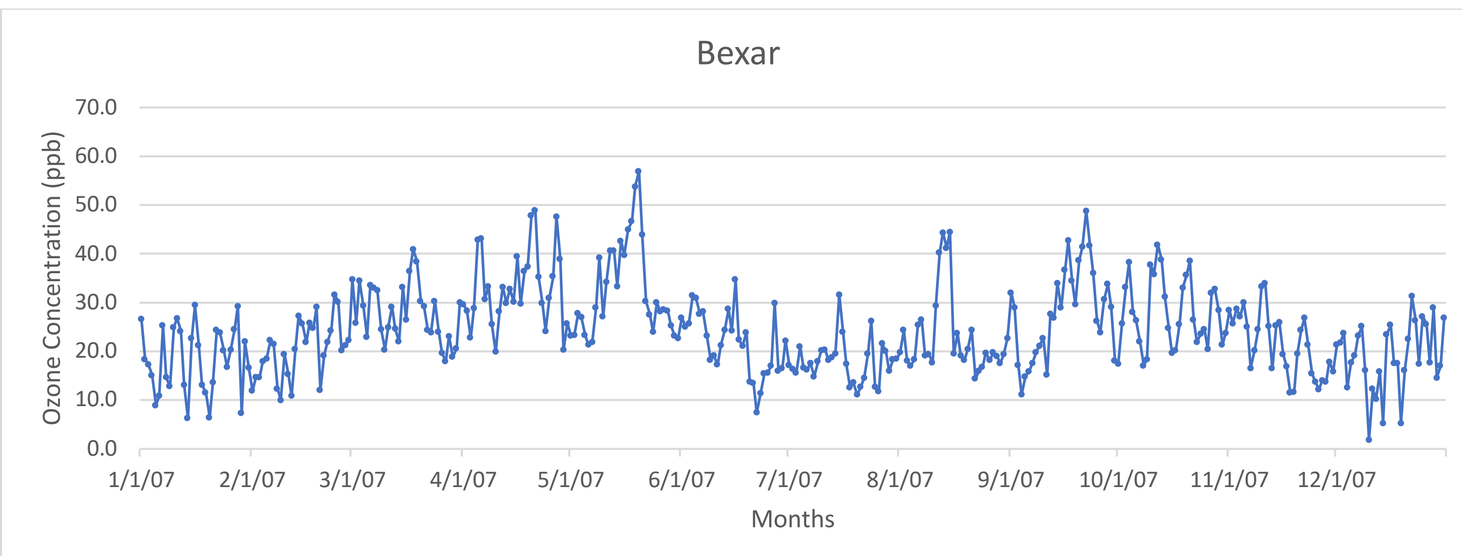
(a)



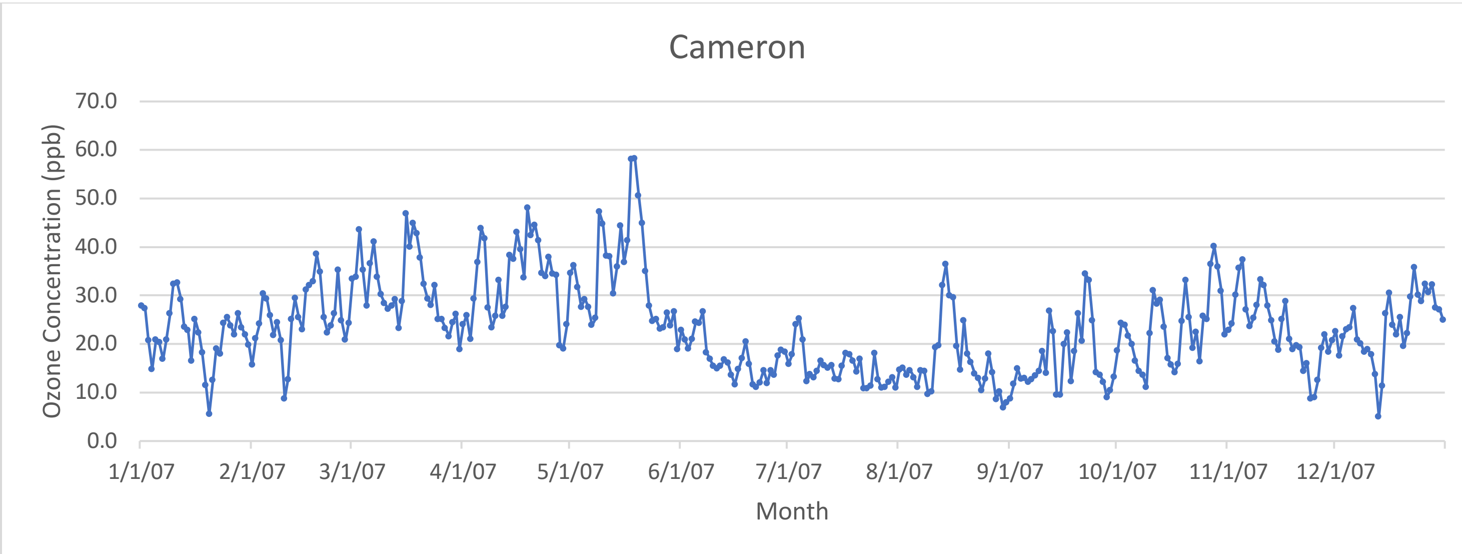
(b)


Jefferson
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Ozone Concentration (ppb)
1/1/07
2/1/07
3/1/07
4/1/07
5/1/07
6/1/07
7/1/07
8/1/07
9/1/07
10/1/07
11/1/07
12/1/07
Months

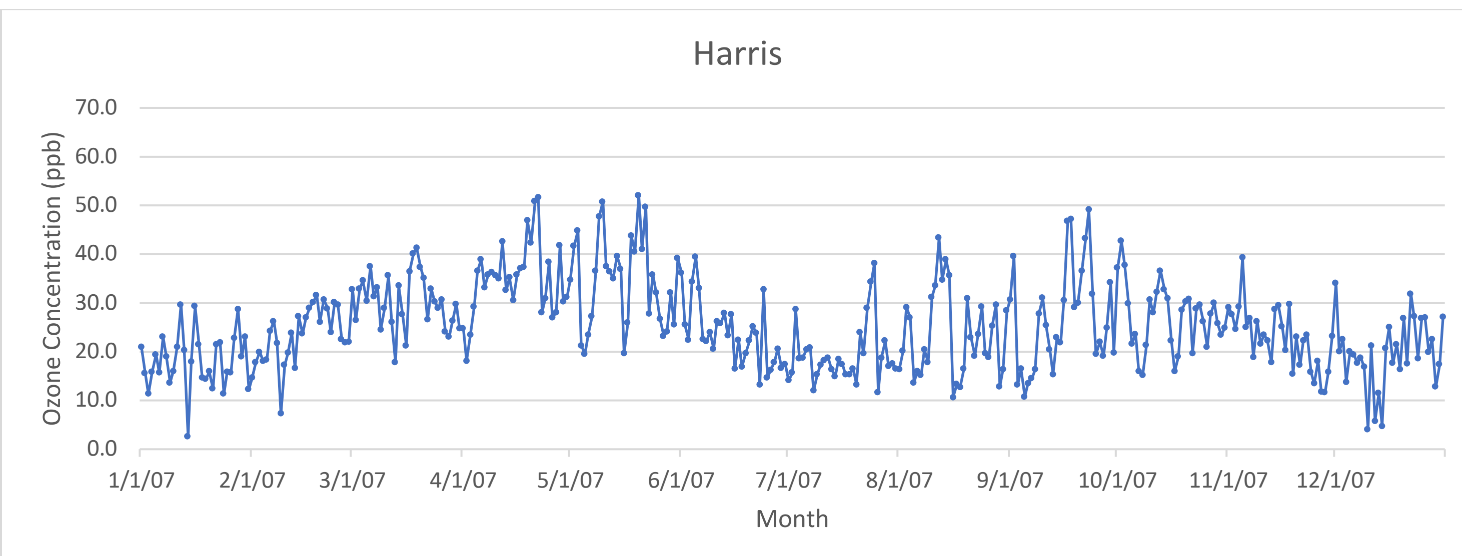
(c)


Bexar
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Ozone Concentration (ppb)
1/1/07
2/1/07
3/1/07
4/1/07
5/1/07
6/1/07
7/1/07
8/1/07
9/1/07
10/1/07
11/1/07
12/1/07
Months

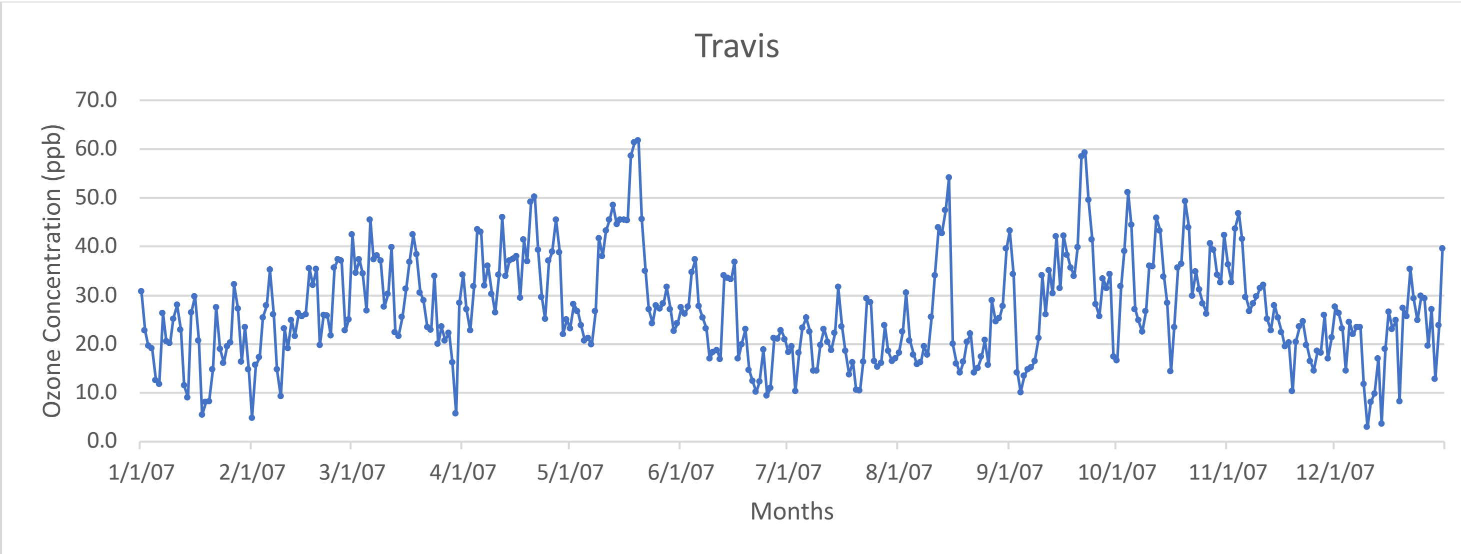
(d)


Cameron
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Ozone Concentration (ppb)
1/1/07
2/1/07
3/1/07
4/1/07
5/1/07
6/1/07
7/1/07
8/1/07
9/1/07
10/1/07
11/1/07
12/1/07
Month

(e)


Harris
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Ozone Concentration (ppb)
1/1/07
2/1/07
3/1/07
4/1/07
5/1/07
6/1/07
7/1/07
8/1/07
9/1/07
10/1/07
11/1/07
12/1/07
Month

(f)


Travis
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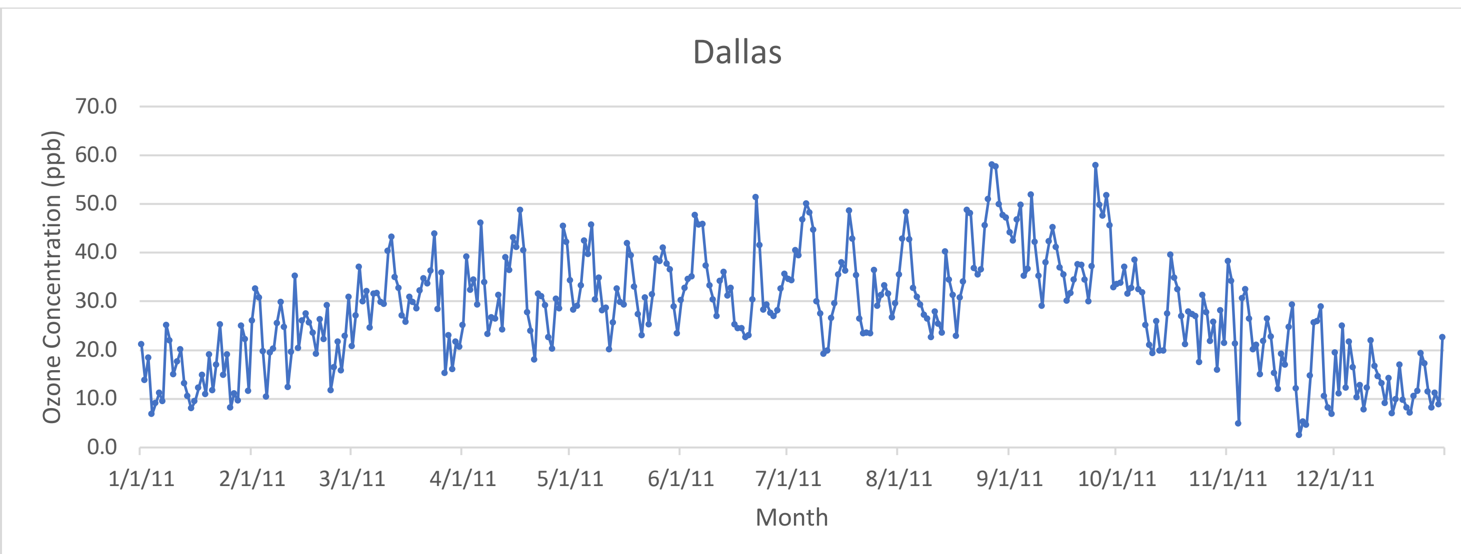
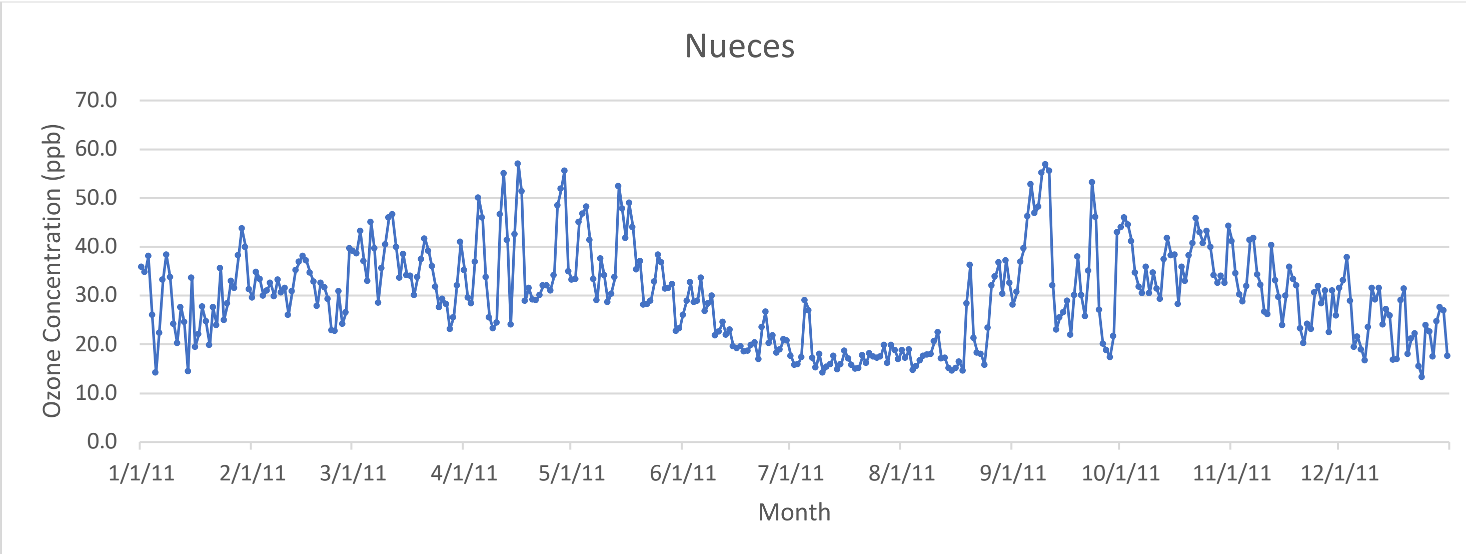
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Ozone Concentration (ppb)
1/1/07
2/1/07
3/1/07
4/1/07
5/1/07
6/1/07
7/1/07
8/1/07
9/1/07
10/1/07
11/1/07
12/1/07
Months

