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Abstract

Assessing Allergenic Vegetation Landscape and Pediatric Respiratory-Related Emergency Department Visits in metro-Atlanta: A novel method

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Allergenic pollen is produced by the flowers of trees, grasses and weeds. Exposure to such pollen grains can exacerbate pollen-related asthma and allergenic conditions such as allergic rhinitis. Understanding the health effects from pollen exposure requires the acquisition of the spatial distribution of pollen-producing vegetation. Connections between ambient air pollution concentrations and health responses have been reported in several studies, but not enough research has been done on spatial distribution of allergenic tree pollen and its health outcomes (Greiner et al., 2011). Children are vulnerable due to their developing physiology and outdoor lifestyle and are thus frequently exposed to such allergenic trees. Maps showing the location of these allergenic taxa have many applications: provide risk assessments; inform research on health impacts based on hospital respiratory admissions; advance pollen emissions models.

This study presents census tract-level maps of selected tree taxa found in Atlanta. We use the novel approach of mapping allergenic vegetation to examine the association between pollen species distribution mixture with asthma-related pediatric emergency department (PED) visits in the city of Atlanta.

We hypothesize that allergenic vegetation count by census tract is a predictor of PED visit rates. The null hypothesis is that allergenic vegetation and asthma PED rates are spatially homogeneous and have no spatial relationship. Taxa mapped in this study were: *Acer* sp. (maple), *Betula* sp. (birch), *Quercus* sp. (oak), *Ulmus* sp.(elm), *Fraxinus* sp. (ash), *Platanus* sp. (sycamore), *Fagus* sp. (beech), *Carya* sp. (hickory), *Populus* sp. (poplar), *Juglans* sp., *and Salix* sp. (willow). PED visit rates for children aged 0–19 years from 2014-2018 are mapped by census tracts. Results show the different geographical distributions of the taxa and PED residences, which can be used to study plants in Atlanta associated with allergy and allergic asthma. Associations between allergenic tree density and pediatric emergency department visit rates were found to be both statistically significant (p=0.00043; 95% CI: 2.16 ± 0.2) and statistically insignificant (p=0.94; 95% CI: 2.16 ± 0.2). Findings can be expected to inform future development and implementation of public health strategies and land management through regionally tailored environmental and healthcare characteristics.

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LIST OF ASSUMPTIONS

This section highlights the assumptions that this study is based on, listing these premises that are understood to be true in this research.

1) Pollen concentration in each area is highly dependent on the pollen-producing level of the plant in question and could be at a higher or lower concentration if the plant is highly allergenic, releases more fine pollen grains which have higher allergenic potential, or is in abundance in a certain area. Come warmer weather-as pollen is also affected by temperature, allergenic plants take the cue and will produce more pollen during its flowering period as a reproductive response. So instead of assessing pollen levels per census tract, our study looks at the allergenic plant spread.
2) The type of tree that comprises the tree canopy is as equally important as increased tree canopy cover.
3) Pollen levels taken from the year 2020 are an accurate representation of general pollen levels throughout the year in Atlanta generally.
4) The study area within the city of Atlanta is a relatively accurate representation of the allergenic treescape and PED asthma visit rates.
5) We assume the PED visits dataset has no association with socioeconomic or demographic factors but should be analyzed for further research.

List of Tables and Figures

CHAPTER 1: INTRODUCTION

This chapter assesses the various health outcomes from allergenic pollen and how they contribute to PED visit rates for asthma and allergic rhinitis in metro-Atlanta.

Health impacts of allergenic pollen

Pollen is a powder-like substance that is made up of microscopic grains or particles that are carried and produced on the anthers/male parts of flowers. Pollen grains are covered in proteins that trigger allergic reactions in sensitive individuals, with the degree of sensitization varying among individuals. Pollen is dispersed by the wind, insects, birds and various other animals (Schmidt, 2016).

Figure 1.1 Pollen (gold spheres) is produced by the stamens (gray)

Source: Schmidt, C. W. (2016). Pollen Overload: Seasonal Allergies in a Changing Climate. Environmental Health Perspectives, 124(4), A70–A75. https://doi.org/10.1289/ehp.124-A70

Pollen contains water-soluble proteins that are released when they come into contact with the mucosa. In sensitive individuals, the immune system generates IgE antibodies in reaction to the proteins. These antibodies bind to the body’s defense cells, mast cells, which then release histamine as an anti-inflammatory response. Histamines stimulate the glands to release secretions and irritate the nerves, which in turn causes the characteristic allergy symptoms of itching, sneezing and swelling of mucus membranes (Schmidt, 2016).

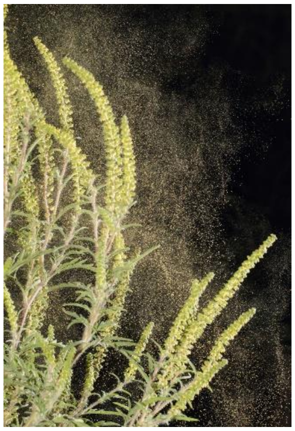


Figure 1.2 Wind-pollinated plant

Exposure to such pollen grains can result in exacerbation of pollen-related asthma and allergenic conditions such as allergic rhinitis (pollenosis or hay fever) (Greiner et al., 2011). According to Lewis Ziska, a plant physiologist with the U.S. Department of Agriculture (USDA), the intensity of an allergic reaction depends on three interrelated factors: how much pollen a given species emits into the air, the exposure duration, and pollen allergenicity.

Is Pollen a Form of Air Pollution?

Pollen is technically a type of particulate matter (PM), but because most intact pollen grains are larger than 10 um, they are not categorized as PM 10 and are far too large in diameter to enter the human lung. However, pollen particles can rupture into smaller particles--these smaller fragments of pollen grain can become small enough to be classified as PM10, or even PM2.5, and can enter our airways. Air pollution may also increase the development of pollen allergy through direct influence on enzymes and plant growth, as well as the pollen grain surface morphology that often carry environmental allergens.

Background to allergenic vegetation mapping

While many studies examine the spatial heterogeneity of asthma prevalence and separately, the association of pollen concentrations and asthma in Atlanta, previous research did not thoroughly examine for the spatial distribution of the major pollen offenders that determine these patterns. This research study addresses this gap by examining the spatial patterns of pediatric asthma ED visits and the coverage of selected allergenic taxa.

What is an Herbarium?

An herbarium is a museum of preserved plant samples that are used for botanical research and education. Plant samples include pressed and mounted plants, microscope slides, and plant parts. The Emory University Herbarium goes beyond just its pressed herbarium specimens and is dedicated to curating ethnobotanical objects such as objects made from plants (instruments, medical tools, etc.) in order to spread awareness of both the importance and potential of plants in our lives.

Figure 1.3 *Quercus alba* vouchers at Emory University Herbarium digitized collection

This study recognizes that herbariums have vast potential for providing information for future GIS studies of past and future collecting expeditions. Coordinates of allergenic tree types were taken from various sources, primarily the Emory University Herbarium, Southeast Regional Network of Expertise and Collections (SERNEC Portal), and Trees Atlanta organization. These maps of allergenic taxa in metro-Atlanta would not be possible without these sources. The Emory University Herbarium has more than 20,200 plant specimens, dating back to the early 1900s. Majority of the collection is composed of plants from the southeast USA with 4,138 taxa in its records, and the recent digitization of these collections has made the plant records readily available for both local and global access for research. The SERNEC portal is a digital consortium of 233 herbaria in 14 states in the southeastern USA.

Availability of these statistics is what limits this approach: information on the abundance of certain taxa for regions is potentially not available or is inaccurate. While many sources exist that refer to the presence or absence of a particular tree type or species, it does not necessarily denote abundance.

What can be done to address this problem would be a potential introduction of top-down methodology: back-trajectories of pollen observations to create footprint areas. Geographic and temporal coverage of monitoring stations are however limiting factors of ‘top down’ methodologies (McInnes et al., 2017)

Furthermore, quality maps are important as it affects how well readership can interpret data and visualizations. High resolution inputs can provide a challenge in terms of larger datasets; lower resolution inputs may be easier to acquire but can miss important spatial detail and compromise quality of maps. This research has compiled as many resources as possible given time and constraints to provide quality mapping. The maps created are at census tract-level as this level of resolution is necessary to be able to visualize the entire study area and the data values mapped. Any clearer resolution is beneficial but not necessary for our research purposes. Findings can be expected to inform the development of improved public health strategies that consider local environmental characteristics.

Pollen Allergies:

Allergic diseases are amongst the most common chronic disorders worldwide. Today, more than 300 million of the population is known to suffer from one or other allergic ailments affecting the socioeconomic quality of life. Major causative agents implicated are pollen grains, fungal spores, dust mites, insect debris, animal epithelia, etc. (Mir et al., 2013).

The respiratory system is the direct target organ of airborne pollen taken in by inhalation. This results in clinically diagnosed manifestations of allergic rhinitis, allergic alveolitis, asthma, atopic dermatitis, etc. (Mir et al., 2013). Wind pollination, the transportation of pollen grains from floral anther to recipient stigma, is critical amongst plants. Successful wind dispersion simultaneously ensures reproductive success and prevalence of human health effects including asthma, rhinitis, atopic dermatitis, etc. Pollen concentration (grains per cubic meter) at any location reflects the changing dynamics of environment due to effects of climactic factors such as pollution, temperature, humidity, wind direction, sunshine, substrate precipitation and other seasonal factors (Mir et al., 2013). Because of change in the climatic conditions, this study aims to establish the temporal relationship between the flowering period of chosen taxa and pollen concentration levels.

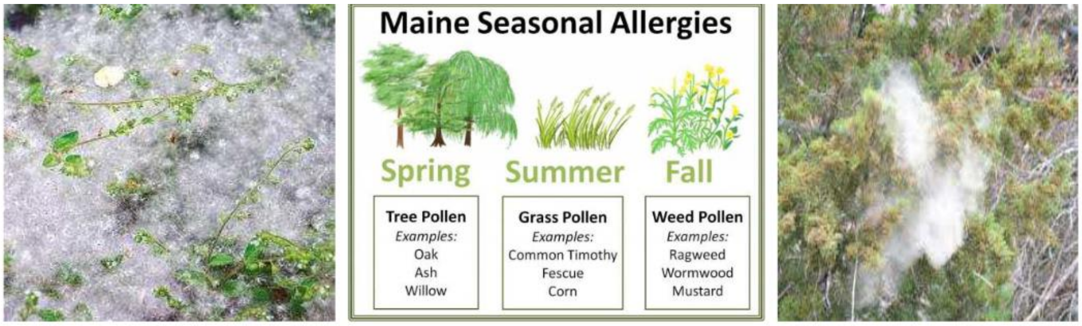


Fig. 1.4 Main seasonal allergens and pollen menace pictured. Primary springtime allergens are trees

Source: Mir, M. A., & Albaradie, R. S. (2013). *International Journal of Pure & Applied Bioscience*. 13.

Allergic response to an allergen:

Allergy is defined as the immediate hypersensitivity to environmental antigens. Fortunately, advances in basic immunology research have enhanced our understanding of the biological basis of the allergic response. Elevated levels of IgE antibodies against specific antigens (allergens) through inhalation, ingestion, or dermal contact are characteristic of the allergic response (Mohapatra et al., 2010).

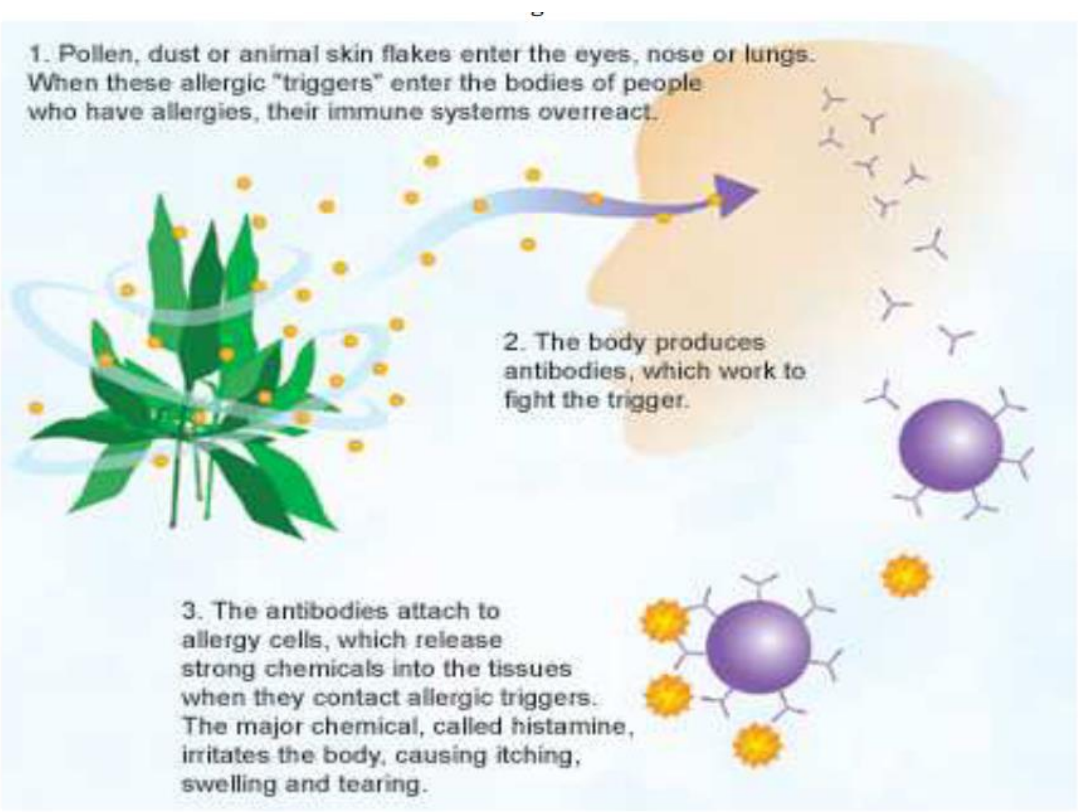


Figure 1.5 Diagram showing how allergies are caused due to allergens like pollen

Source: Mir, M. A., & Albaradie, R. S. (2013). *International Journal of Pure & Applied Bioscience*. 13.

Seasonal allergies in North America generally begin in spring when trees begin to flower and disperse their allergenic pollen into the air. This span of time of flowering and pollen dispersal is called the flowering period. This flowering period is not necessarily the same as flowers and plants blooming in the springtime. A common misconception is that because allergy symptoms often start in correlation with blooming flowers, many believe that the flower pollens contribute to the problem. However, flowers and flowering plants typically disperse pollen through plant-to plant interaction through pollinators such as bees. Allergies are actually due to plants that spread pollen by wind, which is how the pollen enters our eyes, noses, and mouths. Thus, our allergies are mostly due to wind-pollinated plants and due to our time outdoors.

