THE EFFECT OF TREE COVER AND VEGETATION ON INCIDENCE OF CHILDHOOD ASTHMA IN METROPOLITAN STATISTICAL AREAS OF TEXAS

THESIS

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CHAPTER 1

INTRODUCTION

Asthma, the most common disease among children, is a respiratory disorder in which airways to the lungs become constricted, causing a range of symptoms including wheezing, coughing and shortness of breath (Elsom, 1996; Walling, 2002). Studies have shown that from 1980-1994, the number of asthma cases increased more than 160% for children under age 5 and 74% for those ages 5 to 14 years of age (Brown et al., 2004; Lara et al., 2001). Since 2005, it has been reported that 6.5 million children under age 18 currently have asthma, and the percentage nearly doubled from 3.6 to 7.5% from 1980 to 1995 (Akinbami, 2006; Woodruff et al., 2003).

Indoor environmental elements such as tobacco smoke, pet dander, dust mites and cockroaches all contribute to asthma irritation and severity (Edelman, 1997; Lara et al., 2001). Although both indoor and outdoor air pollution contribute to the severity of asthma occurrences and attacks in children, Neidell (2004) reports that the outdoor air pollutants ozone, nitrogen dioxide and particulate matter aggravate pre-existing asthma in children. However, in addressing the epidemic of childhood asthma, researchers have had mixed results in their studies on links between outdoor air pollutants and asthma, suggesting the need for more focused studies on the issue (Neidell, 2004).

Tyrvainen et al. (2005) stated that in some cities, green spaces and trees are widespread in urban areas, which could provide an effective means to improve air conditions in such areas. An increase in tree plantings for urban areas is now being called upon as a solution to the higher heat indexes and pollution rates for more densely populated areas (Journal of Environmental Health, 2000; Kollin, 2003; Moll, 1997). In Texas, the city of Garland has found that an estimated 497,000 pounds of pollutants are removed each year by its urban forest (Journal of Environmental Health, 2000). The leaves of trees can take up a variety of airborne pollutants such as ozone, nitrogen and sulfur dioxides, ammonia and particulates (Tyrvainen et al., 2005), which are thought to have a direct effect on persons with respiratory problems, including both adults and children (Damia et al., 1999; Neidell, 2004). American Forests has stated that urban areas could improve the quality of air, water and soil if they were to accomplish 40% overall tree cover for urban areas (Moll, 1997).

Problem Statement

The purpose of this study was to assess whether there is a spatial relationship between levels of vegetation in Metropolitan Statistical Areas (MSA) of Texas and reported rates of childhood asthma in Texas.

Purpose and Objectives

The main objective for this study was to determine if childhood asthma rates in Metropolitan Statistical Areas of Texas were related to tree cover in Metropolitan Statistical Areas of Texas. Specific objectives for this study included:

1) Collecting published data on childhood asthma rates in Metropolitan Statistical Areas of Texas.

2) Mapping rates of childhood asthma in Metropolitan Statistical Areas of Texas.
3) Mapping the tree/vegetation cover for different Metropolitan Statistical Areas of Texas.
4) Estimating rates of filtration potential for differing vegetative covers in Metropolitan Statistical Areas of Texas.
5) Comparing the childhood asthma rates in different areas of Texas with the mapped tree and vegetation cover areas to determine if asthma rates were related to tree/vegetation coverage.

Hypothesis

It was hypothesized that there was an inverse relationship between childhood asthma rates and tree/vegetation cover. As tree/vegetation cover increased, childhood asthma rates would decrease. Likewise, in areas of decreased tree/vegetation coverage, childhood asthma rates would increase.

Definition of Terms

Asthma – A respiratory disorder in which airways to the lungs become constricted, causing a range of symptoms including wheezing, coughing and shortness of breath (Elsom, 1996; Walling, 2002).

Asthma rate – For the purposes of this study, the percentage of children under the age of 18 that were reported to have asthma (Center for Health Statistics, 2005).

Child – For the purposes of this study, this term was defined as anyone younger than the age of 17 (Texas Department of State Health Services, 2008).

Childhood – Time during which one is a child (Jaggi, 2005).

Coniferous – A cone-bearing plant such as pine or cypress trees (Arnold, 2008).

Deciduous – A plant species that sheds its leaves at certain times of the year in response to cold temperatures, drought/high heat, or day length (Arnold, 2008).

Evergreen – A plant species that retains its foliage throughout the year (Arnold, 2008).

Forests – A plant community formed by trees at least 10 feet tall, with a canopy cover of 60% or more (Diamond et al., 1987).

Gases – Air pollutants such as sulfur dioxide, ozone, fluorides, nitrates and nitrogen oxides (Bennett and Hill, 1975).

Green belt - A linear strip of land that provides a continuous amount of tree cover (Petit et al., 1998).

Herbaceous vegetation – Plant communities dominated by grasses and other non-woody plants, with the canopy cover of woody plant species being less than 26% (Diamond et al., 1987).

Marshes – Herbaceous vegetation-dominated wetlands, with standing surface water for at least half of the year (Diamond et al., 1987).

MSAs – Metropolitan Statistical Area; each MSA is comprised of a county or group of counties with a population of people of at least 75,000 and contains a central city or urbanized area of at least 50,000 people (Labor Market and Career Information Department, 2006).

Nitrogen dioxide – A gaseous pollutant created by high temperature combustions such as motor vehicle emissions, power plants and other fossil fuel burning industries, which contributes to the formation of ozone. Nitrogen dioxide can irritate a person's lungs (Myer et al., 2005).

Ozone – A gaseous pollutant caused by chemical reactions between nitrogen dioxide and volatile organic compounds in the atmosphere; its formation is stimulated by sunlight and heat. It is a powerful respiratory irritant that can cause airway constriction and increased respiratory symptoms in people (Myer et al., 2005).

Particulate matter – Airborne dust and chemical matter that can be inhaled into the lungs, causing decreased lung function and increased respiratory symptoms (Beckett et al., 1998; Myer et al., 2005; Petit et al., 1998; Trowbridge and Bassuk, 2004).

Pollution – For the purposes of this study, outdoor pollutants, including gases and particulate matter found in the atmosphere that adversely affect a person's health and well-being (Bennett and Hill, 1975).

Shrublands – A plant community dominated by shrubs, woody plants that are less than 10 feet tall, with a canopy cover of 26% or more (Diamond et al., 1987).

Sulfur dioxide – A gaseous pollutant that is released into the atmosphere by the combustion of fossil fuels, coal and oil which can constrict airway passages, making it harder to breathe for persons affected by asthma (Bennett and Hill, 1975; Myer et al., 2005).

Swamps - A forest or shrub-dominated wetland with standing surface water for at least half of the year (Diamond et al., 1987).

Vegetation – All the plant species that occur in a particular area (Bennett and Hill, 1975).

Woodlands - A plant community formed by trees that are at least 10 feet tall, with a canopy cover of 26% - 60% (Diamond et al., 1987).

Limitations

A variety of unrelated variables can cause a rise in asthma symptoms and occurrences in children. These include: exposure to tobacco smoke in or outside the home, number of pets in the household (causing an increase in exposure to dog and cat hair), poor living conditions that may contribute to a high cockroach population in the home, or a high concentration of dust particles/mites in the home due to poor cleaning practices.

This study was limited to the Metropolitan Statistical Areas (MSAs) of Texas and their populations and results are not necessarily applicable to other states. This study did not include all MSAs in Texas, and only included counties that had 50 or more reported cases of childhood asthma.

Childhood asthma data were collected from published medical data. Not all children with symptoms of asthma may be treated medically, and therefore they may not be included in published data.

This study is also limited to the years of asthma data that were available for analysis, 2005-2006.

Basic Assumptions

It is assumed that the childhood asthma occurrences were reported with enough accuracy for the purposes of this study.

It was assumed that 2006 was a representative year for both reported asthma rates and vegetation levels for each MSA analyzed in this study.

Delimitations of the Study

This study only focuses on Metropolitan Statistical Areas of Texas and the years for which asthma data information was available.

CHAPTER II

REVIEW OF LITERATURE

This chapter includes an overview of asthma with special attention paid to the following topics:

a. Childhood asthma
b. Costs of asthma
c. Childhood versus adult asthma
d. Asthma and demographics
e. Indoor air pollution and asthma
f. Outdoor air pollution and asthma

In addition, this chapter discusses plant life specifically focused on the following relationships:

a. Plants and indoor air quality
b. Urban areas and pollution
c. Plants and outdoor air quality
d. Vegetation of Texas

Asthma

Williams (2005) defines asthma as a common and chronic inflammatory condition of the airways in which a cause is not completely understood. Elsom (1996) defines asthma as a disorder in which a narrowing of the medium-sized air passages of the lungs causes wheezing, shortness of breath and coughing. The cause of asthma is not completely known, and a combination of host and environmental factors appear to be involved with the development and trigger factors of asthma (Thurston and Ito, 1999; Tunnicliffe and Ayres, 2001). Environmental elements such as tobacco smoke, pet dander, dust mites and cockroaches all contribute to asthma irritation and asthma severity in the indoor environment (Edelman, 1997; Lara et al., 2001). Outdoor air pollution is also known to trigger asthma symptoms in both children and adults (Walling, 2002; Woodruff et al., 2003).

Childhood Asthma

Childhood asthma is the most common chronic disease in children (Asthma Sourcebook, 2006; O'Connell, 2004), with increases in the number of cases occurring in industrialized countries (Walling, 2002). Asthma affects approximately 20 million people in the United States, and children make up more than one-third of those affected (Sommers et al., 2007). In 2000, the American Academy of Pediatrics reported that asthma rates for those 18 years old and younger had increased by more than 70% from 1982 to 1994 (Neidell, 2004). It was also reported that the percentage of children with asthma doubled from 3.6% in 1980 to 7.5% in 1995, and a survey administered in 2001 indicated that 6.3 million or 8.7% of children had asthma (Akinbami, 2006; Woodruff et al., 2003).

In 2001, almost 40% of U.S. children lived in counties that exceeded the 8-hour ozone standard (Woodruff et al., 2003). The 8-hour ozone standard was set by the Environmental Protection Agency (EPA) as a way to measure daily ozone levels in order to protect public health from overexposure (Myer et al., 2005; Williams, 2005). Ozone can constrict airways and an increase respiratory symptom, such as those associated with asthma, and is of particular concern for children because their lungs are continuing to develop and mature (Myer et al., 2005). Children may experience uncomfortable symptoms such as coughing and/or wheezing, chest tightness, shortness of breath combined with nasal congestion and/or runny nose as a result of their asthma (O'Connell, 2004).

Costs of Asthma

Respiratory diseases, such as asthma, can greatly hinder a child's ability to function, causing children to miss school days and limit daily activities such as playtime and exercise (Woodruff et al., 2003). It has been estimated that 10 million school days are missed annually by children suffering from asthma (O'Connell, 2004). A survey of individuals with asthma reported that 48% were limited in sports and recreational activities, 36% were limited in physical exertion and 25% were limited in social activities (O'Connell, 2004). Increased stress, interrupted sleep, disturbed routines and poor school performance have all been reported in those suffering from asthma (O'Connell, 2004). The cost of doctor office visits and medical treatments for an asthmatic child can be significant, often requiring families to reevaluate budgets to allow for the extra expenses (Jaggi, 2005).

Costs associated with the treatment of asthma, both direct and indirect, are significant and studies show these expenses have continued to increase over the years (O'Connell, 2004; Smith et al., 1997; Weiss and Sullivan, 2001; Weiss et al., 2000). Direct costs are those associated with the direct medical expenses and treatment of asthma, including prescribed medications, doctor office visits, visits to the emergency room and hospitalization (O'Connell, 2004; Smith et al., 1997; Weiss and Sullivan, 2001, Weiss et al., 2000). Smith et al. (1997) reported the following direct costs for persons with asthma: (1)An average cost per prescription of $27, with an annual average 6.5 prescriptions per person with asthma; (2)More than $616.2 million in office and clinical visits, with an average annual cost of $131 per person; (3)$566 million in hospital outpatient visits, for an average annual cost of $120 per person; (4)A total cost of $348 million in emergency room visits, the average annual cost per person being $74; (5)An estimated $2.8 billion in hospital stays, for an average annual cost per person of $595.

Indirect costs include lost work and housekeeping time, caregiver time associated with lost school days and bed rest days, and restricted activity days where work productivity is limited (Smith et al., 1997; Weiss and Sullivan, 2001; Weiss et al., 2000). Smith et al. (1997) reported the following indirect annual costs for persons with asthma: (1)An estimated total cost of $242.7 million in lost housekeeping productivity and work time; (2)$194.5 million in work wages lost by caregivers whose children, ages 5-17 years, had to stay home from school; (3)$18.5 million in work wages lost by caregivers whose children, ages 0-4 years, were on bed rest; (4)$217.5 million lost on restricted activity days, where workers could not perform to their full capacity.

Smith et al. (1997) reported that the total cost for asthma in 1994 was approximately $5.8 billion, for an average annual cost of $1,238 per patient. A study by Edelman (1997) estimated that the total cost of asthma care to U.S. citizens is approximately $12.6 billion per year, and O'Connell (2004) estimated this annual cost to be $14 billion, both with consideration of direct and indirect expenses. While Smith et al. (1997) found that hospitalizations accounted for the largest direct expense, Weiss and

Sullivan (2001) reported that medication expenses had surpassed hospitalization expenses.

Childhood vs. adult asthma

It is estimated that 75% of children who are affected by asthma will continue to suffer asthma symptoms into adulthood (Sommers et al., 2007). One study following 350 children treated for asthma between the ages of 8 and 12 found that 85% of females and 78% of males continued to have symptoms into adulthood over 15 years later (Edelman, 1997). Children have a higher incidence of asthma, with 12% suffering from symptoms, compared to the 1 to 5% of the general population reporting to have asthma (Sommers et al., 2007). It is believed that children's asthma is more severe than that of their adult counterparts because airways grow larger as one matures, so inflammation does not obstruct the airways as easily in adulthood (Edelman, 1997). Doctors also believe that adults are more familiar with their disease and, therefore, know how to control it better, making their asthma symptoms less severe than that of children with the same disease (Edelman, 1997).

Asthma and demographics

Asthma incidence patterns vary by region due to differences in population demographics (Akinbami, 2006.) The Texas Asthma Report analyzed data from 1999-2003 and reported the following: (1)African American, non-Hispanic Texans were hospitalized with asthma more often than Caucasian, non-Hispanic and Hispanic Texans; (2)Asthma hospitalizations were highest in children under the age of 5; (3)In children ages 14 and younger, asthma hospitalizations were higher for boys than girls; (4)In ages 15 and above, the hospitalization rate was higher in women than men. In 2006, the

Centers for Disease Control published a press release stating that Puerto Rican and non-Hispanic African American children had the highest percentages of asthma (Akinbami, 2006). Sommers et al. (2007) stated that inner-city children of color had a higher incidence of asthma prevalence and death when compared to Caucasian children. Among children ages 5 to 14, African American children were 4 times more likely to die of asthma when compared to Caucasians (Asthma Sourcebook, 2006). In males, asthma occurs more frequently in those under the age of 14 and over the age of 45, and, for females, asthma occurs primarily between the ages of 15 and 45 years (Sommers et al., 2007). Additionally, asthma is more common in persons living in cities when compared to persons living in suburban and rural areas (Asthma Sourcebook, 2006).

Indoor air pollution and asthma

High levels of indoor pollutants have been found to aggravate asthma symptoms (Godish, 1995). Indoor environmental elements such as tobacco smoke, pet dander, dust mites and cockroaches all contribute to asthma irritation, which increased asthma severity (Edelman, 1997; Lara et al., 2001). Sommers et al. (2007) stated that in patients under 30 years old, 70% of asthma symptoms were caused by indoor allergens such as dust mites, cockroaches and cats. Tobacco smoke, an indoor asthma trigger, increased the risk of wheezing by 280% in children ages 2 to 4 who lived in homes with a smoker when compared to those children who lived in non-smoking homes (Edelman, 1997). In addition to tobacco smoke, other asthma triggers in the home included: nitrogen dioxide emitted by gas heaters and stoves, heavy cooking odors, scented soaps, perfumes and some deodorants (Edelman, 1997).

Outdoor air pollution and asthma

Although air pollution is not believed to be a direct cause of children developing asthma, there is a growing concern that air pollution triggers symptoms in those who suffer from asthma, causing an increase in incidence and severity of asthma attacks, especially in children (Elsom, 1996; Kabesch and Von Mutius, 2002). Furthermore, Dockery et al. (1993) reported that high levels of pollution particles increase asthma prevalence and death. Pollutants can cause a direct irritant effect of the respiratory airways, which aggravates existing asthma (Elsom, 1996). Sommers et al. (2007) stated that non-allergic irritants such as smog are usually the cause of allergic symptoms in patients over 30 years of age. Additionally, Neidell (2004) reported that ozone, nitrogen dioxide and particulate matter air pollutants have a positive correlation with asthma in children. However, the connection between air pollutants and their effect on childhood asthma rates is still unclear, suggesting the need for more focused studies on the issue (Neidell, 2004).

Numerous time-series studies of hospital admissions and emergency visits have suggested a connection between particulate air pollution and asthma attacks (Dockery and Pope, 1996). Elsom (1996) wrote that pollutants including sulfur dioxide, ozone, acid aerosols, fine particulates and nitrogen dioxide are all believed to sensitize people to asthma. Studies of children with asthma at summer camps found that air pollution, particularly ozone, was significantly and consistently correlated with acute asthma exacerbations, chest symptoms and lung function decrements (Thurston and Ito, 1999). One study found that nasal inflammation of allergic asthmatics was increased by air pollutants such as ozone and that repeated exposure to ozone would likely have a detrimental effect on lung function of asthmatics (Devlin et al., 1996).

The main source of pollutants such as nitrogen dioxide and ozone is from the burning of fossil fuels by vehicles and industries (Myer et al., 2005). The formation of particulate matter can come from natural elements such as dust and pollen, or from the soot and aerosols given off during combustion activities of burning, vehicle operation and manufacturing processes (Myer et al., 2005).

Plants and indoor air quality

After 15 years of extensive studies on plants in both lab and "real world" environments, NASA has concluded that plants purify air (Wolverton, 1996). Air in the indoor environment can be 100 times more polluted than the outdoors, and workers often complain of health problems associated with high levels of pollutants in their buildings (Manaker, 1997). However, Wolverton (1996) explains how plants purify the air and examined 50 common houseplants that had high rates of removal of harmful chemicals from an indoor atmosphere. Acetone, methyl alcohol, ethyl acetate, benzene, ammonia, trichloroethylene, formaldehyde and xylene are all chemicals that can be emitted from a wide range of consumer products commonly found in the household (Leslie and Lunau, 1992). In another study, several common indoor plants in sealed chambers were exposed to benzene, formaldehyde and trichloroethylene, which are chemicals that are known to cause health problems (Manaker, 1997). The plants were able to remove almost 87% of the pollutants from the chambers within 24 hours of exposure (Manaker, 1997).

Urban areas and pollution

Carbon dioxide concentrations in the atmosphere have risen dramatically over the past 200 years due to the burning of fuels and forests (Petit et al., 1998). The increase of carbon in our atmosphere is directly related to smog formation in urban areas, heat-island effects in cities and respiratory problems in urban citizens because it traps heat and particulate pollution, which all result in discomfort and illness in humans (Petit et al., 1998). Jaggi (2005) stated that urbanization seemed to be correlated with an increase in the prevalence of asthma in some populations.

Urban heat islands occur when city areas have a greater amount of impenetrable surfaces such as concrete compared to areas with tree canopies (Kollin, 2003). Concrete and other impenetrable surfaces, as well as high levels of fossil fuel combustion, generate more heat in urban areas and lead to larger increases in air pollution when compared to their rural surroundings that have more vegetative coverage (Kollin, 2003; Nowak, 2000). Metropolitan areas that are urban heat islands are significantly warmer than surrounding rural areas, up to 9 degrees warmer during the day and as much as 22 degrees F at night (Oke, 1987 & 1997; Streutker, 2002).

A study conducted on the metropolitan area of Houston, TX using an approximate ten year time frame reported that its population had increased by nearly one million residents and that the urban heat island has also increased by approximately 30% (Streutker, 2003). Increasing urban vegetation in U.S. metropolitan areas that typically have pronounced heat islands, such as Houston, TX, could reduce air pollution associated with health problems and lower temperatures in the city (Akbari, 2002).

Plants and outdoor air quality

Trees help moderate the heat island problem by trapping and storing carbon from the atmosphere, with mature trees each absorbing more than 25 pounds of carbon per year for storage as wood and leafy material and releasing about 13 pounds of oxygen in the process (Nowak et al., 2002; Petit et al., 1998). Nowak (1994) found that a large healthy tree will sequester about 90 times more and store about 1000 times more carbon than that of a smaller healthy tree. Kollin (2003) reported that the city of San Antonio, TX had lost 22%, or 45,000 acres, of heavy tree canopy over a 15 year time period to urbanization. Trees in the San Antonio area currently remove 17.6 million pounds of pollutants and it is estimated that the trees removed between 1985 and 2001 would have removed an additional 3.7 million pounds of pollutants per year (Kollin, 2003). In the city of Garland, TX, it was estimated that 497,000 pounds of pollutants were removed each year by its urban forest, which stored approximately 209,000 tons of carbon and isolated around 531 tons of carbon every year (Journal of Environmental Health, 2000).

