ASSESSING THE RELATIONSHIP BETWEEN URBAN HEAT AND VEGETATION IN ALBUQUERQUE, NEW MEXICO

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To my amazing family.

ACKNOWLEDGMENTS

I thank my family and friends for their support throughout this process. I thank my mentors for their teaching and guidance, and all the ways they helped me grow during my education.

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LIST OF ABBREVIATIONS

GEE	Google Earth Engine – A geospatial tool from Google that allows users to access and analyze raster data
LST	land surface temperature – the temperature of the ground, which varies based on climate, materials, and environment
NDVI	normalized difference vegetation index – an index showing the greenness of vegetation using red and near-infrared satellite bands that is a proxy for vegetation health
SVI	social vulnerability index – tool used to help identify communities that are most vulnerable to disasters and environmental hazards
UHI	urban heat island effect – the phenomenon that metropolitan or built-up areas experience warmer temperatures than surrounding areas

ABSTRACT

The urban heat island effect poses a significant challenge for cities and urbanized areas, particularly those in warm climates. Vegetation, such as urban trees and parks, plays a crucial role in mitigating the effects of urban heat by helping to reduce land surface temperatures. This study explores the relationship between urban heat and vegetation in Albuquerque, New Mexico using remote sensing. To calculate LST and NDVI and identify patterns of heat distribution and vegetation density across the city, the study used Google Earth Engine to process Landsat 8 imagery, and ArcGIS Pro to integrate social vulnerability data and help determine what areas would be most impacted by new vegetation. Additionally, this study assessed the accessibility of this methodology for local governments, emphasizing its potential as a cost-effective approach to urban heat mitigation. By demonstrating the utility of Google Earth Engine and freely available satellite data, this study provides a framework for municipalities to make informed decisions in combating urban heat and enhancing climate resilience. Results showed that there is a positive relationship between urban heat and areas of low vegetation, and GEE is a valuable tool to help government agencies tackle urban heat.

Keywords**:** urban heat, NDVI, LST, UHI, Landsat

INTRODUCTION

Background Information

Urban areas often experience much higher temperatures than their suburban or rural surroundings due to a phenomenon called the urban heat island (UHI) effect (Tamaskani Esfehankalateh et al., 2021). Restricted airflow between buildings, emissions from human activity, and impervious surfaces that absorb solar radiation all contribute to this growing threat (Cheela et al, 2021, Tamaskani Esfehankalateh et al., 2021). As cities rapidly urbanize and face the increasing risk of extreme heat, millions of people are at risk of this environmental hazard and social concern. The effects of this phenomenon are not felt equally, and studies show that areas of higher social vulnerability are disproportionately impacted (Potter, 2021).

Increasing vegetation cover through practices such as tree planting limits the effects of UHIs and lowers overall land surface temperatures (Loughner et al., 2012; Rogan et al., 2013). The shade provided by trees, and evapotranspiration, the process by which trees release water into the atmosphere, cool the ambient temperature around them (Loughner et al., 2012). One study showed that increasing the number of urban trees in an area can lower ambient temperatures by up to 4° Celsius (7.2° Fahrenheit) (Santamouris et al., 2017). New trees in areas with higher social vulnerability also provide a greater impact in reducing ambient temperatures than in wealthier areas that already have higher levels of vegetation (Zhou et al. 2021).

Remote sensing provides researchers or government officials with a valuable tool to track urban heat and understand its causes and impacts. Land surface temperature, measured using satellite remote sensing technology, gives a proxy for heat felt in urban and surrounding areas (Hulley et al., 2019). Studies have shown a relationship between land surface temperature (LST) and Normalized Difference Vegetation Index (NDVI), which shows vegetation health (Grover & Singh, 2015). Social vulnerability indices allow researchers to also understand socioeconomic factors affecting where and who the impacts of urban heat is most felt. A recent study in San Jose created a heat vulnerability index that integrated social and environmental risk factors to understand these relationships (Kannan et al., 2024).

Study Area

Albuquerque, New Mexico (Figure 1) is the largest city in the state with a population of around 600,000 (Visit Albuquerque, 2025). Sitting at an elevation of around 5,312 feet, it is characterized by its high desert climate and arid environment. Summers in the city are typically hot with temperatures often exceeding 90 degrees Fahrenheit. The Rio Grande River runs through the city and supports a network of riparian vegetation areas which are known to help mitigate urban heat (source). Many American cities suffered from historical redlining policies that led to significant income and racial disparities in housing and environmental conditions (Estien et al., 2024; Rivera et al., 2023). Policies like these contribute to decreases in environmental quality, including increased pollution, reduced vegetation, and elevated temperatures in impacted neighborhoods (Estien et al., 2024). The position and allotment of trees and green spaces have been heavily impacted by policies like these, with less affluent areas having almost half the amount of tree canopy cover than wealthier areas. Understanding the distribution of urban heat and vegetation provides important context and information for understanding unequal impacts of UHI and remote sensing is a powerful tool in helping build understanding.