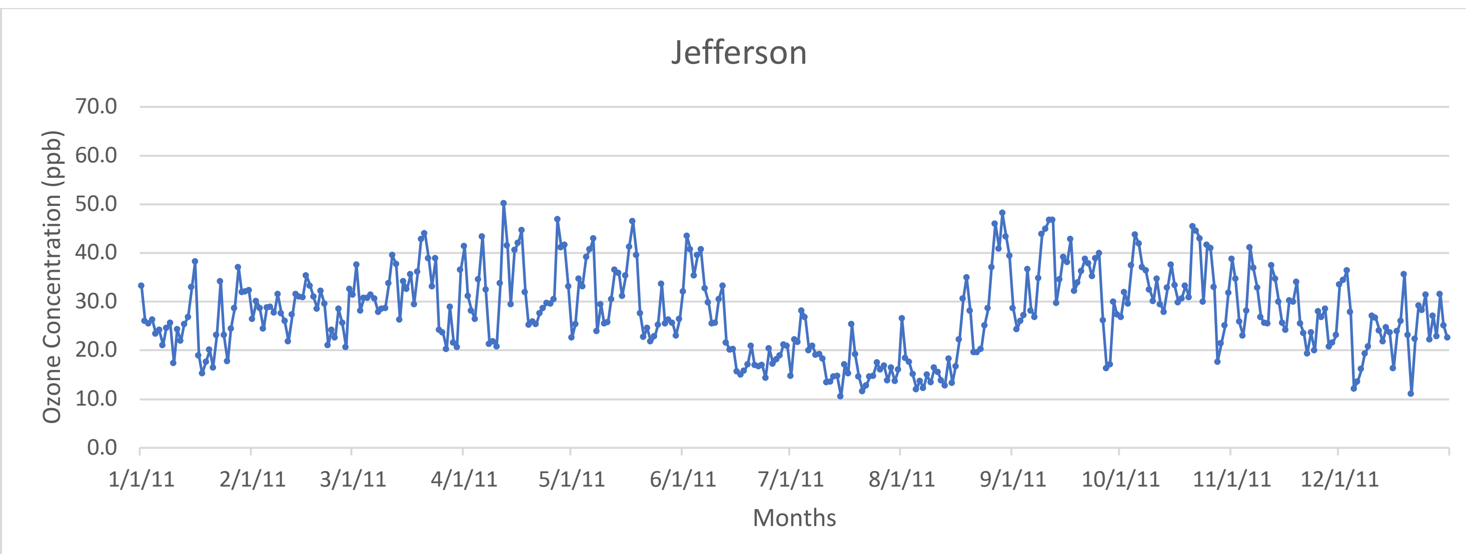
(g)


Dallas
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Ozone Concentration (ppb)
1/1/11
2/1/11
3/1/11
4/1/11
5/1/11
6/1/11
7/1/11
8/1/11
9/1/11
10/1/11
11/1/11
12/1/11
Month

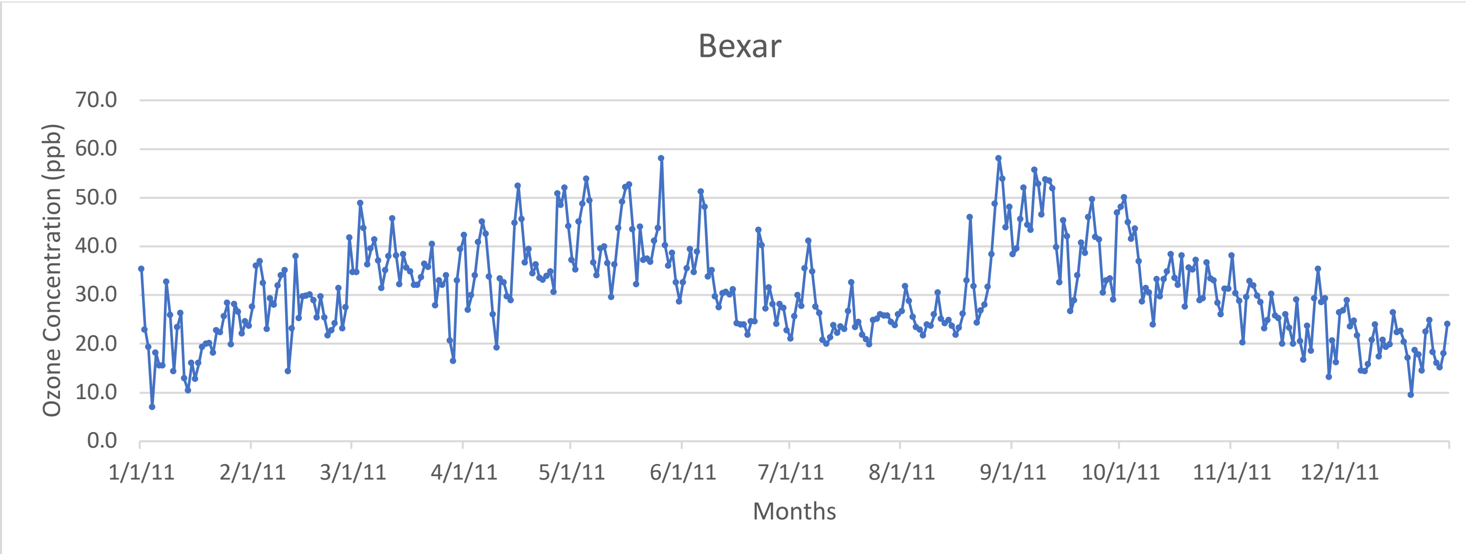
(h)


Nueces
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Ozone Concentration (ppb)
1/1/11
2/1/11
3/1/11
4/1/11
5/1/11
6/1/11
7/1/11
8/1/11
9/1/11
10/1/11
11/1/11
12/1/11
Month

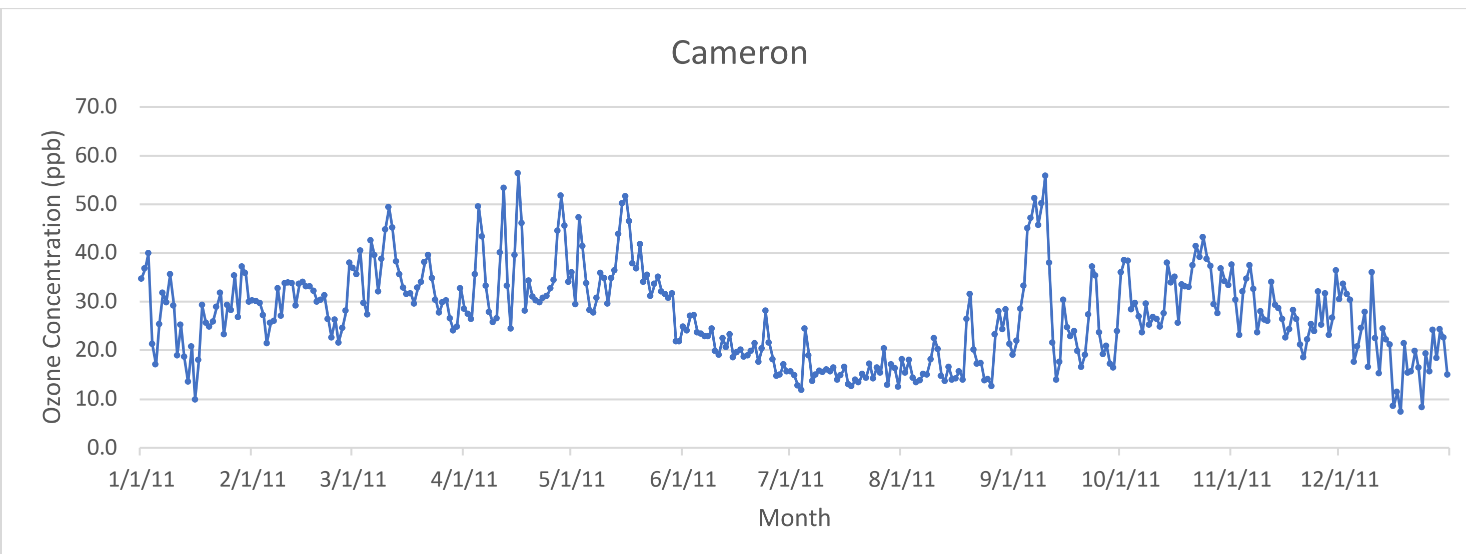
(i)


Jefferson
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Ozone Concentration (ppb)
1/1/11
2/1/11
3/1/11
4/1/11
5/1/11
6/1/11
7/1/11
8/1/11
9/1/11
10/1/11
11/1/11
12/1/11
Months

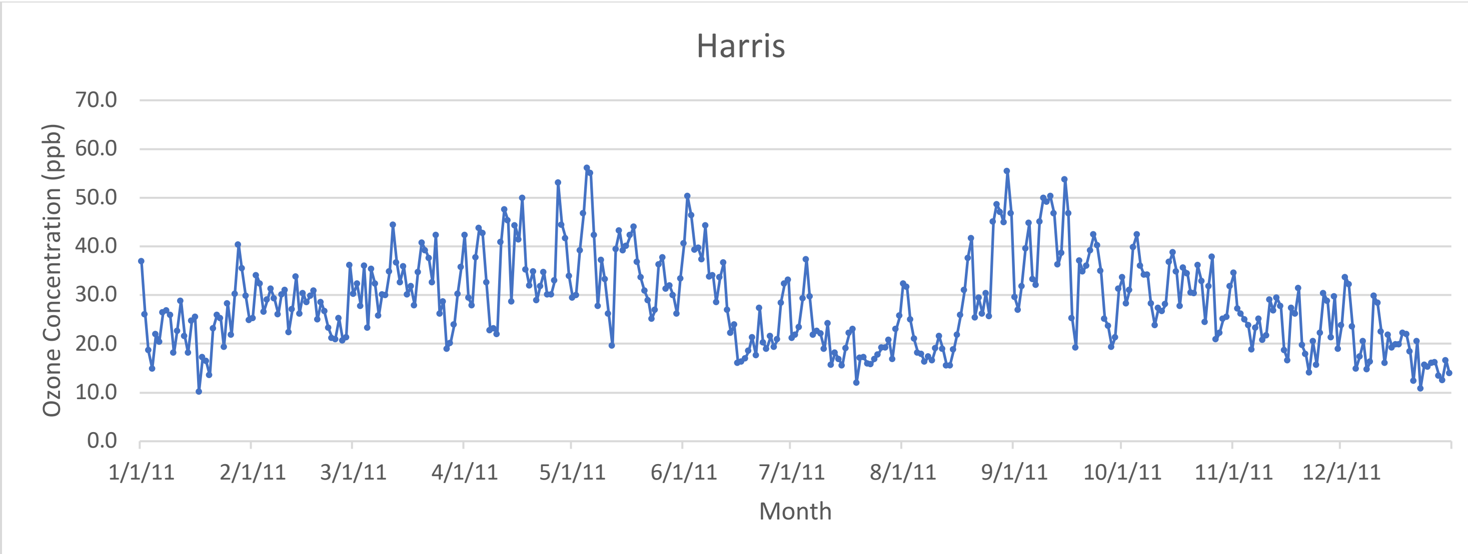
(j)


Bexar
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Ozone Concentration (ppb)
1/1/11
2/1/11
3/1/11
4/1/11
5/1/11
6/1/11
7/1/11
8/1/11
9/1/11
10/1/11
11/1/11
12/1/11
Months