Green belts are linear strips of land that provide a continuous amount of tree cover (Petit et al., 1998). Research has found that green belts around factories and other industrial locations reduce air pollution by serving as a sink for pollutants and checking the flow of dust (Rao et al., 2004). Rao et al. (2004) found that a green belt planting around the industrial area reduced air pollutant emissions by as much as 63%, including sulfur dioxide by 39%, nitrogen oxides by 40%, 37% of particulate matter and a 93% reduction in carbon monoxide levels (Rao et al., 2004). In 1984, it was estimated in Los Angeles that one million new trees would remove 200 tons of particulate pollution each day when the trees reached 10 years old (Petit et al., 1998). American Forests published a report that urban areas should set out to achieve a goal of 40% overall tree cover to improve the quality of air, water and soil (Moll, 1997). Grey and Deneke (1978) wrote that one study showed that if an air mass which contained 150 parts per million (ppm) of ozone stood over a forest for 8 hours, that same forest could absorb about 80% of the pollutant. In some areas, tree shelterbelts are used to block winds that carry dust and particulate matter (Akbari, 2002).

Bennett and Hill (1975) called plants self-renewing, and therefore, excellent filters of pollutants in low concentrations, because they go through regenerative processes and can shed leaves and tissue. Leaves of trees can take up pollutants such as ozone, nitrogen dioxide, ammonia, sulfur dioxide and particles such as aerosols and dust, some of which can cause serious health problems (Tyrvainen et al., 2005). Trees act as natural filters and remove polluting gases by absorption through their leaves and other parts (Trowbridge and Bassuk, 2004). Trees remove airborne dust and chemical matter, or particulate matter from the air, where it is stored on leaves, twigs and trunks until it is washed to the ground by rain (Beckett et al., 1998; Petit et al., 1998; Trowbridge and Bassuk, 2004). Vegetation captures particulate matter on leaf surfaces where it can stay trapped or be washed away by precipitation (Sieghardt et al., 2005). Both trees and herbaceous vegetation can directly absorb gaseous pollutants through stomata openings in their leaves (Akbari, 2002; Sieghardt et al., 2005). Therefore, trees can capture airborne, smog-producing and carcinogenic particles that are by-products of fuel combustion and similar processes (Petit et al., 1998; Trowbridge and Bassuk, 2004). The ability of pollution-tolerant tree species to remove particulates from the air make them excellent management tools for improving air quality, especially when planted in urban settings (Beckett et al., 1998; Farmer, 2002).

Studies have shown that plants with greater leaf area, such as trees, act as better filters of pollution when compared to shrubs or grassland vegetation, which have less leaf area (Bolund and Hunhammar, 1999). Woodlands, or areas with greater tree cover, allow more room for air flow when compared to an area of thick or short vegetation such as grass or shrublands, giving woodland areas better filtering opportunities (Bolund and Hunhammar, 1999; Sieghardt et al., 5002). The needles of coniferous trees, such as pine (*Pinus* spp.) and cypress (*Cupressus* spp.), have a larger total surface area when compared to the leaves of their deciduous cousins, giving them increased filtering ability (Beckett et al., 1998; Beckett et al., 2000; Bolund and Hunhammar, 1999). Additionally, evergreen species, particularly conifers, filter more dust than their deciduous counterparts (Beckett et al., 1998). This is due to the fact that they remain evergreen during the winter months, at a time that coincides with poor air quality (Bolund and Hunhammar, 1999).

Besides differences between evergreen and deciduous species, there are differences within evergreen species, as well, particularly within coniferous species. In one study, it was found that of two different coniferous species; the pine species (*Pinus* spp.) captured significantly more particulates than did the cypress species (*Cupressus* spp.) (Beckett et al., 2000). Although coniferous species have better filtering ability, they are more sensitive to pollution in comparison to deciduous species, which absorb gases more readily (Bolund and Hunhammar, 2005). As a result, a mix of both evergreen and deciduous species would be the best solution for increased filtration of airborne pollutants (Bolund and Hunhammar, 2005).

Vegetation of Texas

Texas has a wide variety of climate and geography conditions across the state, which leads to a wide variety in native vegetation across its natural regions (Diamond et al., 1987). Classifications of different vegetative communities that occur across the state include: forests, woodlands, shrublands, herbaceous vegetation, swamps and marshes (Diamond et al., 1987).

East Texas, also known as the Piney Woods region of Texas, vegetative composition consists of pine-hardwood forests, farmlands and pasture (Diamond et al., 1987; Preserving Texas' Natural Heritage, 1978). The major dominating vegetative type in this area is evergreen pine (*Pinus* spp.) (Diamond et al., 1987; Preserving Texas' Natural Heritage, 1978). Moving west of the Piney Woods border, the Oak Woods and Prairies natural region begins (Preserving Texas' Natural Heritage, 1978). Ranches are common in this region, with oak-hickory forests and tall grass prairies being the dominant vegetation types (Preserving Texas' Natural Heritage, 1978). The Blackland Prairie region, which borders the Oak Woods and Prairies, is a major grassland area of Texas and an ideal location for crop agriculture (Diamond et al., 1987; Preserving Texas' Natural Heritage, 1978). Although this area is historically grassland, several oak (*Quercus* spp.) species have invaded some areas heavily (Preserving Texas' Natural Heritage, 1978).

Much of the Texas coast lies in the Gulf Prairies and Marshes region, historically a mosaic of oak woodlands, grasslands and marshes that have been heavily invaded by mesquite, prickly pear, oaks and acacias (Preserving Texas' Natural Heritage, 1978). The Coastal Sand Plains, a very small natural region lying on the Texas Coast, consists of salt marshes and grasslands that have been taken over by oak (*Quercus* spp.) scrub vegetation (Preserving Texas' Natural Heritage, 1978).

The South Texas Brush Country natural region is dominated by thorny brush vegetation, and as one moves further south, a tropical climate prevails, making it a prime location for tropical vegetation (Preserving Texas' Natural Heritage, 1978). Over the years, much of this tropical vegetation has been largely replaced by agricultural crop land. The Edwards Plateau region, also known as the "hill country", is dominated by scrub forests of ash (*Fraxinus* spp.), juniper (*Juniperus ashei*), live oak (*Quercus virginiana*) and mesquite (*Prosopis glandulosa*), with man-made lakes, ranches and farms scattered throughout (Preserving Texas' Natural Heritage, 1978).

In the Rolling Plains region of Texas, mesquite (*Prosopis glandulosa*), oak (*Quercus* spp.), cedar (*Juniperus* spp.), acacia (*Acacia* spp.) and mimosa (*Albizia julibrissin*) are commonly found mixed with grassland vegetation (Preserving Texas' Natural Heritage, 1978). Covering most of the Texas panhandle, the High Plains region is relatively free of brush and is characterized by short grassland (Preserving Texas' Natural Heritage, 1978). Junipers (*Juniperus* spp.) have invaded and are now common to both the Rolling Plains and High Plains natural regions of Texas (Diamond et al., 1987).

The furthest western region of Texas is known as the Trans Pecos, has a wide range of vegetative communities and is dominated by desert shrublands, desert grasslands, yucca (*Yucca* spp.) and juniper (*Juniperus* spp.) savannas and forests of pine (*Pinus* spp.) and oak (*Quercus* spp.) (Diamond et al., 1987; Preserving Texas' Natural Heritage, 1978).

CHAPTER III

METHODOLOGY

The main objective for this study was to determine if childhood asthma rates in Metropolitan Statistical Areas of Texas were related to tree cover in Metropolitan Statistical Areas of Texas. Specific steps for this study included:

1) Collecting published data on childhood asthma rates in different Metropolitan Statistical Areas of Texas.
2) Mapping rates of childhood asthma in different Metropolitan Statistical Areas of Texas.
3) Mapping the tree/vegetation cover for different Metropolitan Statistical Areas of Texas.
4) Estimating rates of filtration potential for differing vegetative covers in Metropolitan Statistical Areas of Texas.
5) Comparing the asthma rates in different areas of Texas with the mapped tree and vegetation cover areas to determine if asthma rates were related to tree/vegetation coverage.

Metropolitan statistical areas of Texas

The state of Texas has been divided into 25 different Metropolitan Statistical Areas (MSAs) for the purposes of demographic and statistical analyses by various departments and organizations in Texas (Labor Market and Career Information Department of the Texas Workforce Commission, Real Estate Center at Texas A&M University, 2006). Each MSA is comprised of a county or group of counties with a population of at least 75,000 and contains a central city or urbanized area of at least 50,000 (Labor Market and Career Information Department, 2006). Metropolitan Statistical Areas, or MSAs, include the following regions: Abilene, Amarillo, Austin-Round Rock, Beaumont-Port Arthur, Brownsville-Harlingen, College Station-Bryan, Corpus Christi, Dallas-Fort Worth-Arlington, El Paso, Houston-Sugarland-Baytown, Killeen-Temple-Fort Hood, Laredo, Longview, Lubbock, McAllen-Edinburg-Mission, Midland, Odessa, San Angelo, San Antonio, Sherman-Denison, Texarkana, Tyler, Victoria, Waco and Wichita Falls.

Childhood asthma data collection

Children's asthma data was collected from the Center for Health Statistics, Texas Department State Health Services for the years 2005-2006 (Vincent, 2008). For this study, childhood asthma data was available and collected for all counties in Texas with reported populations of 50 or more children (Vincent, 2008). In order to determine the population for each sample, adult respondents had to provide a valid response of "yes" or "no" to the two questions on a survey concerning a select child under the age of 17 in their household (Cook, 2010.) The questions asked were as follows: "Has a physician/medical care provider ever told you that this child has asthma?" and "Does this child still have asthma?" (Texas Department of State Health Services, 2008). Adults who answered "yes" to the two questions concerning a select child under the age of 17 in their household were considered the asthma sample (Texas Department of State Health Services, 2008). In order to normalize the sample to the general population, the asthma sample was weighted in calculating the percentage of children with asthma (Cook, 2010).

The asthma data collected was then compared to the 25 Metropolitan Statistical Areas of Texas to see the areas of correspondance (Pimpler, 2008). Of the 25 MSAs, data on childhood asthma rates corresponded with the following 14: Amarillo, Austin-Round Rock, Beaumont-Port Arthur, Brownsville-Harlingen, Corpus Christi, Dallas-Fort Worth-Arlington, El Paso, Houston-Sugarland-Baytown, Killeen-Temple-Fort Hood, Longview, Lubbock, McAllen-Edinburg-Mission, San Antonio and Tyler. Therefore, these 14 MSAs were included in the study. The remaining 11 MSAs were dropped because they included counties with a sample size of less than 50 children and, therefore, data was not available from the reporting agency (Vincent, 2008).

Mapping of asthma data with corresponding vegetative cover

The data files containing statistics on childhood asthma occurrence for the chosen MSAs along with vegetation coverage in the state of Texas were sent to GeoSpatial Training Services™ in San Antonio, Texas. The asthma rate for each MSA was graphed in pie chart form and inserted into a corresponding vegetation map for that particular MSA using ArcView© 9.1 GIS (Redlands, CA) software.

Mapping of tree coverage/vegetation rates

Tree coverage/vegetation rates were examined for each Metropolitan Statistical Area (MSA) of Texas and were mapped out for illustration using ArcView© 9.1 GIS (Redlands, CA) software.

To determine the information regarding percent vegetation/greenness for the Metropolitan Statistical Areas (MSAs) in this study, a normalized difference vegetation index (NDVI) was calculated from satellite imagery (Landsat) for each MSA. Landsat imagery contains the two bands (near infrared and red) required to calculate NDVI. This index is a simple numerical indicator used to analyze remote sensing measurements to determine the amount of green vegetation in the observed target. The resulting index range for this calculation is -1 to 1 (barren/non-vegetation to dense green vegetation, respectively).

The calculation is as follows (NIR = near infrared): NDVI = (NIR-Red)/(NIR + Red)

Landsat 5^{TM} imagery was obtained from United States Geological Survey (U.S.G.S.) Glovis site (U.S. Department of the Interior, 2010). Image "tiles" were downloaded to cover the extent of all MSAs included in the study. Each "tile" covered an area of 185 km (115 mi) wide. In order to obtain an accurate NDVI for each MSA, the imagery must be high quality and as cloud free as possible. The images selected and used in the study were designated by U.S.G.S. as having a cloud cover of 0% and an image quality of 9 out of 10. (Note that 0% cloud cover may still include isolated clouds.) The downloaded image tiles were for the months of April to July 2006 when possible.

This timeframe ensured that vegetation would be present after winter dormancy conditions in the plants, and yet still be prior to summer heat and drought conditions that would affect greenness levels. The year 2006 was chosen in order to coincide with the collected asthma data. If data with the above criteria were not available, the next closest date to that (skipping dormant months) was acquired. Out of the 14 MSAs used in this study, the following three had image tiles that were pulled from either September or October of 2006 instead of April to July 2006: Dallas-Fort Worth-Arlington, Lubbock, and Killeen-Temple-Fort Hood.

The tiles were then "mosaiced" or pieced together to create one seamless image for each MSA. "Mosaicing" merges adjacent tiles into one image file removing overlapping values between tiles. The NDVI was calculated for each image using ENVI™ (Redlands, CA) image- processing software. This process resulted in a grid with values ranging from of -1 to 1.

The NDVI grid was transferred to the GIS software, where statistics were calculated for each MSA. Statistics included the minimum NDVI value, the maximum NDVI value, and mean NDVI value. The result was a table with each MSA, and its minimum, maximum, and mean greenness value.

Percent canopy cover was also calculated for each MSA to determine what proportion of each MSA is groundcover versus woody vegetation such as trees and shrubs. Statistics were also calculated for the MSAs using the Multi-Resolution Land Characteristics (MRLC) National Land Cover Data canopy cover dataset. The result was a table with each MSA and what percent of that MSA contained woody vegetation. This table was used in conjunction with the NDVI results and the acreage in each MSA to further determine statistical significance.

Data analysis

Asthma data, NDVI and canopy cover data were analyzed using SPSS 17.0™ (Seattle, WA). Descriptive statistics, frequencies and correlations, as well as regression analyses were calculated to analyze the data for the tree coverage/vegetation rates and asthma rates variables.

CHAPTER IV

RESULTS

The main objective for this study was to determine if childhood asthma rates in Metropolitan Statistical Areas of Texas were related to tree cover in Metropolitan Statistical Areas of Texas. Specific steps for this study included:

1) Collecting published data on childhood asthma rates in different Metropolitan Statistical Areas of Texas.
2) Mapping rates of childhood asthma in different Metropolitan Statistical Areas of Texas.
3) Mapping the tree/vegetation cover for different Metropolitan Statistical Areas of Texas.
4) Estimating rates of filtration potential for differing vegetative covers in Metropolitan Statistical Areas of Texas.
5) Comparing the asthma rates in different areas of Texas with the mapped tree and vegetation cover areas to determine if asthma rates were related to tree/vegetation coverage.

Findings Related to Objective One

The first objective included collecting published data on childhood asthma rates for different areas of Texas. Children's asthma data were collected from the Center for

Health Statistics, Texas Department State Health Services for the years 2005-2006 (Vincent, 2008). In order to determine if children had asthma, parents or guardians of children had to answer "yes" to two questions on a survey concerning a select child under the age of 17 in their household (Texas Department of State Health Services, 2008). The questions asked were as follows: "Has a physician/medical care provider ever told you that this child has asthma?" and "Does this child still have asthma?" (Texas Department of State Health Services, 2008). A total of 13,366 adult respondents were interviewed, and 4,329 adults with children provided a valid response of "yes" for the two questions concerning asthma (Cook, 2010). The sample size for each area was determined by the number of respondents answering "yes" to the questions, and only those areas with a sample size of 50 or more where used for the purposes of this study. In order to normalize the sample to the general population, the asthma sample was weighted in calculating the percentage of children with asthma (Cook, 2010).

The state of Texas has been divided into 25 different Metropolitan Statistical Areas (MSAs) for the purposes of demographic and statistical analyses by various departments and organizations in Texas (Labor Market and Career Information Department of the Texas Workforce Commission, Real Estate Center at Texas A&M University, 2006). Each MSA is comprised of a county or group of counties with a population of at least 75,000 and contains a central city or urbanized area of at least 50,000 (Labor Market and Career Information Department, 2006). Metropolitan Statistical Areas, or MSAs, include the following regions: Abilene, Amarillo, Austin-Round Rock, Beaumont-Port Arthur, Brownsville-Harlingen, College Station-Bryan, Corpus Christi, Dallas-Fort Worth-Arlington, El Paso, Houston-Sugarland-Baytown, Killeen-Temple-Fort Hood, Laredo, Longview, Lubbock, McAllen-Edinburg-Mission, Midland, Odessa, San Angelo, San Antonio, Sherman-Denison, Texarkana, Tyler, Victoria, Waco and Wichita Falls.

The asthma data collected were then compared to the 25 Metropolitan Statistical Areas of Texas to see which areas they corresponded to (Vincent, 2008). MSAs that included counties with a childhood asthma sample size of less than 50 children were not included for analysis purposes (Table 1) (Vincent, 2008). Each MSA was analyzed and ranked in order from highest to lowest percentage of childhood asthma (Table 1).

The Amarillo MSA had the highest childhood asthma rate at 15% (Table 1). There was a 5.2% difference in asthma rates between Amarillo and the second highest level of asthma, which was 9.8% for the San Antonio MSA. After that, the drop in asthma rates across the different MSAs becomes much smaller, ranging from 0.1 to 1.4 percentage points. The Killeen-Temple-Fort Hood MSA had the lowest childhood asthma rate, at 3.1% (Table 1).

Table 1. Compilation of results for childhood asthma rates per Metropolitan Statistical Area (MSA), ranked in order from highest to lowest, in the study of the effect of tree cover and vegetation on incidence of childhood asthma[z] in Metropolitan Statistical Areas of Texas.

Ranking	MSA	Population sample (no.)	Asthma sample (no.) [x]	Asthma %
1 – highest	Amarillo	58	9	15
2	San Antonio	355	35	9.8
3	Dallas-Fort Worth-Arlington	780	69	9.0
4	Longview	60	5	8.8
5 – tie	Corpus Christi	50	4	8.5
5 – tie	Houston-Sugarland-Baytown	536	46	8.5
6	Beaumont-Port Arthur	53	4	7.1
7	Austin-Round Rock	364	25	6.8
8	El Paso	489	31	6.3
9	Lubbock	162	9	5.7
10	Tyler	79	4	4.6

Table 1 cont.

11	Brownsville-Harlingen	51	2	4.3
12	McAllen-Edinburg-Mission	132	5	3.7
13 – lowest	Killeen-Temple-Fort Hood	66	2	3.1

[z] Data on percentage of children with asthma were obtained from the Center for Health Statistics, Texas Department State Health Services for the years 2005-2006. The data were rounded to the next highest or lowest raw number based on the normalized percentage of children reported to have asthma in the overall population.

Findings Related to Objective Two

The second objective of the study included mapping rates of childhood asthma and vegetative composition for each Metropolitan Statistical Area (MSA) of Texas. The data files containing statistics on childhood asthma occurrence, obtained from Center for Health Statistics, Texas Department State Health Services for the years 2005-2006, for the 14 MSAs were sent to GeoSpatial Training Services™ in San Antonio, Texas. The childhood asthma percentage for each MSA was graphed in pie chart form and inserted into general vegetation maps for each MSA using ArcView© 9.1 GIS (Redlands, CA) software (Figures 1 – 13). An overall map of asthma rates as it related to specific MSA and location in Texas did not appear to reflect any clear pattern of asthma rates in different vegetative regions of the state (Figure 1).

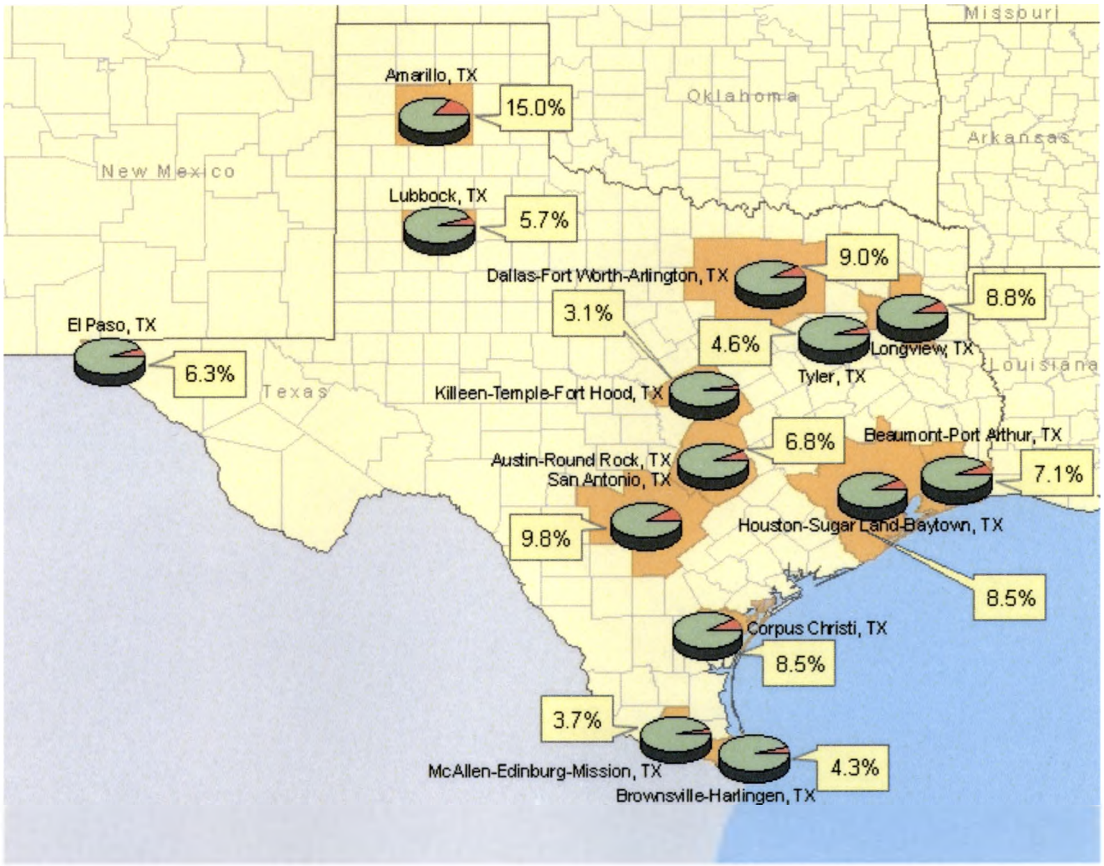

Figure 1. Childhood asthma data graphed in pie chart form and inserted into a general Texas state map and including corresponding Metropolitan Statistical Area (MSA) of Texas.

