Equality of Sun Belt Sprawl: The Intersection Between Land Cover, Air Pollution, and Demographics in Phoenix and Houston

2025 Provost's Undergraduate Research and Creative Activity Summer Fellowship Proposal

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Abstract

This study aims to compare the interactions between changes in urban sprawl, demographics, and air pollution in the cities of Houston, Texas and Phoenix, Arizona. Population increases and land cover changes consistent with urban sprawl may lead to changes in air pollution, which is not always equally distributed across sociodemographic categories. Pollutant concentrations tend to be higher in areas with high percentages of racial and ethnic minorities and low average socioeconomic status areas. This study will analyze land cover, race, ethnicity, income, and concentrations of ozone, sulfur dioxide, carbon monoxide, nitrogen dioxide, and 10 micrometer diameter particulate matter. Landsat satellite data will be used to examine land cover changes to approximate urban sprawl. Demographic data will come from census data archives at the National Historical Geographic Information System. Air pollution data will come from the EPA's network of ambient air pollution sensors. The connection between changes in land cover, demographics, and air pollution will be studied individually for each city, as well as compared to identify the overall impacts of urban sprawl. This research fills a gap in the existing literature by investigating the intersection of urban sprawl, demographics, and air pollution in two cities. The results of this study will add to the collective knowledge base about these topics and could be used to influence policy or urban planning decisions. It also creates a framework that could be replicated to perform similar research on different locations or time periods.

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Background

The rapid urbanization of cities can lead to environmental degradation. Cities that have experienced urban sprawl often are characterized by large areas of automobile-dependent lower density development. Not all new urban development is considered sprawl, which Ewing 1997 defines as "leapfrog or scattered development, commercial strip development, or large expanses of low-density or single-use development." Other indicators of urban sprawl include "poor accessibility and lack of functional open space" (Ewing 1997) leading to an increase in driving time and dependence on cars. Urban sprawl is also associated with a change in land cover through an increase in impervious surfaces and a larger urban footprint (Smiley and Hakkenberg 2020). It has been found that the urban form and density of development has a large impact on air pollution concentrations. For example, Bereitschaft and Debbage 2013 studied 86 metropolitan areas in the United States and found that "an increase in residential density and street network connectivity was associated with a significant decrease in the ambient concentration of O_3 and $PM_{2.5}$." This trend also holds true for NO_X and CO_2. A variety of sprawl indexes were used in this study, and they found that areas with a higher amount of urban sprawl exhibited increased concentrations of air pollutants. Depending on the index used, a one standard deviation increase in urban sprawl led to as much as a 14% increase in CO_2 and an 11% increase in $PM_{2.5}$. While the density of urbanization has a large impact on air pollution, overall population also plays a role. As stated by Bereitschaft and Debbage 2013, "when residential density was controlled for, one standard deviation increase in population was associated with a 6.1% rise in O_3 concentration, a 146% increase in CO_2 emissions from on road sources, a 97% increase in VOCs a 97% increase in NO_x emissions and a 56% increase in PM2.5 emissions." Increases in metropolitan land areas were also connected to increases in NOx, $PM_{2.5}$, and CO_2 emissions.

Increases in urban sprawl can lead to increases in air pollution, but what does that mean for those living in areas of urban sprawl? Some of the most commonly monitored air pollutants are ozone (O_3), sulfur dioxide (SO_2), carbon monoxide (CO), nitrogen dioxide, (NO_2) and particulate matter. Particulate matter consists of different airborne particles and is often classified by its diameter with 2.5 micrometer ($PM_{2.5}$) and 10 micrometer (PM_{10}) being the most commonly measured. The EPA classifies these pollutants, plus lead (Pb), as criteria air pollutants (US EPA 2016). Criteria pollutants are monitored, as mandated by the Clean Air Act, to ensure that concentrations are at healthy levels that meet National Ambient Air Quality Standards (US EPA 2016). All of these pollutants have significant health impacts. According to Manisalidis et al. 2020, ozone affects the upper layers of skin, the tear ducts, and can lead to depletion of vitamins C and E. Sulfur dioxide mainly impacts the lungs. It can lead to respiratory irritation and bronchitis. Carbon monoxide is known for its poisoning symptoms that include headache, dizziness, weakness, and loss of consciousness. Long term carbon monoxide exposure also leads to a lack of oxygen in the blood. Nitrogen dioxide is a lung irritant that can cause coughing, wheezing, and chronic lung disease. Particulate matter, of both 2.5 and 10 micrometer diameters, can lead to cardiovascular and lung problems. People with pre-existing health conditions are more vulnerable to the effects of all of these air pollutants.

Exposure to air pollution, often through long term exposure to levels of pollution slightly above the National Ambient Air Quality Standards, can have devastating health impacts. However, these health impacts do not impact all Americans equally. It has been shown that there are disparities in air pollution exposure in the United States by race, ethnicity, and socioeconomic status. While exact statistics may vary by location or specific air pollutant studied, it generally holds that the lowest levels of air pollution exposure are found in areas that are primarily white, high income, high socioeconomic status, high employment rate, and high education rate (Bell and Ebisu 2012; Rosofsky et al. 2018; Liu et al. 2021; Jbaily et al. 2022;). Studies have examined the overall air pollution and environmental inequality of specific cities. There have also been comparative studies looking at multiple locations, pollutants, and other variables. However, there are very few studies that have looked at the intersection between urban sprawl, air pollution, and demographics. There are even fewer studies looking at those variables in multiple locations and no studies could be found comparing these metrics in Phoenix, Arizona and Houston, Texas.