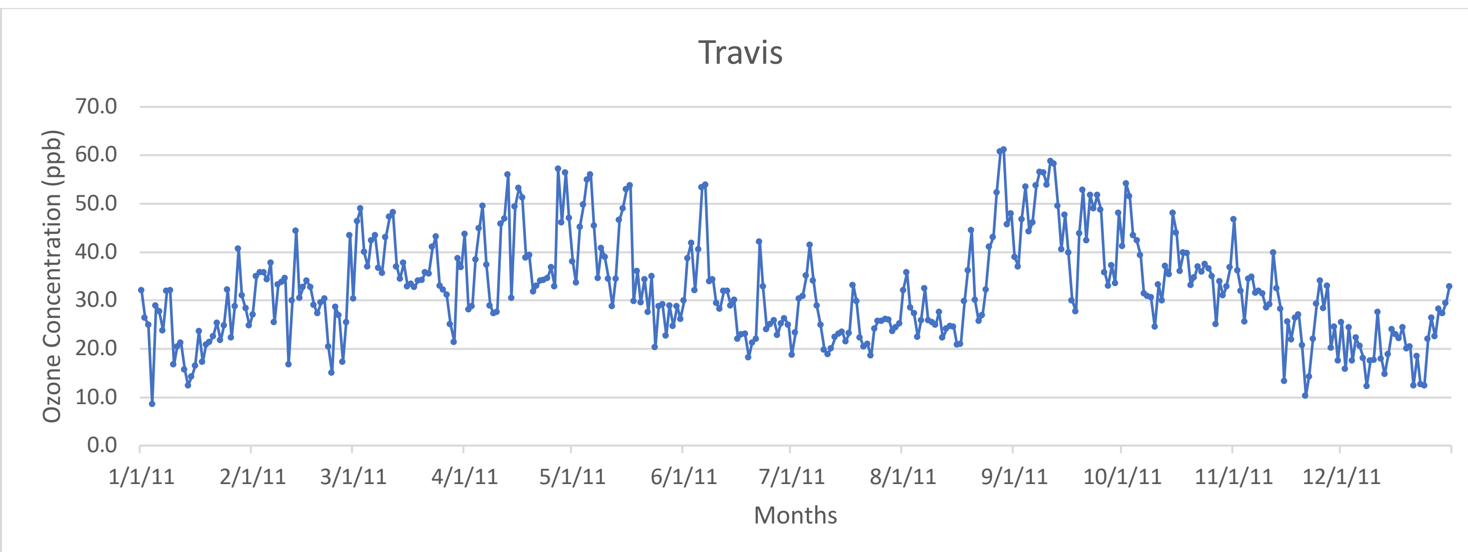
(k)


Cameron
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Ozone Concentration (ppb)
1/1/11
2/1/11
3/1/11
4/1/11
5/1/11
6/1/11
7/1/11
8/1/11
9/1/11
10/1/11
11/1/11
12/1/11
Month

(l)



(m)



(n)

Figure39: Annual variation of ozone in selected eastern Texas counties, 2007 (a-g) and 2011 (h-n).

Dallas followed a clear trend of high ozone concentrations in summer and low ozone concentrations in the winter both in 2007 and 2011. However, this wasn't the case for other counties at all. All the other counties had a high ozone concentration in April-May, dipped in

June-July only to peak again in September. Bexar and Travis had a less pronounced variations than Cameron, Harris, Jefferson and Nueces counties. Cameron, Harris, Jefferson and Nueces are designated as coastal counties. Table 7 summarizes the high ozone days (HODs), low ozone days (LODs), minimum and maximum daily averaged ozone concentration during 2007 and 2011. High ozone days were defined as days when ozone concentration was > 50 ppb and low ozone days were defined as days when ozone concentration was < 15 ppb.

Table 7: Summary of HODs, LODs, minimum and maximum daily averaged ozone concentration in selected eastern Texas counties for 2007 and 2011

	Dallas		Nueces		Jefferson		Bexar		Cameron		Houston		Travis	
	2007	**2011**	**2007**	**2011**	**2007**	**2011**	**2007**	**2011**	**2007**	**2011**	**2007**	**2011**	**2007**	**2011**
HODs	5.0	31	18.0	29	20.0	8	7.0	36	6.0	18	10.0	21	23.0	52
LODs	71.0	52	68.0	9	38.0	25	46.0	11	82.0	34	35.0	12	42.0	12
Min	1.6	2.5	5.5	13.3	4.7	10.5	1.8	7.0	5.0	7.3	2.6	10.2	3.0	8.5
Max	64.5	57.0	58.0	50.2	57.0	58.1	58.3	56.3	52.1	56.1	61.7	61.1	64.5	57.0

Table 8 summaries seasonal ozone variation for spring, summer and fall in selected eastern Texas counties during 2007 and 2011. Spring includes March and April, Summer includes June and July, and fall includes September and October. The table clearly shows that the ozone concentration in 2011 was higher than the ozone concentration in 2007 except for Jefferson county. The maximum ozone concentration for Dallas was seen in April-May and September-October during 2007 and 2011 respectively. Jefferson and Travis followed the trend recorded in Dallas. The maximum ozone concentration for Nueces was seen in April-May for Nueces in both 2007 and 2011 followed by September-October and June-July. The maximum ozone concentration for Bexar, Cameron and Harris was seen in April-May for both 2007 and 2011 followed by September-October and June-July. It is also clear that the coastal counties, Bexar and Travis county observed very low ozone concentration in June-July compared to Dallas.

Table 8: Summary of average spring, summer and fall ozone concentration in selected eastern Texas counties for 2007 and 2011

	Dallas		**Nueces**		**Jefferson**		**Bexar**		**Cameron**		**Houston**		**Travis**	
	2007	**2011**	**2007**	**2011**	**2007**	**2011**	**2007**	**2011**	**2007**	**2011**	**2007**	**2011**	**2007**	**2011**
Mar-Apr	27.5	31.2	34.8	36.6	37.0	32.5	30.3	36.2	32.3	35.1	32.6	34.0	32.6	38.7
Jun-Jul	23.6	33.3	15.7	20.4	23.3	20.8	19.8	28.5	16.0	18.2	21.3	24.7	20.8	27.9
Sep-Oct	24.6	33.9	28.4	36.4	26.8	33.6	28.0	38.1	20.0	30.8	26.9	33.7	32.8	41.1

Lower concentration of ozone in the coastal cities during summer is very pronounced and is somewhat perplexing. However, these differences correspond with the wind speed and wind direction effects. The detailed account of the role of wind speed and wind direction using wind rose diagrams follows.

Figure 40 clearly shows the fluctuation of wind speed and wind direction in four eastern Texas cities during spring of 2011. Wind speed designated by the sky-blue color means calmer winds. Southerly wind dominated spring 2011 in Dallas and accounted for approximately 35% of all hourly wind directions. The wind rose also provides details on speed of wind from various directions. The range of prevailing wind speed was 13 mph to 25 mph. Considering winds from south, the longest spoke, it can be estimated that approximately 15% of the time the southerly wind blew at speed between 13-19 mph. A few wind speeds greater than 25 mph was also observed. The wind rose diagram also shows that wind rarely blows from the west. In Houston, southerly winds prevailed followed by south-southeastern winds. Both directions accounted for approximately 55% of all hourly wind directions. The range of prevailing wind speed is 8 m/s to 13 m/s. Wind speed greater than 25 mph were non-existent. South-southeastern winds dominated in San Antonio closely followed by southerly and southeasternerly winds. Three spokes accounted for a little over 65% of all hourly wind directions. Corpus Christi is dominated by south-southeasternerly and southeasternerly winds which accounted for approximately 60% of all hourly wind directions. The magnitude of prevailing winds ranges from 13 mph to 32 mph. Corpus Christi also recorded the largest percentage of wind speed greater than 25 mph in spring of 2011 compared to other cities. Wind speed greater than 25 mph was also observed coming from N to S, N-N-E and N to E.

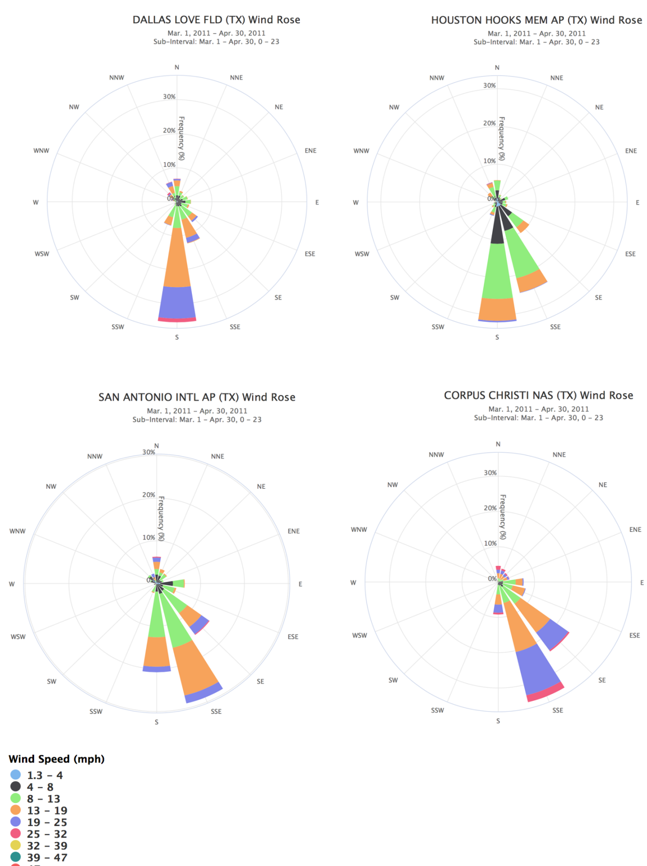


Figure 40: Wind rose diagram for March-April 2011

Trends for winds Dallas in the June-July were similar compared to the patterns in spring. Figure 41 shows the fluctuation of wind speed and wind direction in four eastern Texas cities during summer of 2011.The dominant direction was southerly, but the frequency of southerly wind direction increased from approximately 35% of all hourly directions in spring to approximately 45% in summer. In terms of winds from south, it can be estimated that approximately 35% of the time the southerly wind blew at speed between 8-13 mph compared to approximately 7% in the spring. Southerly winds of magnitude 13-19 mph decreased by approximately 5% in summer. Northerly winds were non-existent in summer. The magnitude of southerly and south-southeasternerly wind speed, the prominent direction, decreased for Houston compared to spring. South-southeasternerly wind decreased by approximately 10%. A little over 15% of south-southeasternerly winds were also observed in summer which was 5% less than spring. Wind greater than 19 mph was very minimal. Northerly winds were non-existent in summer. In San Antonio, southerly and south-southeasternerly wind still dominated the region but the frequency of the wind speed from this prevailing direction increased by approximately 15%. This is a huge change. Some winds greater than 25 mph were observed in south-southeasternerly direction which were non-existent in spring. Northerly winds were non-existent in summer. Frequency and relative intensity of wind flow from S-S-E, S to N and S to E still prevailed, accounting to approximately 75% of all hourly wind directions compared to 60% in spring in Corpus Christi. This was a significant change. Wind directions from other directions were non-existent in summer although some northerly winds had been observed in spring.

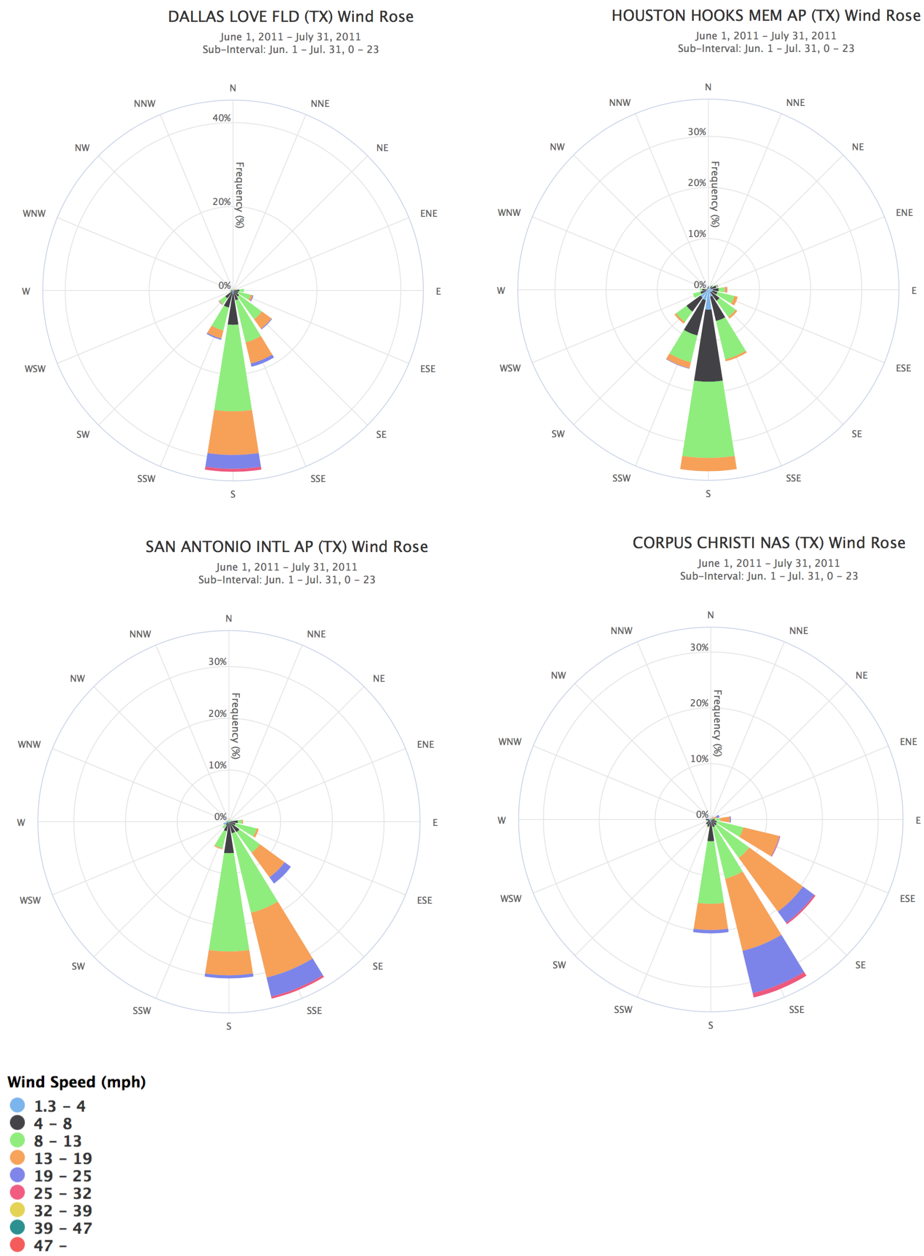


Figure 41: Wind rose diagram for compared June-July 2011

Figure 42 shows the fluctuation in wind speed and wind direction in four eastern Texas cities during fall of 2011. A significant change was seen in wind patterns during fall 2011. Wind speed between 8 to 13 mph was more pronounced in all cities compared to other seasons. Frequency of wind directions that was not observed before were observed in the fall. This led to lesser contribution from one directions. For example, northerly wind flow made a significant contribution. Northerly winds were not observed in either spring or summer in Dallas. Although traces of northerly winds were recorded in Houston, San Antonio and Corpus sites in spring and summer, the contribution in the fall season was large. Although southerly and southeasternerly winds were still dominant in San Antonio, the frequency of northerly winds greater than 25 mph increased in San Antonio. Some northwesterly winds were also observed for the first time. Approximately 10% easternerly winds were recorded in Corpus Christi, which was observed in spring and summer, but to a lesser degree. Cumulative flow of winds from south, S-S-E, S-E, E-S-E and eastern accounted for 64% of all hourly directions, but it was less than the summer contribution. Winds speed greater than 25 mph was seen in Corpus Christi (weaker than summer), San Antonio (stronger than summer) and Dallas sites. Wind speed of magnitude 32-39 mph was seen for the first time in Corpus Christi even if the frequency was very small.