Texas has a wide variety of climate and geography conditions across the state, which leads to a wide variety in native and endemic vegetation across its natural regions (Diamond et al., 1987). This variety in climate and geography also leads to a wide variety of agricultural and horticultural crops that can be grown in each natural region of the state (Texas CropMAP, 2003) (Appendix 1).

Amarillo asthma rates and vegetative cover

Studies have shown that plants with greater leaf area, such as trees, act as better filters of pollution when compared to shrubs or grassland vegetation, which have a smaller leaf areas (Bolund and Hunhammar, 1999). Amarillo (Figure 2) had the highest percentage of childhood asthma at 15%. The vegetation for the region is a mix of cropland and mesquite (*Prosopis glandulosa*) brush/shrubland. This area of Texas has a lot of flat grasslands and farmlands with very few trees. Major crops grown in the Amarillo MSA include cereals such as corn, wheat and sorghum, soybeans, and hay, with smaller acreage in pecans and cotton (Texas CropMAP, 2003).

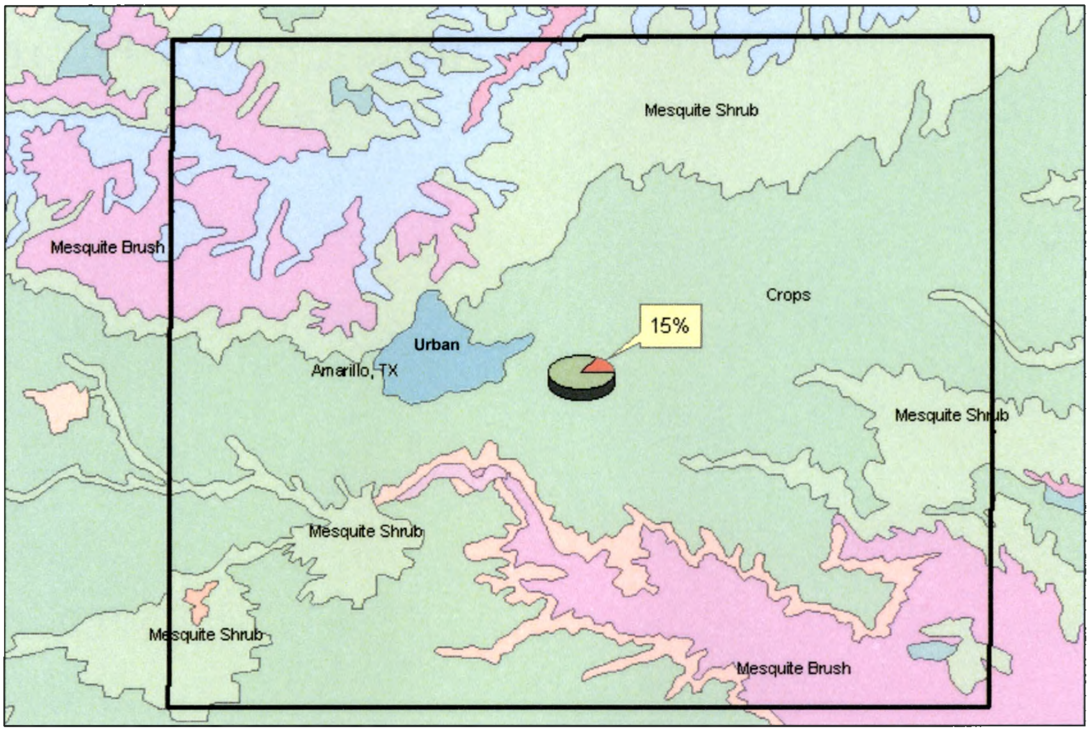

Figure 2. Native and cropland vegetative composition and childhood asthma rate for the Amarillo MSA (MSA outlined in black) in the study of the effect of tree cover and vegetation on incidence of childhood asthma in Metropolitan Statistical Areas of Texas.

Austin-Round Rock asthma rates and vegetative cover

Vegetation in the Austin-Round Rock MSA consists of a mix of Live Oak (*Quercus virginiana*)-Ashe Juniper (*Juniperus ashei*) woodlands, Live Oak (*Quercus virginiana)*-Mesquite (*Prosopis glandulosa*)-Ashe Juniper (*Juniperus ashei*) Parks, Post Oak (*Quercus stellata*) Wood and Forest-grassland mosaic, Silver Bluestem (*Bothriochloa saccharoides*)-Texas Wintergrass (*Nassella leucotricha*) grasslands, along with areas of cropland throughout (Figure 3). Austin-Round Rock is ranked number four of the largest four major metropolitan/urban areas of Texas (U.S. Census, 2008), but its asthma rate is only 6.8%, which is lower when compared to any of the other major urban areas of Texas (Table 1; Figure 3) and ranked 7th highest asthma rate of the 14 MSAs used in this study. Austin has been named one of America's top 10 greenest cities (Svoboda, 2008). The city of Austin devotes 15% of its land to parks and other open spaces and boasts 32 miles of bike trails (Grist, 2007). Major crops grown in the Austin-Round Rock MSA include cereal crops such as corn, sorghum, wheat and oats, hay, with smaller acreages in a variety of vegetable, fruit and nuts crops, cotton and nursery/floriculture crops (Texas CropMAP, 2003) (Appendix 1).

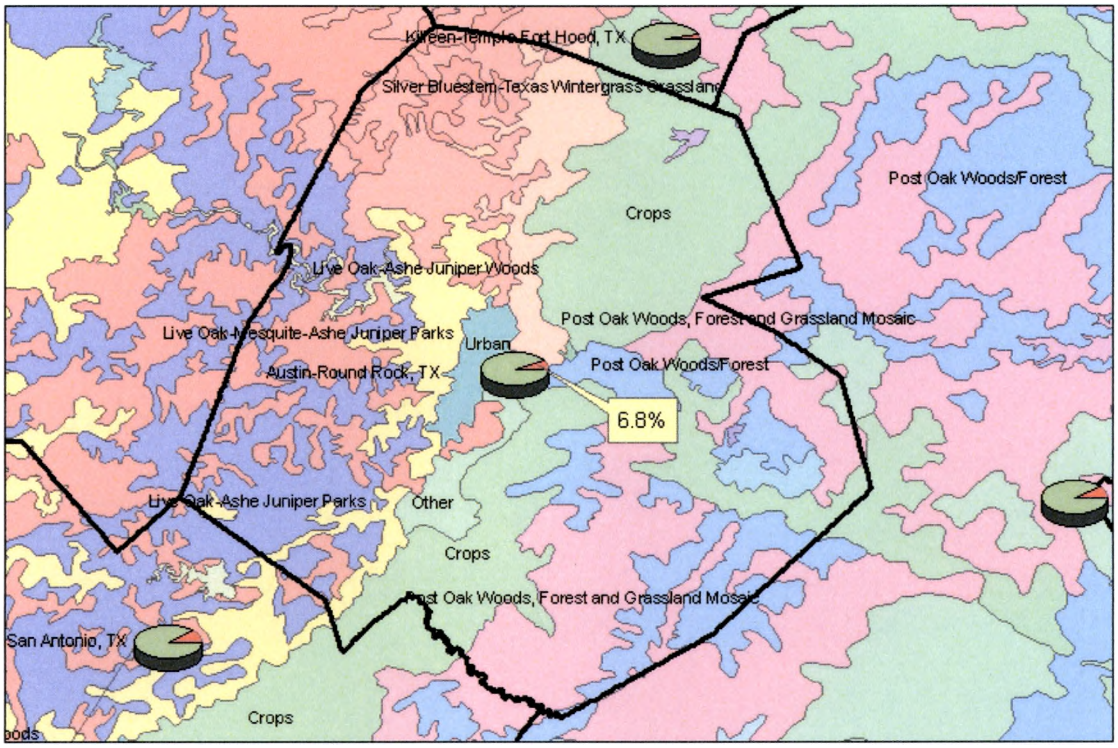

Figure 3. Native and cropland vegetative composition and childhood asthma rate for the Austin-Round Rock MSA (MSA outlined in black) in the study of the effect of tree cover and vegetation on incidence of childhood asthma in Metropolitan Statistical Areas of Texas.

<u>Beaumont-Port Arthur asthma rates and vegetative cover</u>

Vegetative composition of the Beaumont-Port Arthur MSA consists of Pine (*Pinus spp.*)-Hardwood forests, cropland, and Willow Oak (*Quercus phellos*)-Water Oak (*Q. nigra*)-Blackgum (*Nyssa sylvatica*)forests (Figure 4). Crops of the Beaumont-Port Arthur MSA include cereal crops of rice, grain legumes and soybeans, hay and forage crops, fruit and nut crops, cotton and nursery/floriculture crops (Texas CropMAP, 2003) (Appendix 1). Beaumont-Port Arthur MSA ranks 6th highest of the 14 MSAs, with a 7.1% childhood asthma rate. Beaumont-Port Arthur is situated within a coastal area, and has higher humidity levels that are also linked to asthma irritation (Mireku et al., 2009).

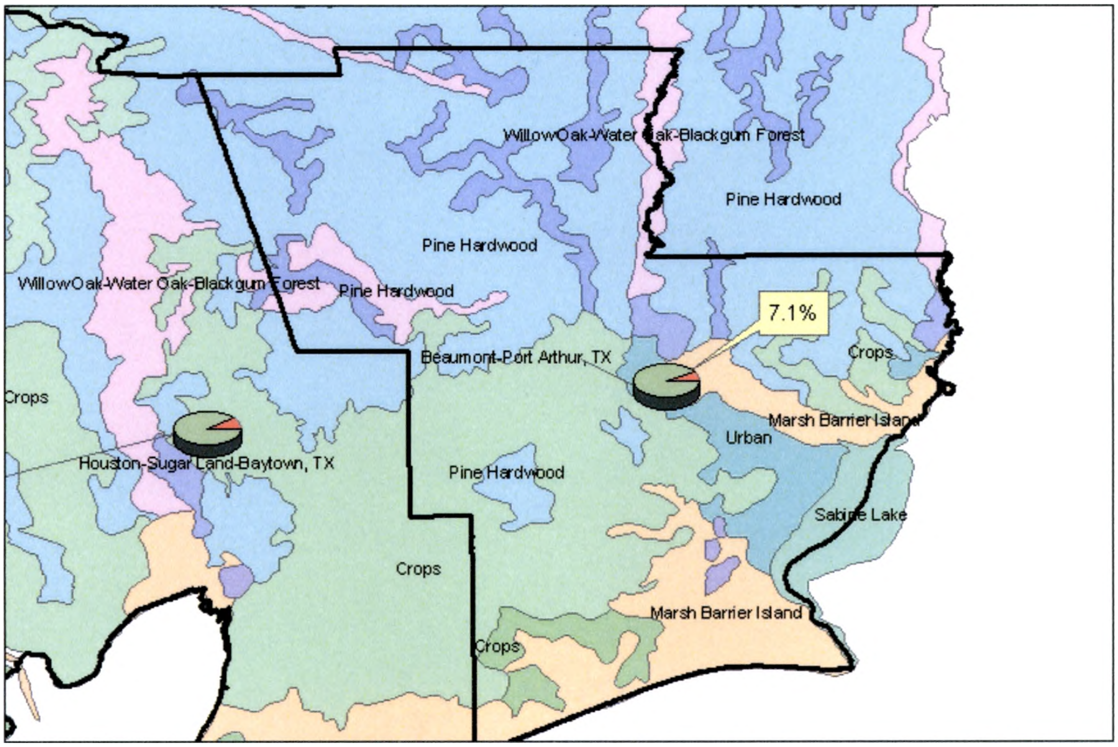

Figure 4. Native and cropland vegetative composition and childhood asthma rate for the Beaumont-Port Arthur MSA (MSA outlined in black) in the study of the effect of tree cover and vegetation on incidence of childhood asthma in Metropolitan Statistical Areas of Texas.

Corpus Christi asthma rates and vegetative cover

The Corpus Christi MSA has a large amount of agronomic cropland, with Mesquite (*Prosopis glandulosa*)-Blackbrush (*Acacia rigidula*) brushlands and Live Oak (*Quercus virginiana*) Wood/Parklands occurring only in two small areas of this MSA (Figure 5). The asthma rate for this area stands at 8.5%, which is the same as Houston-Sugarland-Baytown, and it is ranked the 5^{th} highest asthma rate of the 14 MSAs used in this study. Crops that are commonly grown in the Corpus Christi MSA include cereal crops such as corn, sorghum, wheat, hay, vegetable crops of sweet corn and watermelon, cotton, fruit and nut crops of peaches and pecans and nursery/floriculture crops (Texas CropMAP, 2003) (Appendix 1).

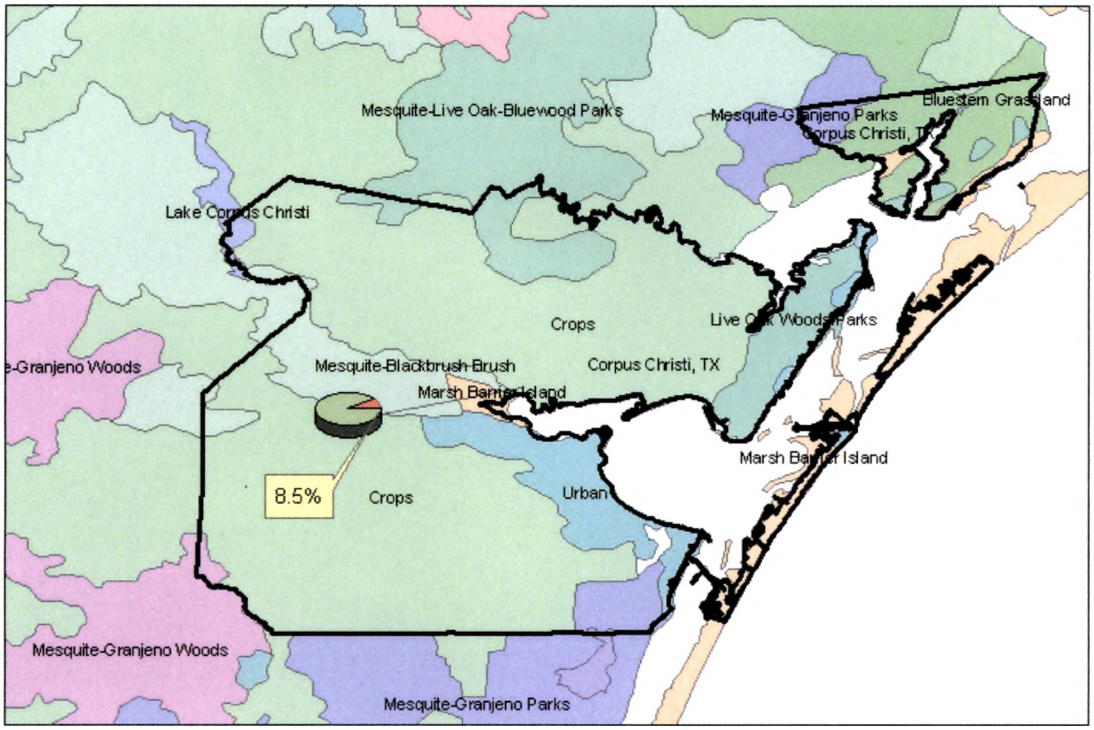

Figure 5. Native and cropland vegetative composition and childhood asthma rate for the Corpus Christi MSA (MSA outlined in black) in the study of the effect of tree cover and vegetation on incidence of childhood asthma in Metropolitan Statistical Areas of Texas.

Dallas-Fort Worth-Arlington asthma rates and vegetative cover

At 9.0%, the Dallas-Fort Worth-Arlington MSA (Figure 6) has the 3rd highest asthma rate of the 14 MSAs used in this study. Dallas-Fort Worth-Arlington is the largest of Texas' top four major metropolitan areas (U.S. Census, 2008). More concrete and less tree cover in urban areas create higher temperatures and higher ozone levels, which can aggravate asthma symptoms and severity (Kollin, 2003). Vegetation for the Dallas-Fort Worth-Arlington MSA consists of Post Oak (*Quercus stellata*) Woods/Forests and grassland mosaic, Bluestem (*Bothriochloa spp.*) (*Schizachyrium spp.*) grasslands, Elm (*Ulmus spp.*)-Hackberry (*Celtis spp.*) Parks/woods, Silver Bluestem (*Bothriochloa saccharoides*)-Texas Wintergrass (*Nassella leucotricha*) grasslands, along with areas of cropland. Major crops grown in counties that occur in the Dallas-Fort

Worth-Arlington MSA include cereal crops such as corn, sorghum, wheat and oats, hay, varieties of vegetable, fruit and nut crops, cotton and nursery/floriculture crops (Texas CropMAP, 2003) (Appendix 1).

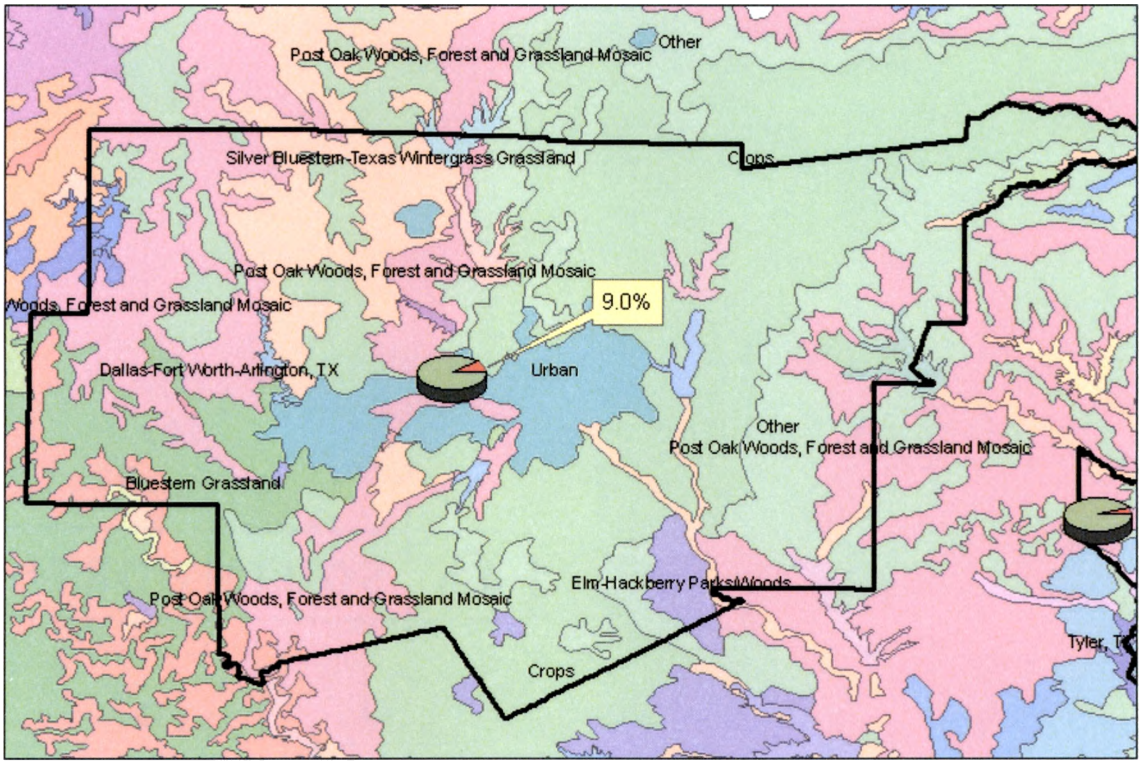

Figure 6. Native and cropland vegetative composition and childhood asthma rate for the Dallas-Fort Worth-Arlington MSA (MSA outlined in black) in the study of the effect of tree cover and vegetation on incidence of childhood asthma in Metropolitan Statistical Areas of Texas.

El Paso asthma rates and vegetative cover

El Paso (Figure 7) is comprised of arid lands, desert grasslands, called Tobosa (*Hilaria mutica*)-Black Grama (*Bouteloua eriopoda*) grasslands and cropland, in a region of Texas with the least amount of rainfall to wash away particulate matter (Diamond et al., 1987; Preserving Texas' Natural Heritage, 1978). El Paso vegetation is also comprised of thick, heavy brush/shrublands called the Mesquite (*Prosopis glandulosa*)-sandsage (*Artemesia filifolia*) shrublands. Thicker vegetation results in less air flow through the canopies and less filtration of pollutants (Bolund and Hunhammar, 1999; Sieghardt et al., 2002). Crops grown in the El Paso MSA include sorghum, wheat and oats, hay and forage crops a wide variety of vegetable and fruit and nut crops, cotton and nursery/floriculture crops (Texas CropMAP, 2003) (Appendix 1). The asthma rate for the El Paso MSA was 6.3%, which ranked 8th highest of the 14 MSAs used in this study.