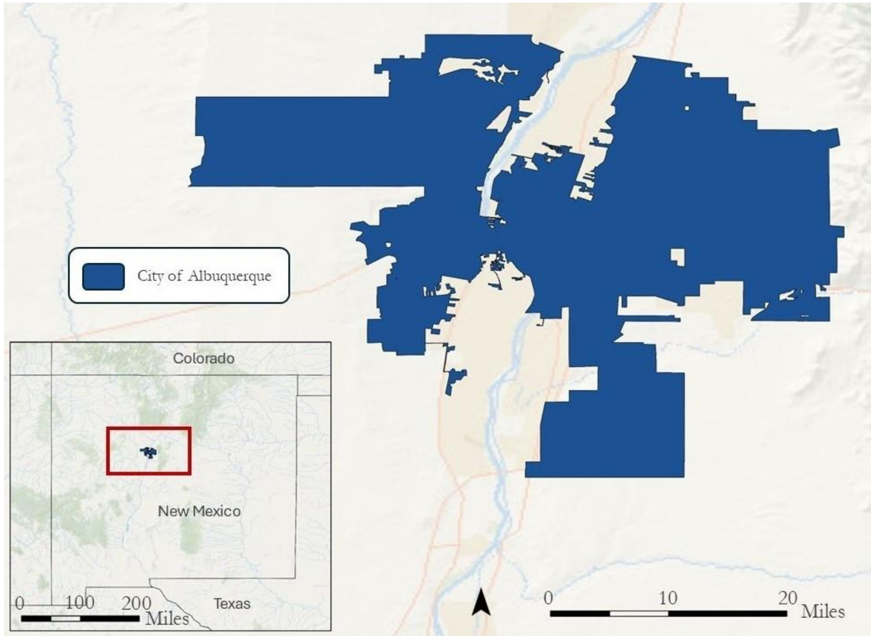

Figure 1. Study Area of Albuquerque, New Mexico

METHODS

Data Acquisition

Urban Heat

To investigate LST, the study used Collection 2 Level 2 data from NASA's Landsat 8 Thermal Infrared Sensor (TIRS). Using Google Earth Engine, data for the summer months of May, June, July, and August from 2014-2024 were accessed to calculate LST and understand urban heat distribution. Images with more than 10% cloud cover were excluded to ensure only clear images were used in processing.

Vegetation

To investigate vegetation, the study used Collection 2 Level 2 data from NASA's Landsat 8 Operational Land Imager (OLI). Using Google Earth Engine, data for the summer months of May, June, July, and August from 2014-2024 were accessed to calculate NDVI and assess urban vegetation distribution. Images with more than 10% cloud cover were excluded to ensure only clear images were used in processing.

Social Vulnerability

To assess social vulnerability, the study used the Center for Disease Control (CDC) Social Vulnerability Index (SVI). This index uses data from the American Community Survey (ACS) to assess vulnerability, using demographic data such as income, education level, housing status, and more. Census tract level data was accessed as a geodatabase to use with environmental data to understand where urban vegetation would have the most impact.

Table 1. Datasets used in this study

Dataset	Spatial Resolution	Time Period	Description	Source

Landsat 8 TIRS	30m	2014–2024	Long-wave infrared band: used to calculate LST	GEE
Landsat 8 OLI	30m	2014-2024	Red and Near-Infrared bands used to calculate NDVI	GEE
CDC Social Vulnerability Index	Census Tract	2022	Social Vulnerability Index using American Community Survey data	CDC

Data Processing

Urban Heat

The long-wave infrared band, lwir11, provides temperature data for the study. To calculate LST, the study used GEE to convert the data, now excluding images with cloud cover, from the Digital Number (DN) to Kelvin and then from Kelvin to Celsius. To visualize seasonal changes and validate the data, the study created a time series plot showing land surface temperature values throughout the study period. The mean temperature for summer months (May, June, July, August) from 2014-2024, calculated in GEE, gave an overview of LST in Albuquerque during that time. The researcher exported this raster image to be used in ArcGIS Pro to compare with vegetation and SVI data.

Normalized Difference Vegetation Index

The Near-Red Infrared (NIR) and Red bands were used to calculate NDVI in GEE (Equation 1). To show seasonal changes in vegetation throughout the year the researcher created a time series plot showing NDVI throughout the study period. The mean NDVI for May, June, July, and August from 2014-2024 calculated using GEE, shows vegetation health in Albuquerque during that time. Once exported to ArcGIS Pro, the data was visualized on a scale of -1 to 1, and compared to LST and SVI data.

$$\text{NDVI} = \frac{(\text{NIR - Red})}{(\text{NIR + Red})} \tag{1}$$

Normalized Difference Vegetation Index equation using near infrared and red bands (Kriegler et al., 1969).