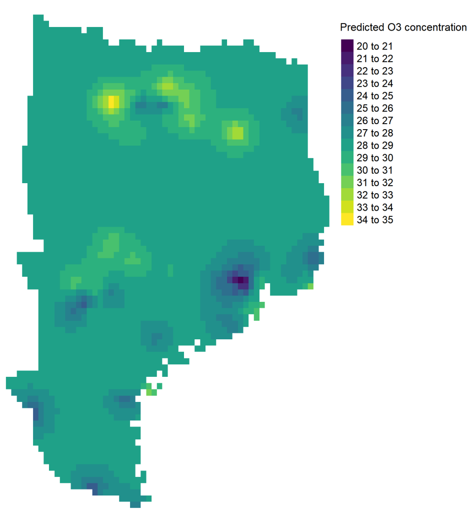
Figure 42: Wind rose diagram for Sep-Oct 2011

Table 9 shows the frequency of days in selected eastern Texas counties with wind speed >13 mph and wind direction 90°-180° on a same day. Corpus Christi has 54 days in June-July with wind speed >13 mph and wind direction 90°-180° compared to San Antonio (43 days), Dallas (21 days) and Houston (19 days).

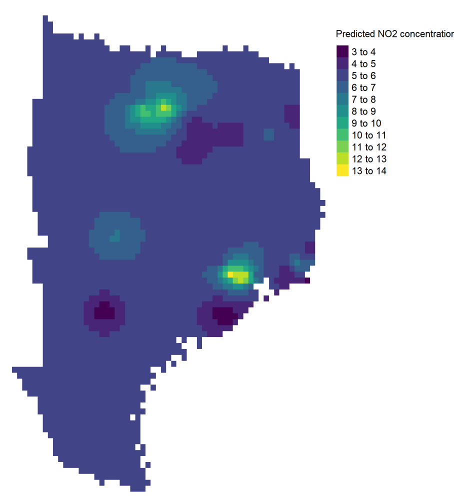
Table 9: Seasonal frequency of days with wind speed >13 mph and wind direction (90°-180°) in selected eastern Texas counties, 2011

Cities	Months	Number of days with wind speed > 13 mph and wind direction between 90-180
Dallas	Apr-Mar	25
	Jun-Jul	21
	Sep-Oct	11
Houston	Apr-Mar	34
	Jun-Jul	19
	Sep-Oct	7
Bexar	Apr-Mar	37
	Jun-Jul	43
	Sep-Oct	12
Nueces	Apr-Mar	48
	Jun-Jul	54
	Sep-Oct	39

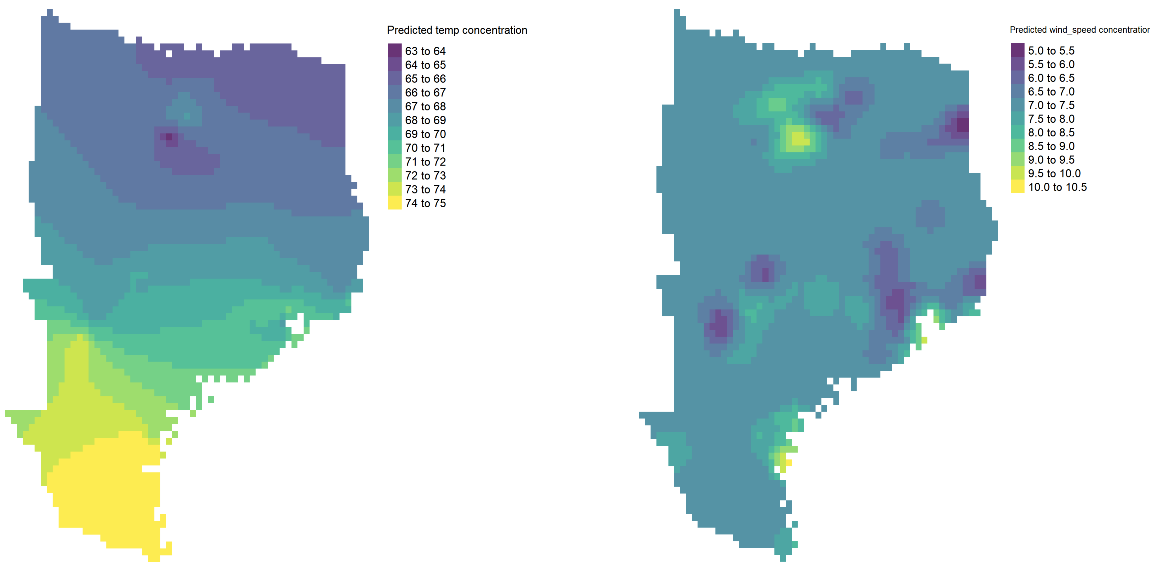
Annual average spatial distribution of predicted data for ozone, NO_2, temperature and wind speed in eastern Texas for 2005 to 2011 are presented below in figure 43.



(a)



(b)



(d)

(c)

Figure 43: Spatial distribution of annual average a) Ozone; b) NO_2; c) Temperature; d) Wind Speed for eastern Texas, 2005-2012

The spatially created maps show that maximum ozone concentrations are found in counties in Dallas-Fort Worth-Arlington metro area followed by counties in Austin-Round Rock metro area. Parker, Kaufman, Rockwall, Collin and Travis counties were among the counties with high ozone concentrations. Ozone concentration were at a minimum around the coastal metro areas (Houston-The Woodlands-Sugarland, Corpus Christi) and the southern part of Texas. Harris and Nueces counties were among the counties with low ozone concentrations. Nitrogen dioxide (NO_2) concentrations were at a maximum in Houston-The Woodlands-Sugarland metro area followed by the western counties in the Dallas-Fort Worth-Arlington metro area. Harris, Tarrant and Dallas counties were among the counties with high NO_2 concentrations.

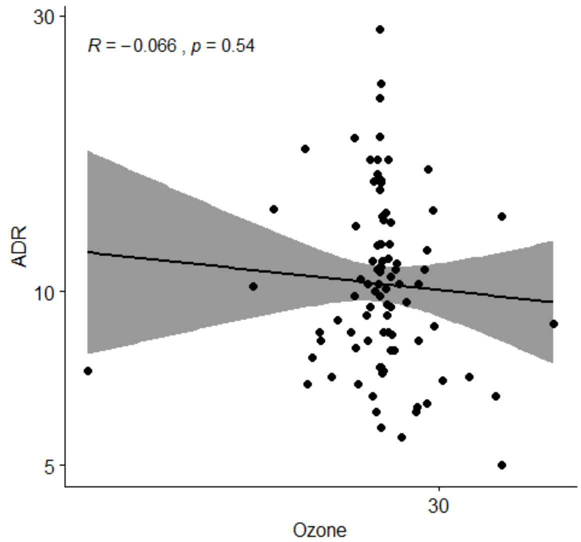
Nitrogen dioxide (NO_2) concentrations were at minimum south of Houston (Brazoria county), eastern counties of Dallas (Navarro county) and eastern of San Antonio (Wilson county). The spatial distribution of temperature clearly shows that temperature values in the counties in South Texas (Willacy, Star, Webb, Nueces) were maximal and gradually decreased northwards. The spatial variations in wind speed showed the coastal counties in Corpus Christi (San Patricio, Nueces), Houston-The Woodlands-Sugarland metro (Galveston) and counties around Dallas-Fort Worth-Arlington metro area (Johnson, Denton, Ellis) were maximal.

Sum of squared error of each variable for the semivariogram model for the accuracy of fitness is listed in a Table 10. As discussed earlier, a good fitting model will yield a sum of squared error close to zero. Ozone, temperature and wind speed yields sum of squared error close to zero, which is desired. NO_2 has a very high sum of squared error according to the results here.

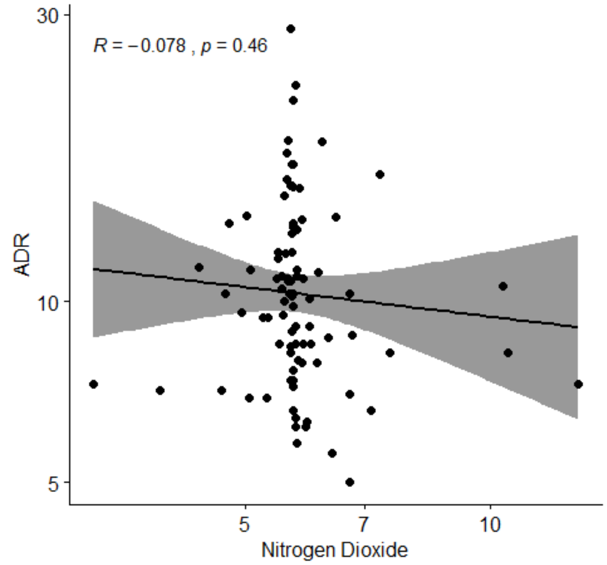
Table 10: Sum of Squared Error (SSE) of pollutant & meteorological parameters for semivariogram model

	Sum of Squared Error (SSER)
Ozone	0.2157
NO2	1.4219
Temperature	0.3548
Wind Speed	0.1559

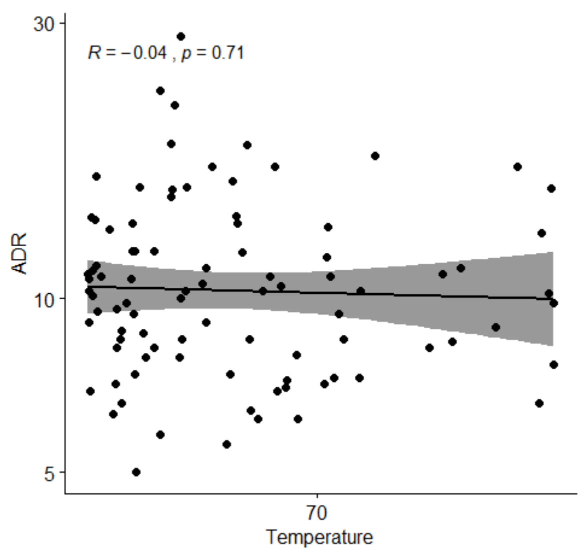
Pairwise correlation was computed for both adult and child asthma hospital discharge rate with air pollutants (ozone, NO_2) and meteorological parameters (temperature and windspeed). Air pollutants and meteorological variables were log transformed to attain normality before conducting the pairwise correlations. The distribution of ozone, NO_2, temperature and windspeed for both adult and childhood asthma are included in figure 44 below:


R = −0.066 , p = 0.54
ADR
30
10
5
30
Ozone

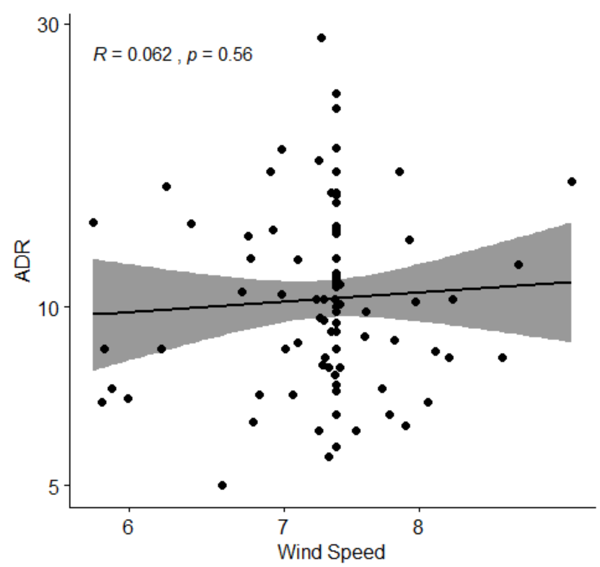
(a)


R = −0.078 , p = 0.46
ADR
30
10
5
5
7
10
Nitrogen Dioxide

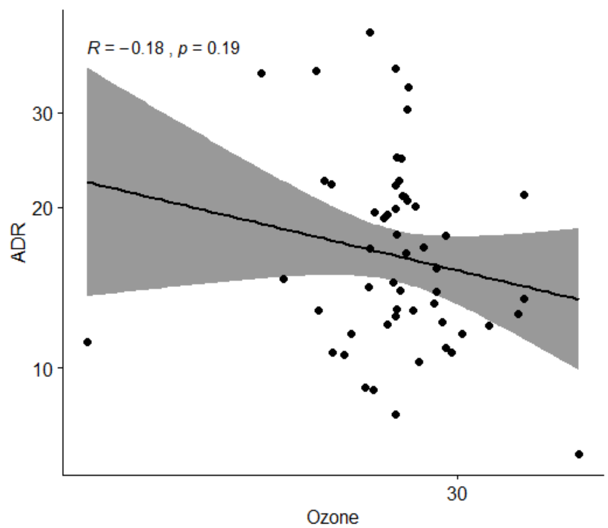
(b)


R = −0.04 , p = 0.71
ADR
30
10
5
70
Temperature

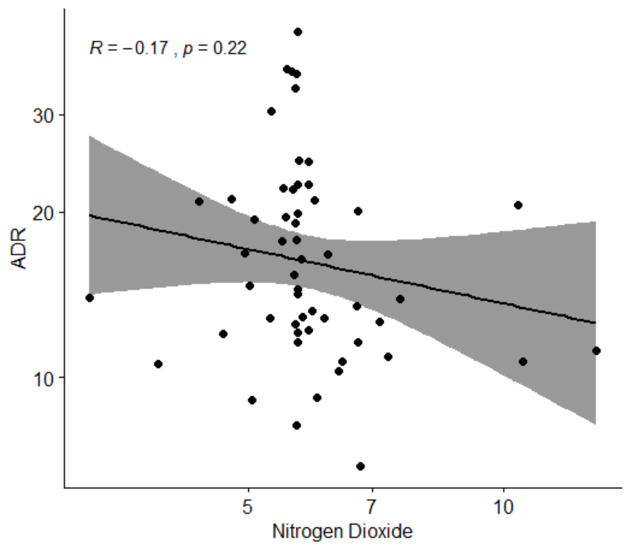
(c)