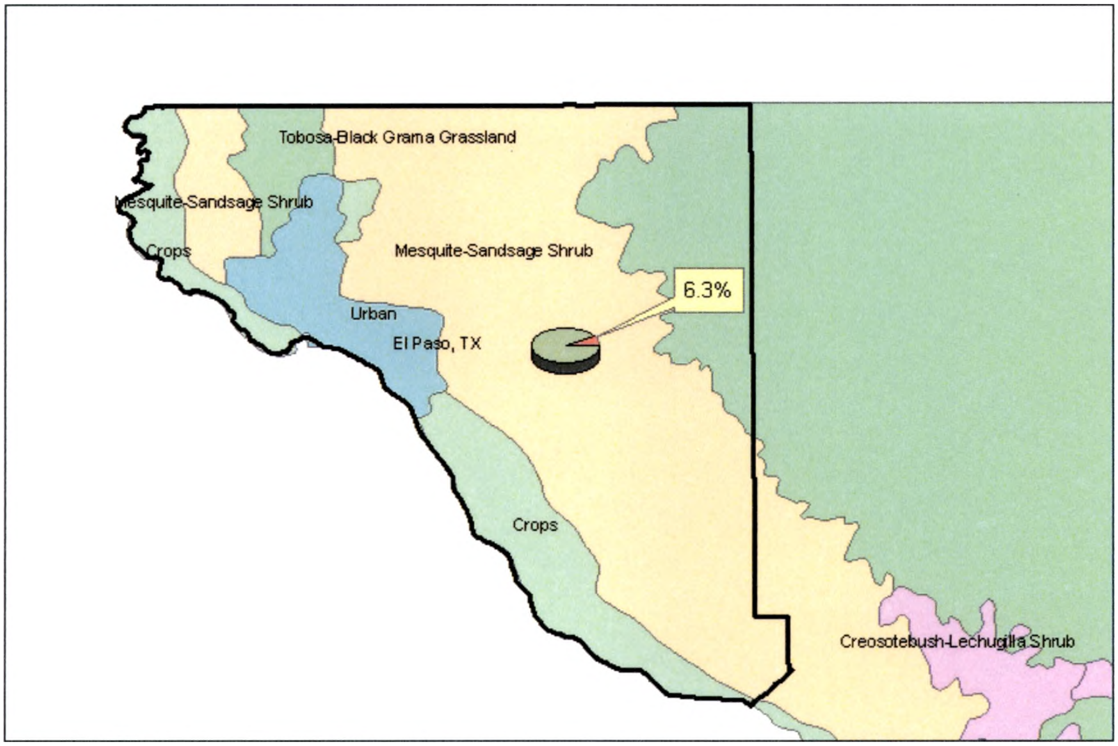

Figure 7. Native and cropland vegetative composition and childhood asthma rate for the El Paso MSA (MSA outlined in black) in the study of the effect of tree cover and vegetation on incidence of childhood asthma in Metropolitan Statistical Areas of Texas.

<u>Houston-Sugarland-Baytown asthma rates and vegetative cover</u>

Vegetative composition of the Houston-Sugarland-Baytown MSA consists of Pine (*Pinus spp.*)-Hardwood forests, cropland, Willow Oak (*Quercus phellos*)-Water Oak (*Q. nigra*)-Blackgum (*Nyssa sylvatica*) forests, and Bluestem (*Bothriochloa spp.*) (*Schizachyrium spp.*) grasslands (Figure 8). Major crops grown in the counties of the Houston-Sugarland-Baytown MSA include cereal crops such as corn, sorghum, wheat and rice, soybeans, hay and forage crops, a wide variety of vegetable, fruit and nut crops, cotton and nursery/floriculture crops (Texas CropMAP, 2003) (Appendix 1).

The Houston-Sugarland-Baytown MSA (Figure 8), with an 8.5% childhood asthma rate, ranks 5th highest of 14 MSAs and ties with Corpus Christi in the top half of MSA asthma rates in Texas. Houston MSA is closer to coastal areas, which means it has higher humidity levels. Higher humidity levels are also linked to asthma irritation (Mireku et al., 2009). Houston is ranked number 2 of Texas' major metropolitan areas, which typically have higher temperatures and ground level ozone, causing more irritation to those residents who suffer from asthma (Kollin, 2003).

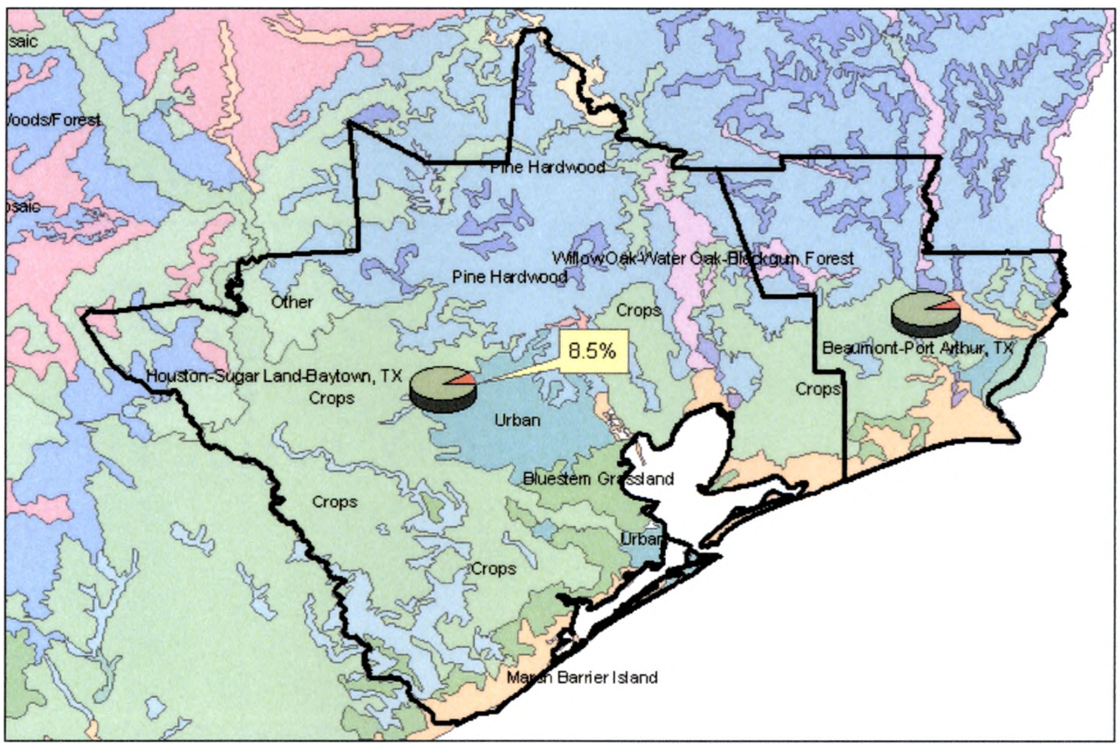

Figure 8. Native and cropland vegetative composition and childhood asthma rate for the Houston-Sugarland-Baytown MSA (MSA outlined in black) in the study of the effect of tree cover and vegetation on incidence of childhood asthma in Metropolitan Statistical Areas of Texas.

Killeen-Temple-Fort Hood asthma rates and vegetative cover

At 3.1%, Killeen-Temple-Fort Hood (Figure 9) has the lowest asthma rate of all 14 MSAs. Vegetative communities of this MSA include a mix of Live Oak (*Quercus virginiana)*-Ashe Juniper (*Juniperus ashei*) woodlands, Live Oak (*Quercus virginiana)*-Mesquite (*Prosopis glandulosa*)-Ashe Juniper (*Juniperus ashei*) Parks/woodlands, Post Oak (*Quercus* stellata) Woods/Forests and grassland mosaic, Silver Bluestem (*Bothriochloa saccharoides*)-Texas Wintergrass (*Nassella leucotricha*) grasslands, along with areas of cropland. Crops grown within the counties of this MSA include cereal crops of sorghum, wheat and oats, hay and forage crops, a variety of vegetable, fruit and nut crops, cotton and nursery/floriculture crops (Texas CropMAP, 2003) (Appendix 1).

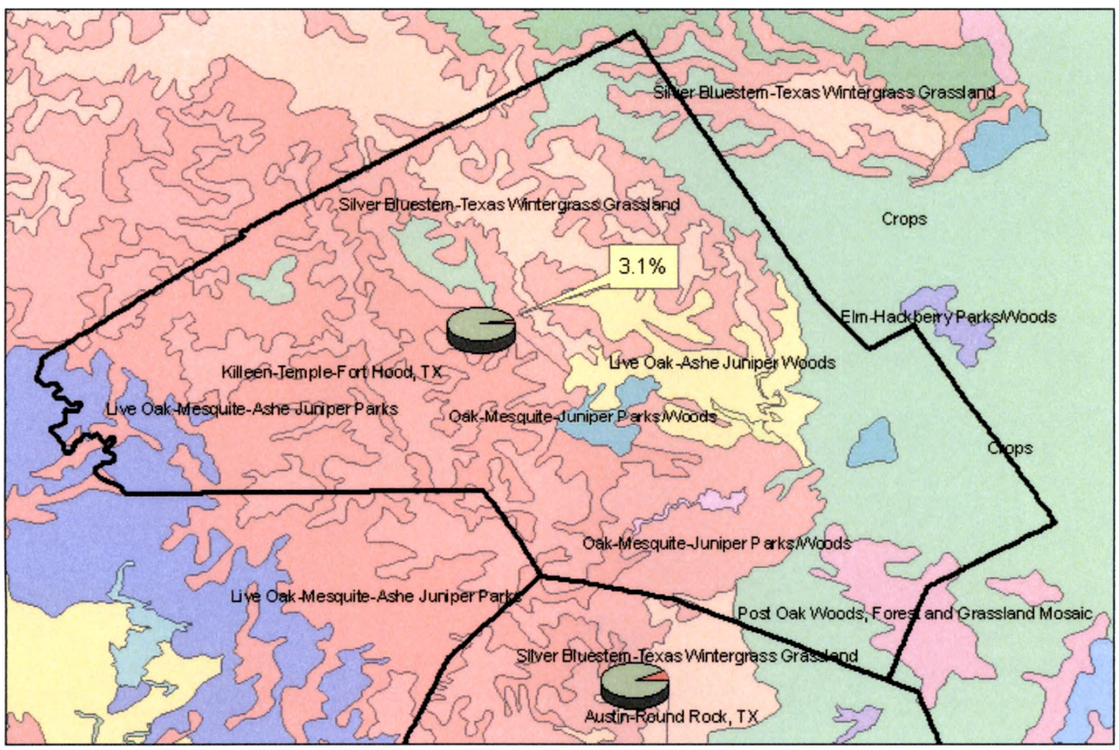

Figure 9. Native and cropland vegetative composition and childhood asthma rate for the Killeen-Temple-Fort Hood MSA (MSA outlined in black) in the study of the effect of tree cover and vegetation on incidence of childhood asthma in Metropolitan Statistical Areas of Texas.

Lubbock asthma rates and vegetative cover

A major portion of the Lubbock MSA consists of cropland, with Mesquite (*Prosopis glandulosa*)-Lotebush (*Zizyphus obtusifolia*) brushland and areas of juniper (*Juniperus spp.*) woods occurring in the more Southeastern corner (Figure 10). Major crops grown in counties of the Lubbock MSA include cereal crops of corn, sorghum, wheat, oats and sunflower seed, grain legumes such as soybeans, cowpeas and southern peas, hay and forage crops, a variety of vegetable, fruit and nut crops, cotton and nursery/floriculture crops (Texas CropMAP, 2003) (Appendix 1). The Lubbock MSA asthma rate, at 5.7%, is ranked 9th highest of all 14 MSAs used in this study.

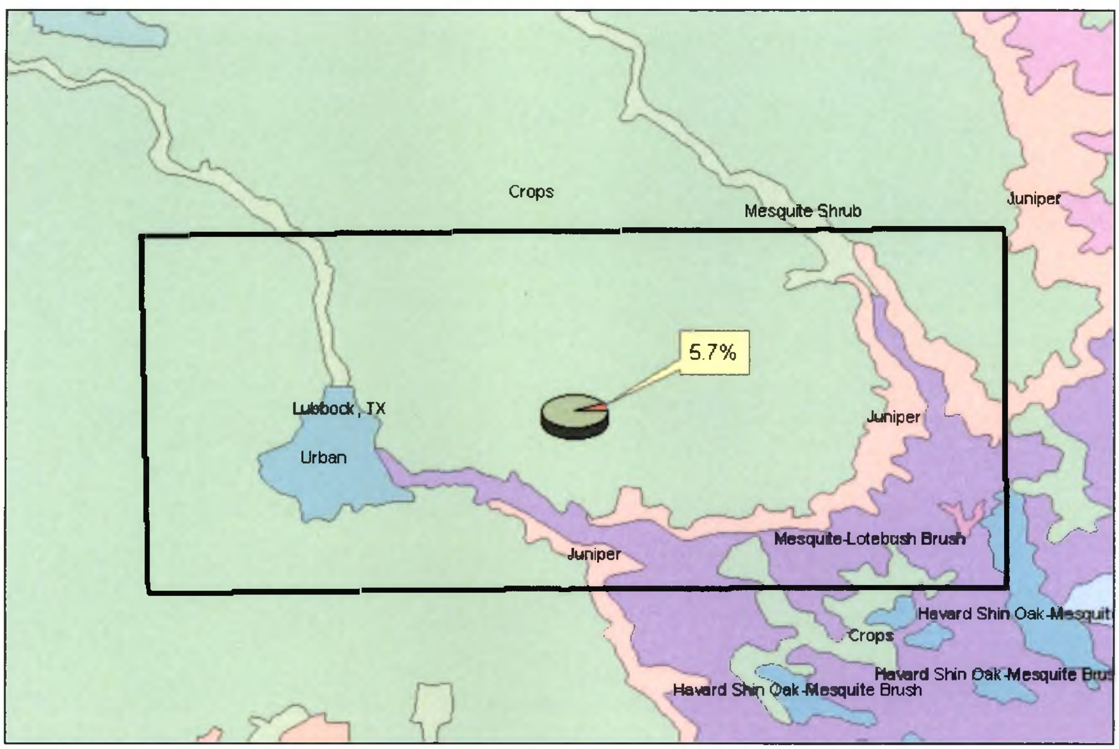

Figure 10. Native and cropland vegetative composition and childhood asthma rate for the Lubbock MSA (MSA outlined in black) in the study of the effect of tree cover and vegetation on incidence of childhood asthma in Metropolitan Statistical Areas of Texas.

McAllen-Edinburg-Mission and Brownsville-Harlingen asthma rates and vegetative cover

The McAllen-Edinburg-Mission and Brownsville-Harlingen MSAs are located in the Lower Rio Grande Valley region of Texas and have two of the lowest childhood asthma rates, at 3.7% and 4.3%, respectively. Both of these areas consist primarily of cropland, but McAllen-Edingburg-Mission MSA does have Mesquite (*Prosopis glandulosa*)-Granjeno (*Celtis pallida*) Parks occuring in its northern portion (Figure 11). The Lower Rio Grande Valley is also located in a subtropical environment, and has much milder winters compared to other areas of Texas, and winter months coincide with poorer air quality (Beckett et al., 1998; Bolund and Hunhammar, 1999). For this reason, both of these MSAs have much larger acreages devoted to a variety of vegetable, fruit and nut crops, cotton, sugarcane and nursery/floriculture crops than any other MSA regions used in this study (Texas CropMAP, 2003) (Appendix 1).

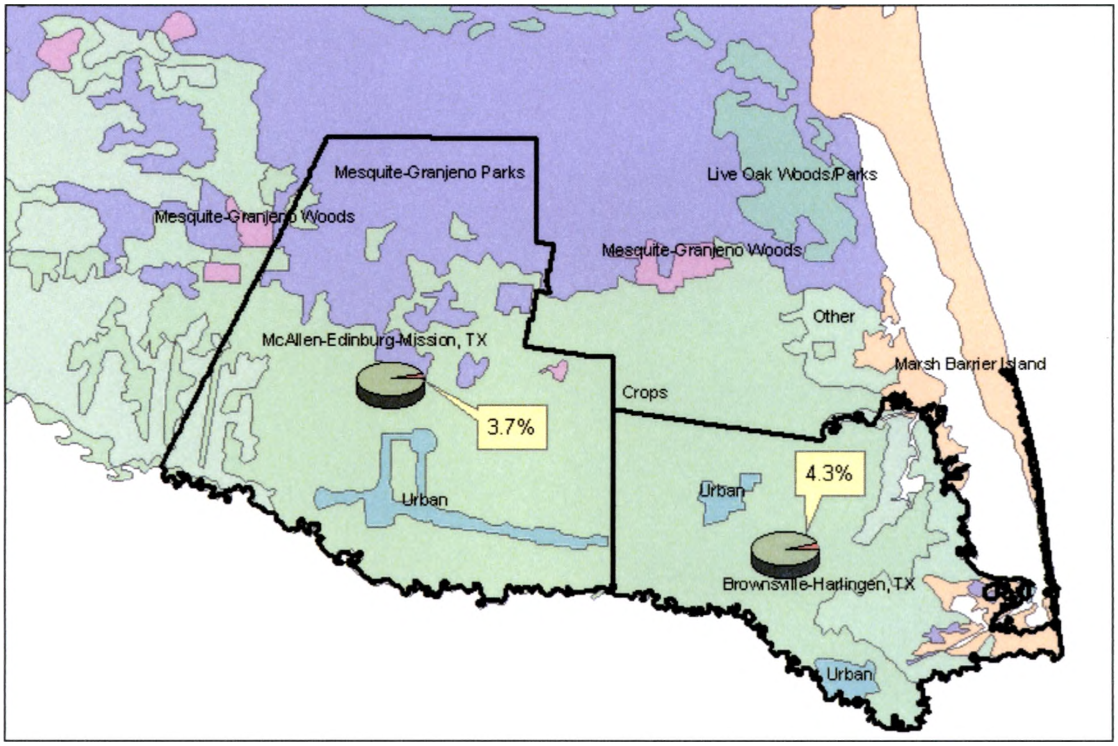

Figure 11. Native and cropland vegetative composition and childhood asthma rate for the McAllen-Edinburg-Mission MSA and the Brownsville-Harlingen MSA (MSAs outlined in black) in the study of the effect of tree cover and vegetation on incidence of childhood asthma in Metropolitan Statistical Areas of Texas.

San Antonio asthma rates and vegetative cover

Vegetation in the San Antonio MSA consists of a mix of Live Oak (*Quercus virginiana*)-Ashe Juniper (*Juniperus ashei*) woodlands and parks, Live Oak (*Quercus virginiana)*-Mesquite (*Prosopis glandulosa*)-Ashe Juniper (*Juniperus ashei*) Parks, Mesquite (*Prosopis glandulosa*)-Live Oak (*Quercus virginiana)*-Bluewood Parks, Post Oak (*Quercus stellata*) woods, forests and grassland mosaic, Mesquite (*Prosopis glandulosa*)-Granjeno (*Celtis pallida*) woodlands, Mesquite (*Prosopis glandulosa*)-Blackbrush (*Acacia rigidula*) brushlands, along with areas of cropland throughout (Figure 12). San Antonio is ranked number 3 of the 4 major metropolitan/urban areas of Texas (U.S. Census, 2008). At 9.8%, the city's childhood asthma percentage is the second highest of all other Texas MSAs used in this study. At one time, it was reported that San Antonio, TX had lost 22%, or 45,000 acres, of heavy tree canopy due to urbanization (Kollin, 2003) and its urban communities are continuing to develop. Crops grown in counties located within the San Antonio MSA include cereal crops such as corn, sorghum, wheat and oats, hay, soybeans, a variety of vegetable, fruit and nut crops, cotton and nursery/floriculture crops (Texas CropMAP, 2003) (Appendix 1).

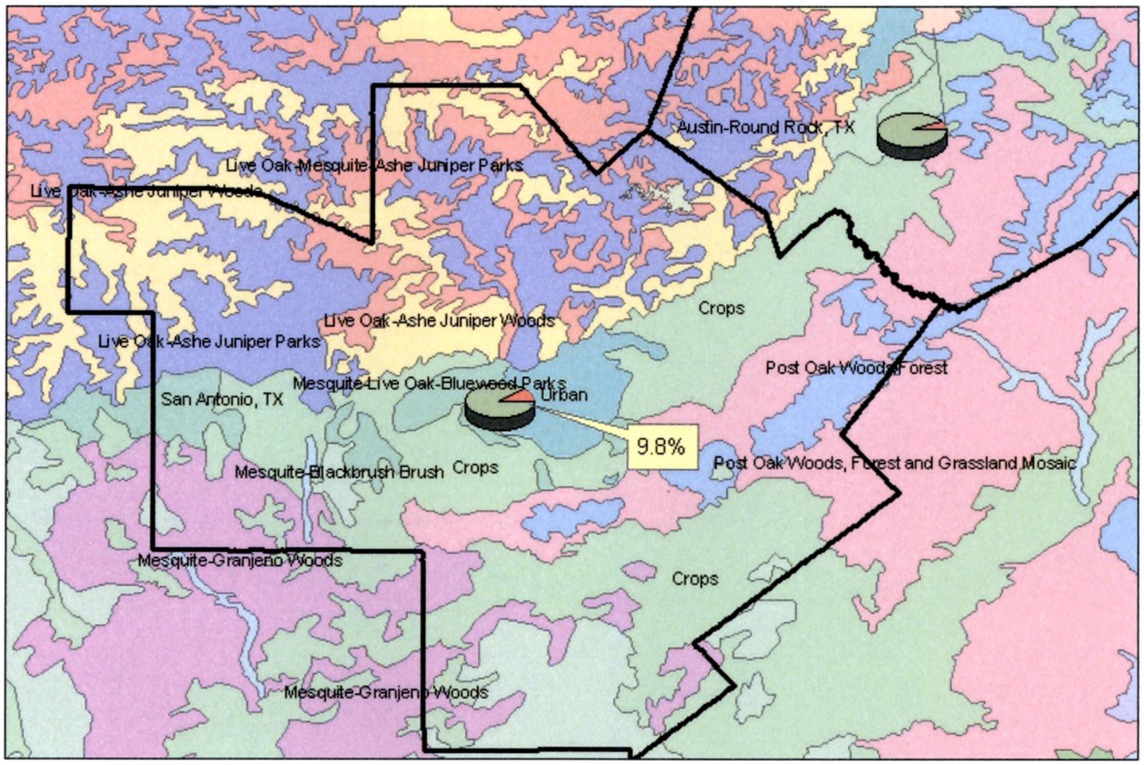

Figure 12. Native and cropland vegetative composition and childhood asthma rate for the San Antonio MSA (MSA outlined in black) in the study of the effect of tree cover and vegetation on incidence of childhood asthma in Metropolitan Statistical Areas of Texas.