Given that trees are wind-pollinated, the main springtime allergens fall upon trees. However, not all trees produce pollen that cause negative respiratory effects. Because of this, only the trees with the highest allergenic impact according to the Fulton County Allergen Report were mapped by census tract in the study. Due to constraints of the study, duration of exposure was not recorded or analyzed.

Common trees that contribute to allergy symptoms include oak, cottonwood, birch, maple, sycamore, ash, elm, hickory, walnut, beech and mulberry. Given that 1) Atlanta is nicknamed "City in a Forest" (GreenLaw [Accessed 30 Aug 2020]) with the largest canopy of any major U.S. urban area with 48% of the city covered by trees (Trees Atlanta) and 2) allergic conditions are major risk factors for asthma (Bochner et al., 1994), it is reasonable to further explore a link between the spatial distribution of high pollen producing tree density and asthma PED rates.

Seasonal allergies and asthma impose significant health burdens, with an estimated 10–30% of the global population afflicted by allergic rhinitis and 300 million people worldwide affected by asthma and its prevalence continues to increase with no sign of stopping (Schmidt, 2016). However, it is important to acknowledge that trends in seasonal allergy prevalence are more difficult to track because symptoms in most cases do not trigger emergency room visits or other types of medical care.

Still, pollen allergies are widespread and associated with several chronic conditions, including allergic rhinitis, allergic conjunctivitis, and allergic asthma (Pawankar et al. 2011). The

Centers for Disease Control and Prevention's 2016 National Health Interview Survey (Centers for Disease Control and Prevention_2016) estimated allergic rhinitis prevalence in the USA at 21.5 million (6.5% of adults and 7.5% of children. Altogether, allergic diseases impose a significant financial burden in the United States, with treatment and medication costs estimated at $81.9 billion in 2005 (AAFA), along with substantial indirect costs from lower work productivity, poor academic performance, and reduced quality of life (Roger et al. 2016).

Allergic Rhinitis:

Allergic rhinitis from pollen allergy is a risk factor for asthma, and the two diseases are highly correlated (Bousquet et al. 2008). Allergic rhinitis is an immunoglobulin E (IgE)-mediated inflammation of the membranes lining the nose (Bousquet et al., 2008). It is established that pollen allergy is a regionally variable disease driven by numerous environmental factors, including local flora, air pollution, climate, and meteorological variables (Lou 2017). Prior pollen exposure drives disease sensitization, while current pollen exposure drives intensity of disease amongst already affected individuals (Kihlström et al. 2002). The temporal and spatial distributions of allergenic pollen types are important to allergic disease epidemiology and in diagnosis and management of allergic diseases, specifically allergic asthma. While some pollen grains can be transported long distances such as hundreds to thousands of kilometers in the atmosphere (Sofiev et al., 2006) local pollen emissions are the primary influence of given pollen concentrations in an area (Ranta et al., 2006). Pollen type maps are thus location specific, with pollen concentrations closely linked to local flora distribution, meteorology, and climate.

What is Asthma?

Asthma is the most common chronic respiratory disease, affecting an estimated 334 million people globally (Global Asthma Network [Accessed 21 Aug 2020]). Asthma is a chronic inflammatory disorder of the airways characterized by episodes of reversible breathing problems due to airway narrowing and obstruction. These episodes can range in severity from mild to life threatening. During asthma episodes, the airway muscles tighten and the airway lining swells, thus making the airways very narrow, leading to difficulty in breathing. Asthma symptoms include wheezing, coughing, chest tightness, and shortness of breath (Global Asthma Network [Accessed 21 Aug 2020]).

In 2011, Atlanta was named an “Asthma Capital” by the Asthma and Allergy Foundation of America (AAFA) (Deganian et al. 2012). Metro Atlanta was also named by Forbes Magazine as one of the “most toxic cities” in the United States (Deganian et al. 2012).

According to Children’s Healthcare of Atlanta and the Asthma and Allergy Foundation, asthma is the leading cause of hospital admissions among chronic children’s diseases. Children are a vulnerable population due to their changing physiology and outdoor lifestyles and daily activities. Currently, there are about 6.2 million children under the age of 18 with asthma in the United States (AAFA [Accessed 25 Aug 2020]).

Asthma takes a relatively large toll on affected individuals, the health care system and society in terms of lost productivity. In a 2010 Asthma Facts CDC report, the CDC states that adults have a total national asthma prevalence of 8.7% and children with a total national prevalence of 8.5% (Nath et al., 2015). The rate of children’s ED visits for asthma increased by 13.3% from 2001 to 2011 to 8.2-9.3 visits per 1000 children. The Georgia Department of Public Health reported that in 2012, there were 25,930 emergency room visits for children. Specifically in our study area of metro-Atlanta, the GDPH reported in 2012 an overall asthma-related ER visit rate of 11.5-20.9 per 1,000 in comparison to the national average of 8.2-9.3 per 1,000. This Atlanta rate is 40.2-124.7% higher than the overall national rate. The total cost for that care was estimated at $70 million. Furthermore, the AAFA named Atlanta as one of the cities with the fewest asthma specialists per asthma patient in 2019. From this evidence, it is clear that this burden and lack of available help contributes to a significant public health concern that ought to be addressed.

Project aims and research questions: a unique approach to predicting health outcomes

The objective of the study is to determine how proximity to areas of more densely populated allergenic trees impact PED visit rates for allergic asthma in metro-Atlanta. This paper presents novel maps of location of taxa and allergy and allergic asthma PED visit rates. This research seeks a relationship between the spatial patterns of PED visits and allergenic tree taxa in the city of Atlanta, Georgia. This is a unique approach that involves combining specific combination of tree taxa density maps with health outcome maps (PED visit rates). While other studies have focused on nature and green space, no study has comprehensively assessed the human health responses associated specifically with certain trees in urban areas. A review by Salmond et al. (2016) focused on street trees and health but did not mention the urban forest configuration and makeup. To address this gap in the literature, this study synthesizes empirical findings about selected taxa that make up our allergenic vegetation in metro-Atlanta and how it effects human health. Using GIS analysis to investigate the relationship, the outcomes of the study will not only be able to be used to predict health outcomes but also inform future public health policy, urban planning for prevention and management of detrimental pollen concentration levels, and individual self-management.

CHAPTER 2: LITERATURE REVIEW

The status of environmental health: A need for research

While risk factors such as genetics, infections, and diet are important asthma risk factors (Liu et al., 2009) they do not adequately explain the reasoning behind the spatial heterogeneity of this asthma burden (Crighton et al., 2012). It is likely that other factors, such as changing diets and better hygiene, contribute to the prevalence of asthma and hay fever by limiting early exposure to allergens and altering the immune system's normal development.

However, there is a growing rise in literature on the relationship between airborne pollen concentrations and asthma prevalence (Crighton et al., 2012). Yet much remains unknown about the relationship between aeroallergens and exacerbation of asthma, especially less severe attacks that are unable to be capture by hospital visit data (Schmier et al., 2009).

Several aerobiological studies have been conducted in various regions of the world to discern different aerial concentration and seasonality of pollen grains. Especially from clinical point of view, it is important to be knowledgeable and aware of the pollen season and pollen load in the atmosphere. The flowering seasons of plants periodically come each season at around the same time, but it may differ from year to year in different geographic locations. Therefore, pollen calendars are very useful tools for an aid to allergy diagnosis and management. But the pollen concentration in each area is highly dependent on the pollen-producing level of the plant in question and could be at a higher or lower concentration if the plant is highly allergenic. Allergenic plants will produce more pollen during its flowering period. So instead of assessing pollen levels per census tract, our study looks at the allergenic plant spread.

Our study proposes that our findings can present urban planning and greenspace landscaping as solutions to maintain pollen concentration level that are detrimental to vulnerable populations. By managing the makeup and configuration of the urban forest and greenspaces, we can keep pollen concentrations under control.

According to Trees Atlanta, Atlanta has the largest canopy of any major U.S. urban area with 48% of the city covered by trees. Urban tree planting initiatives have been actively promoted as an urban planning solution to reduce the environmental degradation caused by urbanization. It is believed that these initiatives can enhance both sustainability and mitigation of climate change and to improve human health (Andersson-Sköld et al., 2018). The generally positive public perception of the value of green spaces and green infrastructure (especially trees) within cities has prompted promotions of the 'greening' of cities through urban reforestation or increasing tree canopy cover, such as the New York City 'Million Trees' program (Salmond et al., 2016). However, this study asserts that what type of tree that comprises this tree canopy is as equally important as increased tree canopy cover. This study employs a novel way in assessing predictors of health outcomes by examining the geographic patterns of tree cover comprised of selected major pollen-offenders and respiratory PED visits to inquire if there is an existing relationship between these two variables, or if Atlanta's titles of "City in a Forest" and "Asthma Capital" are purely coincidental.

Looking beyond individual risk factors, this study uses an environmental-level study design and a spatial analysis approach to examine the potential effect of environmental factors on PED visit rates in the context of Atlanta, Georgia. This is not to discourage future tree plantings or increased tree coverage in major cities, but to spread awareness of the health impacts of allergenic taxa and how mapping can implement preventative practices for not only individuals for self-management of allergies but especially urban planning and land management.

Such preventative practices that can be used for urban planning foster more effective implementation and impact rather than individual self-management. While it is likely that days listed as poor air quality and areas with highly allergenic trees can prompt individuals to limit outdoor exposure, sometimes limiting exposure is not an option for those with busy schedules. These risks may also simply not be enough of a deterrence for vulnerable individuals to go outdoors. Modifying individual behavior can be both difficult and unsustainable, and so urban landscaping modifications for low-allergenicity can thus be more impactful and long-lasting in its effects.

Urban green spaces are a key element in the planning of today's cities, since they favor the interaction between citizens and the environment, as well as promoting human health. However, lack of planning in the design of urban spaces can cause low species biodiversity, overabundance of given species that become key pollen sources, presence of invasive species, and the interaction between pollen and air pollutants that trigger pollen allergies (Carinanos et al., 2011). The findings of our analysis highlight the clear need for guidelines regarding the design and planning of urban green spaces with a low allergy impact. Proposed modifications and future improvements to urban green space planning can include increased biodiversity, careful control when planting exotic species, the use of low pollen producing species, the adoption of appropriate management and maintenance strategies, and active consultation with botanists when selecting the most suitable species for a given green space.

Therefore, good quality maps of allergenic pollen taxa are useful for impact assessment and addresses the need for detailed pollen-related health impact information prior to administering appropriate solutions such as policy and urban planning. These maps can also help public health officials assess exposure, develop early warning systems, improve guidance to limit exposure, develop guidelines for designing urban green zones with low allergy impact, and promote therapy in advance of high pollen loads

Purpose of this work and wider context

The purpose of this study's spatial analysis is to visualize and identify patterns between geographic tree and asthma data and attempt to explain this pattern. Maps can reveal spatial patterns not previously recognized from a table of statistics and can reveal high risk communities or areas (Khamis, 2012). These patterns can be used to inform and improve urban policy and planning for beneficial, wide-scale health impact as well as diving further into future research on potential explanatory variables.

The health issue we address is important because the incidence of asthma and other allergic respiratory diseases has increased dramatically worldwide in the last few decades and is also the leading cause of chronic illness in children and adolescents in the United States (D'Amato et al., 2013; CDC.gov, 2018 [Accessed 25 Aug 2020]). Although genetic factors are important in the development of asthma and allergic diseases, this rising trend can be explained in changes that happened in the environment. Due to climate change, air pollution patterns are changing in several urbanized areas of the world, with a significant effect on respiratory health. Observational evidence indicates that increases in temperature affects a diverse set of biological systems in many parts of the world, such as pollen production and the allergenic potential of pollens (D’Amato et al., 2013). These projected changes caused by climate change magnify the importance of understanding regional pollen differences and its effects on asthma outcomes. Improved understanding of specific exposure-outcome relationships can facilitate a wide range of adaptation activities that might reduce the associated health impacts.

There is a vast body of literature on the association between asthma development and exacerbations and individual level risk factors. Studies have shown strong relationships between asthma outcomes and genetic predisposition (Liu et al., 2009), allergen exposure, and behavioral factors such as smoking and diet (Chen et al., 2006). However, less understood but growing in importance is the role of environmental factors in determining allergic asthma outcomes. For example, a study conducted by Ontario researchers found associations between asthma outcomes and rurality as well as air pollution (Ouedraogo et al., 2018). This shows that asthma outcomes are not spatially homogeneous and are tied to various factors such as socioeconomic demographics and surrounding environments.

Detailed maps of the location of allergenic pollen producing trees for Atlanta can possibly identify the areas that are associated with increased risk of higher hospital admissions for asthma. While it is the pollen grains that are directly affecting respiratory health, pollen emissions are subject to fluctuations and are constantly dynamic due to wind and changing local weather. We established earlier that local pollen emissions are the primary influence of given pollen concentrations in an area (Ranta et al._2006). What is actually causing the presence of these pollen grains and contributing largely to the local pollen concentrations levels are the trees themselves. It is important that we distinguish that we are creating maps of allergenic taxa cover and not maps of allergenic pollen levels. However, future maps can be coupled with meteorological factors such as rain, wind, humidity, and temperature to predict the emissions and dispersion of pollen grains, to provide continuously improving pollen forecasts for Atlanta (Skjoth et al., 2012).

Meanwhile, these vegetation maps can help improve vegetation management practices. Tracking allergenic taxa overall can lead to further research on how to implement evidence-based interventions that reduce asthma-related morbidity and mortality. Continually enhancing surveillance systems to monitor progress can reduce the number of deaths, hospitalizations, emergency department visits, school or workdays missed, limitations on activities due to asthma, and to increase the number of people receiving asthma management education and appropriate care.

CHAPTER 3: METHODOLOGY

Experimental Overview

We conducted an ecological-level study with separate temporal analysis and spatial analysis. For the temporal analysis, the study researched the flowering periods of each taxa. The flowering periods of taxa are generally considered to be the periods in which the taxa emit the highest levels/concentration of pollen (Schmidt, 2016). Establishing the temporal link between the flowering period and time of peak pollen levels suggests that the pollen emitted from the taxa are the major culprits behind pollen concentrations. We assume that this year is an accurate representation of general pollen levels throughout the year in Atlanta.

Pollen Data

Pollen is a common allergen that causes significant health and financial impacts on up to a third of the population of the United States (Lo et al., 2019). Knowledge of pollen seasons can improve diagnosis and treatment of allergic diseases in Atlanta. In Atlanta, a select number of taxa contribute to the bulk of the total pollen concentration, as listed in our objectives. Flowering seasons of taxa were derived from pollen calendars of specific pollen taxa from Lo et al. (2019) by defining their durations as the start and end dates of the pollen seasons. Flowering seasons were also taken from specified months of the taxa from *Manual of the Vascular Flora of the Carolinas* (Radford et al., 1968). Peak pollen levels are emitted by plants during its flowering period (Schmidt, 2016). The flowering seasons of the selected taxa were plotted on a graph along with monthly pollen concentration averages calculated from the daily pollen concentrations from Atlanta Allergy and Asthma Network (AAA) in the year 2020 for the city of Atlanta. Flowering seasons appeared to correlate and overlap with higher pollen concentrations in March to June. With this temporal relationship established between higher pollen concentration averages and the flowering periods of the allergenic taxa, this shows that the pollen emitted by the flowering taxa may be a contributing factor to the high pollen concentrations. Given that airborne pollen concentrations are proven to have negative health effects on individuals and populations as a whole and that the selected taxa are behind these pollen concentrations, we move forward to examine the spatial relationship between allergenic taxa density and how it affects health, specifically by pediatric emergency department visit rates for asthma.