R = 0.062 , p = 0.56
ADR
30
10
5
6
7
8
Wind Speed

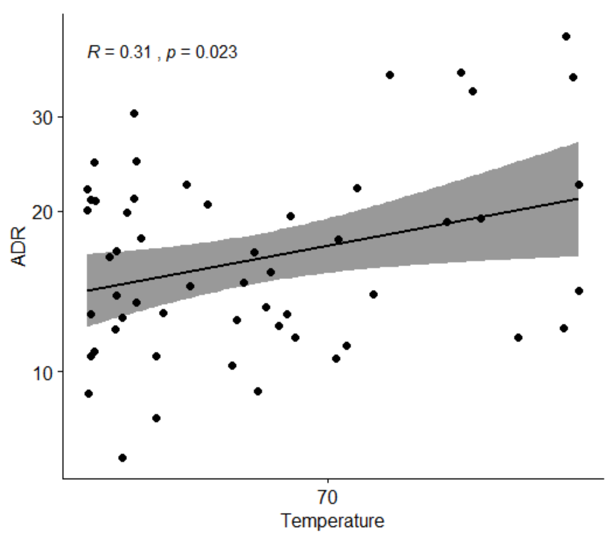
(d)



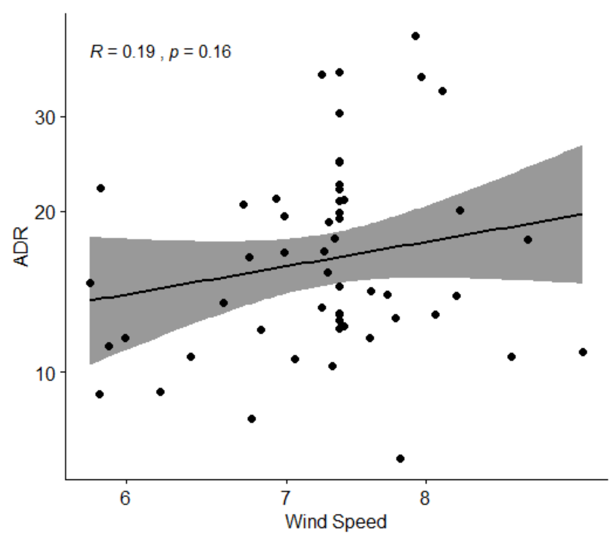
(e)



(f)



(g)



(h)

Figure 44: Pairwise correlation of adults and children asthma hospital discharge rate against a) ozone, b) NO_2, c) temperature, d) windspeed; and Pairwise correlation of child asthma hospital discharge rate against e) ozone, f) NO_2, g) temperature, h) windspeed from 2005-2011 at county level.

Adult asthma hospital discharge rate was negatively correlated with ozone, NO_2 and temperature and positively correlated to wind speed. None of the variables meet the 0.3 correlation coefficients level suggested by Lorden et al. (2011) and the degree of scatter is very high. Among the negatively correlated, the values range from -0.078 to -0.04 which is low. The correlation for the only positive correlated variable (wind speed) is 0.062, which was low as well. P-values for all environmental variables are high ranging from 0.46 to 0.71. Similarly, children's asthma hospital discharge rate was negatively correlated to ozone (-0.18) and NO_2 (-0.17). However, children's asthma hospital discharge rate was positively correlated to temperature and wind speed. Correlation with temperature (0.31) was strong and met the 0.3 level suggested by Lorden et al. (2011) whereas the correlation coefficient with wind speed (0.19) was still below 0.3 level. P-values for ozone, NO_2 and wind speed were high ranging from 0.16 to 0.22. P-value for temperature was 0.023 ($p<0.05$). Although children's asthma hospital discharge rate displays a fair degree of scatter, correlation of the environmental variables with children's asthma hospital discharge rate is apparent as compared to adult asthma hospital discharge rate demonstrating moderate to strong association at county level. The correlation analysis results are summarized in Table 11 below.

Table 11: Pairwise correlation matrix for environmental variables and both adult and children's asthma discharge rates

Parameter	Ozone	NO2	Temperature	Wind Speed	Adult ADR	Children's ADR
Ozone	1.00					
NO2	-0.24	1				
Temperature	-0.40	-0.09	1.00			
Wind Speed	0.19	0.00	0.06	1.00		
Adult ADR	-0.066	-0.078	-0.04	0.062	1.00	
Child ADR	-0.18	-0.17	0.31	0.19	0.20	1.00

Because asthma hospital discharge rates for both adults and children displayed an insignificant relationship to most of the environmental variables, the regression model approach to identify any association is not pursued.

The results of spatial autocorrelation (Global Moran's I) for both adults and children asthma hospital discharge rate is summarized in Table 12.

Table 12: Spatial autocorrelation analysis of both adult and child asthma discharge rate in eastern Texas, 2005-2012

	Morans's Index	Expected Index	Variance	z-score	p-value
Adult Asthma discharge rate	0.040	-0.011	0.0015	1.32	0.19
Child Asthma discharge rate	0.28	-0.019	0.0030	5.46	0.00

Morans's Index is positive for both adults and children's asthma discharge rates and it is greater than the expected value. This implies positive spatial correlation exists across counties meaning a cluster of similar discharge rates is present in eastern Texas. As discussed earlier in this study, positive z-score and a low p-value indicates clusters of high asthma discharges. Although the z-value is a positive value, the p-value for adult asthma discharge rate is not significant which implies that there is a chance that the spatial distribution is a result of random spatial process (ESRI, 2019). But, the p-value is significant for child asthma discharge rate implying more spatially clustered outcome than one would expect by chance alone (ESRI, 2019).

The hotspots for adult and child asthma hospital discharge rates were derived based on the crude hospital discharge rate for eastern Texas counties by averaging data during 2005-2012. An examination of adult and child asthma data sets shows that they have very dissimilar hotspot distributions in eastern Texas. Figure 45a reflects the nature of hotspot analysis for adults during 2005-2012. There are very specific areas that constitute hotspots. Angelina, Jasper and

Polk counties have intense hotspots (statistically significant at 99% confidence level) followed closely by Anderson, Brown, Grimes, Hardin, Leon, San Jacinto and Trinity counties (statistically significant at 95% confidence level). Comanche, Liberty and Walker counties were statistically significant at 90% confidence level. These hotspots are characterized by high adult asthma hospital discharge rates. Most of the counties in eastern Texas counties had not significant results for adult asthma. Comal county (statistically significant at 90% confidence level) observed an intense cold spot followed by Bastrop, Burnet, Caldwell, Hays, Kendall and Travis counties (statistically significant at 90% confidence level). Figure 45b shows the pattern of hotspot analysis for children during 2005-2012. Bell, Jim Wells, Kleberg, Nueces, San Patricio, and Victoria counties had the statistically significant hotspots at 99% confidence level. These hotspots are characterized by high child asthma hospital discharge rates. All counties are in the vicinity of Corpus Christi metro area. In accordance with adult data sets, most of the counties in eastern Texas counties had not significant results for child asthma. Cooke, Liberty and Montgomery counties were statistically significant coldspots at 90% confidence level.

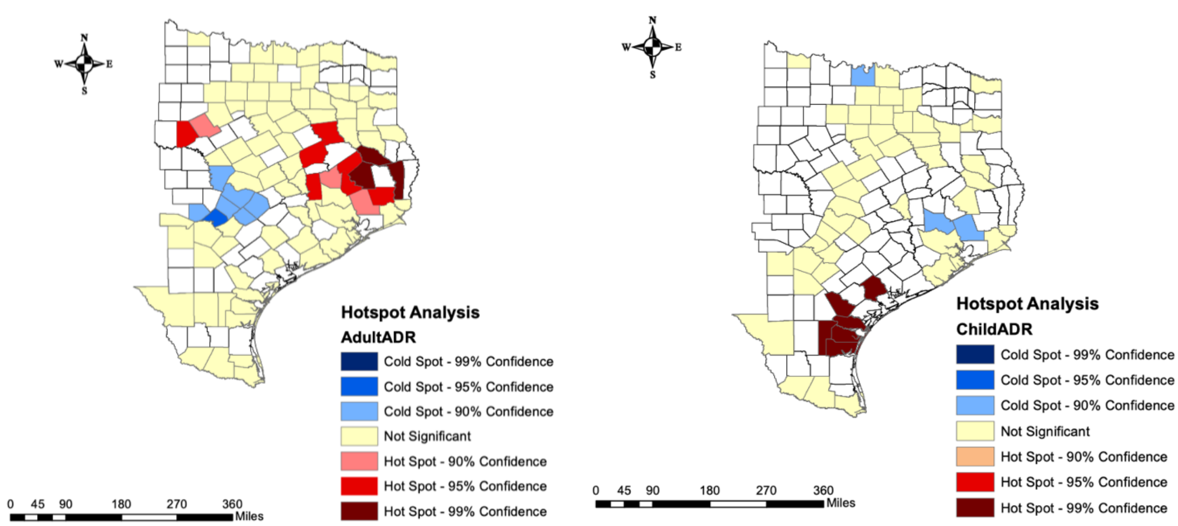


Figure 45: Hotspot Analysis of asthma hospital discharge rate, 2005-2012 a) adult; b) child.

The cluster outlier analysis for adults and children's asthma hospital discharge rates were based on the crude hospital discharge rate for eastern Texas counties by averaging data during 2005-2012. Evaluation of adult and child asthma data sets revealed very dissimilar cluster outlier results in eastern Texas. Figure 46a shows the nature of cluster outlier analysis for adults during 2005-2012. Cluster outlier analysis yields four outputs: High-High cluster (HH), High-Low outlier (HL), Low-High outlier (LH) and Low-Low (LL) cluster. Brown, Comanche, Liberty, San Jacinto, Trinity and Walker counties have statistically significant HH cluster asthma discharge. The average hospital discharge rate around this cluster is 20.7 per 10,000 residents. Counties surrounding the high cluster counties also have hospitals with high asthma discharges to some extent. Caldwell and Victoria counties have statistically significant HL outlier which implies both high and low asthma discharges exist in this region. Counties with high asthma discharge rate are surrounded by counties with low asthma discharge rate in this region. Most of the counties in eastern Texas counties had non- significant results for adult asthma. LH outlier and LL cluster were not observed for adults in eastern Texas during 2005-2012. Figure 63b portrays the spatial pattern of cluster outlier analysis for children during 2005-2012. Bell, Jim Wells, Kleberg, Nueces, San Patricio and Victoria counties have statistically significant HH cluster asthma discharges. The average hospital discharge rate around this cluster is 34.8 per 10,000 residents. The cluster for children is high compared to the cluster for adults. Anderson county had statistically significant HL outlier which indicates both high and low asthma discharges existed in this county. Anderson county is surrounded by counties with low asthma discharge rates. Most of the counties in eastern Texas counties also exhibited non-significant results for adult asthma. Webb county has an LH outlier which means both low and high asthma discharges exist in this region. LL cluster was not observed for adults in eastern Texas during 2005-2012.

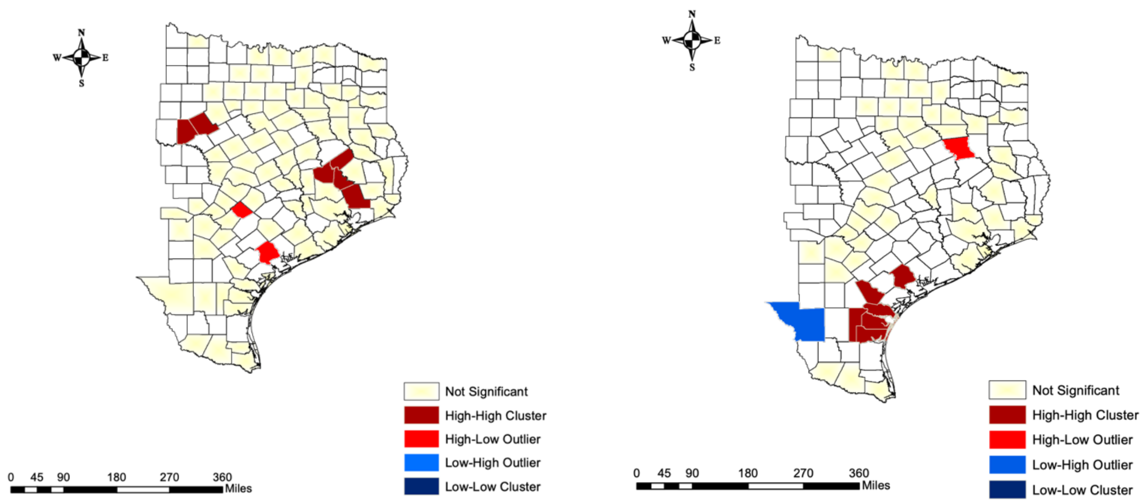


Figure 46: Cluster Outlier Analysis of asthma hospital discharge rate, 2005-2012 a) adult; b) child.