Tyler and Longview asthma rates and vegetative cover

Tyler and Longview MSAs have the same geographic make-up, which includes smaller tracts of cropland dispersed among Pine (*Quercus spp.*)-Hardwood forests (Figure 13). Acres of crops found in these MSAs include hay and forage crops, a variety of vegetable, fruit and nut crops, nursery/floriculture crops, with only a small acreage devoted to the cereal crop of corn (Texas CropMAP, 2003) (Appendix 1). Despite similarities in geographic make-up, Longview's asthma rate at 8.8% is almost double that of Tyler, which has an asthma rate of 4.6%.

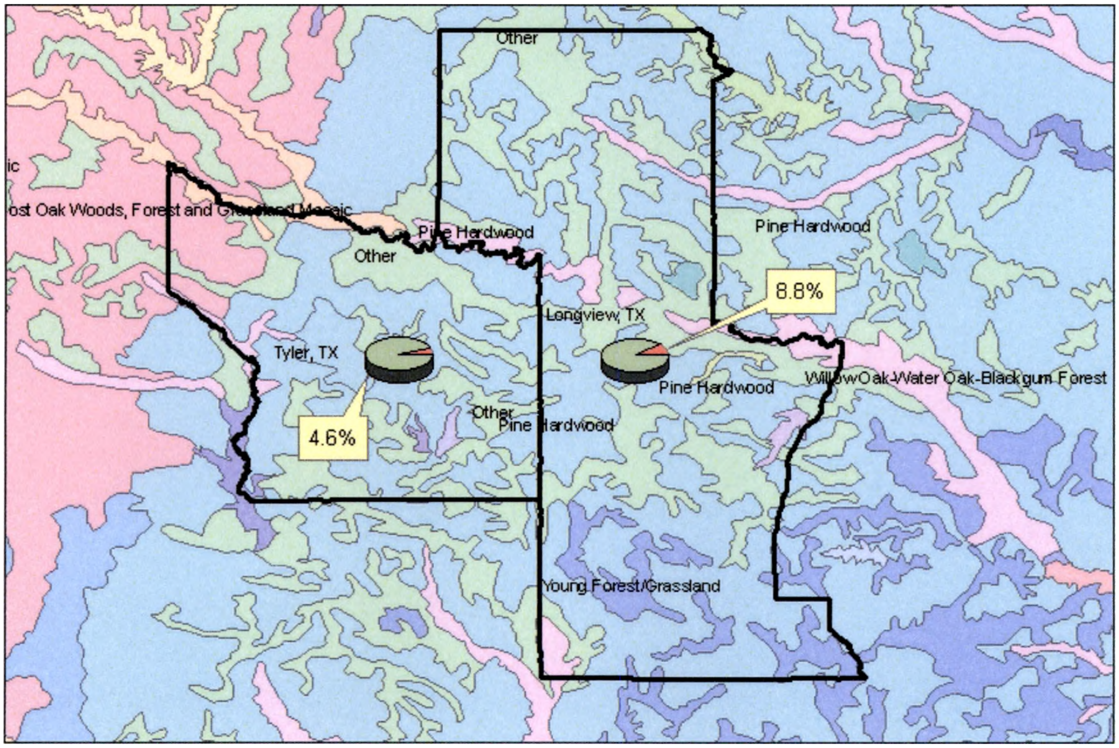

Figure 13. Native and cropland vegetative composition and childhood asthma rate for the Tyler MSA and the Longview MSA (MSAs outlined in black) in the study on the effect of tree cover and vegetation on incidence of childhood asthma in Metropolitan Statistical Areas of Texas.

<u>Findings Related to Objective Three</u>

The third objective of the study was to map the tree/vegetation cover for different Metropolitan Statistical Areas (MSAs) of Texas. Tree coverage/vegetation rates were examined for each MSA of Texas and were mapped for illustration using ArcView© 9.1 GIS (Redlands, CA) software.

To determine the information regarding percent vegetation/greenness for the Metropolitan Statistical Areas (MSAs) in this study, a normalized difference vegetation index (NDVI) was calculated from satellite imagery (Landsat) for each MSA. Landsat imagery contains the two bands (near infrared and red) required to calculate NDVI. This index is a simple numerical indicator used to analyze remote sensing measurements to determine the amount of green vegetation in the observed target. The resulting index range for this calculation is -1 to 1 (barren/non-vegetation to dense green vegetation, respectively).

The calculation is as follows (NIR = near infrared): NDVI = (NIR-Red)/(NIR + Red)

Landsat 5™ imagery was obtained from the United States Geological Survey (USGS) Glovis site (U.S. Department of the Interior, 2010). Image "tiles" were downloaded to cover the extent of all MSAs included in the study. Each "tile" covered an area of 185 km (115 mi) wide. In order to obtain an accurate NDVI for each MSA, the imagery must be high quality and as cloud free as possible. The images selected and used in the study were designated by USGS as having a cloud cover of 0% and an image quality of 9 out of 10 (Note that 0% cloud cover may still include isolated clouds.). The downloaded image tiles were for the months of April to July 2006 when possible. This timeframe ensured that vegetation would be present after winter dormancy conditions in the plants, and yet still be prior to summer heat and drought conditions that would affect greenness levels. The year 2006 was chosen in order to coincide with the dates of the collected asthma data. If data with the above criteria were not available, the next closest date to that (skipping dormant months) was acquired. Out of the 14 MSAs used in this study, the following three had image tiles that were pulled from either September or October of 2006: Dallas-Fort Worth-Arlington, Lubbock and Killeen-Temple-Fort Hood.

The tiles were then “mosaiced” or pieced together to create one seamless image for each MSA (Figures 14-26). “Mosaicing” merges adjacent tiles into one image file removing overlapping values between tiles. High NDVI values are represented by brighter pixels, whereas low NDVI values are represented by darker pixels. Brighter (white) pixels indicate vegetation and different shades of gray represent bare ground to vegetation, depending on the brightness of the pixel. The lighter grays are most likely vegetation whereas the darker grays will be bare ground. Black pixels represent water or cloud coverage.

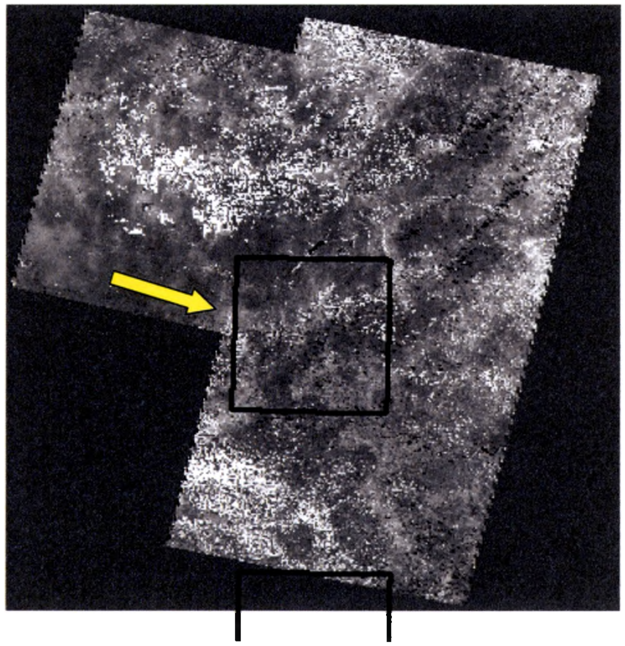

Figure 14. Satellite imagery of vegetative greenness for the Amarillo MSA (MSA outlined in black and indicated with arrow) in the study on the effect of tree cover and vegetation on incidence of childhood asthma in Metropolitan Statistical Areas of Texas.

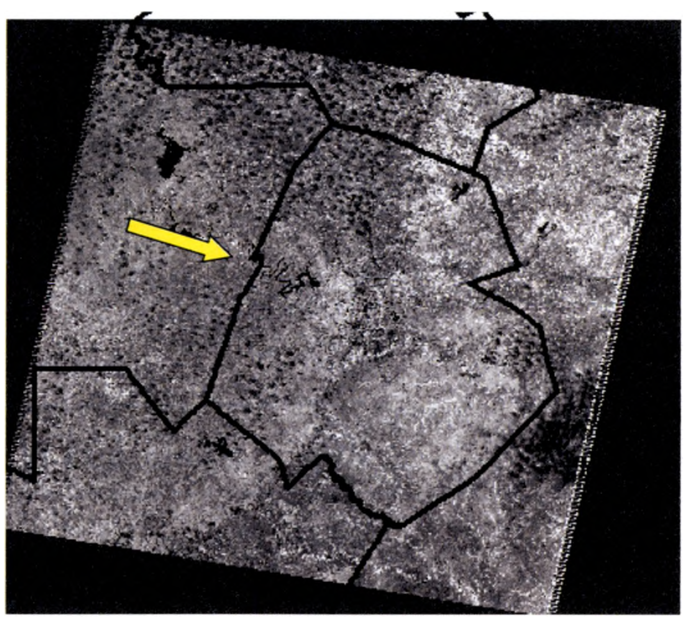

Figure 15. Satellite imagery of vegetative greenness for the Austin-Round Rock MSA (MSA outlined in black and indicated with arrow) in the study on the effect of tree cover and vegetation on incidence of childhood asthma in Metropolitan Statistical Areas of Texas.

Figure 16. Satellite imagery of vegetative greenness for the Beaumont-Port Arthur MSA (MSA outlined in black and indicated with arrow) in the study on the effect of tree cover and vegetation on incidence of childhood asthma in Metropolitan Statistical Areas of Texas.

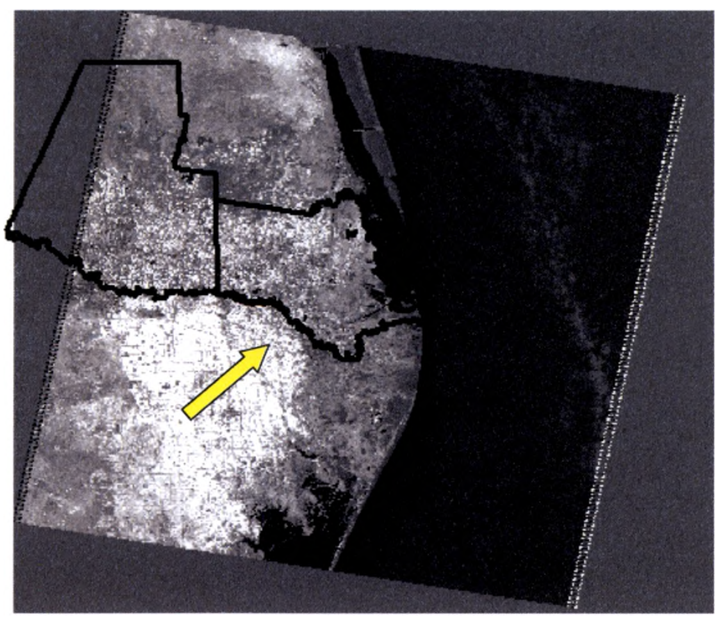

Figure 17. Satellite imagery of vegetative greenness for the Brownsville-Harlingen MSA (MSA outlined in black and indicated with arrow) in the study on the effect of tree cover and vegetation on incidence of childhood asthma in Metropolitan Statistical Areas of Texas.

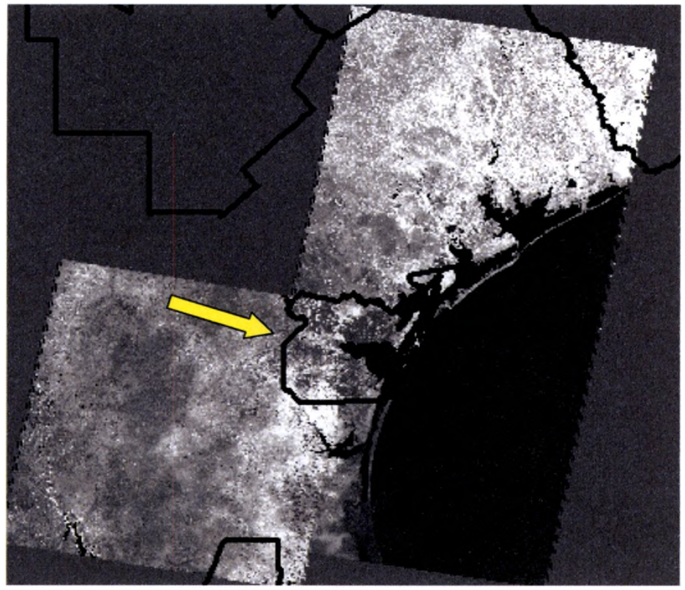

Figure 18. Satellite imagery of vegetative greenness for the Corpus Christi MSA (MSA outlined in black and indicated with arrow) in the study on the effect of tree cover and vegetation on incidence of childhood asthma in Metropolitan Statistical Areas of Texas.

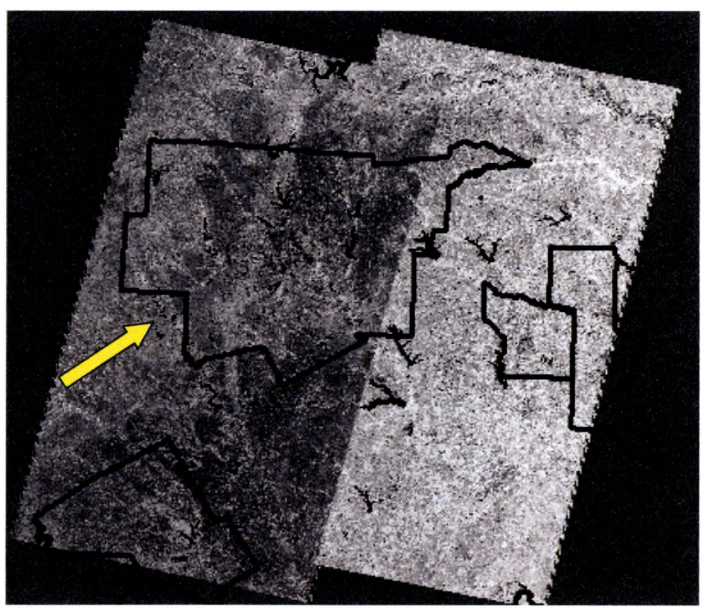

Figure 19. Satellite imagery of vegetative greenness for the Dallas-Fort Worth-Arlington MSA (MSA outlined in black and indicated with arrow) in the study on the effect of tree cover and vegetation on incidence of childhood asthma in Metropolitan Statistical Areas of Texas.

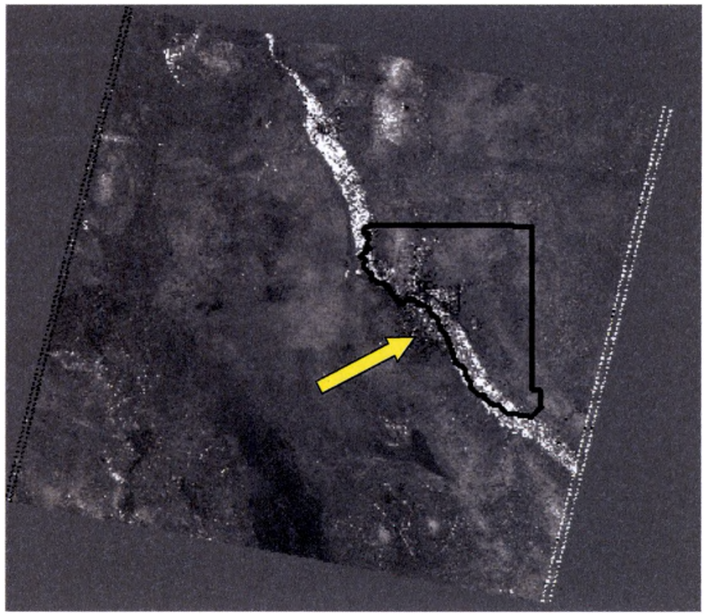

Figure 20. Satellite imagery of vegetative greenness for the El Paso MSA (MSA outlined in black and indicated with arrow) in the study on the effect of tree cover and vegetation on incidence of childhood asthma in Metropolitan Statistical Areas of Texas.

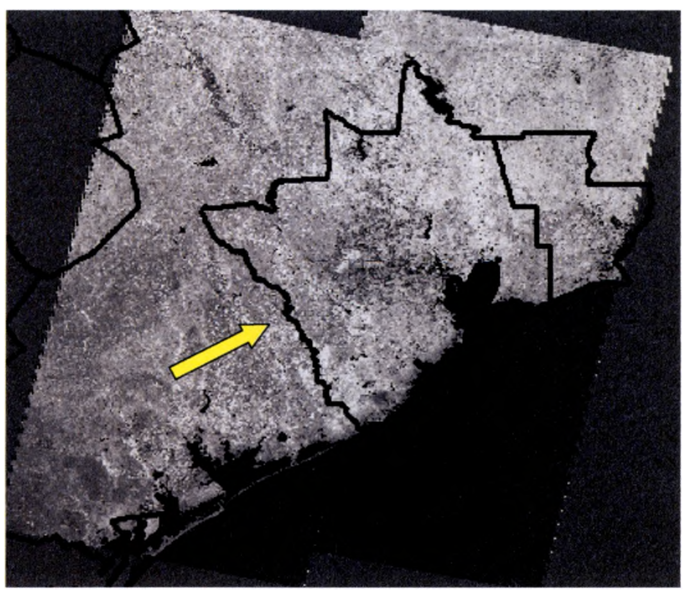

Figure 21. Satellite imagery of vegetative greenness for the Houston-Sugarland-Baytown MSA (MSA outlined in black and indicated with arrow) in the study on the effect of tree cover and vegetation on incidence of childhood asthma in Metropolitan Statistical Areas of Texas.

Figure 22. Satellite imagery of vegetative greenness for the Killeen-Temple-Fort Hood MSA (MSA outlined in black and indicated with arrow) in the study on the effect of tree cover and vegetation on incidence of childhood asthma in Metropolitan Statistical Areas of Texas.

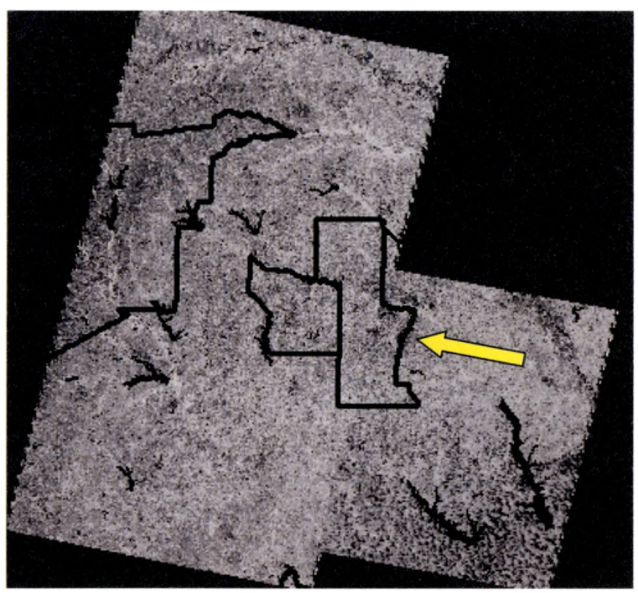

Figure 23. Satellite imagery of vegetative greenness for the Longview MSA in the study on the effect of tree cover and vegetation on incidence of childhood asthma in Metropolitan Statistical Areas of Texas.

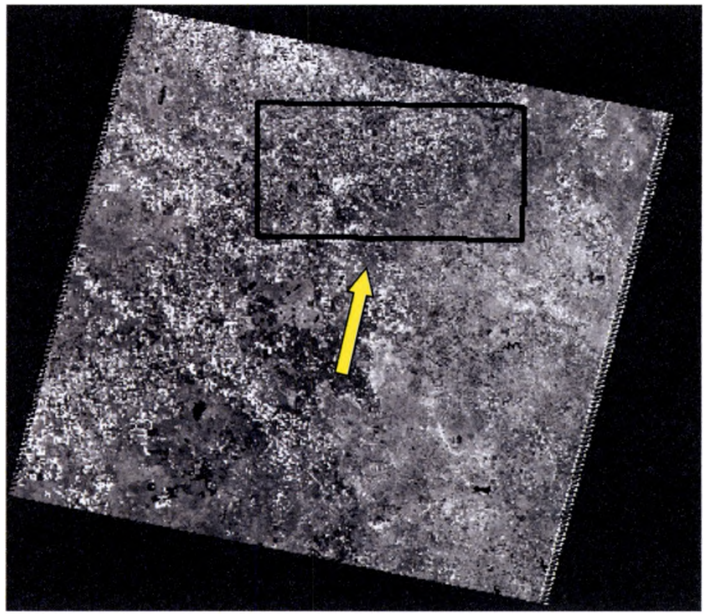

Figure 24. Satellite imagery of vegetative greenness for the Lubbock MSA (MSA outlined in black and indicated with arrow) in the study on the effect of tree cover and vegetation on incidence of childhood asthma in Metropolitan Statistical Areas of Texas.