The Atlanta Allergy & Asthma Pollen Counting Station is certified by the National Allergy Bureau, displaying daily concentrations of pollen load. We obtained pollen data from the AAA pollen station and calculated monthly averages from January to December of 2020. The AAA data was grouped into Top Contributors of trees, grass, weeds, and mold activity per day.

Pollen Calendars

The reasoning behind visualizing pollen calendars is that airborne pollen season varies in time and space depending on the pollen taxon. Lo et al. (2019) defined the start date as the day when the integral of pollen concentration over that pollen year reaches a threshold of 50 pollen grains/m^3. This is relevant for our study to use as literature has found that mild allergy symptoms are observed at relatively low pollen concentrations of ~ 10–20 pollen grains/m^3, moderate symptoms at ~ 50–90 pollen grains/m^3, and severe symptoms at ~ 80–90 pollen grains/m3 (Rapiejko et al. 2007).

Spatial Analysis

To examine the spatial variation of asthma in the city of Atlanta, Georgia and factors that may explain this variation, the study draws from various datasets. The geographic unit of analysis used here is the census tract. Atlanta is divided into 188 census tracts (n =188). A census tract generally encompasses around 2,500-8,000 people. The Bureau of Census describes the census tract as relatively permanent, but they do change over time. Therefore, compiling data on a certain area over the years needs careful attention in order to discern the correct tract number corresponding to each area. Furthermore, census tracts do not necessarily follow city boundaries. Most census tracts are entirely within one city, but some cross over city limits. For this reason, the study uses around 110 census tracts to address the changing census tract allocations in the study period (2014-2018) and to focus on the census tracts within the city of Atlanta that contain valuable tree data (Fig 1). This was performed to keep the number of census tracts as constant as possible with the least data change. The study chose to focus on this consequently smaller study area within the city of Atlanta to not only to keep census tract data constant, but also to focus only on areas with enough tree sampling. We assume that the resulting study area within the city of Atlanta is a relatively accurate representation of the allergenic treescape and PED asthma visits.

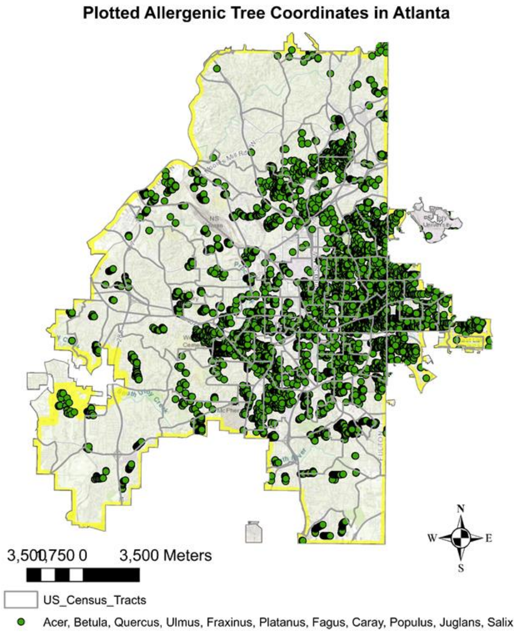


Figure 3.1 City of Atlanta (n=188 census tracts) map with plotted tree coordinates. Shows gradual data amount as the maps spreads outwards towards city limits, indicating missing or uncollected data

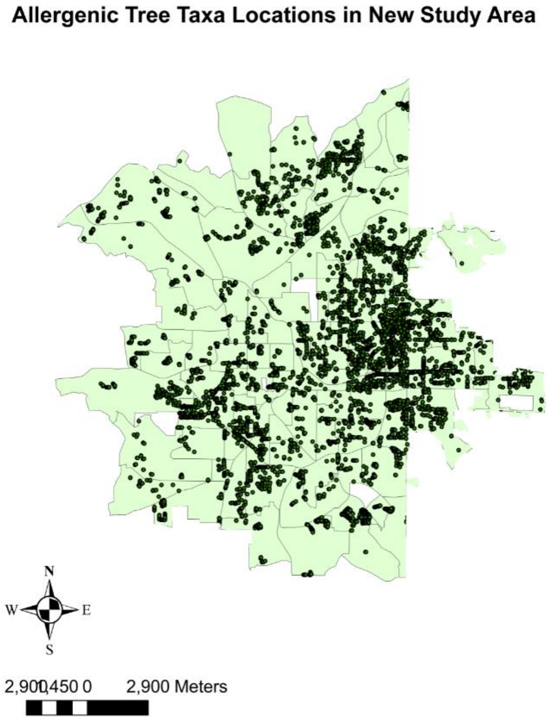


Figure 3.2 New adjusted study area (n=110 census tracts) with 13,347 tree coordinates

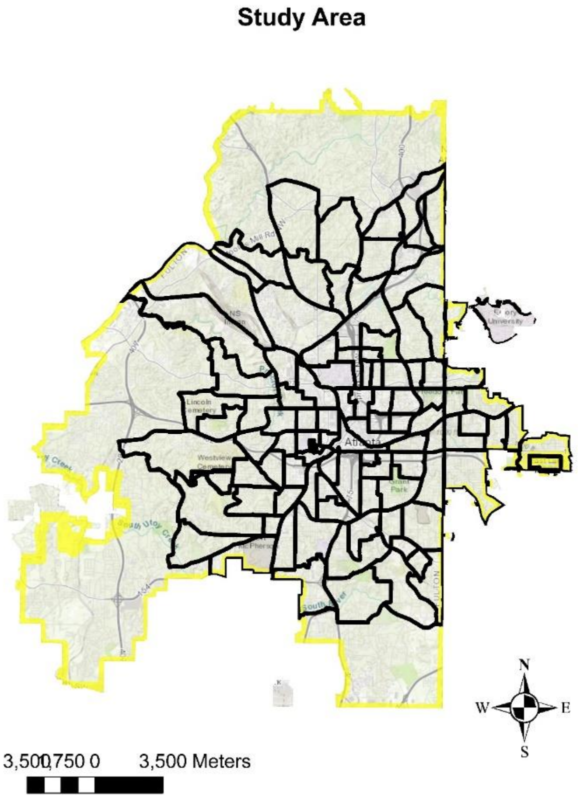


Figure 3.3 Study area comprised of census tracts (n=110) is outlined in black while the city of Atlanta is outlined in yellow. This was done to focus on areas with best data availability

<ins>Variables (Fig.3.4)</ins>

The choice of variables was informed by a population health framework and by the determinants of asthma literature.

Variables	Description	Source	Source
Tree Count per Census Tract	Selected Genera: *Acer* sp., *Betula* sp., *Quercus* sp., *Ulmus* sp., *Fraxinus sp.*, *Platanus* sp., *Fagus sp.*, *Carya sp.*, *Populus* sp., *Salix sp.*, *Juglans sp.*	Trees Atlanta	Emory Herbarium SERNEC Portal
PED Visit Rate per Census Tract	Visits 0-19 years old (ICD-9 classification for asthma, respiratory, allergic rhinitis, allergic asthma, wheezing)	Georgia Hospital Association	Georgia Department of Public Health

Allergenic Vegetation Selection

Trees selected were monitored by the Fulton County Allergen Report where the majority are considered medium to highly allergenic, and for which datasets could be produced covering Atlanta. For convenience, we will refer to them as ‘taxa.’ Trees were selected by genus: *Acer* sp., *Betula* sp., *Quercus* sp., *Ulmus* sp., *Fraxinus sp.*, *Platanus* sp., *Fagus sp.*, *Carya sp.*, *Populus* sp., *Salix sp.*, *Juglans sp.*

Data:

Data collected from Emory University Herbarium, SERNEC Portal, along with the Trees Atlanta occurrence database were used to determine the spatial patterns of coverage by the selected taxa. For (n= 110) census tracts, transformed PED asthma rates and tree count variables were used. The PED asthma rate is defined as the rate of PED asthma check-ins per 1,000 individuals aged 0-19 years. Tree count included the counts of the following genera per census tract: *Acer* sp. (maple), *Betula* sp. (birch), *Quercus* sp. (oak), *Ulmus* sp.(elm), *Fraxinus* sp. (ash), *Platanus* sp. (sycamore), *Fagus* sp. (beech), *Carya* sp. (hickory), *Populus* sp. (poplar), *Juglans* sp.(black walnut), *and Salix* sp (willow).

Allergenic Vegetation Distribution in Metro-Atlanta

Geographic coordinates taken from Emory University Herbarium, SERNEC Portal, and Trees Atlanta databases were mapped onto ArcMap by census tract in the city of Atlanta study area.

In Addressing Abundance:

Incorporation of our map of allergenic taxa is a null model that initially assumes random distribution of species before analysis. Although the model only requires presence/absence data of a single distribution map of a species, it substantially underestimates abundance when applied to empirical data because species are rarely randomly distributed in nature and are typically aggregated (He et al., 2000).

However, due to the nature of herbarium collecting and plotting, it is nearly impossible to fully represent accurate abundance of taxa through geographic coordinates. Due to the scope of the project, the study gathered as much data available to create a comprehensive set of GPS coordinates while recognizing that this dataset is still not as accurate as it could be. For study purposes however, we will assume that the map of coordinates available is an accurate portrayal of true allergenic vegetation landscape in the study area. Well-devised abundance models and ways to calculate species abundance are needed for future herbarium-based GIS studies.

Mapping PED Visit Residences

We capitalize on the availability of public datasets published by the Research & Analytics Group at the Atlanta Regional Commission to show Asthma Related Emergency Room Visits (by census tract) 2014-2018 in Georgia using data from the Georgia Department of Public Health and Census Bureau. Emergency department (PED) visits for children aged under 19 years are obtained from the Georgia Department of Public Health from 2014-2018 (Georgia Department of Public Health). Visits were selected for asthma (identified using primary International Classification of Disease, 9th revision diagnosis codes) by patients residing in ZIP codes located wholly or partially in the study area.

Incidences for respiratory attacks were summarized by frequency and mapped according to census tracts in ArcGIS as a choropleth map. While many health studies georeference by ZIP codes, it is important to remember that ZIP codes were created primarily for delivering mail. While census tracts and block groups were created to have more reliable demographic-economic data, ZIP codes were not and are only delivery statistics developed by the U.S. Postal Service (Waller et al., 2004). A study by Krieger et al. (2003) looked at whether the choice of area-based geographical units really matter for mapping data for public health surveillance. Krieger et al. (2003) reported that measure mapping health outcomes at a ZIP code-level failed to detect patterns or gradients that were otherwise observed with census tracts and block groups. Therefore, for the purposes of spatial autocorrelation through Moran's I analysis of asthma-related PED visit rates, this study will map the visit rates by census tract.

To address non-random spatial distribution, we introduce the use of spatial autocorrelation to detect patterns in our variables.

Visual Assessment of Pediatric Health in Atlanta:

The rate of children's ED visits for asthma increased 13.3% between 2001 and 2010, from 8.2 to 9.3 visits per 1,000 children (p=0.26) (Nath et al., 2015).

This study notes that racial/ethnic differences in asthma frequency, illness and death are highly connected with poverty, city air quality, indoor allergens, not enough patient education/healthcare, and genetics. (CDC.gov. (2018) [Accessed 10 Feb 2021]). For example, the rate of asthma and the prevalence of asthma episodes is highest among overall population of Puerto Ricans compared to all ethnic groups. (CDC.gov. (2018) [Accessed 10 Feb 2021]). However, African-American children have the highest prevalence of asthma, with about 13.4 percent asthma prevalence compared to about 7.4 percent of white children with asthma (CDC.gov. (2018) [Accessed 10 Feb 2021]). For the future, a multivariate logistic regression could be used to determine what demographic, clinical, and structural factors were associated with a child's ED visit being for a potentially preventable asthma crisis.

A map was produced by taking the national rate of 9.3 per 1,000 children that was subsequently used in mapping PED visits and as the divider of high rate versus ‘normal’ rate zones for our 2014-2018 data, applying the national rate as a constant indicator for the metro-Atlanta region.

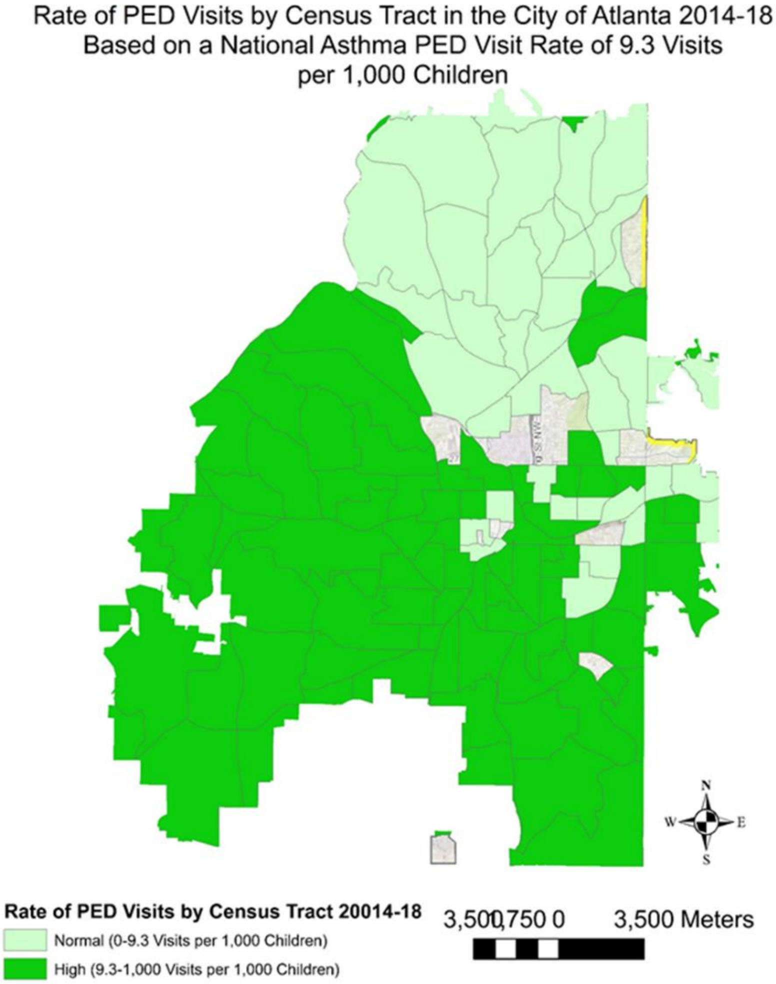


Figure 3.5 Normal vs High Zones of Asthma PED visit rates in metro-Atlanta by census tract (prior to new study area adjustment)

While maps allow visual assessment of spatial patterns, they have two primary limitations: 1) interpretation is subjective and can vary by person, and 2) there is a possibility that even if a pattern is perceived, it may be a result of chance and thus not actually meaningful.