Discussion

In this study, the spatio-temporal variations in ozone, NO_2, temperature and wind speed in the most populous counties in eastern Texas from 2005 to 2012 was analyzed. The issue of ozone in eastern Texas is still of huge concern. Concentrations of ozone are increasing year by year in most of the metro areas. However, NO_2 is on a downward trend. As discussed previously, the concentration of ozone mainly depends on photochemical reactions that involves the presence of NO_2, temperature and wind speed. It is evident from the analysis of air pollutants and meteorological parameters in eastern Texas that the production of ozone can be attributed to the aforementioned variables. In terms of diurnal variation of ozone in eastern Texas, it is favored by the presence of NO_2 in the morning. NO_2 undergoes photolysis and as the temperature increased during the day, ozone production occurs. As temperature decreases, ozone production weakens and NO_2 accumulation occurs. This synergistic process is validated in in many studies (Peters et al., 2018; Romer et al. 2018; Verma et al., 2016). The times when ozone production doesn't coincide with the NOx and temperature, wind speed and wind direction may play a role. The results provide insights into how strong southeasternerly winds bringing cleaner air inland from the Gulf of Mexico disperses the ozone in coastal cities. This is a result of a temperature difference between the land and the sea during a summer day. As the intensity of solar radiation increases as the day progresses, land temperature increases faster than the sea temperature. This propels a breeze inland and the resulting sea breeze lowers the mixing ratios of the precursors of ozone in coastal cities causing a decrease in concentration of ozone. The incoming sea breeze also disperses the ozone away from the coastal cities. This is consistent with the work of Liu et al. (2015) where a similar pattern was seen in Houston area. Liu and colleagues documented the rise in southerly winds from 2000 to 2013. This is probably a result of temperature differences between land and sea, largest difference occurring in June. In addition, surface pressure over Gulf of Mexico has increased whereas the surface pressure over coastal cities eastern Texas had decreased. Liu et al. (2015) suspected this also contributes to the rising southerly wind phenomenon. Over the past two decades, Bloomer et al. (2010) document studies that show reduction in summertime ozone despite an increase in temperature levels in the eastern US. Reduced ozone concentration is also seen in another study of eastern US cities conducted by Cooper et al. (2012). Cooper and colleagues attribute this to the decreasing NOx emissions. A decrease in NO_2 concentration is seen around the coastal cities mentioned in this study as well. Lower levels of ozone concentration were also observed in eastern Mediterranean during July in response to sea-breeze cells in coastline (Kalabokas et al., 2013). The concentration of ozone has been observed to dip during summer in coastal cities in China (Zhang et al., 2018) and India (Lu et al., 2018) because of sea breezes. Lower concentrations of ozone may also be attributed to time required to form ozone and NO_x scavenging effects (TCEQ, 2015). Lower concentration of ozone in Dallas-Fort Worth-Arlington metro can be attributed to NO scavenging ozone as explained in Beck et al. (1998). NO consumes ozone to form NO_2, which in turn produces Nitric acid (HNO_3) and prevents oxidation of VOCs, which suppresses the formation of ozone.

Adult asthma discharge rates show no statistical significance with ozone, NO_2, temperature and wind speed. Child asthma discharge rate is significantly positively associated with temperature only ($r=0.31$, $p<0.05$). Ozone and NO_2 show an inverse association with adult and child asthma discharge rates. A significant temperature change was observed in Corpus Christi on a month-to-month basis compared to other counties. According to the study conducted by Lin et al. (2013), large temperature difference between neighboring days was associated with increased respiratory symptoms. A positive/negative change of 3 °F in neighboring days was significantly associated with increased risk of respiratory and cardiovascular diseases (Guo et al. 2011). Song et al. (2008) also showed a significant association between a 1°C diurnal change for a 4-day moving average and chronic obstructive pulmonary diseases.

Drastic change of temperature and presence of air pollutants can act as an additive dose for asthma related issues. Corpus Christi metro includes many refineries in its ports in Corpus Bay and Nueces bay. Locations of major refineries in and around the vicinity of corpus Christi are shown in figure 47. A study done by the Agency for Toxic Substances and Disease Registry (ATSDR) in 2016 indicated that refineries in this area emit significant amounts of PM2.5, SO_2 and benzene over the course of a year. Corpus Christi was ranked 4th in total benzene emissions in U.S. during 2010. The ATSDR study listed the aforementioned pollutants as a major concern for health. Refinery row is stretched over 10 miles of the city and mostly processes crude oil. A combined high exposure to benzene, PM2.5, SO_2, hydrogen sulfide and its interaction with other petroleum related VOCs may have an additive effect to human health and lead to higher respiratory illness and hospitalizations (Bergstra et al., 2018; Rovira et al., 2014; Wichmann et al., 2009). Some of the aforementioned chemicals might have harmful effects even at lower concentrations (ATSDR, 2016). Although southeasternerly winds are prevalent during June-July and can disperse the pollutants away from residential neighborhoods, it should be noted that there is a greater variability in wind direction for fall and winter in Corpus Christi and northerly winds can carry pollutants to nearby neighborhoods south of industrial corridor. The ATSDR study also indicated that there are plenty of households with low socioeconomic status within the 2-mile buffer south of refinery row. There are 16 childcare centers and 6 elder care within the 2-mile buffer of the industrial corridor (ATSDR, 2016).

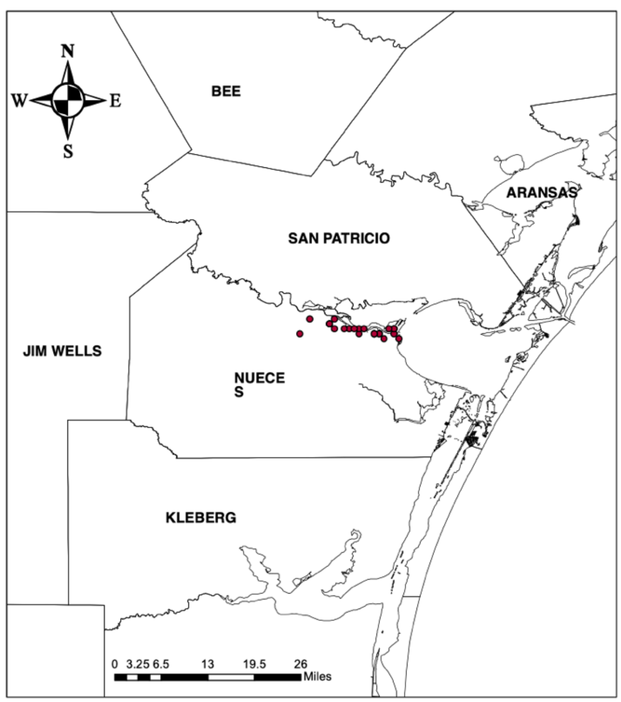


Figure 47: Major Refineries in Nueces County

Although there was no significant relationship between our environmental variables and adult and child asthma hospital discharges except for temperature variable, a cautious approach should be taken to interpret these findings. Ozone may not be a stand-alone risk factor for asthma hospitalization in eastern Texas. This research also suggests further analysis on weather patterns and air pollutants is worthwhile.

Chapter 4 – Final Conclusions

The study explored the association of socioeconomic indicators and environmental parameters with spatio-temporal variation of asthma hospital discharge rate for both children and adult in eastern Texas. Socioeconomic indicators were associated with asthma discharge rate both at county and census tract. Among the various socioeconomic indicators linked to asthma, percentage of families living in poverty, percentage of people with white collar occupation (management, arts, sciences etc.), percentage of people who have an income of less than $15,000, percentage of children in the population under 5 years, percentage of elderly population (65 years and over), percentage of people who use wood for heating purposes, percentage of family households with no vehicles, percentage of people who have no salary or wage income and percentage of people who receive cash public assistance or Food Stamps/SNAPS were the most influential.

Temperature was the only environmental variable with significant association to children asthma discharge rate. Coastal cities recorded a summer low, and a spring and fall high ozone concentrations. Southeasternerly wind is prominent in these parts during summer, and it is possible wind may have played a part to suppress the mixing ratio of precursors of ozone by dispersing the pollutants away from these coastal cities. NO_2 is very higher in Texas, which may be attributed to vehicle emissions. This study recommends examination of traffic volume in metros cities across eastern Texas. However, Corpus Christi, one of the coastal cities has high children asthma hospitalization compared to other parts of Texas. As suggested, in this study, there exists a greater variability of wind speed and wind direction during the spring and fall when the polluted air is carried to the neighborhood close to the industrial corridor.

One of the major limitations of this study was the inaccessibility of daily hospital admissions data. A lot of counties did not report if there were fewer than 12 asthma hospitalizations. According to DSHS, the data does not include any emergency department visits that did not result in hospitalization. If a person was hospitalized for more than once for same condition, there is no way to identify the person. Also, some of the hospitals in eastern Texas were exempt from reporting asthma discharges. The severity of each cases is not reported as well. Asthma data in this study also does not account for people that live in one county and could have visited a hospital in another county. The crude asthma discharge rate available for this study was aggregated annually to explore the spatio-temporal distribution which is one of the reasons why time-lag associations could not be studied. There was a limited number of counties with continuous air monitoring stations and there are a limited number of stations with equipment to measure pollutants of concern. In addition, CAMS are not uniformly distributed throughout eastern Texas which may lead to biased and inaccurate GIS predictions. Missing data was a regular occurrence which is why spatial interpolation was applied to produce an approximation of unknown locations for air pollutants/meteorological parameters based on its neighbors. Socioeconomic indicators were available for all counties and census tracts for our period of study which is why interpolation was not required in that case. Because of the discussed limitations, conclusions of causal nature because of the environmental variables used in his study may be obscure. In conclusion, and with the limitations of the study, previous studies have highlighted our study findings that low socioeconomic status is associated with high asthma incidences, but further study is required to explain the relationship between environmental variables and asthma in eastern Texas.

Along with all the direct, indirect and intangible asthma costs discussed in this study and its asthma's so increasing prevalence, the burden of asthma can be pinned down mostly due to severity of the disease, and the extent at which the patients take care of themselves (Bousquet et al., 2005; Schwenkglens et al., 2003). Health professionals should work together with asthmatic patients to develop personal action plans to avoid exposure to asthma triggers and to monitor asthma, set patient follow-up care (e.g. pulmonary testing) and use medications properly. Communities with higher rates of asthma hospitalization and mortality should be one of our main focus, especially inner cities and low-income communities. In a study conducted by National Institute of Allergy and Infectious Diseases (NIAID) per Szefler et al. (2010), no single factor was associated with high prevalence and morbidity of asthma in inner city children. Therefore, a multifactorial intervention is required which allows for an asthma counselor and him/her to tailor an approach to tackle the specific risks of each child. American Academy of Allergy, Asthma and Immunology Asthma (AAAAI) IQ program is developing an electronic medical record-based asthma management program in Colorado that may be useful in adjusting treatment steps for patients (Szefler et al., 2010). Since children spend a large chunk of their time at school, school support programs and neighborhood-based programs at homes and communities should also be encouraged to advance asthma care.

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A Step-by-Step Approach to Using SAS® for Factor Analysis and Structural Equation Modeling, Second Edition by Norm O'Rourke, Ph.D., and Larry Hatcher, Ph.D. Copyright © 2014, SAS Institute Inc., Cary, North Carolina, USA. ALL RIGHTS RESERVED.

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Appendix A:

Table A-1:

Geography	Average Asthma Child	Average Asthma Adult	Below Poverty Families	Unemployment	White Collar Occupation (Management, Business, Science, and Arts)	Education less than 9th grade	Bachelor's degree or higher	Income less than 15000	Overcrowded Conditions
Texas	16.3	9	13	7	33.7	10	17.8	13.4	4.8
Anderson	31	9.5	12.3	7	23.5	8.3	6.5	18.7	3.7
Angelina	8.2	12.1	13.3	6.2	27.9	9.5	10.1	15.8	3.6
Atascosa	22.8	11.5	15.3	9.5	25	14.5	7.5	15.5	5.7
Bastrop	12.5	11.4	9.8	6.5	32.2	9.3	10.1	10.5	4.2
Bee	36.8	11.1	15.9	9	24.5	14.5	2.7	22.1	5
Bell	21.9	8.4	11.2	7.6	31.7	4.5	12.5	11.7	2.7
Bexar	22.2	8.5	13.2	6.9	33.7	9	17.1	14.6	4
Bowie	23.7	12	12.7	7.9	30.2	5.9	9.2	17.3	1.7
Brazoria	11.4	7.2	8.2	5.5	38.7	6.6	20.4	8.7	3.7
Brazos	12.2	7.3	15.8	6.4	39.3	6.9	21.3	24.4	3.7
Brooks	79.2	27.1	29.7	8.1	26.3	27.5	7.8	38.7	4.1
Brown	14.2	22.1	12	3.6	27	6.8	10	19.1	1.7
Burnet	18.2	8.1	9	5.3	28.6	7.7	5.3	12.2	4.5
Caldwell	12.5	18.4	16	10.8	27.1	10.8	7.1	14.8	6.7
Callahan	46.5	13.4	11.6	5.3	24.9	4.7	11.8	15.4	1.6
Cameron	13.7	9.8	30	7.4	26.7	24.5	9.1	24.9	10.9
Chambers	15	6.7	7.7	6.2	31.2	5.1	7	8	2.9
Cherokee	14.5	12.2	18.3	5.6	23.2	10.9	3.5	19.2	5.4

Collin	12.9	6.7	4.8	5	50.2	3.3	35.8	5.5	2
Comal	14.6	11	6	5.7	37.8	5.1	19.3	8.1	3.7
Cooke	22.6	11.6	11.8	7.2	28	7.3	9.1	14.4	4.8
Coryell	13.2	5.8	11.4	8.3	28.1	3.7	7.9	11.2	2.5
Dallas	21.5	10.6	14.3	7.8	32.1	11.9	20.5	12.3	6.1
Denton	14	8.5	4.9	6.2	42	3.7	27.8	6.7	2.1
DeWitt	32.8	14.4	12.6	4.7	24	11.5	6.8	15.4	3.4
Ellis	20.3	10.3	8.7	6.6	31.8	6.7	13	8.2	4.3
Falls	30.4	11	16.3	7.9	23.9	10.8	4.6	25.4	2.7
Fort Bend	8.1	5.1	6.1	5.1	45.7	5.6	26.7	6	3.1
Freestone	27.4	15.7	10.1	6.5	34.9	7.3	10.4	15	1.9
Galveston	18.2	11.1	9.2	6.9	38.1	5.7	18.4	11.9	3.3
Grayson	12.5	11.5	10.2	7.5	30.2	5.4	11.5	13.5	2.5
Gregg	17.5	13	12.1	7.4	29.2	7.2	14.3	16	3.9
Guadalupe	12.6	6.7	7.8	6.3	33.9	6.8	15.8	9.4	3.6
Hardin	13.7	9.1	10.1	6.1	28.6	3.9	12.1	13.7	2.1
Harris	11.1	7.3	13.7	7.3	33.2	12	19.3	12.1	6.2
Harrison	9.7	7.1	12.3	7.9	25.5	4.9	10	15.5	2.2
Hays	13.4	6.2	6.7	6.5	38.6	5.5	17.1	14.4	2.7
Henderson	18.7	10.4	12.1	8.2	25.8	8.1	7.3	18.1	3.2
Hidalgo	24	8.3	30.5	9.9	25.9	26.2	10.3	25.1	13.3
Hill	25.4	14.2	11.3	6.7	25.2	9.1	8.7	15.9	3.2
Hood	15.4	8.5	7.9	4.9	34.9	4.5	12.5	8.9	1.5
Hopkins	18.2	5.1	12.8	7	28.5	8.6	10.4	16.1	3.6
Houston	29.7	19.4	19	9.1	22.2	8.4	6	23.4	3.5
Hunt	11.9	14.2	14.4	8.7	29.8	7	11.6	16.8	3.7
Jackson	32.5	10.8	8.6	5.3	30.4	8.8	10.7	12.1	5.1
Jasper	17.2	9.4	14.9	7.3	26.7	6	7.5	19.1	3.2