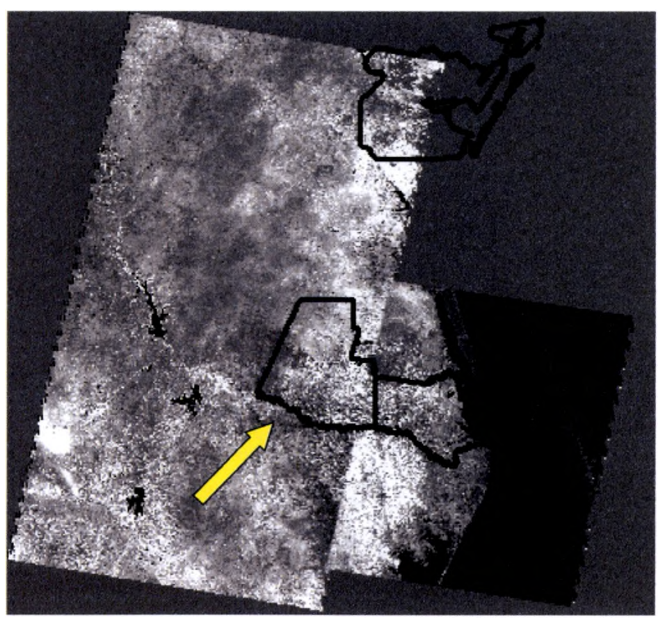

Figure 25. Satellite imagery of vegetative greenness for the McAllen-Edinburgh-Mission MSA (MSA outlined in black and indicated with arrow) in the study on the effect of tree cover and vegetation on incidence of childhood asthma in Metropolitan Statistical Areas of Texas.

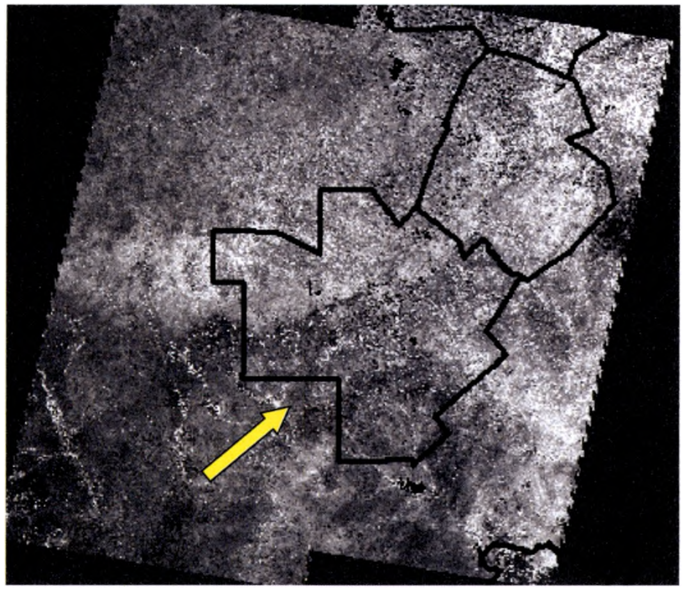

Figure 26. Satellite imagery of vegetative greenness for the San Antonio MSA (MSA outlined in black and indicated with arrow) in the study on the effect of tree cover and vegetation on incidence of childhood asthma in Metropolitan Statistical Areas of Texas.

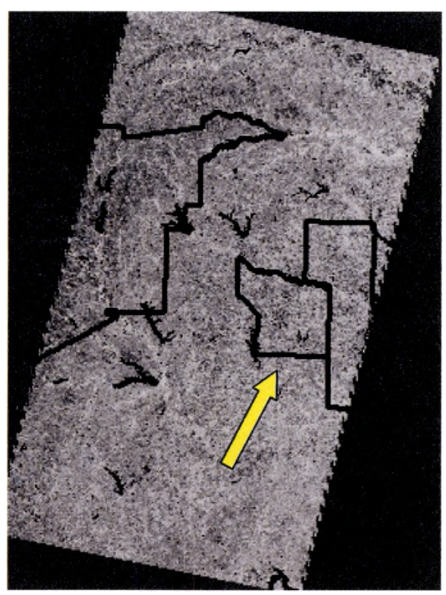

Figure 27. Satellite imagery of vegetative greenness for the Tyler MSA (MSA outlined in black and indicated with arrow) in the study on the effect of tree cover and vegetation on incidence of childhood asthma in Metropolitan Statistical Areas of Texas.

Findings Related to Objective Four

The fourth objective of the study was to estimate rates of filtration potential for differing vegetative covers in the Metropolitan Statistical Areas (MSAs) of Texas.

Calculating canopy cover

Percent canopy of woody vegetation was calculated for each MSA to determine what proportion of each MSA was herbaceous low groundcover vegetation versus that of woody plant materials such as trees and taller shrubs. Statistics were calculated for each MSA using the Multi-Resolution Land Characteristics (MRLC) National Land Cover Data canopy cover dataset (Table 2).

Table 2. Ranking of Metropolitan Statistical Areas (MSAs) in order of highest to lowest percent canopy cover[z] and total MSA acreage in the study of the effect of tree cover and vegetation on incidence of childhood asthma in Metropolitan Statistical Areas of Texas.

Ranking	MSA	Acres	Percent canopy[z]
1 – highest	Longview	1,159,916.6	45.31
2	Tyler	609,491.7	39.28
3	Beaumont-Port Arthur	1,457,562.6	34.83
4	Houston-Sugarland-Baytown	5,895,401.9	28.52
5	Austin-Round Rock	2,739,283.9	23.51
6	San Antonio	4,722,912.8	20.43
7	Killeen-Temple-Fort Hood	1,828,212.9	17.47
8	Dallas-Fort Worth-Arlington	5,943,136.1	9.71
9	Corpus Christi	1,142,613.3	6.67
10	Brownsville-Harlingen	602,397.6	3.66
11	McAllen-Edinburg-Mission	1,013,246.9	2.44
12	Amarillo	2,358,170.7	2.32
13	El Paso	656,445.2	0.38
14 – lowest	Lubbock	1,154,110.7	0.27

[z] Percent canopy was calculated using a normalized difference vegetation index calculated from satellite imagery (Landsat) to determine what proportion of each MSA was groundcover versus woody vegetation such as trees and shrubs.

The MSAs located in and around the Piney Woods natural region of East Texas had the highest rates of percent canopy cover. Longview had the highest percent canopy cover with 45.31%; Tyler MSA had 39.28% canopy cover and Beaumont-Port Arthur had 34.83% canopy cover (Table 2). The Piney Woods region of Texas vegetative composition is composed of pine-hardwood forests (*Pinus* spp.), with tracts of farmlands and pasture throughout (Diamond et al., 1987; Preserving Texas' Natural Heritage, 1978). The major dominating vegetative type in this area is evergreen pine (*Pinus* spp.) (Diamond et al., 1987; Preserving Texas' Natural Heritage, 1978).

The lowest percent canopy cover occurred in MSAs located in the furthest west region of Texas (El Paso) and the Texas Panhandle area (Lubbock and Amarillo). Covering most of the Texas panhandle, the High Plains region is relatively free of brush and is characterized by short grassland (Preserving Texas' Natural Heritage, 1978). Junipers (*Juniperus* spp.) have invaded and are now common to both the Rolling Plains and High Plains natural regions of Texas (Diamond et al., 1987). Lubbock had the lowest percent canopy cover at 0.27%; El Paso had just 0.38% and Amarillo, the third lowest, had 2.32% canopy cover (Table 2). El Paso MSA in west Texas is comprised of arid lands, desert grasslands and desert scrub/shrubland (Diamond et al., 1987; Preserving Texas' Natural Heritage, 1978).

<u>Calculating vegetative cover</u>

As stated in the methodology, the NDVI grid was transferred to ENVI™ (Redlands, CA) image processing software, where statistics were calculated for each MSA. Normalized difference vegetation index, or NDVI, was calculated from satellite imagery (Landsat) for each MSA. Landsat imagery contains the two bands (near infrared and red) required to calculate NDVI. This index is a simple numerical indicator used to analyze remote sensing measurements to determine the amount of green vegetation in the observed target. The resulting index range for this calculation is -1 to 1 (barren/non-vegetation to dense green vegetation, respectively). Descriptive statistics determined included minimum NDVI value, maximum NDVI value, and the average NDVI value for each MSA within the study (Table 3). The MSAs were listed in order from highest to lowest average NDVI value.

Table 3. Minimum, maximum and average normalized difference vegetation index (NDVI)[z] for Metropolitan Statistical Areas (MSA), ranked in order highest to lowest average NDVI, in the study of the effect of tree cover and vegetation on incidence of childhood asthma in Metropolitan Statistical Areas of Texas.

Ranking	MSA	MinNDVI	MaxNDVI	AvgNDVI
1 – highest	Longview	-0.488372	0.780488	0.530203
2	Tyler	-0.485149	0.786802	0.512377
3	Beaumont-Port Arthur	-0.654321	0.954023	0.447722
4	Houston-Sugarland-Baytown	-0.661972	0.824176	0.435199
5	Austin-Round Rock	-0.542857	0.719457	0.297422
6	Dallas-Fort Worth-Arlington	-0.987730	0.815385	0.255332
7	Lubbock	-0.542857	0.787709	0.246645
8	San Antonio	-0.975904	0.782609	0.242554
9	McAllen-Edinburg-Mission	-0.979798	0.769231	0.214654
10	Killeen-Temple-Fort Hood	-0.655172	0.740113	0.192114
11	Corpus Christi	-0.720930	0.752294	0.189288
12	Brownsville-Harlingen	-0.489362	0.729167	0.156736
13	Amarillo	-0.533333	0.790476	0.109435
14 – lowest	El Paso	-0.555556	0.758140	0.018904

[z] Normalized difference vegetation index, or NDVI, was calculated from satellite imagery (Landsat) for each MSA. Landsat imagery contains the two bands (near infrared and red) required to calculate NDVI. This index is a simple numerical indicator used to analyze remote sensing measurements to determine the amount of green vegetation in the observed target. The resulting index range for this calculation is -1 to 1 (barren/non-vegetation to dense green vegetation, respectively).

When comparing MSAs based on average NDVI, the top three locations for percent canopy were also the same top three for average NDVI. Longview MSA averaged 0.53 NDVI, while Tyler had a 0.51 average NDVI and the Beaumont-Port Arthur average NDVI value was 0.45 (Table 3). However, when looking at the MSAs with the lowest three average NDVI scores, there was some variation when compared to the percent canopy cover order. El Paso averaged the lowest rate of vegetation at 0.02, while Amarillo stood at 0.11. Previously, El Paso was 2nd lowest with respect to percent canopy, while Amarillo was 3rd lowest. Brownsville-Harlingen had the third lowest average NDVI score, at 0.16 (Table 3). The biggest difference between percent canopy and average NDVI was seen in the Lubbock MSA, which had the lowest percent canopy cover, but jumped to the 7th highest out of 14 MSAs, based on an average NDVI of 0.25 (Table 3). The reason for this was probably due to the fact that while Lubbock is lacking in heavy tree cover, the majority of the MSA is used for agricultural crops, which would have increased the vegetative NDVI index score.

Studies have shown that plants with greater leaf area, such as trees, act as better filters of pollution when compared to shrubs or grassland vegetation, which have less leaf area (Bolund and Hunhammar, 1999). Woodlands, or areas with greater tree cover, allow more room for air flow when compared to an area of thick or short vegetation such as grass or shrublands, giving woodland areas better filtering opportunities (Bolund and Hunhammar, 1999; Sieghardt et al., 5002).

Findings Related to Objective Five

The fifth objective of the study was to compare the asthma rates in different areas of Texas with the mapped tree and vegetation cover areas to determine if asthma rates were related to tree/vegetation coverage.

The calculated vegetative and tree cover data values for each MSA were compared to their corresponding percentage of childhood asthma from objective one. Upon first review, no clear corresponding orders were seen in rankings between the childhood asthma percentages and the corresponding percent canopy covers for each MSA (Table 4).

Table 4. Comparison of ranking of Metropolitan Statistical Areas (MSAs) for highest to lowest childhood asthma rate[z] and lowest to highest percent canopy[y] in the study on the effects of tree cover and vegetation on childhood asthma rates in regions of Texas.

Asthma ranking	MSA	Canopy ranking	MSA
1 – highest asthma	Amarillo	1- lowest canopy	Lubbock
2	San Antonio	2	El Paso
3	Dallas-Fort Worth-Arlington	3	Amarillo
4	Longview	4	McAllen-Edinburg-Mission
5	Corpus Christi	5	Brownsville-Harlingen
5	Houston-Sugarland-Baytown	6	Corpus Christi
6	Beaumont-Port Arthur	7	Dallas-Fort Worth-Arlington
7	Austin-Round Rock	8	Killeen-Temple-Fort Hood
8	El Paso	9	San Antonio
9	Lubbock	10	Austin-Round Rock
10	Tyler	11	Houston-Sugarland-Baytown
11	Brownsville-Harlingen	12	Beaumont-Port Arthur
12	McAllen-Edinburg-Mission	13	Tyler
13 – lowest asthma	Killeen-Temple-Fort Hood	14 – highest canopy	Longview

[z] Data on percentage of children with asthma was obtained from the Center for Health Statistics, Texas Department State Health Services for the years 2005-2006. The data were rounded to the next highest or lowest raw number based on the normalized percentage of children reported to have asthma in the overall population.

[y] Percent canopy was calculated using a normalized difference vegetation index calculated from satellite imagery (Landsat) to determine what proportion of each MSA was groundcover versus woody vegetation such as trees and shrubs.

However, it was noticed that the Amarillo MSA, which had the highest childhood asthma rate did, in fact, correspond with a lower canopy percent when compared to other MSAs. This made sense with regards to the literature that suggested plants with greater leaf area, such as trees, act as better filters of pollution when compared to shrubs or grassland vegetation, which have less leaf area (Bolund and Hunhammar, 1999). Amarillo is located mainly in the High Plains, and partially in the Rolling Plains regions of the Texas panhandle, both of which are characterized by dominant grassland vegetation and sparse woody vegetation when compared to other regions of Texas (Preserving Texas' Natural Heritage, 1978).

A mix of both evergreen and deciduous species would be the best solution for increased filtration of airborne pollutants, some of which can cause serious health problems (Bolund and Hunhammar, 2005; Tyrvainen et al., 2005). Therefore, it was surprising that both the Tyler and Longview MSAs, located in the Piney Woods region of Texas, which is characterized by pine-hardwood forests (Diamond et al., 1987; Preserving Texas' Natural Heritage, 1978) did not have lower childhood asthma rates considering the vegetation. This could be due to Tyler and Longview MSAs having a larger African-American population when compared to most other MSAs. This demographic group is known to have a higher incidence of asthma-related illness (The Texas Asthma Report, 2004).

The results for percent canopy within each MSA were used in conjunction with the corresponding NDVI results to further assess association.

<u>Percent canopy cover and childhood asthma rates</u>

A Pearson product-moment correlation analysis was performed to determine if percent canopy cover was associated with childhood asthma percentage. The analysis determined that there was no statistically significant relationship (P=0.993) between the variables of childhood asthma rate and percent canopy cover (Table 5).

Table 5. Results of a Pearson's product-moment correlation comparing the relationship between percent canopy[z] and childhood asthma percentage[y] in the study on the effects of tree cover and vegetation on childhood asthma rates in regions of Texas.

		Childhood Asthma rate
Percent canopy	Pearson Correlation	0.002
	P	0.993
	N	14

[z] Percent canopy was calculated using a normalized difference vegetation index calculated from satellite imagery (Landsat) to determine what proportion of each MSA was groundcover versus woody vegetation such as trees and shrubs.

[y] Data on percentage of children with asthma were obtained from the Center for Health Statistics, Texas Department State Health Services for the years 2005-2006. The data were rounded to the next highest or lowest raw number based on the normalized percentage of children reported to have asthma in the overall population.

Literature from previous research has stated that urban areas should set out to achieve a goal of 40% overall tree cover to improve the quality of air, water and soil (Moll, 1997). However, Longview was the only MSA that had a percent canopy cover above 40%, and yet its childhood asthma rate ranking was the 4th highest of the 14 MSAs used in this study. When looking at MSAs with respect to lower percent canopy and childhood asthma rates, both the Brownsville-Harlingen and McAllen-Edinburg-Mission MSAs had a percent canopy cover that fell well below 5%, and yet still had two of the lowest three childhood asthma rates of all 14 MSAs used in this study.

According to the literature, the leaves of trees can take up pollutants such as ozone, nitrogen dioxide, ammonia, sulfur dioxide and particles such as aerosols and dust, some of which can cause serious health problems (Tyrvainen et al., 2005). These pollutants can cause a direct irritant effect of the respiratory airways, which aggravates existing asthma (Elsom, 1996).

The ability of pollution-tolerant tree species to remove particulates from the air make them excellent management tools for improving air quality, especially when planted in urban settings (Beckett et al., 1998; Farmer, 2002). However, statistical results were nonsignificant regarding the relationship between tree cover and childhood asthma rate.

NDVI and childhood asthma rates

Pearson product-moment and Spearman's rho correlation analyses were conducted to investigate the relationship between minimum NDVI, maximum NDVI and/or average NDVI with childhood asthma percentage. The analyses determined no statistically significant relationships between minimum NDVI (*P*=0.557), maximum NDVI (*P*=0.076) or average NDVI (*P*=0.866) and childhood asthma percentage (Table 6).

Table 6. Results of correlation analyses of association between minimum NDVI[z], maximum NDVI[z] and average NDVI[z] and childhood asthma percentage[y] in the study on the effects of tree cover and vegetation on childhood asthma rates in regions of Texas.

		Childhood Asthma rate
Minimum NDVI	Spearman correlation	-0.172
	P	0.557
	N	14
Maximum NDVI	Spearman correlation	0.489
	P	0.076
	N	14
Average NDVI	Pearson correlation	-0.050
	P	0.866
	N	14

[z] Normalized difference vegetation index, or NDVI, was calculated from satellite imagery (Landsat) for each MSA. Landsat imagery contains the two bands (near infrared and red) required to calculate NDVI. This index is a simple numerical indicator used to analyze remote sensing measurements to determine the amount of green vegetation in the observed target. The resulting index range for this calculation is -1 to 1 (barren/non-vegetation to dense green vegetation, respectively).

[y] Data on percentage of children with asthma were obtained from the Center for Health Statistics, Texas Department State Health Services for the years 2005-2006. The data were rounded to the next highest or lowest raw number based on the normalized percentage of children reported to have asthma in the overall population.

Given that both woody and herbaceous vegetation have the ability to remove gaseous pollutants from the outdoor environment (Akbari, 2002; Sieghardt et al., 2005), and that those same types of pollutants are known to irritate the respiratory airways and aggravate existing asthma (Elsom, 1996), this finding was surprising.

A Spearman's rho correlation was performed to analyze the relationship between low, middle and high average NDVI scores and childhood asthma rates within the 14 MSAs (Table 7). Low average NDVI scores ranged from 0.00-0.19, while middle average NDVI scores ranged from 0.20-0.30 and high average NDVI scores were 0.31 and higher (Salim et al., 2008). The analysis determined that there was no relationship between groups of low, middle and high average NDVI scores (*P*=0.591) and childhood asthma percentage (Table 7).

Table 7. Results of Spearman's Rho correlation analysis of association between low[z], middle[z] and high[z] average NDVI[y] scores and childhood asthma percentage[x] in the study on the effects of tree cover and vegetation on childhood asthma rates in regions of Texas.

Average NDVI ranking	MSA	Avg. NDVI[z] score		Childhood asthma
Low	El Paso	0.018904	Spearman correlation	0.158
	Amarillo	0.109435	*P*	0.591
	Brownsville-Harlingen	0.156736	N	14
	Corpus Christi	0.189288		
	Killeen-Temple-Fort Hood	0.192114		
Middle	McAllen-Edinburg-Mission	0.214654		
	San Antonio	0.242554		
	Lubbock	0.246645		
	Dallas-Fort Worth-Arlington	0.255332		
	Austin-Round Rock	0.297422		
High	Houston-Sugarland-Baytown	0.435199		
	Beaumont-Port Arthur	0.447722		
	Tyler	0.512377		
	Longview	0.530203		

[z] Low average NDVI scores ranged from 0.00-0.19, while mid average NDVI scores ranged from 0.20-0.39 and high average NDVI scores were 0.40 and higher.

[y] Normalized difference vegetation index, or NDVI, was calculated from satellite imagery (Landsat) for each MSA. Landsat imagery contains the two bands (near infrared and red) required to calculate NDVI. This index is a simple numerical indicator used to analyze remote sensing measurements to determine the amount of green vegetation in the observed target. The resulting index range for this calculation is -1 to 1 (barren/non-vegetation to dense green vegetation, respectively).

[x] Data on percentage of children with asthma were obtained from the Center for Health Statistics, Texas Department State Health Services for the years 2005-2006. The data were rounded to the next highest or lowest raw number based on the normalized percentage of children reported to have asthma in the overall population.

Demographic considerations and childhood asthma rates

Because population demographics are known to influence asthma rates, the overall population for each MSA, along with the corresponding breakdown of ethnic population percentage and childhood asthma rate was put into table form for comparison (Table 8).

Table 8. Demographic breakdown, including overall population and percent ethnicity, and childhood asthma rate for each Metropolitan Statistical Area (MSA) included in the study on the effects of tree cover and vegetation on childhood asthma rates in regions of Texas.