For these given reasons, it makes sense to compute a numerical measure of spatial pattern, which can be accomplished by spatial clustering and bivariate analysis.

Analysis:

Data analysis involved five steps. In step 1, the tree count and PED visit rates were tested for normal distribution. They were not found to follow normal distribution. Therefore, both variables were transformed to follow normal distribution by applying log transformation using Python 3. In step 2, calculation of global Moran's *I* for transformed tree count and PED visit rates was performed to detect the global clustering and the significance of *I*-statistic using permutation test for each variable examined. Step 3 involved the application of local Moran's *I* to detect the local clusters for transformed tree count and PED visit rates. In step 4, visual inspection and evaluation of local Moran's I values for each variable was carried out based on choropleth mapping. Lastly, in step 5, the bivariate relationship between tree count and PED rates were analyzed through scatter plot matrix observations, Ordinary Least Squares regression in Python, and followed by Geographically Weighted Regression in ArcMap 10.8.1. Python packages used were: panda, numpy, matplotlib.pyplot, seaborn, scipy.stats, csv, matplotlib, and statsmodels.api.

The tree count and PED rate values were categorized into five classes using natural breaks. These intervals were used for all maps using darker shades of green to indicate increasing values of the two variables in order to simplify qualitative assessment of spatial relationship and pattern. In this research neighboring structure was defined as census tracts that share at least one boundary. The *second order* method (queen pattern) which included both the first-order neighbors (rook pattern) and those diagonally linked (bishop pattern) was used.

Introduction of Spatial Autocorrelation and Identification of global spatial clustering:

Spatial autocorrelation analyses Moran’s I is a commonly used indicator of spatial autocorrelation. The goal of a global index of spatial autocorrelation is to summarize the degree to which similar observations happen near each other geographically. Spatial autocorrelation using standard normal deviate (z-value) of Moran’s I under normal assumption was tested. Moran’s I is a coefficient used to measure strength of a spatial autocorrelation given regional data. However, this test does not account for statistical significance of local clustering.

Local Spatial Clustering:

A global clustering test can determine clustering but not individual clusters (Waller et al., 2004). Local Moran’s I statistic is used to test local autocorrelation, where local spatial cluster—hot spots—can be identified. As the name suggests, the local indicators of spatial association measure the degree of spatial autocorrelation at each specific location. Local indicators may help with assessing the influence of individual locations on the magnitude of the global statistic and to identify outliers.

In this study, local Moran’s I was used following global Moran’s I. Its values range from −1 to 1. The value “1” means perfect positive spatial autocorrelation (high values or low values cluster together), while “−1” suggests perfect negative spatial autocorrelation, and lastly “0” implies perfect spatial randomness (Fu et al., 2014). Because it is good for identifying local spatial cluster patterns and spatial outliers (Fu et al., 2014), this study used this spatial analysis method to apply to tree count and PED visit rates.

Analyzing bivariate relationships:

We test the autocorrelation of both variables because either one depends on the other or because the same underlying process structures both variables. Because autocorrelation in one variable (high pollen-producing taxa distribution) could cause the same spatial pattern in another variable that depends on it (ED visit rate distribution), it is necessary to account for this autocorrelation. Therefore, Ordinary Least Squares and Geographically Weighted Regression are applied to estimate the spatial correlation between the two variables.

The Ordinary Least Squares (OLS) regression is a very most well-known technique that explores spatial patterns. It applies a global model in which one equation is generated for the entire study area to generate predictions and models the dependent variable (PED rates) in terms of its relationship to the independent variable (tree count). Once the tree count, the independent variable, is identified, and there is a theoretical basis for its spatial heterogeneity, the Geographically Weighted Regression (GWR) is the appropriate next step.

GWR is an extension of the linear model which allows for its analysis/model to vary over space. Unlike Ordinary Least Squares Regression analysis, the GWR analysis looks for geographical differences and looks at spatial variations in the relationship between the dependent variable and the independent variables locally.

Consequently, geographically weighted regressions can be seen as an outgrowth of ordinary least squares regression (OLS) and adds a level of modeling sophistication by allowing the relationships between the tree count and PED rates to vary by locality. It also takes into account the spatial autocorrelation of variables. The study chose to perform a GWR because the method echoes the central dogma of this research in that it addresses how variables vary across a landscape.

CHAPTER 4: RESULTS

The temporal relationship between taxa flowering periods and peak pollen months was deemed through visual evaluation to be positively correlated, establishing the link between the high average pollen concentrations during those months of flowering taxa. This shows that the pollen emitted by the flowering taxa may be a contributing factor to the high pollen concentrations.

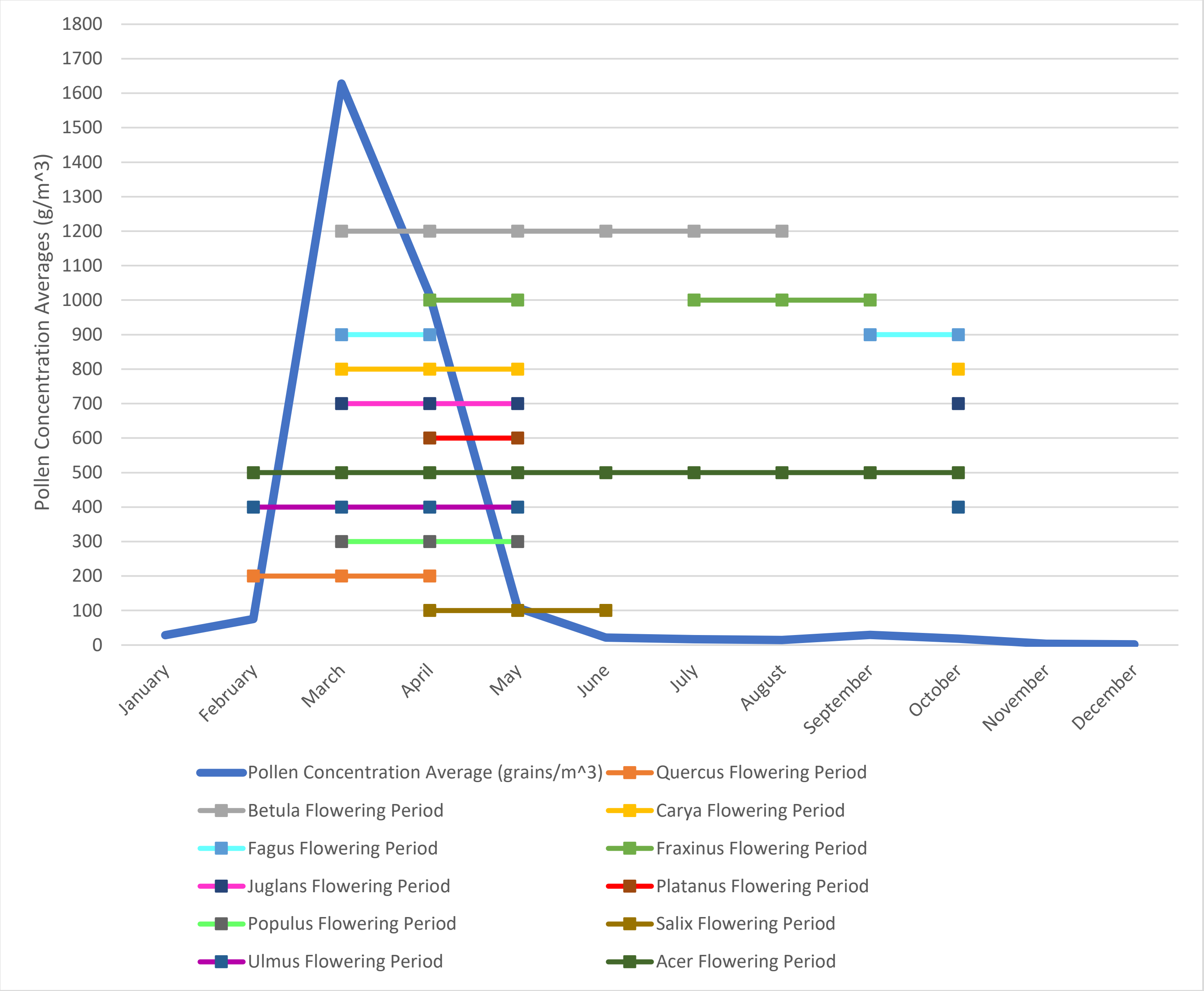
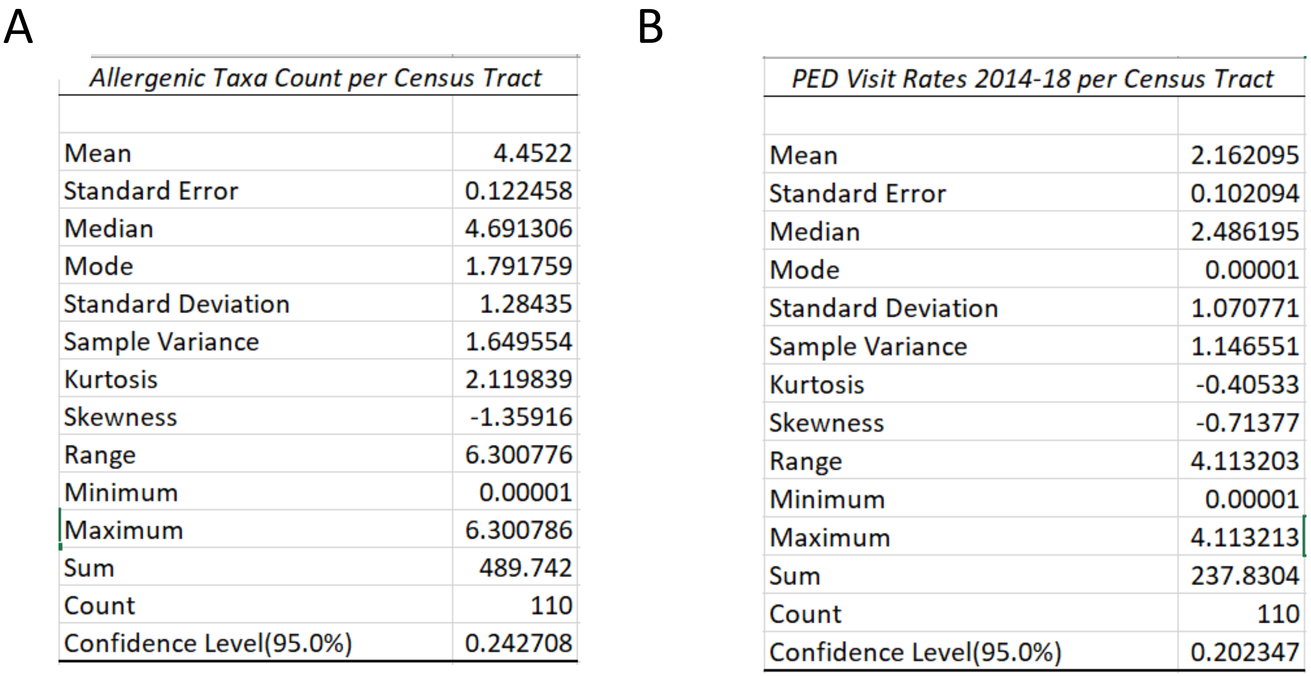


Figure 4.1 Monthly pollen concentration averages and genus flowering periods. Pollen concentration (g/m^3) peaks in the months of March-May, during which the majority of the taxa have their flowering periods/begin peak pollination

Data sources from: Lo et al. - 2019—Pollen calendars and maps of allergenic pollen in .pdf. (n.d.). Retrieved March 25, 2021, from https://atmos.uw.edu/~david/Lo_etal_2019.pdf; Radford, A. E., Ahles, H. E., & Bell, C. R. (1968). *Manual of the vascular flora of the Carolinas by Albert E. Radford, Harry E. Ahles and C. Ritchie Bell*. Chapel Hill: University of North Carolina Press; *Pollen Count History | Atlanta Allergy & Asthma*. (n.d.). Retrieved Feb 19, 2021, from https://www.atlantaallergy.com/pollen_counts

Descriptive analyses were then performed to assess the demographic characteristics of the data sets. The mean and standard deviation for transformed tree count data 4.45 and 1.28 respectively; skewness and kurtosis were found -1.36 and 2.12, respectively. Summary of transformed tree count data set consists of: Min=0.00, Max=6.30, and Sample Variance=1.65. In addition, descriptive statistics were calculated for transformed PED visit rates, where the mean and standard deviation were found 2.16 and 1.07 respectively; skewness and kurtosis were found -0.71 and -0.41 respectively. The summary of transformed PED data set was: Min=0, Max=4.11, and Sample Variance=1.15.



A

Allergenic Taxa Count per Census Tract	
Mean	4.4522
Standard Error	0.122458
Median	4.691306
Mode	1.791759
Standard Deviation	1.28435
Sample Variance	1.649554
Kurtosis	2.119839
Skewness	-1.35916
Range	6.300776
Minimum	0.00001
Maximum	6.300786
Sum	489.742
Count	110
Confidence Level(95.0%)	0.242708

B

PED Visit Rates 2014-18 per Census Tract	
Mean	2.162095
Standard Error	0.102094
Median	2.486195
Mode	0.00001
Standard Deviation	1.070771
Sample Variance	1.146551
Kurtosis	-0.40533
Skewness	-0.71377
Range	4.113203
Minimum	0.00001
Maximum	4.113213
Sum	237.8304
Count	110
Confidence Level(95.0%)	0.202347

Figure 4.2 (A) Descriptive statistics for allergenic taxa count per census tract after log transformation; (B) Descriptive statistics for PED visit rates 2014-2018 per census tract after log transformation

We see visualizations of trends/patterns of high concentration coverage and low concentration coverage from allergenic vegetation and PED visit residences in the resulting maps. The figures show maps of visualizations of transformed tree count and PED rates. There is an unclear spread of tree count across census tracts. Visual inspection of transformed tree count map shows a negligible landscape of higher counts and lower counts of major pollen-producing trees within the study area.