Johnson	12.1	16.7	7.7	7.2	28.7	6.6	10.2	8.8	3.3
Lamar	14.8	10.1	12.4	6.8	28.4	5.7	9.5	18.2	2.6
Liberty	16.7	19	12.1	9	23.4	9.5	6.3	14.3	5.9
McLennan	25.5	7.5	14.1	7.2	31.1	8.2	12.7	18.4	3.3
Medina	19.5	8	12.5	8.6	32.9	11.3	9.5	14.2	4.5
Milam	28.9	12.3	12.5	5.6	27.4	7.7	9.2	17.7	3.6
Montgomery	8.9	8.5	7.9	6.1	36.8	5.5	18.6	7.8	3.8
Nacogdoches	19.6	16.3	17.5	7.3	31.1	8.2	11	22.7	4.1
Navarro	22.2	11	14.9	8	26.8	9.7	9.1	15.6	5.3
Nueces	38.6	9.9	15.1	7.9	30.5	10.3	11.8	16.4	4.4
Orange	14.7	14.6	11.5	7.4	27.1	4.4	7.4	15.2	2.8
Panola	25.7	11.3	8.6	5.6	25.3	6.5	5.5	14.9	2.2
Parker	6.9	8.3	7.1	6.1	34.1	3.7	11.9	10.4	2.4
Polk	16.7	11.5	17.7	9.1	23.4	8.7	6.7	21	4.6
Robertson	38.3	16.3	17.4	7.9	27.4	11.5	8.9	18.8	4.9
Rockwall	14.4	5	4.2	5.7	42.8	3.9	25	5	2.2
Rusk	11.2	8.2	8.3	5	25.2	7.9	10.2	12.9	2.7
San Patricio	35.8	7.7	14.6	7.5	28.4	12.3	8.3	15.8	4.7
Shelby	20.8	10.7	21.5	7.3	26.8	9.8	9.4	19.5	6.8
Smith	11.7	7.1	11.3	7.2	32.1	6.8	14	13.2	3.9
Starr	11.5	7.1	35.1	9.7	24.3	36.2	9.3	31.9	11.4
Tarrant	11.3	8.3	10.4	7.4	34.8	7.3	20.1	10.4	3.7
Travis	11.6	7	11.1	6.4	43.8	7.4	31.6	11.9	4
Trinity	66.9	29.4	11.6	6.3	22.3	7.4	6	16.7	1.5
Upshur	16.7	10.1	9.9	6.8	25.8	5.4	8.6	15.1	3.6
Van Zandt	11.8	11.3	11.1	6.7	28	6.9	6.9	15.3	3.3
Victoria	33.8	17.4	12.8	7	29.8	8.9	11.1	12.8	3.9
Walker	18.5	16.3	15.7	7.1	30.6	7.9	8.1	25.7	1.9

Waller	13.4	9.1	14.4	6.9	29.3	8.1	9	15.5	4.3
Webb	11.7	9.1	25.4	7.5	24.9	23.1	11.5	20.1	15.7
Wichita	20.2	10.4	11.9	5.8	28.1	6	14	15.6	2.5
Willacy	21.5	15.5	39.4	7.4	22.6	28.6	3.9	40	10.3
Williamson	10.4	5.6	4.7	6.5	44.7	3.9	28	5.7	2.5
Wilson	14.4	7.5	6.5	5.6	35	8	12.5	8.8	3.2
Wise	12	6.8	7.8	8.1	26.6	6.8	11.2	10.3	2.5

Table A-2:

Geography	Divorced	Under 5 years	Elderly (65 years and over	Black	Single mothers with children under 18 yrs	Foreign Born_Not a US Citizen	Ethnic Minority Householder	Heating with gas (Bottled, tank, or LP gas)	Heating with fuel oil, kerosene, etc.	Heating with wood
Texas	10.5	7.8	10.1	12.4	24.2	11	14.1	4.1	0.1	0.5
Anderson	16.1	5.6	12.5	22.1	21.1	4.6	12.9	13.1	0	2.9
Angelina	12.2	7.6	13.3	15.6	29.1	5.9	14.1	6.8	0.1	2.3
Atascosa	9.3	7.9	12.1	1.4	27.1	4	1.4	10.8	0.1	0.4
Bastrop	13.3	6.9	11	8.9	19.8	7.7	8.4	15.2	0	1.2
Bee	11.3	5.9	10.4	9.7	28.9	3.9	0.6	13.3	0	0.6
Bell	12.3	9.1	8.7	23.2	30.4	4.5	20.7	2.4	0.1	0.5
Bexar	11.6	7.8	10.2	8.1	27.4	7.7	9.8	1.3	0.1	0.1
Bowie	13.2	6.5	13.8	25	29.5	2.5	20.3	3.6	0	2.4
Brazoria	10.9	8	9.3	12.4	18.3	7	13.7	6.4	0.1	0.3
Brazos	6.4	6.5	7.1	11.8	27.5	10	14.1	3.6	0	0.2
Brooks	8.9	6.5	17.3	0	30.5	3.4	0.3	5.4	0	1

Brown	13.2	6.6	16.6	4.5	22.6	2.4	3.3	10.9	0.1	1.4
Burnet	12.6	6	18	2	24.9	5.4	2.1	13.3	0	2.9
Caldwell	12	7.4	11.7	7.7	23.4	4.2	6	14	0.2	0.4
Callahan	13.3	5.8	17.6	1.5	23.6	1.5	0.4	16.3	0	2.2
Cameron	7.5	9.5	10.9	0.6	27.5	17.4	1.2	4.8	0.2	0
Chambers	9.5	6.9	9.5	9.5	13.5	4.4	10.2	13.8	0.5	0.4
Cherokee	11.8	7.3	14.5	16	21.5	8.4	10.6	13	0.1	2.7
Collin	9.7	7.9	7.2	8.6	14.3	9.8	17.2	2.1	0	0.1
Comal	9.4	5.9	14.9	2.1	15.4	3.9	2	8.1	0.2	0.9
Cooke	11.3	6.8	15.7	3.5	21.4	6.7	3.8	12.8	0.3	2
Coryell	11.6	8.2	7.3	18.5	26.2	2.7	14.4	3.7	0.1	1.3
Dallas	10.7	8.3	8.6	22.8	27.9	17.3	25	0.7	0.1	0.1
Denton	9.7	7.8	6.5	8.9	16.2	8.7	13.1	2.3	0.1	0.1
DeWitt	12.7	5.9	18	11	27.2	2.4	7.2	15.2	0.1	1.6
Ellis	9.7	7.5	9.7	9.5	18.5	5.5	9.7	8.3	0	0.2
Falls	10.6	5.5	16.7	24.4	32.9	3.2	18	20	0.2	2.1
Fort Bend	7.8	7.6	7	22.2	15.9	12.1	34.6	3	0.1	0.1
Freestone	13.9	6.5	16.6	17.4	18.5	4.1	11.7	13.4	0.1	2.7
Galveston	11.9	7	11.1	14.5	24.1	6	14	2.2	0.1	0.1
Grayson	13.6	6.6	15.2	6.5	24.9	4.2	6.3	8.2	0.2	1.3
Gregg	12.5	7.5	13.4	20.7	25.7	6.8	19.6	1.7	0.1	0.6
Guadalupe	9.2	7.1	11.5	6.8	20.1	4	7.3	5.3	0	0.4
Hardin	11.2	6.7	13.3	6.3	18.9	0.8	5.8	7.2	0	1.4
Harris	9.9	8.4	7.9	19.5	25.1	17.2	23.4	0.9	0	0.1
Harrison	13.2	7	13.1	22.8	26.8	4.3	19.1	4.8	0.6	1
Hays	8.5	6.7	8.3	4.1	15.6	4.4	4.2	9.3	0	0.9
Henderson	12.4	6.1	18.7	6.7	22.9	4.3	6.2	13.2	0.1	2
Hidalgo	6.6	10.2	9.3	0.6	25.9	22	1.5	4.9	0.2	0

Hill	11.9	6.7	17.9	7.3	18.3	6.1	6.2	23	0.2	1.2
Hood	11.3	5.8	20.2	0.7	17.4	2.9	1.1	11.9	0.4	0.7
Hopkins	12.2	7	15.2	8.6	23.4	6.5	7.8	13.3	0	2.6
Houston	9.2	5.8	18.8	27.3	34.9	3.3	17.1	20.2	0.3	4.3
Hunt	12.1	6.8	13.4	9.1	24.5	4.9	7.9	12.6	0	1.3
Jackson	10.2	7	16	8.7	27.9	3.9	6.6	11.1	0.5	1.3
Jasper	13	6.7	16.3	17.3	27	2.7	13.1	11.7	0	3.1
Johnson	11.3	7.2	11.1	3.1	18.9	5.3	3	10.3	0.1	0.8
Lamar	11.4	6.4	16.3	13.9	22.6	2.9	12.2	11.5	0.1	1.7
Liberty	12.1	6.9	10.8	11.7	21.2	5.2	9.1	19.5	0	1.7
McLennan	11.8	7.1	12.4	15.6	30.2	6.1	15.2	4.7	0.1	0.5
Medina	8.5	6.7	12.9	2.9	18.8	4	2.6	12.5	0.4	1.4
Milam	8.6	7	17.6	10.7	19.5	3.8	9.8	16.8	0	3.9
Montgomery	9.9	7.4	9.9	4.6	16.8	8.4	5.7	7.6	0	0.5
Nacogdoches	8.4	6.9	11.8	18.9	30.1	6.5	16.8	5.9	0	2.3
Navarro	11.8	7.5	14	15.8	26.2	8.8	13.5	10.6	0	0.8
Nueces	12.6	7.3	11.7	4.4	29.4	4.5	5.3	1.6	0	0.1
Orange	13.1	6.5	13.9	9.1	25.1	1.4	8.8	4	0.1	0.7
Panola	12.9	6.5	15.6	17.1	29.3	2.4	12.8	8.7	0.6	2.3
Parker	11	6.3	11.7	2.1	15.9	2.6	1.7	14.1	0.2	0.9
Polk	15.1	5.8	19	12.1	39.2	4.3	7.4	17.2	0	3.2
Robertson	10.7	6.9	17.2	22.1	34.2	5.6	16.8	14.5	0.1	2.6
Rockwall	9.9	7.6	9	5.6	15.2	5.9	7.3	4.1	0	0.4
Rusk	11.2	6.5	14.3	18.7	20.1	4.8	15.6	7.8	0.2	2.5
San Patricio	10.6	7.6	12.2	2.4	25.2	3.3	2.5	5.7	0.1	0.3
Shelby	9.7	7.6	15.6	18.9	31.4	7.4	15.5	13	0.2	3.3
Smith	10.8	7.2	14.1	18.8	24.9	6.6	17.4	5	0	0.9
Starr	6.7	9.7	10.3	0.1	23.9	21.6	0.6	6	0.1	0.1

Tarrant	11.6	8.1	8.7	15.2	24.2	10.6	17.6	1	0	0.1
Travis	10.5	7.5	7	9.2	24.4	13.4	13.3	3	0	0.2
Trinity	11.9	6.4	22.2	10.8	27.7	3.2	7	16.1	0	3.9
Upshur	12.6	6.4	15.1	9.4	23.4	2.6	8.8	7.7	0	3.2
Van Zandt	12.5	6.1	17.7	3.2	19.3	2.8	3.9	14.6	0	3.6
Victoria	11.2	7.6	13.1	7.4	32.4	4	7	4	0.1	0.3
Walker	11.8	4.6	9.9	23.3	32.8	6	16.9	8.8	0.9	1.2
Waller	7.9	7.3	9.8	26	24	12	23	16.4	0.3	1
Webb	8.3	10.5	7.7	0.5	28.1	20.9	1.5	1.2	0	0.1
Wichita	12.5	6.9	12.8	11.2	28.1	3.9	10.5	2.4	0.1	0.6
Willacy	9.4	7.5	11.8	2.1	27.6	8.8	0.6	13.9	0	0
Williamson	10.3	8.2	8.5	7	16.8	6.4	9.6	4.2	0.1	0.4
Wilson	7.8	6.5	12.1	2.2	12.1	2.7	2	13.8	0.1	1.1
Wise	11.9	6.7	11.7	1.5	14.5	5.1	1.5	14.6	0.1	1.4

Appendix B:

Table B-2: Active continuous air monitoring stations in eastern Texas, 2005-2012

CAMS Region	Stations	Site Name	Latitude	Longitude
4_DFW	C13	Ft. Worth Northwest	32.8058183	-97.356568
4_DFW	C17	Keller	32.9224736	-97.282088
4_DFW	C31	Frisco	33.1324201	-96.786404
4_DFW	C52	Midlothian	32.4820815	-97.026922
4_DFW	C56	Denton Airport South	33.2190564	-97.196287
4_DFW	C60	Dallas Hinton St.	32.8200608	-96.860117
4_DFW	C61	Arlington Municipal Court	32.6563574	-97.088585
4_DFW	C63	Dallas North No. 2	32.9192056	-96.808498
4_DFW	C69	Rockwall Heath	32.936523	-96.459211
4_DFW	C70	Grapevine Fairway	32.9842595	-97.063705
4_DFW	C71	Kaufman	32.5649518	-96.317677
4_DFW	C73	Granbury	32.4423048	-97.803539
4_DFW	C75	Eagle Mountain Lake	32.9878908	-97.477175
4_DFW	C76	Parker County	32.8687727	-97.905931
4_DFW	C77	Cleburne Airport	32.3535934	-97.436748
4_DFW	C402	Dallas Executive Airport	32.6764506	-96.87206
4_DFW	C1006	Greenville	33.1530774	-96.115561
4_DFW	C1032	Pilot Point	33.4106378	-96.944598
4_DFW	C1044	Italy	32.1754284	-96.87018
4_DFW	C1051	Corsicana Airport C1051	32.0319398	-96.399138
5_Tyler	C19	Longview	32.3786823	-94.711811
5_Tyler	C82	Tyler Airport Relocated	32.3440079	-95.415752
5_Tyler	C85	Karnack	32.6689873	-94.167457