MSA	Population	% Caucasian	% African American	% Asian	% Hispanic (of any race)	Childhood asthma rate
El Paso	734,669	73.9	3.1	1.0	78.2	6.3
Amarillo	242,240	79.1	5.9	1.8	19.6	15
Lubbock	267,211	74.3	7.7	1.3	27.5	5.7
Dallas- Fort Worth- Arlington	6,145,037	70.8	18.2	3.6	20.6	9.0
Tyler	198,705	72.6	19.1	0.7	11.2	4.6
Longview	203,611	74.6	19.5	0.5	7.1	8.8
Killeen- Temple- Fort Hood	370,008	64.4	21.1	2.2	14.7	3.1
Austin- Round Rock	1,598,161	72.5	8.0	3.5	26.2	6.8
San Antonio	1,990,675	70.6	6.6	1.5	51.2	9.8
Houston- Sugarland- Bay Town	5,628,101	69.5	14.1	3.1	24.6	8.5
Beaumont- Port Arthur	376,241	68.2	24.8	2.1	8.0	7.1

Table 8 cont.

Corpus Christi	**414,376**	**72.9**	**4.0**	**1.1**	**54.7**	**8.5**
McAllen-Edinburg- Mission	**710,514**	**77.7**	**0.5**	**0.6**	**88.3**	**3.7**
Brownsville-Harlingen	**387,210**	**80.3**	**0.5**	**0.5**	**84.3**	**3.7**

Based on the literature, asthma incidence patterns vary by region due to the influence of differences in population demographics (Akinbami, 2006.) The Texas Asthma Report for the years 1999-2003 stated that African American, non-Hispanic Texans were hospitalized with asthma more often when compared to Caucasian, non-Hispanic and Hispanic Texans. In 2006, the Centers for Disease Control published a press release stating that Puerto Rican and non-Hispanic African American children had the highest percentages of asthma (Akinbami, 2006).

A Spearman's correlation analysis was conducted to make comparisons between demographic groups and percent canopy cover within the regions of interest, this analysis determined there were statistically significant relationships with regards to percent canopy cover and the demographics groups of African Americans (P = 0.004) and Hispanics (P = 0.008). The top four highest African American populations (above 19%), a demographic known to be more prone to asthma in children (Akinbami, 2006), were seen in the Tyler, Longview, Killeen-Temple-Fort Hood and Beaumont-Port Arthur MSAs. Of those 4, the Longview, Tyler and Beaumont-Port Arthur MSAs had the highest percent canopy of all 14 MSAs. Larger Hispanic populations (above 70%), a demographic group known to be less susceptible to asthma occurrence (Texas Asthma Report, 2004), were seen in the El Paso, McAllen-Edinburg-Mission and Brownsville-Harlingen MSAs, which all had lower percent canopy when compared to other MSAs.

Therefore, a partial correlation analysis was run to control for the impact of demographics on childhood asthma percentage in each MSA. The controlled demographic variable was ethnicity, including Caucasian, African American, Asian and Hispanic (of any race). Correlations were conducted in order to look for relationships between percent canopy cover, minimum NDVI, maximum NDVI, average NDVI and childhood asthma rates. No statistically significant relationships were found between any of the variables of interest even when influences of ethnic background of MSAs were considered (Table 9).

Table 9. Results of a partial correlation analysis comparing percent canopy[z], minimum NDVI[y], maximum NDVI, average NDVI and asthma rates[x] while controlling for the impact of the demographic variable of ethnicity on childhood asthma percentage in the study on the effects of tree cover and vegetation on childhood asthma rates in regions of Texas.

Control variables Caucasian, African American, Asian and Hispanic (of any race)	Variables of interest	Correlation	df	*P*
	Percent canopy	0.026	8	0.943
	Minimum NDVI	-0.428	8	0.218
	Maximum NDVI	0.472	8	0.168
	Average NDVI	-0.184	8	0.611

[z] Percent canopy was calculated using a normalized difference vegetation index calculated from satellite imagery (Landsat) to determine what proportion of each MSA was groundcover versus woody vegetation such as trees and shrubs.

[y] Normalized difference vegetation index, or NDVI, was calculated from satellite imagery (Landsat) for each MSA. Landsat imagery contains the two bands (near infrared and red) required to calculate NDVI. This index is a simple numerical indicator used to analyze remote sensing measurements to determine the amount of green vegetation in the observed target. The resulting index range for this calculation is -1 to 1 (barren/non-vegetation to dense green vegetation, respectively).

[x] Data on percentage of children with asthma were obtained from the Center for Health Statistics, Texas Department State Health Services for the years 2005-2006. The data were rounded to the next highest or lowest raw number based on the normalized percentage of children reported to have asthma in the overall population.

Therefore, despite removing the influence of ethnic background in MSAs like Tyler and Longview that have a larger African-American population when compared to most other MSAs, no statistically significant relationships were seen between asthma rates and percent canopy cover, minimum, maximum and average NDVI.

Population size and childhood asthma rates in MSAs

According to the literature, concrete and other impenetrable surfaces, as well as high levels of fossil fuel combustion, generate more heat in urban areas and lead to larger increases in air pollution in comparison to their rural surroundings that have more vegetative coverage (Kollin, 2003; Nowak, 2000). Jaggi (2005) stated that urbanization was correlated with an increase in the prevalence of asthma in some populations. Because urban heat islands have been known to influence variables that are associated with asthma, MSAs were grouped into 3 different metropolitan size categories based on population size (Table 10). Population categories were as follows: large MSAs – 750,000 or more people; medium MSAs – 300,000 to 749,000 people; small MSAs – 200,000 to 299,000 people (U.S. Census, 2008).

Table 10. Large, medium or small[z] metropolitan size classification for each Metropolitan Statistical Area (MSA) included in the study on the effects of tree cover and vegetation on childhood asthma rates in regions of Texas.

MSA	Population
Large metropolitan size[z]	
Dallas-Fort Worth-Arlington	6,300,006
Houston-Sugar Land-Baytown	5,728,143
San Antonio	2,031,445
Austin-Round Rock	1,652,602
Medium metropolitan size[z]	
El Paso	742,062
McAllen-Edinburg-Mission	726,604
Corpus Christi	415,376
Brownsville-Harlingen	392,736

Table 10 cont.

Killeen-Temple-Fort Hood	378,935
Beaumont-Port Arthur	378,225
Small metropolitan size[z]	
Lubbock	270,610
Amarillo	243,838
Longview	204,746
Tyler	201,277

[z] Population categories were broken down as follows:
large MSAs – 750,000 or more people;
medium MSAs – 300,000 to 749,000 people;
small MSAs – 200,000 to 299,000 people
(US Census, 2008).

Based on the population divisions determined, large, medium and small metropolitan areas were compared by size categories using a regression analysis to determine if percent canopy, minimum NDVI, maximum NDVI and/or average NDVI were predictors of childhood asthma percentage/prevalence (Table 11).

Regression analyses performed for large metropolitan MSAs determined that percent canopy (P=0.650), minimum NDVI (P=0.110), maximum NDVI (P=0.316) and average NDVI (P=0.722) were not indicators of childhood asthma percentage when childhood asthma percentage was the dependent variable in cities with populations of 750,000 or more people (Table 11).

Regression analyses performed for medium metropolitan MSAs determined that percent canopy (P=0.698), minimum NDVI (P=0.875), maximum NDVI (P=0.414) and average NDVI (P=0.718) were not predictors of childhood asthma rates in cities with populations of 300,000 to 749,000 people (Table 11).

Regression analyses performed for small metropolitan MSAs determined that percent canopy (P=0.618), minimum NDVI (P=0.642), maximum NDVI (P=0.670) and average NDVI (P=0.358) were not indicators of childhood asthma rates when childhood asthma rates was the dependent variable in cities with populations of 200,000 to 299,000 people (Table 11).

Table 11. Results of a linear regression analysis using percent canopy^z, minimum normalized difference vegetation index (NDVI)^y, maximum NDVI^y, average NDVI^y as predictors and childhood asthma percentage^x as the dependent variable while controlling for the impact of large^w, medium^v and small^u metropolitan populations on childhood asthma percentage in the study on the effects of tree cover and vegetation on childhood asthma rates in regions of Texas.

Percent canopy^z/childhood asthma percentage^x/large MSAs^w	**df**	**Mean square**	**R^2**	**B**	**F**	***P***
Regression	1	0.593	0.077	-0.056	0.280	0.650
Residual	2	2.117				
Total	3					
Minimum NDVI^y/childhood asthma percentage^x/large MSAs^w						
Regression	1	3.827	0.793	-5.033	7.651	0.110
Residual	2	0.500				
Total	3					
Maximum NDVI^y/childhood asthma percentage^x/large MSAs^w						
Regression	1	2.255	0.467	18.267	1.754	0.316
Residual	2	1.286				
Total	3					
Average NDVI^y/childhood asthma percentage^x/large MSAs^w						
Regression	1	0.374	0.077	-4.000	0.168	0.722
Residual	2	2.227				
Total	3					
Percent canopy^z/childhood asthma percentage^x/medium MSAs^v						
Regression	1	1.014	0.042	0.034	0.174	0.698
Residual	4	5.841				
Total	5					
Minimum NDVI^y/childhood asthma percentage^x/medium MSAs^v						
Regression	1	0.171	0.007	1.088	0.028	0.875
Residual	4	6.052				
Total	5					
Maximum NDVI^y/childhood asthma percentage^x/medium MSAs^v						
Regression	1	4.186	0.172	10.823	0.829	0.414
Residual	4	5.049				
Total	5					

Table 11 cont.

Average NDVI[y]/childhood asthma percentage[x]/medium MSAs[v]						
Regression	1	0.883	0.036	3.027	0.150	0.718
Residual	4	5.874				
Total	5					
Percent canopy[z]/childhood asthma percentage[x]/small MSAs[u]						
Regression	1	9.548	0.146	-0.075	0.342	0.618
Residual	2	27.920				
Total	3					
Minimum NDVI[y]/childhood asthma percentage[x]/small MSAs[u]						
Regression	1	8.361	0.128	-55.795	0.293	0.642
Residual	2	28.513				
Total	3					
Maximum NDVI[y]/childhood asthma percentage[x]/small MSAs[u]						
Regression	1	7.109	0.109	364.740	0.244	0.670
Residual	2	29.139				
Total	3					
Average NDVI[y]/childhood asthma percentage[x]/small MSAs[u]						
Regression	1	26.966	0.412	-14.549	1.404	0.358
Residual	2	19.211				
Total	3					

[z] Percent canopy was calculated using a normalized difference vegetation index calculated from satellite imagery (Landsat) to determine what proportion of each MSA was groundcover versus woody vegetation such as trees and shrubs.

[y] Normalized difference vegetation index, or NDVI, was calculated from satellite imagery (Landsat) for each MSA. Landsat imagery contains the two bands (near infrared and red) required to calculate NDVI. This index is a simple numerical indicator used to analyze remote sensing measurements to determine the amount of green vegetation in the observed target. The resulting index range for this calculation is -1 to 1 (barren/non-vegetation to dense green vegetation, respectively).

[x] Data on percentage of children with asthma were obtained from the Center for Health Statistics, Texas Department State Health Services for the years 2005-2006. The data were rounded to the next highest or lowest raw number based on the normalized percentage of children reported to have asthma in the overall population.

[w] MSAs included in large classification include: Dallas-Fort Worth-Arlington, Houston-Sugar Land-Baytown, San Antonio and Austin-Round Rock

[v] MSAs included in medium classification include: El Paso, McAllen-Edinburg-Mission, Corpus Christi, Brownsville-Harlingen, Killeen-Temple-Fort Hood, Beaumont-Port Arthur.

[u] MSAs included in small classification include: Lubbock, Amarillo, Longview and Tyler.

Although the review of literature found that urbanization seemed to be correlated with an increase in the prevalence of asthma in some populations (Jaggi, 2005), and that concrete and higher levels of fossil fuel combustion generated more heat in urban areas leading to larger increases in air pollution in comparison to their rural surroundings that have more vegetative coverage (Kollin, 2003; Nowak, 2000), control for large versus smaller urban metropolitan population size did not reveal any statistical relationships between vegetation levels and childhood asthma rates.

CHAPTER V

SUMMARY, CONCLUSIONS, RECOMMENDATIONS

Purpose of the Study

The purpose of this study was to determine if childhood asthma rates in Metropolitan Statistical Areas of Texas are related to tree cover in Metropolitan Statistical Areas of Texas. Specific steps for this study included:

1) Collecting published data on childhood asthma rates in different Metropolitan Statistical Areas of Texas.
2) Mapping rates of childhood asthma in different Metropolitan Statistical Areas of Texas.
3) Mapping the tree/vegetation cover for different Metropolitan Statistical Areas of Texas.
4) Estimating rates of filtration potential for differing vegetative covers in Metropolitan Statistical Areas of Texas.
5) Comparing the asthma rates in different areas of Texas with the mapped tree and vegetation cover areas to determine if asthma rates were related to tree/vegetation coverage.

Summary of the Review of Literature

Asthma is a common and chronic inflammatory condition of the airways that can lead to wheezing, shortness of breath and coughing in individuals (Elsom, 1996; Williams, 2005). Childhood asthma is the most common chronic disease in children (Asthma Sourcebook, 2006; O'Connell, 2004), and a 2001 survey indicated that 6.3 million or 8.7% of U.S. children had asthma (Akinbami, 2006; Woodruff et al., 2003). It is believed that children's asthma is more severe when compared to that of their adult counterparts because airways grow larger as one matures, so inflammation does not obstruct the airways as easily in adulthood (Edelman, 1997). It is estimated that 75% of children who are affected by asthma will continue to suffer asthma symptoms into adulthood (Sommers et al., 2007).

Asthma incidence patterns vary by region due to differences in population demographics (Akinbami, 2006.) The Texas Asthma Report analyzed data from 1999-2003 and reported the following: (1)African American, non-Hispanic Texans were hospitalized with asthma more often when compared to Caucasian, non-Hispanic and Hispanic Texans; (2)Asthma hospitalizations were highest in children under the age of 5 years old; (3)In children ages 14 years and younger, asthma hospitalizations were higher for boys than girls; (4)In ages 15 years and above, the hospitalization rate was higher in women than men. Additionally, asthma is more common in persons living in cities when compared to persons living in suburban and rural areas (Asthma Sourcebook, 2006).

The cause of asthma is not completely known, and a combination of host and environmental factors appear to be involved with the development and trigger factors of asthma (Thurston and Ito, 1999; Tunnicliffe and Ayres, 2001). Environmental elements such as tobacco smoke, pet dander, dust mites and cockroaches all contribute to asthma irritation and asthma severity in the indoor environment (Edelman, 1997; Lara et al., 2001). Outdoor air pollution is also known to trigger asthma symptoms in both children and adults (Walling, 2002; Woodruff et al., 2003). Numerous time-series studies of hospital admissions and emergency visits have suggested a connection between particulate air pollution and asthma attacks (Dockery and Pope, 1996). Neidell (2004) reported that ozone, nitrogen dioxide and particulate matter air pollutants have a positive correlation with asthma in children. Additionally, studies of children with asthma at summer camps found that air pollution, particularly ozone, was significantly and consistently correlated with acute asthma exacerbations, chest symptoms and lung function decrements (Thurston and Ito, 1999).

Carbon dioxide concentrations in the atmosphere have risen dramatically over the past 200 years due to the burning of fuels and forests (Petit et al., 1998). The increase of carbon in the atmosphere is directly related to smog formation in urban areas, heat-island effects in cities and respiratory problems in urban citizens because smog traps heat and particulate pollution, which all result in discomfort and illness in humans (Petit et al., 1998). Jaggi (2005) stated that urbanization seemed to be correlated with an increase in the prevalence of asthma in some populations.

Trees help moderate the heat island problem by trapping and storing carbon from the atmosphere, with mature trees each absorbing more than 25 pounds of carbon per year for storage as wood and leafy material and releasing about 13 pounds of oxygen in the process (Nowak et al., 2002; Petit et al., 1998). Leaves of trees can take up pollutants such as ozone, nitrogen dioxide, ammonia, sulfur dioxide and particles such as aerosols and dust, some of which can cause serious health problems (Tyrvainen et al., 2005). Trees remove airborne dust and chemical or particulate matter from the air where it is then stored on leaves, twigs and trunks until it is washed to the ground by rain (Beckett et al., 1998; Petit et al., 1998; Trowbridge and Bassuk, 2004). Vegetation captures particulate matter on leaf surfaces where it can stay trapped until washed away by precipitation (Sieghardt et al., 2005). Both trees and herbaceous vegetation can directly absorb gaseous pollutants through stomata openings in their leaves (Akbari, 2002; Sieghardt et al., 2005).

The ability of pollution-tolerant tree species to remove particulates from the air make them excellent management tools for improving air quality, especially when planted in urban settings (Beckett et al., 1998; Farmer, 2002). Increasing urban vegetation in U.S. metropolitan areas that typically have pronounced heat islands could reduce air pollution associated with health problems and lower temperatures in the city (Akbari, 2002). American Forests published a report that urban areas should set out to achieve a goal of 40% overall tree cover to improve the quality of air, water and soil (Moll, 1997).

Texas has a wide variety of climate and geography conditions across the state, which leads to a wide variety in native vegetation across its natural regions (Diamond et al., 1987). Classifications of different vegetative communities that occur across the state include forests, woodlands, shrublands, herbaceous vegetation, swamps and marshes (Diamond et al., 1987).

Methodology

Metropolitan statistical areas of Texas

The state of Texas has been divided into 25 different Metropolitan Statistical Areas (MSAs) for the purposes of demographic and statistical analyses by various departments and organizations in Texas (Labor Market and Career Information Department of the Texas Workforce Commission, Real Estate Center at Texas A&M University, 2006). Each MSA is comprised of a county or group of counties with a population of at least 75,000 inhabitants and contains a central city or urbanized area of at least 50,000 people (Labor Market and Career Information Department, 2006). Metropolitan Statistical Areas, or MSAs, include the following regions: Abilene, Amarillo, Austin-Round Rock, Beaumont-Port Arthur, Brownsville-Harlingen, College Station-Bryan, Corpus Christi, Dallas-Fort Worth-Arlington, El Paso, Houston-Sugarland-Baytown, Killeen-Temple-Fort Hood, Laredo, Longview, Lubbock, McAllen-Edinburg-Mission, Midland, Odessa, San Angelo, San Antonio, Sherman-Dension, Texarkana, Tyler, Victoria, Waco and Wichita Falls.

Childhood asthma data collection

Children's asthma data were collected from the Center for Health Statistics, Texas Department State Health Services for the years 2005-2006 (Vincent, 2008). For this study, childhood asthma data was available and collected for all counties in Texas with reported populations of 50 or more children having asthma (Vincent, 2008). In order to determine the sample, adult respondents needed to provide a valid response of "yes" or "no" to the two questions concerning a select child under the age of 17 living in their household (Cook, 2010). The questions asked were as follows: "Has a physician/medical care provider ever told you that this child has asthma?" and "Does this child still have asthma?" (Texas Department of State Health Services, 2008). Adults who answered "yes" to the two questions on a survey concerning a select child under the age of 17 in their household were considered the asthma sample (Texas Department of State Health Services, 2008). In order to normalize the sample to the general population in Texas, the asthma sample was weighted in calculating the percentage of children with asthma (Cook, 2010).

The asthma data collected was then compared to the 25 Metropolitan Statistical Areas of Texas to see the areas they corresponded to (Pimpler, 2008). Of the 25 MSAs, data on childhood asthma rates corresponded with the following 14: Amarillo, Austin-Round Rock, Beaumont-Port Arthur, Brownsville-Harlingen, Corpus Christi, Dallas-Fort Worth-Arlington, El Paso, Houstoo9n-Sugarland-Baytown, Killeen-Temple-Fort Hood, Longview, Lubbock, McAllen-Edinburg-Mission, San Antonio and Tyler. Therefore, these 14 MSAs were included in the study. The remaining 11 MSAs were dropped because they included counties with a sample size of less than 50 children reported with asthma and, therefore, data was not available from the reporting agency (Vincent, 2008).

<u>Mapping of asthma data with corresponding vegetative cover</u>

The data files containing values for childhood asthma occurrence for various MSAs along with vegetation coverage in the state of Texas were sent to GeoSpatial Training Services™ in San Antonio, Texas. The asthma rate for each MSA was graphed in pie chart form and inserted into a corresponding vegetation map for that particular MSA using ArcView© 9.1 GIS (Redlands, CA) software.

Tree coverage/vegetation rates were examined for each MSA of Texas and were mapped for illustration using ArcView© 9.1 GIS (Redlands, CA) software. To determine the value of percent vegetation/greenness for the Metropolitan Statistical Areas (MSAs) in this study, a normalized difference vegetation index (NDVI) was calculated from satellite imagery (Landsat) for each MSA. Landsat imagery contains the two bands (near infrared and red) required to calculate NDVI. This index is a simple numerical indicator used to analyze remote sensing measurements to determine the amount of green vegetation in the observed target. The resulting index range for this calculation is -1 to 1 (barren/non-vegetation to dense green vegetation, respectively).

The calculation is as follows (NIR = near infrared): NDVI = (NIR-Red)/(NIR + Red)

Landsat 5^{TM} imagery was obtained from United States Geological Survey (USGS) Glovis site (U.S. Department of the Interior, 2010). Image "tiles" were downloaded to cover the extent of all MSAs included in the study. Each "tile" covered an area of 185 km (115 mi) wide. In order to obtain an accurate NDVI for each MSA, the imagery must be high quality and as cloud free as possible. The images selected and used in the study were designated by USGS as having a cloud cover of 0% and an image quality of 9 out of 10. (Note that 0% cloud cover may still include isolated clouds.) The downloaded image tiles were collected for the months of April to July 2006 when possible. This ensured that vegetation would be present after winter dormancy conditions in the plants, and yet still be prior to summer heat and drought conditions that would affect greenness levels. The year 2006 was chosen in order to coincide with the dates of the collected asthma data. If data with the above criteria was not available, the next closest date to that (skipping dormant months) was acquired. Out of the 14 MSAs used in this study, the following three had image tiles that were pulled from either September or October of 2006: Dallas-Fort Worth-Arlington, Lubbock and Killeen-Temple-Fort Hood.