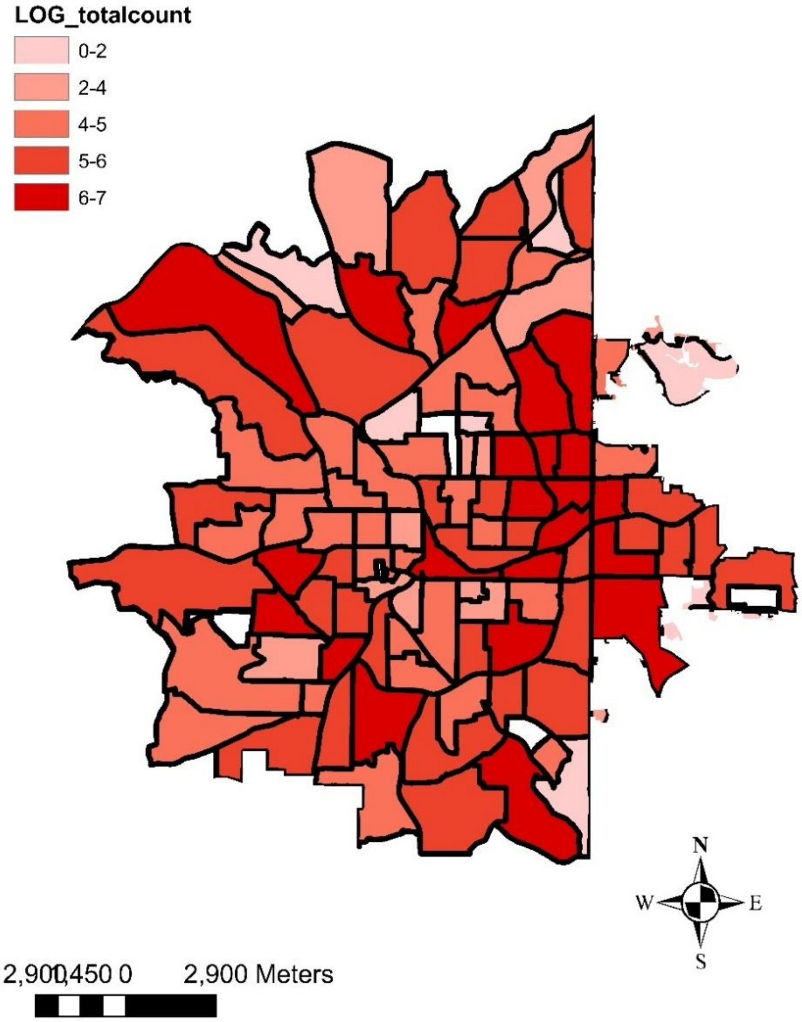


Figure 4.3 Transformed tree count per census tract displayed. There is an unclear pattern of tree count.

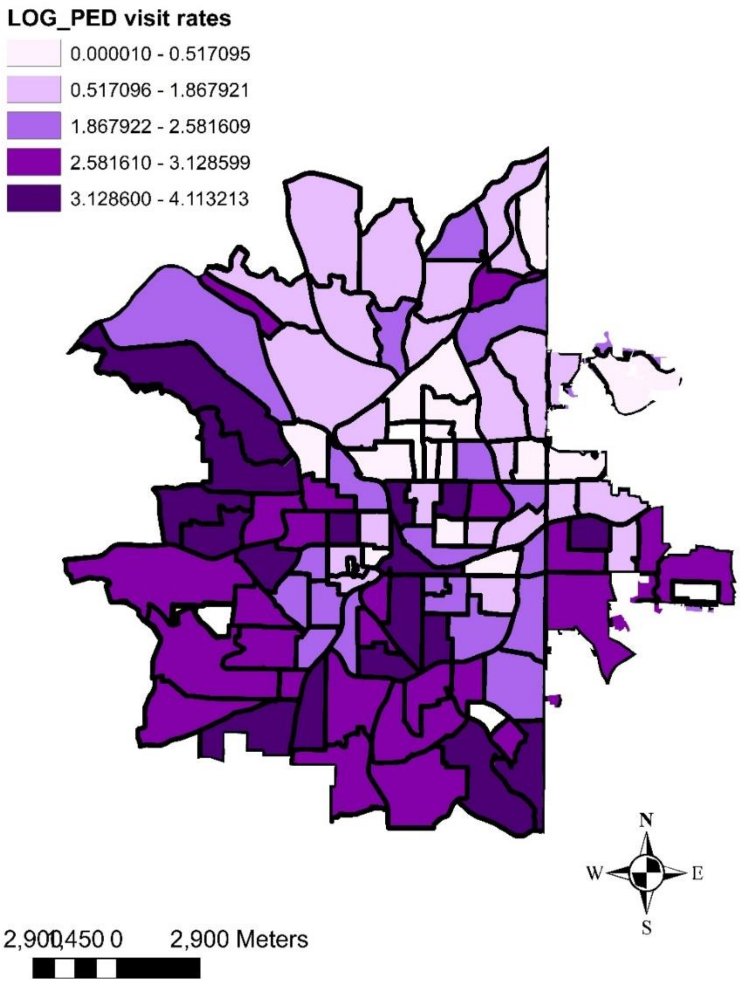
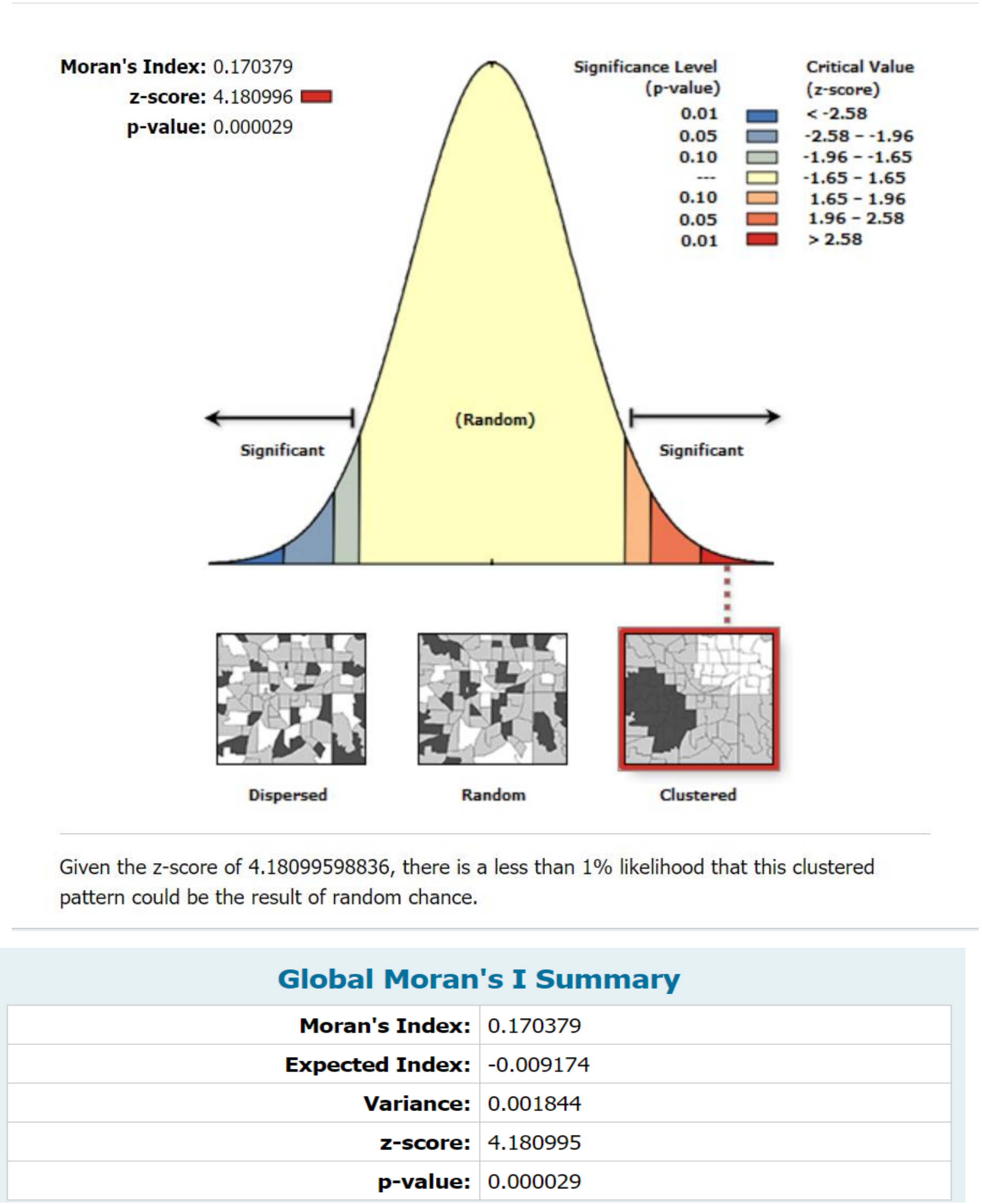


Figure 4.4 Transformed PED visit rate per census tract displayed. There is a pattern of higher rates from the southwest area of metro-Atlanta study area.

Visual observation of transformed PED rates shows higher rates of PED visits (an overall worsening pattern) in the southwest region of the Atlanta study area.

Spatial clustering was confirmed for log transformed allergenic tree taxa count by a positive significant global Moran’s I of 0.17 and an associated standard normal z-value of 4.18 and p-value of 0.000029. Strong spatial clustering of log transformed PED visit rates was also confirmed by a positive significant global Moran’s *I* of 0.29 with an associated standard normal *z*-value of 6.91 and *p*–value = 0.00000.

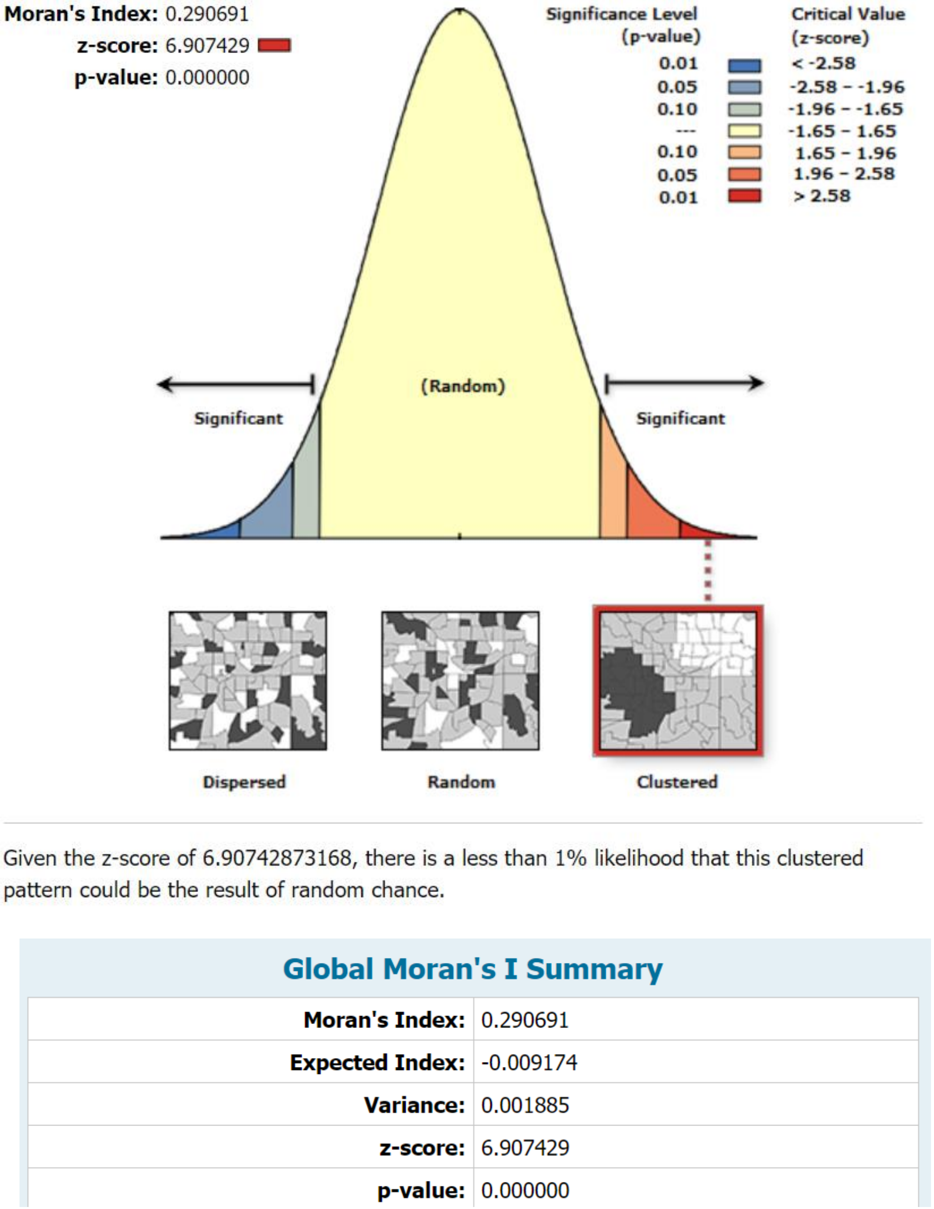


Given the z-score of 4.18099598836, there is a less than 1% likelihood that this clustered pattern could be the result of random chance.

Global Moran's I Summary

Moran's Index:	0.170379
Expected Index:	-0.009174
Variance:	0.001844
z-score:	4.180995
p-value:	0.000029

Figure 4.5 Global Moran’s I results for transformed tree count per census tract



Moran's Index: 0.290691
z-score: 6.907429
p-value: 0.000000

Given the z-score of 6.90742873168, there is a less than 1% likelihood that this clustered pattern could be the result of random chance.

Global Moran's I Summary

Moran's Index:	0.290691
Expected Index:	-0.009174
Variance:	0.001885
z-score:	6.907429
p-value:	0.000000

Figure 4.6 Global Moran's I results for transformed PED visit rate per census tract

Global spatial clustering was further investigated using permutation tests, where the permutation p-value for transformed tree count was found insignificant at p=0.09. The permutation p-value for PED visit rates was p=0.02 and was found to be statistically significant.

Thus, the null hypothesis of no spatial autocorrelation was rejected for PED rates but not rejected for tree count.