Both Phoenix and Houston are located in the colloquial Sun Belt region of the United States. The Sun Belt is generally defined as the region below the 36 degree 30 minutes north latitude line marked by rapid urbanization and growth (Olin 2020). In addition to Phoenix and Houston, the Sun Belt is also home to the cities of Atlanta, Las Vegas, Los Angeles, Nashville, and New Orleans (Smiley and Hakkenberg 2020). While they are in the same region, Phoenix and Houston have significant differences in key characteristics to make them a unique and intriguing pair for research. Phoenix has a population of about 1,650,000 ("U.S. Census Bureau QuickFacts: Houston City, Texas; Phoenix City, Arizona," n.d.) and is in the subtropical desert Köppen-Geiger climate zone (National Oceanic and Atmospheric Administration, n.d.). Houston has an estimated population of 2,315,000 and is in the humid subtropical climate zone. Both cities have undergone rapid population growth and have population densities and urban forms associated with urban sprawl. These factors make Phoenix and Houston a good pair for a comparative study of urban sprawl, air pollution, and demographics in the Sun Belt. Due to the lack of previous studies in this area, several questions remain.

Research Questions

- How do changes in urban land cover affect the temporal and spatial trends of air pollution in Houston and Phoenix?
- In what ways has urban sprawl, shown through land cover change, influenced changes in the demographic composition and distribution of Houston and Phoenix?
- How strong is the relationship between demographic changes and air pollutant concentration changes in Houston and Phoenix?
- Do the overall impacts of urban sprawl vary between Houston and Phoenix?

Objectives

- To analyze satellite data to measure changes in land cover in Houston and Phoenix between 1990 and 2024.
- To examine air pollution and demographic data for Houston and Phoenix between 1990 and 2024.
- To evaluate the relationship between changes in demographics and changes in air pollution.
- To compare the findings between Houston and Phoenix to look at overarching impacts of urban sprawl and if urban sprawl impacts both cities similarly.

Data and Methods

Landsat satellite data will be used to look at land cover changes. Air pollution data from EPA outdoor air quality monitors are available in Phoenix and Houston for ozone, sulfur dioxide, carbon monoxide, nitrogen dioxide, and 10 micrometer particulate matter. There are multiple sensors in each city used to collect data on critical pollutants for National Ambient Air Quality Standards requirements. The Clinton location sensor will be used for Houston as it provides the largest time range of data closest to the center of the city. The Central and West sensors will be used in Phoenix. The Central sensor is one of the few that has sulfur dioxide data over a long period of time. The West sensor offers the longest time range for all pollutants except for sulfur dioxide. Other sensors may be used if additional data is needed. For the majority of locations and pollutants, data is available from 1990 to present. Demographic data will come from the National Historical GIS database as it provides census data for a wider time range than the U.S. Census Bureau provides. The U.S. Census Bureau's TIGER/Line shapefile data will be used for census block group outlines, city outlines, and any other necessary shapes or geographies.

The analysis for this project will be completed using Google Earth Engine, ArcGIS Pro, and R. Google Earth Engine will be used to access, process, and classify satellite data by land cover type through the random forest machine learning model. Normalized difference vegetation index (NDVI) and normalized difference built-up index (NDBI) values will be calculated to quantify land cover changes. According to Yasin et al. 2022, NDVI measures the depth or thickness of vegetation while NDBI measures the density of urbanization through the amount of built-up area. An increase in urbanization is marked by a decrease in NDVI values and an increase in NDBI values as vegetated land is replaced by areas that are classified as built-up such as buildings, roads, or parking lots. ArcGIS Pro will be used to connect processed land cover data with air pollution and demographic data. ArcGIS Pro will be utilized for spatial analysis, zonal statistics, and cartographic visualization. R will be used for advanced data processing and statistical analysis including regression analysis, calculation of correlation coefficients, and non-cartographic data visualization.

Expected Results and Outcomes

- Improve understanding of the relationship between demographics, air pollution, and urban sprawl in Phoenix and Houston.
- Uncover trends in Phoenix and Houston that demonstrate the overall impacts of urban sprawl that could be expected throughout the Sun Belt region.

- Identify differential trends between the two cities as well as combined temporal patterns.
- Publish research in a refereed scholarly journal to disseminate knowledge gained from this study.
- Present at the Southwestern Division of the American Association of Geographer's 2025 annual meeting at New Mexico State University in Las Cruces, New Mexico.
- Produce frameworks and methods that can be used for future projects such as honors research and capstone projects.

Timeline

Week	Goals and Benchmarks
Week 1	Download, preprocess, and compile data. Meet with mentor.
Week 2	Format and set up data. Start preliminary data analysis. Meet with mentor.
Week 3	Perform land cover change analysis using machine learning. Meet with mentor.
Week 4	Connect processed land cover change data to processed demographic and air pollution data. Start performing detailed statistical and spatial analysis. Meet with mentor.
Week 5	Continue detailed statistical and spatial analysis. Perform correlation and regression analysis. Submit mid-project report to mentor.
Week 6	Finish detailed statistical and spatial analysis. Start comparison of two cities for overall impact of urban sprawl. Meet with mentor.
Week 7	Finish analysis. Meet with mentor.
Week 8	Create maps and visualizations. Meet with mentor.
Week 9	Create manuscript for submission to refereed scholarly journal. Meet with mentor.
Week 10	Wrap up project. Week reserved for buffer time in case earlier tasks take longer than expected. Write UReCA final report. Meet with mentor.

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