The tiles were then "mosaiced" or pieced together to create one seamless image for each MSA. "Mosaicing" merges adjacent tiles into one image file removing overlapping values between tiles. The NDVI value was calculated for each image using ENVI™ (Redlands, CA) image processing software. This resulted in a grid with values ranging from -1 to 1.

The NDVI grid was transferred to a GIS software, where statistics were calculated for each MSA. Statistics included the minimum NDVI value, the maximum NDVI value, and mean NDVI value. The result was a table with each MSA, and its minimum, maximum, and mean greenness value.

Percent canopy cover was also calculated for each MSA to determine what proportion of each MSA was groundcover such as grasses and forbs versus woody vegetation such as trees and shrubs. Statistics were calculated for each MSA using the Multi-Resolution Land Characteristics (MRLC) National Land Cover Data canopy cover dataset. The result was a table with each MSA and the percent canopy cover which was contained in the MSA. This table was used in conjunction with the NDVI results and the acreage in each MSA to further assess associations.

Data analysis

Asthma data, NDVI and canopy cover data were analyzed using SPSS 17.0™ (Seattle, WA). Descriptive statistics, frequencies, Spearman and Pearson product-moment correlation coefficients, as well as regression analyses were calculated to analyze data.

Results and Discussion

This study did not find that childhood asthma rates in Metropolitan Statistical Areas of Texas were related to tree cover in Metropolitan Statistical Areas of Texas. Conclusions drawn from research and results presented in previous chapters are summarized as follows:

Amarillo

It was noticed that the Amarillo MSA (Figure 2), which had the highest childhood asthma rate at 15%, did, in fact, correspond with a lower canopy percent when compared to other MSAs. Percent canopy cover for the Amarillo MSA stood at only 2.32%, which was one of the three lowest for all MSAs. Average NDVI rating for Amarillo MSA was 0.12, which was the second to lowest rating of all other MSAs.

The superficial findings made sense with regards to the literature that suggested plants with greater leaf area, such as trees, act as better filters of pollution when compared to shrubs or grassland vegetation, which have less leaf area (Bolund and Hunhammar, 1999). Amarillo is located mainly in the High Plains and partly in the Rolling Plains regions of the Texas panhandle, both of which are characterized by dominant grassland vegetation and sparse woody vegetation when compared to other regions of Texas (Preserving Texas' Natural Heritage, 1978).

Austin-Round Rock

Austin-Round Rock is the fourth largest of the four major metropolitan/urban areas of Texas (U.S. Census, 2008). However, this MSA's childhood asthma rate, of 6.8%, was lower when compared to any of the other major metropolitan areas of Texas (Table 1; Figure 3) and right in the middle (7th) of the 14 MSAs used in this study. Percent canopy and average NDVI score for this MSA were also near the middle (5th highest of all 14 MSAs), at 23.51% and 0.30, respectively. Austin has been named one of America's top 10 greenest cities (Svoboda, 2008). The city of Austin devotes 15% of its land to parks and other open spaces and boasts 32 miles of bike trails (Grist, 2007). This MSA's commitment to green space could be a reason why its urban heat island does not seem to have as much impact on the childhood asthma rate.

Beaumont-Port Arthur

The Beaumont-Port Arthur MSA's (Figure 4) childhood asthma rate (7.1%) was the 6th highest of all 14 MSAs although its percent canopy was the 3rd highest of 14 MSAs. Beaumont-Port Arthur had the highest African American population (24.8%), a demographic known to suffer more asthma-related illness (Asthma Sourcebook, 2006; CDC, 2006; Texas Asthma Report, 2004; Sommers et al., 2007). This MSA is also situated along a coastal area, which typically have higher humidity levels that have been linked to asthma irritation (Mireku et al., 2009). Demographics and humidity could play a role in this MSAs higher asthma rates despite the fact that it has higher vegetation values.

Corpus Christi

The Corpus Christi MSA has a large amount of agronomic cropland, with Mesquite (*Prosopis glandulosa*)-Blackbrush (*Acacia rigidula*) brushlands and Live Oak (*Quercus virginiana*) Woods/Parks occurring only in two small areas of this MSA (Figure 5). It had the 9th highest percent canopy of 14 MSAs (6.67%), but the 4th lowest average NDVI score at 0.19. The asthma rate for this area stands at 8.5%, which is the same as Houston-Sugarland-Baytown, and it is ranked the 5th highest asthma rate of the 14 MSAs used in this study.

Studies have shown that plants with greater leaf area, such as trees, act as better filters of pollution when compared to shrubs or grassland vegetation, which have less leaf area (Bolund and Hunhammar, 1999). Woodlands, or areas with greater tree cover, allow more room for air flow when compared to an area of thick or short vegetation such as grass or shrublands, giving woodland areas better filtering opportunities (Bolund and Hunhammar, 1999; Sieghardt et al., 5002). Given that a major portion of this MSA is devoted to agricultural cropland with very little tree canopy cover, it seemed reasonable that this MSA had a higher childhood asthma rate. Corpus Christi is also situated along the Texas coast, which means it has higher humidity levels when compared to regions of Texas further inland (Mireku et al., 2009).

Dallas-Fort Worth-Arlington

The Dallas-Fort Worth-Arlington MSA (Figure 6) had the 3rd highest asthma rate of 14 MSAs, at 9.0%, the 8th greatest canopy cover at 9.71% and the 6th highest average NDVI score of 0.26. Dallas-Fort Worth-Arlington is Texas' largest major metropolitan area (U.S. Census, 2008). More concrete and less tree cover in urban areas create higher temperatures and higher ozone levels, which aggravate asthma symptoms and severity (Kollin, 2003). Therefore, it made sense that this MSA should have a higher asthma rate.

El Paso

El Paso (Figure 7) is comprised of arid lands and desert grasslands, in a region of Texas with the least amount of rainfall to wash away particulate matter. Vegetation captures particulate matter on leaf surfaces where it can stay trapped or be washed away by precipitation (Sieghardt et al., 2005). El Paso vegetation is also comprised of thick heavy brush/shrublands, and the thicker the vegetation, the lesser the air flow through the canopy, so less filtration of pollutants (Bolund and Hunhammar, 1999; Sieghardt et al., 5002). Although this area's geographic/vegetative composition leads us to believe that it would have a higher asthma incidence rate, at 6.3%, the asthma rate is still very low, ranking 8th highest of 14 MSAs in the study. Just as was noted in the McAllen-Edinburg-Mission and Brownsville-Harlingen MSAs, this area has a larger Hispanic population of 78.2%, a demographic with the lowest asthma susceptibility (CDC, 2006; Texas Asthma Report, 2004).

Houston-Sugarland-Baytown

Although the Houston-Sugarland-Baytown MSA had the 4th highest percent canopy of 14 MSAs, at 28.52%, this MSA (Figure 8) had a childhood asthma rate of 8.5%, ranking 5th highest of 14 MSAs and tying with Corpus Christi. Just like the Corpus Christi MSA, Houston-Sugarland-Baytown is situated along a coastal area, which typically has higher humidity levels which are also linked to asthma irritation (Mireku et al., 2009). Houston is also the second largest of Texas' major metropolitan areas, which typically have higher temperatures and ground level ozone, causing more irritation to those residents who suffer from asthma (Kollin, 2003).

Killeen-Temple-Fort Hood

At 3.1%, Killeen-Temple-Fort Hood (Figure 9) has the lowest asthma rate of all 14 MSAs. Although it had the lowest asthma rate, this MSA was only ranked 8th highest of 14 MSAs with respect to percent canopy cover, which stood at 17.47%. Although this MSA had the lowest childhood asthma rate, there was no statistically significant relationship between this variable and percent canopy.

Longview

Longview's (Figure 13) percent canopy cover (45.31%) was the highest of all the MSAs used in this study. However, Longview's childhood asthma rate (8.8%) was the 4th highest of all 14 MSAs. This MSA had one of the highest African American populations (19.5%), a demographic most at risk for suffering asthma symptoms (Asthma Sourcebook, 2006; CDC, 2006; Texas Asthma Report, 2004; Sommers et al., 2007).

Lubbock

The Lubbock MSA (Figure 10) had the lowest canopy cover of all 14 MSAs and yet a childhood asthma rate of only 5.7%, which was the 5th lowest. This MSA is located mainly in an area of Texas characterized by dominant grassland vegetation and sparse woody vegetation (Preserving Texas' Natural Heritage, 1978), so a low asthma rate was not necessarily expected.

McAllen-Edinburg-Mission and Brownsville-Harlingen

When looking at MSAs with respect to lower percent canopy and childhood asthma rates, both the McAllen-Edinburg-Mission and Brownsville-Harlingen MSAs

(Figure 11) had a percent canopy cover that fell well below 5%, and yet still had two of the lowest childhood asthma rates of all 14 MSAs used in this study (3.7% and 4.3%, respectively). Both of these MSAs have over an 80% Hispanic population and Hispanics have lesser incidence of asthma when compared to other demographic groups (CDC, 2006; Texas Asthma Report, 2004).

San Antonio

Although the San Antonio MSA (Figure 12) neighbors the Austin MSA (Figure 3) and the two areas are very similar in geographic and vegetative make-up, childhood asthma rate for San Antonio MSA, at 9.8%, is 3% higher than the Austin MSA. Although San Antonio ranks closely (6^{th} highest) to Austin-Round Rock (5^{th} highest) with respect to percent canopy cover, its 20.43% canopy is still 3% lower than its sister MSA. San Antonio ranks 8^{th} highest of 14 MSAs with respect to its 0.24 average NDVI score. San Antonio is the third largest of four major metropolitan areas of Texas and its total population is approximately 450,000 people larger than that of the Austin MSA (U.S. Census, 2008). At one time, it was reported that San Antonio, TX had lost 22%, or 45,000 acres, of heavy tree canopy to urbanization (Kollin, 2003) and they are continuing to develop their urban communities.

Tyler

The Tyler (Figure 13) MSA's vegetative make-up was identical to that of its sister MSA Longview, with smaller tracts of cropland dispersed among Pine-Hardwood forests. Percent canopy cover for this MSA stood at 39.28%, which ranked 2^{nd} highest of all 14 MSAs. Tyler's childhood asthma rate was only 4.6%, the 4th lowest asthma rate of 14 MSAs. Previous literature mentioned a mix of both evergreen and deciduous species as the best solution for increased filtration of airborne pollutants (Bolund and Hunhammar, 2005), so it made sense that this MSA should have a lower childhood asthma rate.

However, when comparing the Tyler MSA data with its sister MSA Longview, there were many contradictions. Longview's asthma rate was almost double at 8.8%, which might have been explained by its high population of African Americans (19.5%), a demographic more prone to asthma illness (Asthma Sourcebook, 2006; CDC, 2006; Texas Asthma Report, 2004; Sommers et al., 2007). However, the Tyler MSA's African American population (19.1%) was almost identical to that of Longview and yet the two MSAs had marked difference in childhood asthma rates. The differences seen between these two MSAs, so similar in vegetative and demographic composition and so different with respect to asthma rates, were an indicator that tree cover might not be related to childhood asthma rates.

Summary of Statistical Analyses

A Pearson product-moment correlation analysis was performed to determine if percent canopy cover was associated with childhood asthma percentage. Additionally, appropriate correlation analyses were conducted to assess if minimum NDVI, maximum NDVI and/or average NDVI were related to childhood asthma percentage. A Spearman's rho correlation analysis was performed to compare MSAs within the categories of low, middle and high average NDVI scores to look for relationships between vegetation levels within the 14 MSAs and childhood asthma rates. A partial correlation analysis was conducted to control for the impact of demographics on childhood asthma percentage in each MSA while looking for relationships between asthma percentages and minimum, maximum and average NDVI, as well as percent canopy cover. Finally, MSAs were grouped into large, medium and small population divisions and regression analyses were run to determine if percent canopy, minimum NDVI, maximum NDVI and/or average NDVI were predictors of childhood asthma percentage/prevalence. In all of the statistical analyses conducted, no statistically significant results were found.

Statement of Conclusions

It is concluded from this research that although childhood asthma rates in some areas of Texas with known lesser tree/vegetation cover are indeed lower, statistical analyses of collected data did not reveal any relationships between variables. However, results of this study also did not suggest that childhood asthma rates were aggravated by the presence of increased tree/vegetation cover.

Childhood asthma occurrence has many extraneous variables such as tobacco smoke, pet dander, dust mites and cockroaches related to the disease which may have influenced the research and results (Edelman, 1997; Lara et al., 2001). Tree pollens from species such as ash, elm, oak and sycamore, as well as, grass pollens are also linked to seasonal asthma in certain patients and these pollens are generally higher in the spring and summer months, the same time frame of this study (MacNaughton, 2007).

Recommendations for Further Research

1) It is recommended that when conducting future research that more detailed asthma data sources be used since data for this study was somewhat limited.
2) It is recommended that future research consider humidity levels within regions and control for their impact on childhood asthma rates since conclusions drawn from research were that it could potentially have influenced the final results of this study.

3) It is recommended that future research focus on comparing the relationship of childhood asthma and tree/vegetative cover between geographical/vegetative regions of the entire United States in order to look at more extensive data with regards to sample group sizes and vegetative data.

APPENDIX

Main crops and approximate acreage totals for each county in the Metropolitan Statistical Areas used for this study.

MSA	County	Main Crops	Acreage
Amarillo	Carson	Cereals	162940
		Grain legumes	4492
		Forages	13360
	Potter	Cereals	21072
		Forages	4955
	Randall	Cereals	112770
		Forages	28564
		Fruits & Nuts (pecans)	12
		Horticulture	14
	Armstrong	Cereals	66716
		Forages	6181
		Other (cotton)	361
Lubbock	Lubbock	Cereals	38334
		Grain legumes	5027
		Forages	15033
		Vegetables	468
		Fruits & Nuts	4681
		Other (cotton)	279205
		Horticulture	1168
	Crosby	Cereals	35320

		Grain legumes	979
		Forages	8476
		Fruits & Nuts	877
		Other (cotton)	233538
Dallas-Fort Worth-Arlington	Johnson	Cereals	27937
		Forages	114106
		Vegetables	25
		Fruits & Nuts	810
		Other (cotton)	1205
		Horticulture	138
	Tarrant	Cereals	18534
		Forages	32894
		Vegetables	39
		Fruits & Nuts	639
		Other (herbs)	11
		Horticulture	400
	Denton	Cereals	69374
		Grains legumes	796
		Forages	87935
		Vegetables	23
		Fruits & Nuts	2635
		Other (cotton)	1303
		Horticulture	1070
	Parker	Cereals	1825
		Forages	87922
		Vegetables	193
		Fruits & Nuts	4996

		Horticulture	262
	Wise	Cereals	8504
		Forages	97268
		Vegetables	431
		Fruits & Nuts	2457
		Horticulture	118
	Delta	Cereals	10008
		Grains legumes	18818
		Forages	33591
		Fruits and Nuts	145
		Other (cotton)	1904
	Kaufman	Cereals	20549
		Grains legumes	2876
		Forages	108494
		Fruits and Nuts	216
		Other (cotton)	757
		Horticulture	453
	Rockwall	Cereals	6341
		Forages	10442
		Fruits & Nuts	39
	Hunt	Cereals	29624
		Grains legumes	6059
		Forages	105214
		Vegetables	111
		Fruits and Nuts	1282
		Other (cotton)	11202
		Horticulture	177
	Ellis	Cereals	65468

		Grains legumes	4261
		Forages	97144
		Fruits and Nuts	728
		Other (cotton)	30737
		Horticulture	221
	Collin	Cereals	82177
		Grains legumes	1781
		Forages	70087
		Vegetables	67
		Fruits and Nuts	399
		Other (cotton)	6478
		Horticulture	232
	Dallas	Cereals	19531
		Grains legumes	3143
		Forages	30210
		Vegetables	6
		Fruits and Nuts	257
		Other (cotton)	114
		Horticulture	581
Tyler	Smith	Cereals	47
		Forages	83022
		Vegetables	768
		Fruits & Nuts	846
		Horticulture	2032
Longview	Upshur	Forages	49806
		Vegetables	63
		Fruits & nuts	210
		Horticulture	150

	Gregg	Forages	12528
		Vegetables	14
		Fruits & nuts	110
		Horticulture	30
	Rusk	Cereals	94
		Forages	58674
		Vegetables	1084
		Fruits & nuts	176
		Horticulture	5
Beaumont-Port Arthur	Jefferson	Cereals	29623
		Grain legumes	3445
		Forages	24965
		Fruits & Nuts	175
		Other (cotton)	310
		Horticulture	2052
	Hardin	Cereals	10
		Forages	9112
		Vegetables	165
		Fruits & Nuts	160
		Horticulture	221
	Orange	Cereals	1446
		Forages	9290
		Fruits & Nuts (Pecans)	9
		Horticulture	63
Houston-Sugarland-Baytown	Brazoria	Cereals	35025
		Grains legumes	9018
		Forages	43918

		Vegetables	448
		Fruits & Nuts	1257
		Other (cotton)	7211
		Horticulture	5054
	Galveston	Cereals	1150
		Forages	15006
		Vegetables	78
		Fruits & Nuts	165
		Other (herbs)	11
		Horticulture	477
	Chambers	Cereals	21958
		Grain legumes	3465
		Forages	15264
	Harris	Cereals	14722
		Grain legumes	2722
		Forages	41794
		Vegetables	603
		Fruits & Nuts	1179
		Horticulture	8792
	Liberty	Cereals	20790
		Grain legumes	37309
		Forages	39123
		Vegetables	16
		Fruits & Nuts	132
		Horticulture	1703
	Austin	Cereals	9286
		Forages	87694
		Vegetables	1

		Fruits & Nuts	1487
		Other (cotton)	2844
		Horticulture	500
	Waller	Cereals	16346
		Grain legumes	2569
		Forages	52292
		Vegetables	106
		Fruits & Nuts	3506
		Horticulture	524
	Montgomery	Forages	25226
		Vegetables	4
		Fruits & Nuts	120
		Horticulture	1244
	San Jacinto	Forages	21164
		Fruits & Nuts	71
		Horticulture	189
Killeen-Temple-Fort Hood	Lampasas	Cereals	6729
		Forages	32802
		Vegetables	41
		Fruits & Nuts	1890
		Horticulture	18
	Bell	Cereals	102777
		Grain legumes	483
		Forages	63207
		Vegetables	3
		Fruits & Nuts	2856
		Other (cotton)	3611

		Horticulture	102
	Coryell	Cereals	35634
		Forages	59187
		Fruits & Nuts	2150
		Other (cotton)	812
Austin-Round Rock	Hays	Cereals	15949
		Forages	18899
		Vegetables	21
		Fruits & Nuts	210
		Other (cotton)	210
		Horticulture	81
	Williamson	Cereals	126232
		Forages	77309
		Vegetables	13
		Fruits & Nuts	1142
		Other (cotton)	33182
		Horticulture	89
	Travis	Cereals	35363
		Forages	31511
		Vegetables	9
		Fruits & Nuts	1353
		Other (cotton)	5230
		Horticulture	338
	Caldwell	Cereals	11087
		Forages	40526
		Vegetables	48
		Fruits & Nuts	1121
		Other (cotton)	4163

	Bastrop	Cereals	4330
		Forages	63524
		Vegetables	87
		Fruits & Nuts	3105
		Other (cotton)	835
		Horticulture	1051
San Antonio	Atascosa	Cereals	15428
		Forages	80419
		Vegetables	1055
		Fruits & Nuts	14432
		Other (cotton)	220
		Horticulture	385
	Wilson	Cereals	34777
		Grain legumes	432
		Forages	87243
		Vegetables	560
		Fruits & Nuts	11683
		Other (cotton)	1662
		Horticulture	3
	Bandera	Cereals	641
		Forages	11562
		Fruits & Nuts	457
		Horticulture	94
	Kendall	Cereals	1702
		Forages	21823
		Fruits & Nuts	166
		Horticulture	68
	Comal	Cereals	3896

		Forages	18365
		Fruits & Nuts	160
		Horticulture	25
	Medina	Cereals	89813
		Forages	44670
		Vegetables	2557
		Fruits & Nuts	3844
		Other (cotton)	3364
		Horticulture	8
	Bexar	Cereals	37436
		Forages	69544
		Vegetables	798
		Fruits & Nuts	1858
		Other (herbs)	50
		Horticulture	3355
	Guadalupe	Cereals	48433
		Forages	64246
		Vegetables	56
		Fruits & Nuts	3828
		Other (cotton)	661
		Horticulture	225
Corpus Christi	San Patricio	Cereals	156751
		Forages	11006
		Vegetables	10
		Other (cotton)	81685
	Nueces	Cereals	212617
		Forages	20443
		Vegetables	6

		Fruits & Nuts	24
		Other (cotton)	10597
	Aransas	Forages	1262
Brownsville-Harlingen	Cameron	Cereals	108288
		Grain legumes	4131
		Forages	13050
		Vegetables	2765
		Fruits & Nuts	3888
		Other (cotton & sugarcane)	61678
		Horticulture	2276
McAllen-Edinburg-Mission	Hidalgo	Cereals	196909
		Grain legumes	1343
		Forages	21834
		Vegetables	31032
		Fruits & Nuts	26173
		Other (cotton, herbs & sugarcane)	76610
		Horticulture	1948
El Paso	El Paso	Cereals	1722
		Forages	14850
		Vegetables	2412
		Fruits & Nuts	7361
		Other (cotton)	27103
		Horticulture	3

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