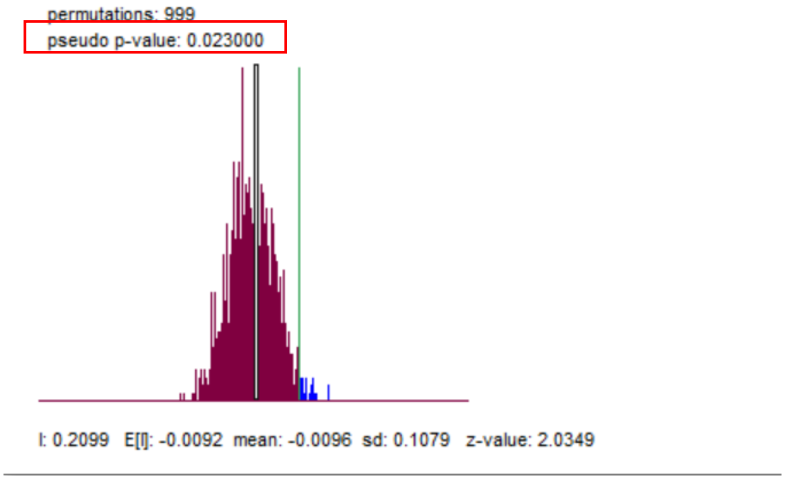


Figure 4.7 Permutation test results for transformed PED visit rates per census tract

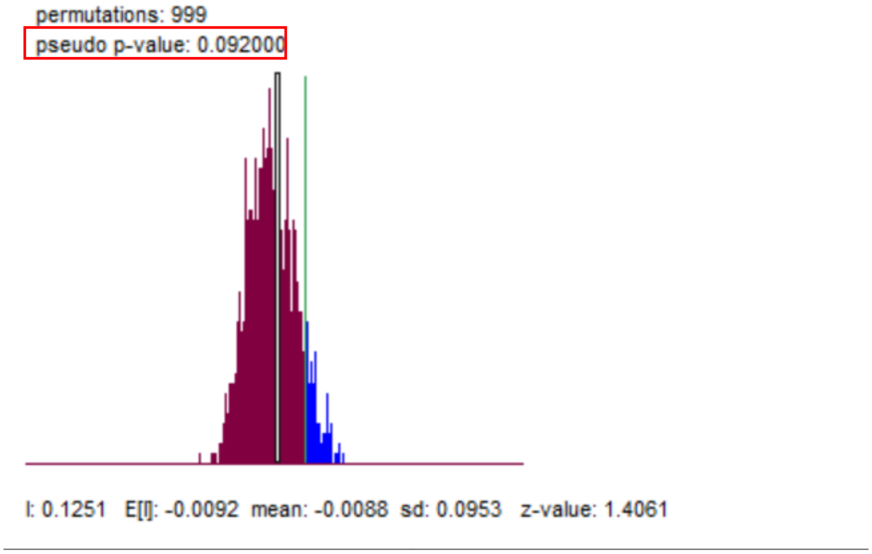


Figure 4.8 Permutation test results for transformed tree count per census tract

The local Moran's I map shows high-high clusters for tree count within the center of the study area. Local Moran's I map of PED rates shows high-high clustering in the southwest region, and then a mixture of high-low and low-low clustering in the northeast area of the map.

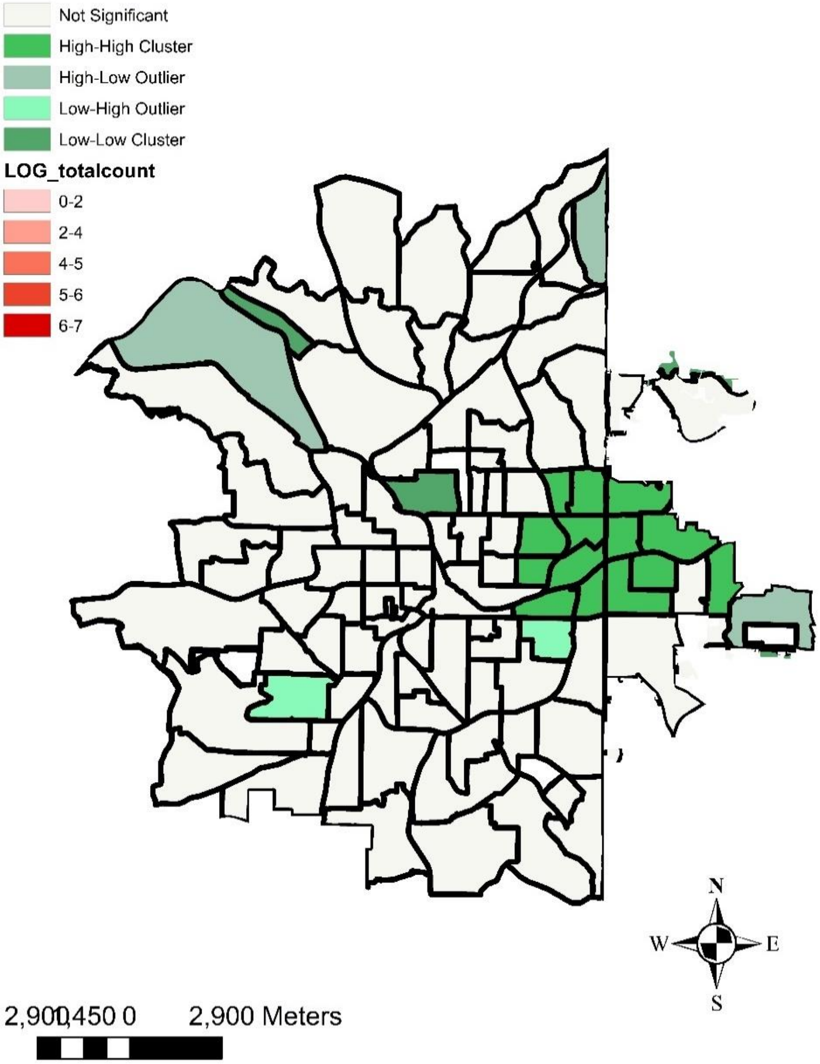


Figure 4.9 Local Moran's I results for transformed tree count

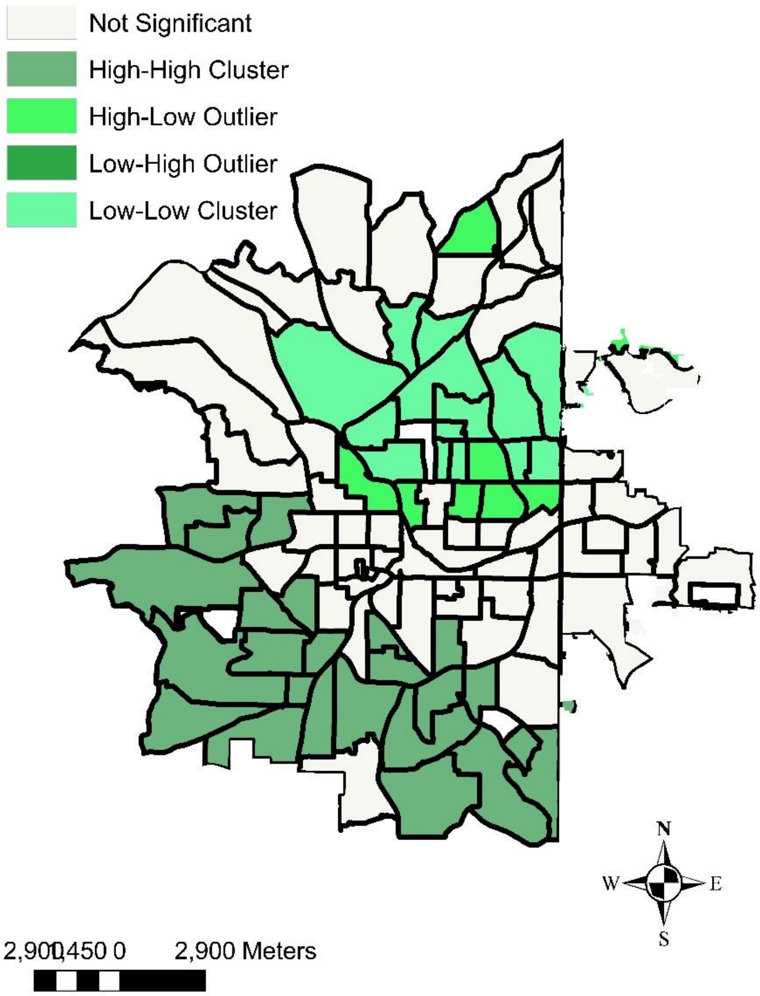
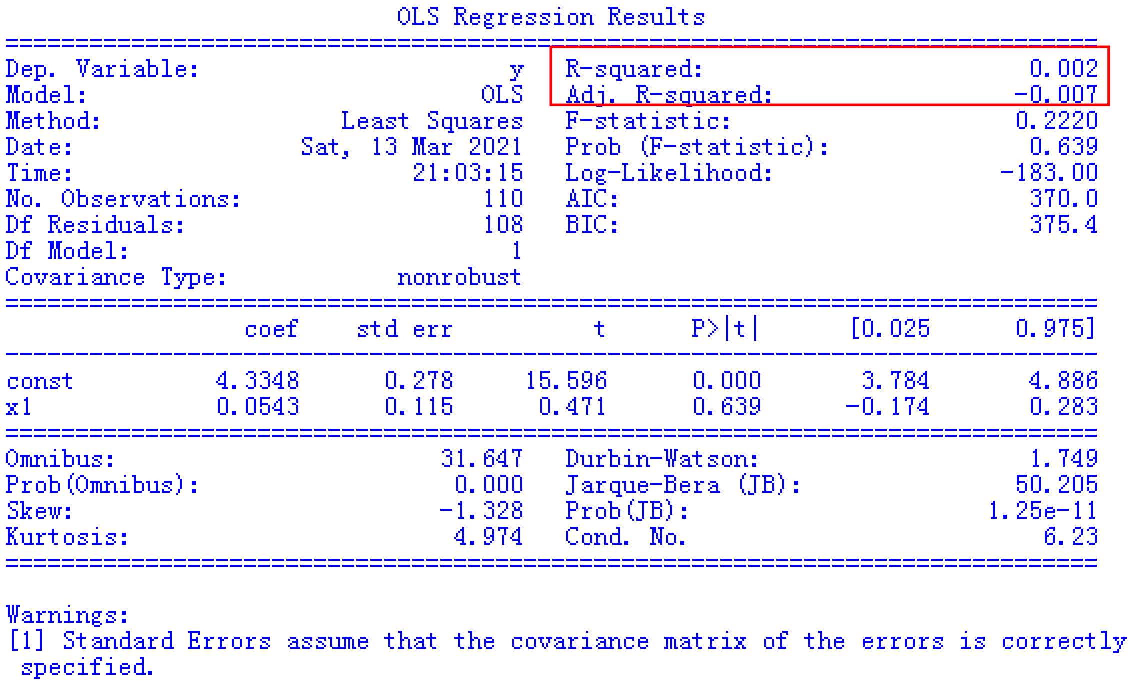