6_El Paso	C12	El Paso UTEP	31.7682914	-106.50126
6_El Paso	C37	Ascarate Park SE	31.7467425	-106.40278
6_El Paso	C41	Chamizal	31.7656976	-106.45522
6_El Paso	C49	Socorro Hueco	31.6675	-106.288
6_El Paso	C72	Skyline Park	31.8939125	-106.42581
6_El Paso	C316	BRAVO Big Bend	29.3025518	-103.17791
6_El Paso	C414	Ivanhoe	31.7857687	-106.32358
6_El Paso	C663	Cd Juarez Delphi	31.712222°	-106.395278°
9_Waco	C1037	Waco Mazanec	31.6530743	-97.070698
9_Waco	C1047	Killen Skylark Field	31.0880022	-97.679734
10_Beaumont	C2	Beaumont-Downtown	30.0364396	-94.071091
10_Beaumont	C9	West Orange	30.0852629	-93.761341
10_Beaumont	C28	Port Arthur West	29.8975	-93.9911
10_Beaumont	C64	Hamshire	29.8639525	-94.3178
10_Beaumont	C311	SETRPC Maurisville	30.1946263	-93.86721
10_Beaumont	C628	SETRPC Port Arthur	29.867756	-93.951163
10_Beaumont	C640	SETRPC 40 Sabine Pass	29.728	-93.894
10_Beaumont	C643	SETRPC 43 Jefferson Co Airport	29.9425	-94.000556
10_Beaumont	C1035	Nederland High School	29.9789239	-94.010872
11_Austin	C3	Austin Northwest	30.3544356	-97.760255
11_Austin	C38	Audubon	30.4831681	-97.872301
11_Austin	C601	Fayette County	29.9624745	-96.745875
11_Austin	C614	Dripping Springs School	30.2146162	-98.083347
11_Austin	C684	CAPCOG McKinney Roughs	30.140877	-97.458897
11_Austin	C690	CAPCOG Lake Georgetown	30.6664421	-97.734579
12_Houston	C1	Houston Eastern	29.7679707	-95.220587
12_Houston	C15	Channelview	29.8027073	-95.125495

12_Houston	C26	Northwest Harris Co.	30.039524	-95.673951
12_Houston	C35	Houston Deer Park #2	29.670025	-95.128508
12_Houston	C45	Seabrook Friendship Park	29.5830473	-95.015544
12_Houston	C53	Houston Bayland Park	29.6957435	-95.499262
12_Houston	C78	Conroe Relocated	30.3503017	-95.425128
12_Houston	C84	Manvel Croix Park	29.520278	-95.3925
12_Houston	C114	HRM 3 Haden Rd	29.7647877	-95.178538
12_Houston	C403/C304	Clinton	29.7337263	-95.257593
12_Houston	C405	Houston North Wayside	29.8280859	-95.284096
12_Houston	C406	Houston Monroe	29.625556	-95.267222
12_Houston	C408	Lang	29.834167	-95.489167
12_Houston	C409	Houston Croquet	29.623889	-95.474167
12_Houston	C410	Houston Westhollow	29.723333	-95.635833
12_Houston	C411	Houston Texas Ave	29.752778	-95.350278
12_Houston	C416	Park Place	29.686389	-95.294722
12_Houston	C551	Sheldon	29.8586111	-95.160278
12_Houston	C552	Baytown Wetlands Center	29.7330556	-94.984722
12_Houston	C553	Crosby Library	29.9208333	-95.068333
12_Houston	C554	West Houston	29.8330556	-95.656944
12_Houston	C556	La Porte Sylvan Beach	29.6552778	-95.009722
12_Houston	C557	Mercer Arboretum	30.0380556	-95.381111
12_Houston	C558	Tom Bass	29.5894444	-95.353611
12_Houston	C559	Katy Park	29.8105556	-95.806111
12_Houston	C560	Atascocita	29.961944	-95.235
12_Houston	C561	Meyer Park	30.011667	-95.5225
12_Houston	C562	Bunker Hill Village	29.778333	-95.538056
12_Houston	C563	Huffman Wolf Rd	30.057860°	-95.061470°
12_Houston	C617	Wallisville Rd	29.821389	-94.99

12_Houston	C618	Danciger	29.148889	-95.765
12_Houston	C619	Mustang Bayou	29.308562°	-95.199910°
12_Houston	C620	Texas City 34th St.	29.4057	-94.94712
12_Houston	C696	UH-Sugarland	29.5741	-95.6497
12_Houston	C1015	Lynchburg Ferry	29.7616528	-95.081386
12_Houston	C1016	Lake Jackson	29.0437592	-95.472946
12_Houston	C1034	Galvaston 99th St.	29.2544736	-94.861289
13_San Antonio	C23	San Antonio NorthWest	29.51509	-98.620166
13_San Antonio	C58	Camp Bullis	29.6320582	-98.564936
13_San Antonio	C59	Calaveras Lake	29.2753812	-98.311692
13_San Antonio	C501	Elm Creek Elementary	29.276667	-98.724444
13_San Antonio	C502	Fair Oaks Ranch	29.73	-98.625556
13_San Antonio	C503	Bulverde Elementary	29.7608333	-98.462778
13_San Antonio	C504	New Braunfels Airport	29.7041667	-98.028889
13_San Antonio	C505	City of Garden Ridge	29.6391667	-98.298611
13_San Antonio	C506	Seguin Outdoor Learning Center	29.588611	-97.932222
13_San Antonio	C622	Heritage Middle School	29.3529047	-98.332821
13_San Antonio	C678	CPS Pecan Valley	29.4072945	-98.431251
14_Corpus Christi	C4	Corpus Christi West	27.7653345	-97.434247
14_Corpus Christi	C21	Corpus Christi Tuloso	27.832408	-97.555395
14_Corpus Christi	C87	Victoria	28.8361654	-97.005534
14_Corpus Christi	C624	Coleto	28.720926	-97.220882
14_Corpus Christi	C660	Holly Road	27.703056	-97.3875
14_Corpus Christi	C664	Violet	27.757778	-97.619444
14_Corpus Christi	C685	Ingleside	27.901667	-97.249167
15_Harlingen (Lower Rio Grande)	C43	Mission	26.2262097	-98.291069

15_Harlingen (Lower Rio Grande)	C80	Brownsville	25.8925176	-97.49383
16_Laredo	C44	Laredo Vidaurri	27.5174485	-99.515219

Table: Pollutant and Meteorological Parameters from Interpolated Maps for counties in eastern Texas, 2005-2012

County	Ozone	NO2	Temperature	Wind Speed
Anderson	28.7	5.3	66.5	7.4
Angelina	28.4	5.7	66.9	6.8
Archer	28.4	5.7	66.4	7.4
Atascosa	28.2	5.1	72.9	7.4
Austin	28.3	5.8	69.6	7.5
Bandera	28.5	5.7	70.2	7.4
Bastrop	29.6	5.9	69.1	7.4
Baylor	28.4	5.7	66.7	7.4
Bee	28.4	5.5	72.5	7.4
Bell	28.5	5.9	67.4	7.4
Bexar	26.9	5.5	70.5	5.9
Blanco	29.0	6.0	68.3	7.4
Bosque	28.5	5.9	66.4	7.4
Bowie	28.4	5.6	65.7	7.4
Brazoria	27.1	3.9	70.2	7.1
Brazos	28.4	5.7	68.3	7.4
Brooks	28.4	5.7	74.5	7.4
Brown	28.4	5.7	67.3	7.4
Burleson	28.5	5.7	68.5	7.4
Burnet	28.8	6.1	67.4	7.4
Caldwell	28.6	5.7	69.2	7.8

Calhoun	28.3	5.6	71.6	7.3
Callahan	28.4	5.7	67.2	7.4
Cameron	27.8	5.7	74.8	7.6
Camp	28.5	5.6	65.8	7.4
Cass	28.2	5.3	65.6	7.1
Chambers	28.6	5.3	70.1	8.6
Cherokee	28.7	5.5	66.5	7.4
Clay	28.4	5.7	66.2	7.4
Coleman	28.4	5.7	67.5	7.4
Collin	31.6	7.1	66.3	7.8
Colorado	28.4	5.6	69.9	7.4
Comal	29.4	5.7	69.0	7.3
Comanche	28.4	5.8	67.0	7.4
Cooke	28.6	6.0	65.8	7.4
Coryell	28.4	5.8	67.0	7.4
Dallas	28.7	10.4	67.8	6.7
De Witt	28.1	5.5	70.7	7.3
Delta	28.5	5.9	65.7	7.2
Denton	29.4	7.5	66.2	8.2
Duval	28.4	5.7	74.0	7.4
Easternland	28.4	5.7	66.9	7.4
Ellis	28.9	6.7	65.7	8.3
Erath	28.7	5.9	66.7	7.3
Falls	28.4	5.7	67.1	7.4
Fannin	28.6	6.0	65.7	7.3
Fayette	28.9	5.7	69.4	7.6
Fort Bend	26.9	5.8	70.0	6.9
Franklin	28.5	5.7	65.7	7.4

Freestone	28.5	5.1	66.4	7.4
Frio	28.3	5.6	72.9	7.4
Galveston	29.7	5.5	70.2	8.8
Gillespie	28.5	5.8	68.7	7.4
Goliad	28.2	5.5	71.6	7.4
Gonzales	28.2	5.5	69.9	7.4
Grayson	28.9	6.1	65.8	7.4
Gregg	28.7	5.8	66.1	6.8
Grimes	28.3	5.6	68.6	7.1
Guadalupe	26.6	5.3	69.2	8.1
Hamilton	28.4	5.8	66.9	7.4
Hardin	28.1	5.8	67.9	7.4
Harris	21.7	12.9	70.3	5.9
Harrison	27.8	5.0	65.7	5.8
Hays	29.4	5.9	68.9	7.2
Henderson	29.1	4.9	66.2	7.3
Hidalgo	26.7	5.7	74.8	7.4
Hill	28.6	5.9	65.8	7.4
Hood	29.9	6.3	66.7	7.1
Hopkins	28.6	5.8	65.8	7.3
Houston	28.4	5.6	67.2	7.4
Hunt	29.8	6.5	65.8	6.4
Jack	29.1	5.8	66.2	7.4
Jackson	28.1	5.5	70.9	7.3
Jasper	28.3	5.6	67.4	7.4
Jefferson	27.9	5.5	69.3	7.0
Jim Hogg	28.4	5.7	74.4	7.4
Jim Wells	28.2	5.7	74.2	7.5

Johnson	29.7	7.3	65.8	9.3
Karnes	28.4	4.7	71.5	7.4
Kaufman	31.8	4.8	66.5	6.9
Kendall	29.7	5.8	68.7	6.8
Kenedy	28.4	5.7	74.6	7.4
Kerr	28.5	5.7	69.4	7.4
Kleberg	27.8	5.7	74.5	7.9
La Salle	28.4	5.7	73.2	7.4
Lamar	28.4	5.8	65.7	7.4
Lampasas	28.4	5.8	67.2	7.4
Lavaca	28.3	5.6	70.3	7.4
Lee	28.6	5.8	68.8	7.4
Leon	28.4	5.6	67.2	7.4
Liberty	27.8	6.2	68.6	7.0
Limestone	28.4	5.5	66.5	7.4
Live Oak	28.4	5.6	73.0	7.4
Llano	28.5	5.8	67.8	7.4
Madison	28.4	5.6	67.9	7.2
Marion	27.8	4.9	65.6	6.1
Mason	28.4	5.7	68.3	7.4
Matagorda	28.1	4.7	70.9	7.2
McCulloch	28.4	5.7	67.9	7.4
McLennan	28.4	5.7	66.6	7.4
McMullen	28.4	5.6	73.2	7.4
Medina	28.1	5.7	72.2	7.3
Milam	28.5	5.8	67.9	7.4
Mills	28.4	5.7	67.2	7.4
Montague	28.5	5.8	66.0	7.4

Montgomery	27.7	6.0	68.7	6.2
Morris	28.4	5.6	65.7	7.4
Nacogdoches	28.4	5.7	66.6	7.3
Navarro	28.6	4.4	65.8	7.4
Newton	28.3	5.6	67.4	7.4
Nueces	25.2	5.7	74.7	8.0
Orange	25.7	5.0	68.4	5.8
Palo Pinto	29.3	5.9	66.5	7.5
Panola	28.3	5.6	66.2	7.2
Parker	33.4	6.8	66.3	7.8
Polk	28.4	5.7	67.5	7.4
Rains	29.0	5.6	65.9	7.2
Red River	28.4	5.7	65.7	7.4
Refugio	28.5	5.7	71.9	7.4
Robertson	28.4	5.7	67.5	7.4
Rockwall	31.8	6.7	66.6	6.6
Rusk	28.6	5.8	66.3	7.0
Sabine	28.4	5.7	66.9	7.4
San Augustine	28.4	5.7	66.8	7.4
San Jacinto	28.1	5.7	68.0	6.9
San Patricio	28.7	5.7	72.7	8.1
San Saba	28.4	5.7	67.5	7.4
Shackelford	28.4	5.7	67.0	7.4
Shelby	28.4	5.7	66.5	7.4
Smith	30.9	4.7	66.2	6.8
Somervell	29.0	6.1	66.6	7.5
Starr	28.2	5.7	74.5	7.4
Stephens	28.5	5.7	66.8	7.4

Tarrant	26.9	10.5	66.9	8.7
Throckmorton	28.4	5.7	66.8	7.4
Titus	28.4	5.7	65.7	7.4
Travis	30.1	6.7	69.4	6.0
Trinity	28.4	5.7	67.4	7.3
Tyler	28.3	5.7	67.4	7.4
Upshur	28.6	5.5	65.9	7.3
Van Zandt	29.4	5.2	66.2	7.2
Victoria	26.5	5.6	71.1	7.2
Walker	28.3	5.6	68.4	6.2
Waller	27.8	5.8	69.6	7.3
Washington	28.5	5.7	69.1	7.4
Webb	27.3	5.7	73.6	7.6
Wharton	28.1	5.3	70.4	7.4
Wichita	28.4	5.7	66.4	7.4
Wilbarger	28.4	5.7	66.6	7.4
Willacy	28.2	5.7	74.7	7.4
Williamson	29.0	6.4	68.3	7.3
Wilson	28.5	3.2	70.8	7.7
Wise	29.4	6.0	66.1	7.9
Wood	28.8	5.5	65.9	7.4
Young	28.5	5.7	66.5	7.4
Zapata	28.2	5.7	74.1	7.4