Figure 4.10 Local Moran's I results for transformed PED visit rates

OLS yielded an adjusted R^2 value of -0.007 and a corresponding p-value of p=0.94, which was statistically insignificant. Interestingly, the GWR resulted in unadjusted R^2 or R^2=0.33 and a corresponding p-value of p=0.00043 which is statistically significant. The figures show the GWR results and local R^2 values, which is to say the measure of the quality of prediction for each census tract. The relevance of the adjusted R^2 value is that it explains about 33% of the variance and behavior of the dependent variable.



```
                            OLS Regression Results
==============================================================================
Dep. Variable:                      y   R-squared:                       0.002
Model:                            OLS   Adj. R-squared:                 -0.007
Method:                 Least Squares   F-statistic:                    0.2220
Date:                Sat, 13 Mar 2021   Prob (F-statistic):              0.639
Time:                        21:03:15   Log-Likelihood:                -183.00
No. Observations:                 110   AIC:                             370.0
Df Residuals:                     108   BIC:                             375.4
Df Model:                           1
Covariance Type:            nonrobust
==============================================================================
                 coef    std err          t      P>|t|      [0.025      0.975]
------------------------------------------------------------------------------
const          4.3348      0.278     15.596      0.000       3.784       4.886
x1             0.0543      0.115      0.471      0.639      -0.174       0.283
==============================================================================
Omnibus:                       31.647   Durbin-Watson:                   1.749
Prob(Omnibus):                  0.000   Jarque-Bera (JB):               50.205
Skew:                          -1.328   Prob(JB):                     1.25e-11
Kurtosis:                       4.974   Cond. No.                         6.23
==============================================================================

Warnings:
[1] Standard Errors assume that the covariance matrix of the errors is correctly
 specified.
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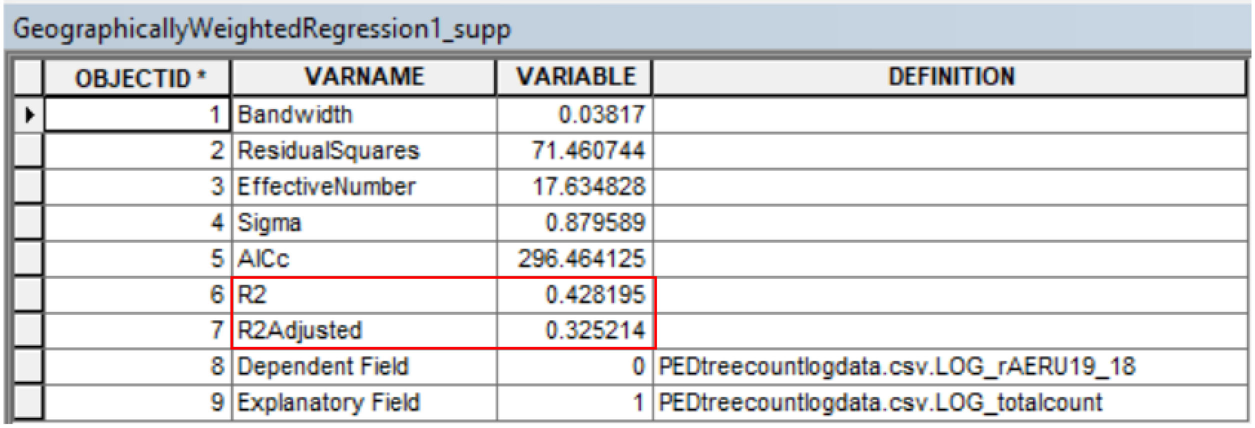
Figure 4.11 OLS regression results. The red box outlines the R-squared values



GeographicallyWeightedRegression1_supp

OBJECTID *	VARNAME	VARIABLE	DEFINITION
1	Bandwidth	0.03817	
2	ResidualSquares	71.460744	
3	EffectiveNumber	17.634828	
4	Sigma	0.879589	
5	AICc	296.464125	
6	R2	0.428195	
7	R2Adjusted	0.325214	
8	Dependent Field	0	PEDtreecountlogdata.csv.LOG_rAERU19_18
9	Explanatory Field	1	PEDtreecountlogdata.csv.LOG_totalcount

Figure 4.12 GWR regression results. The red box outlines the R-squared values

The map of GWR standardized residuals (**Figure 4.13**) shows differences of expected and observed values. The areas in red show where real values are higher than predicted and the blue areas show where real values are lower than predicted. There is no pattern evident in the map, which is ideal as an existing pattern would indicate another geographical phenomenon present, which would mean another confounding variable/variables. In other words, statistically significant spatial autocorrelation of residuals is almost always a symptom of misspecification (a key variable is missing from the model).

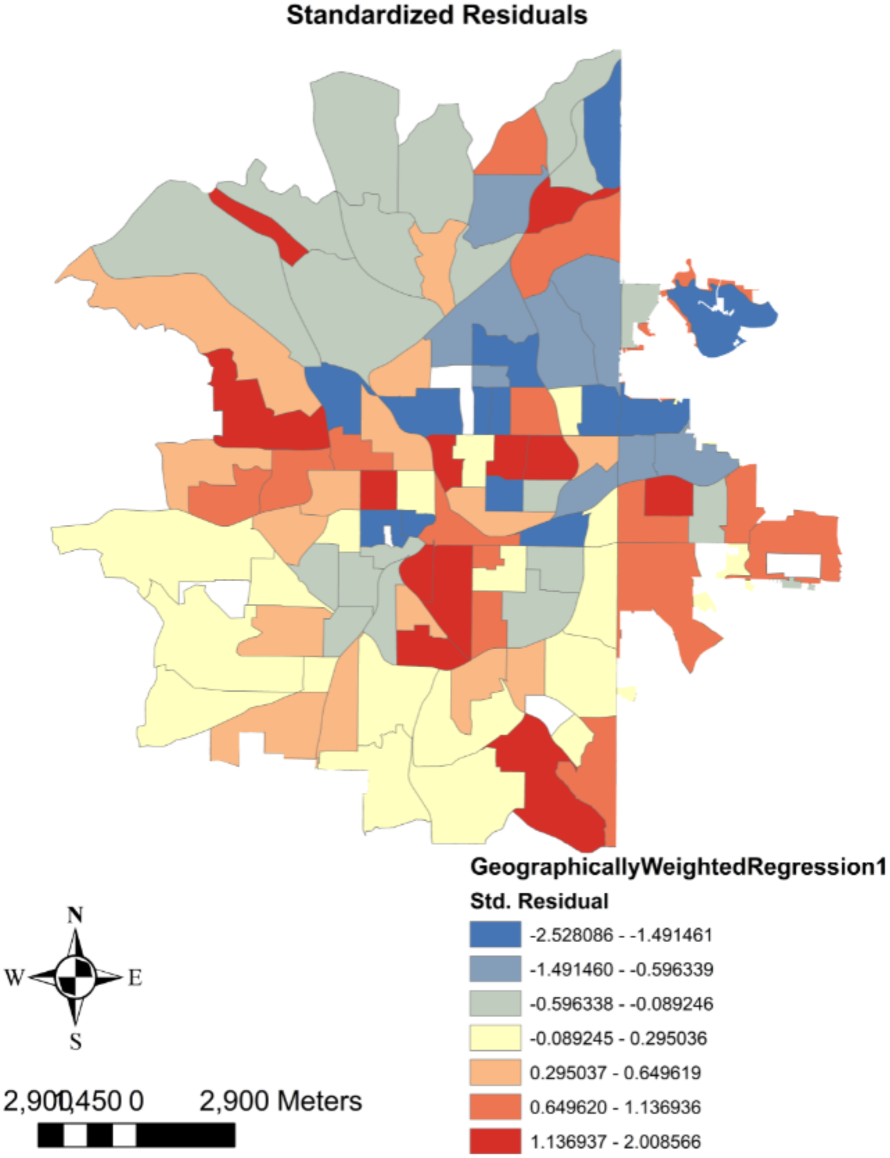


Figure 4.13 Map of GWR standardized residuals

The GWR results were able to show local geographic variation in the performance of the model regression equation. The map of local R^2 values shows how well the model is able predict PED visit rates using tree count in parts of the study area. There appears to be regional variability in the ability to predict PED visit rates based on the map. The blue areas represent less predictive ability while the red areas represent greater predictive ability. The map appears to show greater predictive ability in the center of the study area, diminishing in predictive ability as it progresses towards the outer region.

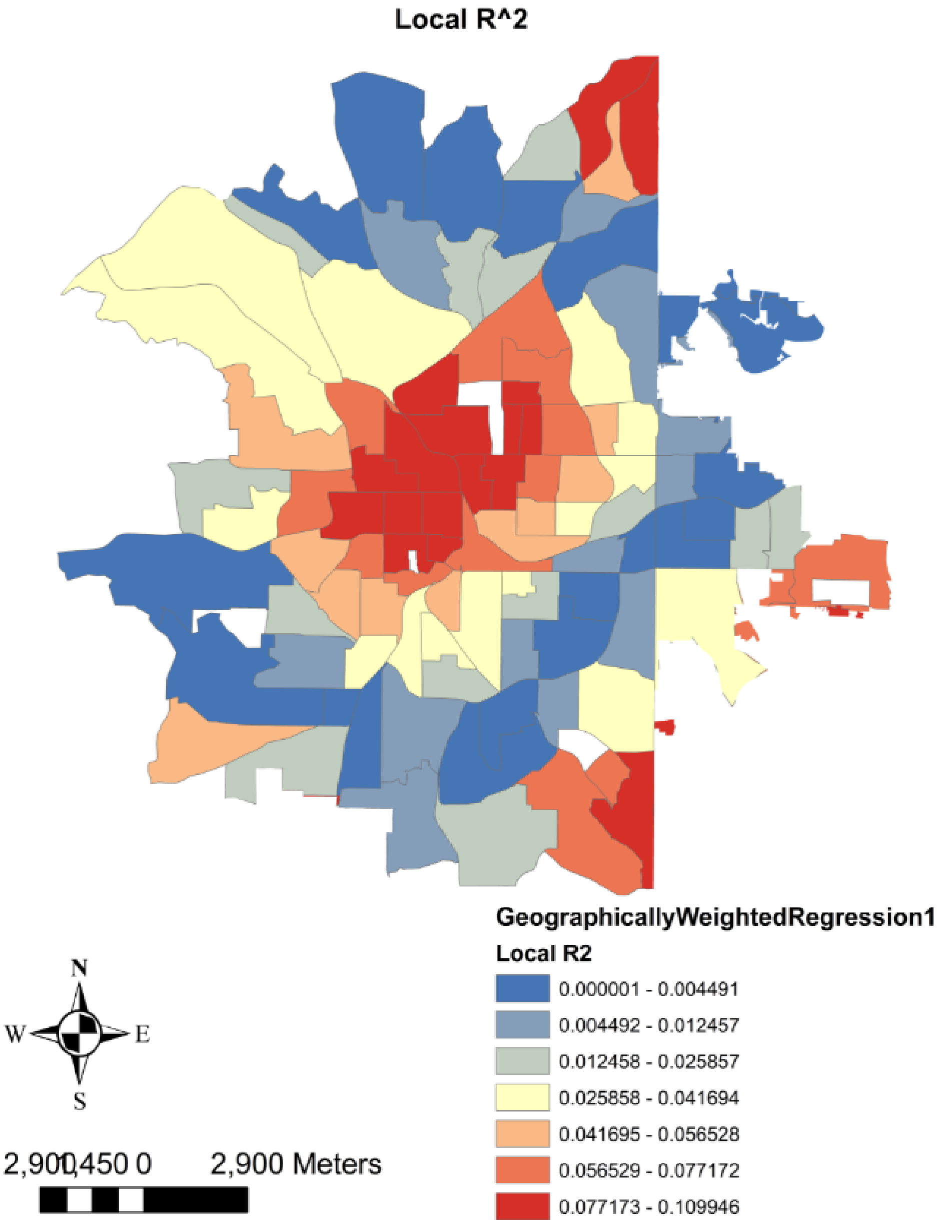


Figure 4.14 Map of GWR Local R^2 values

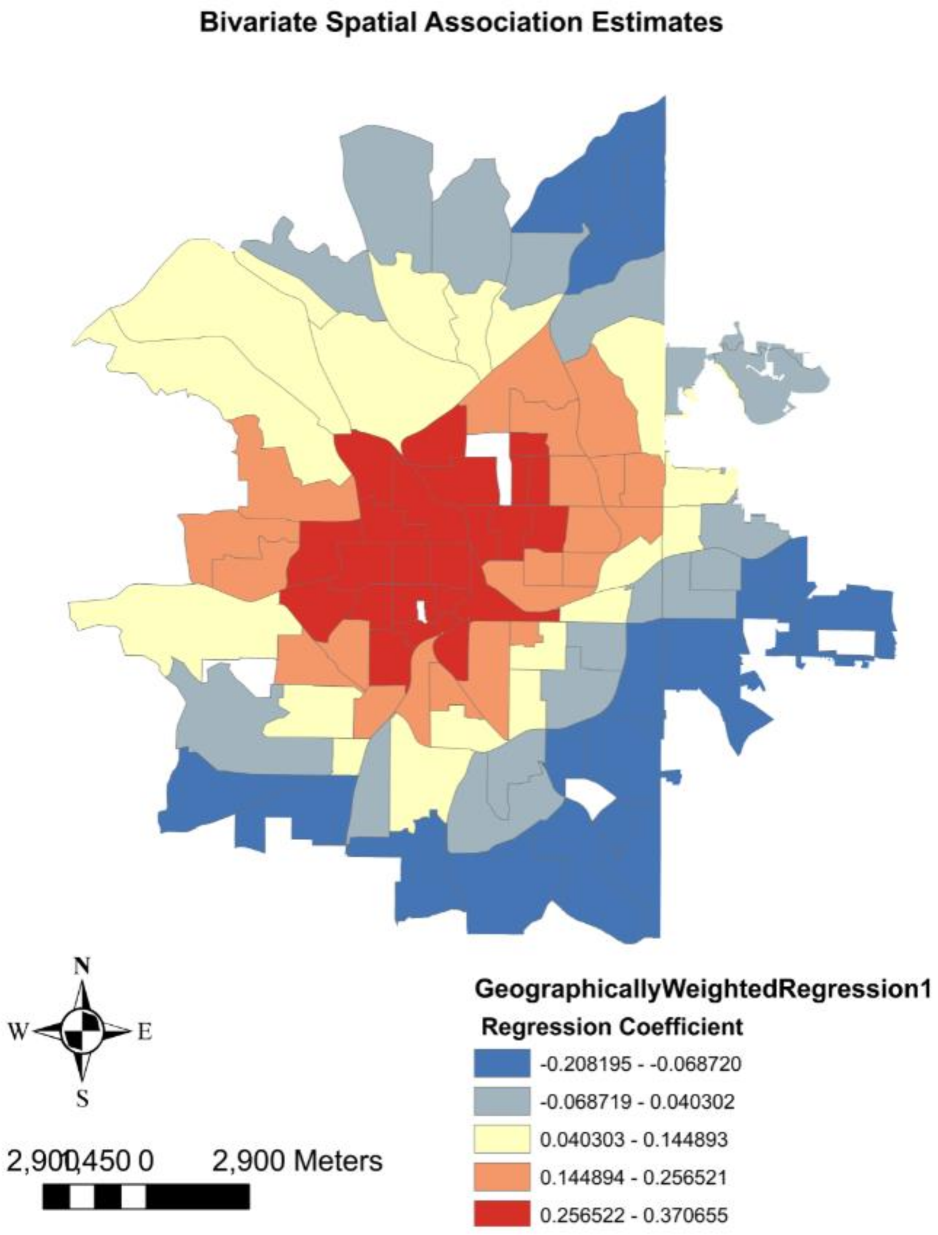


Figure 4.15 Map of spatial association estimates between tree count and PED visit rates

The map of the bivariate spatial association estimates indicates the regression coefficient by tract. The sign of the regression coefficient tells you whether there is a positive or negative correlation. We see that there is positive correlation in the center of the study area and negative as it progresses to the study area limits.

CHAPTER 5: DISCUSSION

Implications of Results:

Spatial Autocorrelation

ArcGIS performed both Global and Local Moran's I on transformed tree count and PED visit rate datasets. While both Global Moran's indices indicated that the two variables had significant spatial clustering, the permutation tests applied following the procedure revealed that that while the null hypothesis of PED visit rates was rejected, the null hypothesis for tree count failed to reject with a p-value of p=0.09.

Local Moran's I visualizations showed high-high clusters on different regions for both variables mapped, meaning that there are areas of clusters of features with similarly high values near each other to the degree that they are statistically significant. Similarly, there were also low-low clusters, in which there are areas of clusters of features with similarly low values near each other. High-low clusters were particularly present on the PED visit rate Local Moran's I map in the northeastern area, in which high PED rates were surrounded by particularly low PED rates.

Bivariate Analysis

While OLS analysis found the relationship between tree count and PED visit rates to be statistically insignificant, we cannot discount that the GWR analysis found there to be a statistically significant association between the two variables, but that this association is not the same in every location. Therefore, this evidence suggests that there is potentially an existing spatial relationship between allergenic tree count and PED visit rates, and that the density of major pollen-producing trees may be used to predict allergic asthma outcomes. Proximity to allergenic taxa and consequent exposure to pollen produced by the taxa is important to acknowledge. Looking at Figure 5.1, Grove Park, West End, Grant Park, and downtown Atlanta are areas that healthcare providers and policymakers should gain a better understanding of why these higher PED rates are occurring (**Figure 4.10**) and how allergenic tree taxa density is influencing these outcomes and how correlated these two variables are (**Figure 4.14, 4.15**), based on local Moran’s I and GWR maps (**Figures 4.10, 4.14, 4.15**).

Figure 5.1 Neighborhoods of Atlanta

However, since the OLS analysis prior to the GWR analysis yielded a statistically insignificant result, it is necessary to take caution in assuming such a spatial association, as results may indicate presence of confounding variables. Furthermore, the GWR Local R^2 map shows us the regional variation in the regression model's ability to predict PED visit rates from tree count, which is not the same as correlation in values between the two variables. The GWR adjusted R^2 value was also relatively low at .33. The regression coefficients mapped also shows the heterogeneity of the study area, with negative correlation along the border of the city. With the relatively low R^2, this has implications of confounding. Consideration of external factors must be taken into consideration before implementing policy measures in order to prevent any adverse effects as we cannot be certain of this relationship.

Despite the results, this study performed novel research by illustrating the geographical distributions of allergenic trees and can be used to study taxa in Atlanta that are associated with allergy and allergic asthma. These maps have been made to study environmental exposure and human health but have other possible applications. We note that certain taxa are considered more important aeroallergens than others. For example, *Pinus* sp. (pine) is considered to be a mild allergen as its released pollen grains are generally far too large to enter our eyes, nose, and mouth to cause any histamine reaction or inflammatory response from our immune system.

This method not only provides novel maps of many different allergenic taxa, but also fills a need for a pilot vegetation map for environmental exposures in Atlanta. This method presented here could be duplicated for other cities and counties and can be further improved with an initial assessment of data availability and expertise on plant types and land cover. The information mapped can serve to be useful indicators of potential risk zones for populations vulnerable to allergy-related asthma and other respiratory conditions, honing in on the predictive value of allergenic tree taxa distribution on asthma PED rates .

Uncertainty with respect to species information and inventory method

Lack of regional-level species information is what is likely to cause the largest uncertainties in our maps as it can be difficult to obtain comprehensively or in full. The consequence is that our mapping will underestimate the abundance of certain species in regions, as lack of information takes away from accuracy. Particularly with mapping our results, it is difficult to be exact with the aggregation of trees, weeds, and grasses as environmental changes can occur such as construction, renovation, and deforestation that is not documented and thus not readily available as information. Improvements in mapping this area could be obtained with focused herbarium studies or high-resolution satellite remote sensing. A limitation to herbarium collection studies would be collection bias, as species collected by a collector may not capture the true allergenic landscape. Therefore, satellite remote sensing may address this issue and work as a less biased approach.

Public Health Relevance

The maps presented provide locations of tree taxa that contribute to allergenic pollen levels in Atlanta. There is increasing evidence that children and adolescents exposed to outdoor pollen may be at an increased risk of asthma exacerbations requiring ED visits. Given this risk, simple yet effective interventions for the management of asthma exacerbations could be explored and developed. This study is important because it guides us to many simple and cost-effective local public health preventative strategies can avoid pollen exposures during pollen seasons such as planting nonallergenic plants and not mowing grass and staying indoors on high pollen days. For example, certain cities have media alerts of high pollen day forecasts implemented in various media networks during the pollen seasons (Erbas et al., 2007). At the primary care level, using the maps made can better understanding of this risk will enable healthcare providers to encourage patients to take medication more diligently as a precaution and understand where they are coming from in context of areas with higher allergenic taxa density.

The health detriments of high allergenic taxa density are influenced by many factors. Considering the impact of evolving allergenicity of pollen, climate change, air quality, socioeconomic factors, and possible solutions to these problems that impact public health are addressed in the following sections. In summary, pollen of different taxa is an important risk factor for asthma exacerbations.

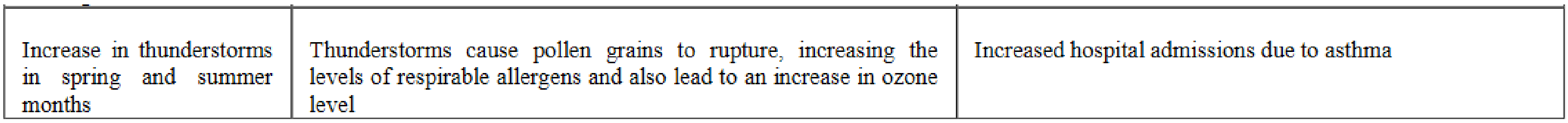
Timing of Release of Pollen Grains

Timing of peak pollen emissions and flowering seasons for each allergenic taxa was examined in the study is given. Peak pollen emissions were recorded because this time period is when allergy symptoms typically tend to worsen.

Effect of Climate Change

Impact of Climate change on pollen allergy:

A body of evidence suggests that major changes involving the anthropogenic-induced climate change may have an impact on the biosphere and human environment. We see that pollen allergy is frequently used to study the interdependency between air pollution and allergic respiratory diseases—allergic rhinitis and asthma (D’Amato et al., 2015). Epidemiologic studies have demonstrated that urbanization is correlated with an increase in the frequency of pollen-induced respiratory allergy in people who live in urban areas compared with those who live in rural areas (Mir et al., 2013). Despite this, studies on the effects of climate changes on respiratory allergy are still lacking. The current knowledge is provided by epidemiological and experimental studies on the relationship between asthma and factors such as meteorological variables, allergens, and air pollution (Mir et al., 2013).



Increase in thunderstorms in spring and summer months	Thunderstorms cause pollen grains to rupture, increasing the levels of respirable allergens and also lead to an increase in ozone level	Increased hospital admissions due to asthma

Figure 5.2 Cause and effect of thunderstorm asthma

Studies on plant responses to elevated CO2 concentrations show that plants exhibit increased photosynthesis and as a result, produce more pollen (D'Amato, 2000). Meteorological factors (temperature, wind speed, humidity, thunderstorms, etc.) along with the climate of the region can affect both biological and chemical components of this interaction. Climatic factors (temperature, wind speed, humidity, thunderstorms (**Figure 5.1**), etc.) can affect both components (biological and chemical) of this interaction (Mir et al., 2013). By attaching to the surface of pollen grains, pollutants could modify not only the makeup of pollen grains but also their allergenic potential.

Interaction with Air Quality

According to D'Amato et al., (2007), people who live in urban areas have been shown to be more affected by pollen allergies (asthma and allergic rhinitis) than those who live in rural areas (D'Amato et al., 2007). Air pollution, which increases airway permeability, can overcome the mucosal barrier through inflammation of the airway, leading to the priming of allergen-induced responses (Mir et al., 2013). However, the relationship between air pollution, pollen exposure, and respiratory allergy varies for each individual's response to air pollution, which also depends on what the pollution is comprised of. Therefore, further research is required to conclude definitively on the interaction between air pollutants and pollen.

Due to the interdependency of air pollution and pollen exposure on asthma outcomes, it is difficult to separate the primary causative agent. However, various studies have done more comprehensive research on the connection between air pollution and asthma, and the findings look at breakdowns of levels of PM2.5, PM10, NOx, ozone, etc. These findings can be used to better understand how alternative sources of exposure that can affect allergic asthma outcomes and respiratory health: proximity to urban plants, factories, waste management facilities, etc.

Again, detailed maps of the location of pollen producing plants are key to a future pollen forecasting system. Maps can be coupled with key weather variables such as wind direction and speed, precipitation, humidity and temperature, and both phenological and dispersion models, to predict the emission timing and pollen amount in the given region.

Mitigation and Adaptation

To mitigate the health effects of pollen from allergenic trees in urban areas, this study emphasizes adaptation measures specifically urban planning and policies to oversee planting of allergenic taxa in urban areas such as planting non-allergenic trees. Furthermore, the current practice of the planting of solely male trees in urban areas in order to reduce street litter from seeds and fruit increases the total pollen load, and so consideration of reduction of pollen exposure through female tree planting could mitigate the effects (McInnes et al., 2017).

Vegetation mapping of plants with allergenic pollen may also help affected individuals better manage their symptoms of allergy or asthma. Once these allergenic taxa are linked with health effects, another application of these maps will be to provide advice for vegetation management practices. These practices can include the picking tree species, deciding sex of tree for planting, and grass cutting regimes to limit exposure to the most allergenic pollen. However, the interaction between trees, pollen, air pollution, meteorology, and climate is extremely interdisciplinary and many variables must be considered. And based on the results of statistical analysis in which it was suggestive of no spatial relationship or one with several external variables, any recommendations must be proceeded with caution and further research for assessment of potentially beneficial and adverse effects.

COVID-19 Relation and Less Outdoor Activity Over Time

Interestingly, a new study published online in the Annals of the American Thoracic Society discusses a steep drop off from prior years in asthma-related emergency department (ED) visits at Boston Children's Hospital during the spring 2020 COVID-19 surge and lockdown (Simoneau et al., 2020). The hospital's ED visits for asthma treatment between Jan. 5 and May 23 in 2018, 2019 and 2020 were analyzed. Based on the established notion that pediatric asthma flare ups frequently result in emergency department visits, researchers determined they would compare two time periods for each of the three years: Jan. 5-March 21 ("pre-shutdown") and March 22-May 23 ("post-shutdown") to determine whether the number of pediatric asthma ED visits changed year-to-year. For the week of March 15-March 21 (pre-shutdown), the rate of ED visits was similar across the three years included in the study. However, the following week (post-shutdown) the rate of ED visits decreased 80 percent and 82 percent in 2020 relative to 2018 and 2019, respectively. This decrease in visits continued through May 23, with an 82 percent reduction from the 2018 rate and 87 percent reduction from the 2019 rate. However, the proportion of asthma-related ED visits that required hospital admission remained similar to previous years.

While there are many unmeasured factors that contribute to the decision to admit someone to the hospital, these findings are reflective of an overall decrease in exacerbations. This study adds that from a purely quantitative perspective, COVID-19 does not necessarily increase asthma exacerbations but rather, seem to have a decreasing effect on exacerbations. This decrease can be due to ER hesitancy given pandemic fears and fear of exposure to COVID-19 and the stigma that surrounds medical settings in the time of a pandemic.

But two primary factors other than fear of COVID-19 can be responsible for the decrease in asthma-related PED visits that are relevant to the purposes of our study: 1) less outdoor activity, and 2) use of face masks.

Due to the fact that as schools adapt to the lockdowns, students are attending classes from home and spending more time indoors as a result and therefore have less exposure duration to allergenic pollen and taxa (Bonal et al., 2020). However, our study believe that it is important to acknowledge that the purpose of the study is not to encourage a significant decrease of outdoor activity in children in order to mitigate exacerbation of allergic asthma and rhinitis symptoms, but to highlight supporting evidence of the link between the environment and asthma ED visits and human health in general.

It must also be taken into account that in order to combat the sedentary lifestyle of the pandemic, certain households are taking in extra effort to be more active and may actually spend more time outdoors. The difference is that with masks being mandatory, perhaps masks are part of the reduction in exacerbations. Rationalization for face mask usage during the current pandemic is for reducing transmission of coronavirus. In addition to preventing pathogen penetration, face masks potentially lower the burden of other inhaled airborne particles including allergens and air pollutants. A decrease in symptom severity with mask usage highlights the potential benefit of face masks for patients with allergic rhinitis. Therefore, the study suggests that vulnerable children take caution on days with heavy pollen levels and poor air quality by perhaps staying indoors when necessary and wearing masks if need be. One thing that needs to be considered, however, is the level of effectiveness of masks based on the type of mask used, which should be examined more in-depth.

Conclusion

In this paper we present a methodology to examine novel maps of selected trees to study allergenic taxa coverage in Atlanta that are associated with allergy and allergic asthma—specifically PED visits (0-18 years). These maps and our study's findings contribute to the research on environmental exposure and human health as taxa maps combined with health data including pediatric emergency hospital admissions for asthma to study the impact/relationship of exposure to allergenic taxa coverage in Atlanta have not been done before. While results of the GWR were statistically significant, the results of the OLS analysis was statistically significant and failed to reject the null hypothesis that transformed tree count is spatially homogeneous throughout the study area. Many factors can influence this result, particularly the characteristics of the study population and data availability, which warrants further research in the future. Ultimately, these findings that inform the link between the greenspace makeup of trees and the wellbeing of the surrounding population emphasize the importance of urban planning and land management in metropolitan areas such as Atlanta, but also have many other possible applications.

Limitations

There were several limitations in the study that ought to be addressed for future research. Limitations were due to uncertainty with respect to absence of exposure time data, input data, species information, and inventory: the information provided may be at a coarse scale and therefore fail to accurately represent smaller units at a finer resolution such as 1km.

It is also important to address that aggregating data to month or even week would (1) take away a huge amount of information, but (2) would likely result in a dataset that would be far more convenient to model in terms of distribution and auto-correlation (Waller et al., 2004). This is what was done for the PED data in that it was aggregated to a 4-year time period from 2014-2018. Individual-level data for PED visits were unable to be acquired for this project given constraints.

Furthermore, it is extremely difficult or nearly impossible to find a complete dataset that is comprehensive enough for study interests. Databases suffer from primarily lack of extent and lack of resolution. For example, most environmental datasets provide point features, but these are often very localized and specific to a particular region. On the other hand, while it is very easy to obtain national or state-level datasets, the data provided is usually not readily available at finer resolutions. It was relatively difficult to supplement data specific to our needs for this study, specifically tree-level data for the city of Atlanta as well as pollen levels and PED visits.

Moreover, due to the study's choice of census tract prevalence data, we cannot additionally explore the distribution of prevalence within tracts without additional information. In addition, aggregate data presented in this form are subject to the modifiable areal unit problem (MAUP) (Waller et al., 2004) where statistical bias can occur when samples in a given area are used to represent information. Because the area defined—in this case, the census tracts—is often arbitrary, the associations could be deceptive as the data could have different results based on the shape and scale chosen for analysis. For example, aggregating data to larger or smaller spatial units could change associations and result in either an overestimation or underestimation of severity (Waller et al., 2004). One possible way to check the validity of the results after spatial autocorrelation analysis is to alter the scale of aggregation and perform the analysis again to evaluate for any significant changes in new results. Due to lack of data availability and flexibility, only permutation tests were applied after Moran's I. But it is necessary for this study to recognize that any statistically significant clustering at the census tract level does not necessarily imply significant clustering at other spatial area unit levels.

Future Directions

We recognize that this pilot study is only the beginning to a field of future study directions. Future directions include, but are not limited to, pairing these maps with duration of exposure, modeling detailed pollen forecasts in Atlanta, and urban land management adaptations. The maps and spatial analysis will provide valuable information on which area in the Atlanta region is most affected by allergenic taxa density. Furthermore, in the future these maps could also form part of an Atlanta pollen forecast model, to provide detailed taxon-specific, localized information to the public. This method to examine environmental exposure could be duplicated in many other regions of the world, given the resources.

Known as the "City in a Forest," Atlanta has many urban green spaces to offer. However, this paper hopes to shed light on the major causes of allergenicity and health from the low biodiversity in such green spaces. Continuous monitoring of airborne pollen has highlighted the major contribution of plants growing in urban green spaces to the development of allergy symptoms in Atlanta as well as other parts of the world. This is in addition to the fact that recent data suggest that people living in urban areas are 20% more likely to suffer airborne pollen allergies than those living in rural areas (D'Amato et al., 2007).

In many cities with a temperate climate, urban green spaces are often characterized by an overabundance of low diversity, and is commonly populated with high pollen-producing species such as oaks (*Quercus* spp.), elms (*Ulmus* spp.), etc. The microenvironmental conditions found in these urban areas can affect the quality of life of its residents. This is in conjunction with research that have noted that the increased allergenic potential of pollen grains when enhanced by the presence of other air pollutants due to the action of gases such as CO2 (Ziska et al., 2004).

Therefore, increased biodiversity would reduce the planting of traditional species for which allergenic capacity has been clearly demonstrated. This is important in light of the recent rise in greenspace building in urban areas: not only should we address trees that have high allergenicity, but we should also address trees that emit high levels of volatile organic compounds (VOCs) that interact with ozone and other chemicals to create secondary organic aerosols (SOAs), solids or particles of liquid suspended in gas. Trees can pollute as well—the source of dangerous aerosol pollution may be contributed by trees and other green plants which in turn, can exacerbate detrimental respiratory health outcomes. From forming smog to influencing cloud formation, SOAs drive a number of atmospheric and climatic processes. This interaction between VOCs, SOAs, and other biological emissions create one of the biggest uncertainties in climate models (Fitsky et al., 2019). With greenspace building, planners should be thinking about large-scale planting to pick the right trees—low-emitting VOC trees instead of high-emitting VOC trees.

Our study ultimately aims to prompt public health officials to take a closer look at the outcome of this project to inform its policy. Emphasis should be placed on investing in nature as preventative medicine such as introducing local guidelines for designing low allergy impact green zones based on biodiversity principles as well as researching to gain a better understanding of how trees’ emissions shape the air around us, investing more capital into nature.

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