Social Vulnerability

To prepare the SVI component of our analysis, census tract level data for Albuquerque, New Mexico was brought into ArcGIS Pro. These data were projected to match LST and NDVI data and clipped to the study area. Attribute data was cleaned to only include relevant details that will be included in the summary report showing areas where new vegetation will have the most impact.

Data Analysis

Urban Heat

GEE exported TIFF files showing mean LST for Albuquerque, New Mexico for May-August 2014-2024 provided the necessary data to evaluate urban heat in the city. In ArcGIS Pro, the researcher created a raster map that showed heat distribution. They then used the Zonal Statistics tool to show mean LST in each census tract for that time to allow comparison with other data.

Vegetation

The TIFF file showing NDVI for May-August 2014-2024, exported from GEE, shows vegetation health across the study area. The raster image was visualized on a scale of -1 to 1 to show the distribution of healthy vegetation. The researcher used the Zonal Statistics tool in ArcGIS Pro to calculate NDVI in each census tract to compare with other data.

Social Vulnerability

The CDC SVI imported into ArcGIS Pro allows the researcher to compare the environmental risk associated with urban heat and vegetation with social factors. With all data standardized by census tract, the researcher created bivariate maps that visualize social vulnerability with LST and with NDVI.

RESULTS

Analysis of Results

Urban Heat

The mean LST map (Figure 2) shows how the mean temperature for the seasonal summer months of May, June, July, and August from 2014-2024 is distributed across the study area. Lower temperatures can be seen in the Sandia Mountains to the east of the city, often referred to as a sky island due to the ecological diversity caused by their elevation and climate. The map also shows the cooler areas around the Rio Grande River that flows through the city. Small areas of purple shown within the city boundary represent parks or other green spaces. Highly developed areas clearly contrast less developed areas and natural areas such as parks and riparian zones. The mean LST by census tract map (Figure 3) shows land surface temperature calculated for each census tract in Bernalillo County, where Albuquerque is located. Tracts closer to the Rio Grande show lower temperatures, as well as areas close to the Sandia Mountains east of the city. The areas west of the Rio Grande, as well as between the Sandia Mountains and the Rio Grande show higher temperatures. The graph (Figure 4) shows LST throughout the whole year for 2014-2024. It shows how the peak values are in June or July and decrease significantly through the winter. As expected, areas away from the riparian zones and mountains have higher temperatures.

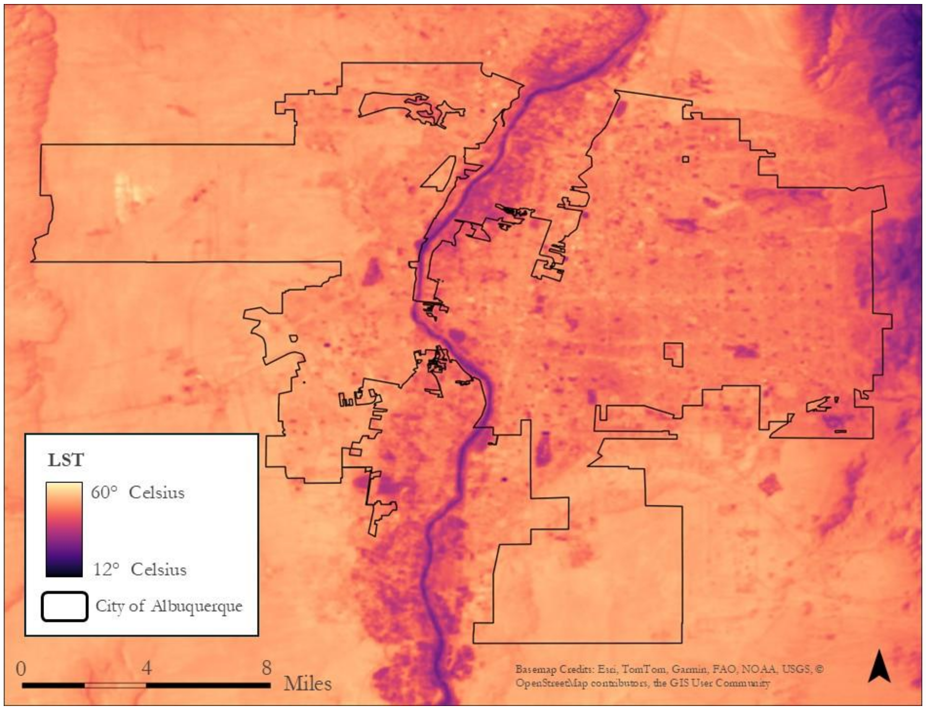

Figure 2. Mean LST (ºC) for the months of May, June, July, and August from 2014-2024 in Albuquerque, New Mexico

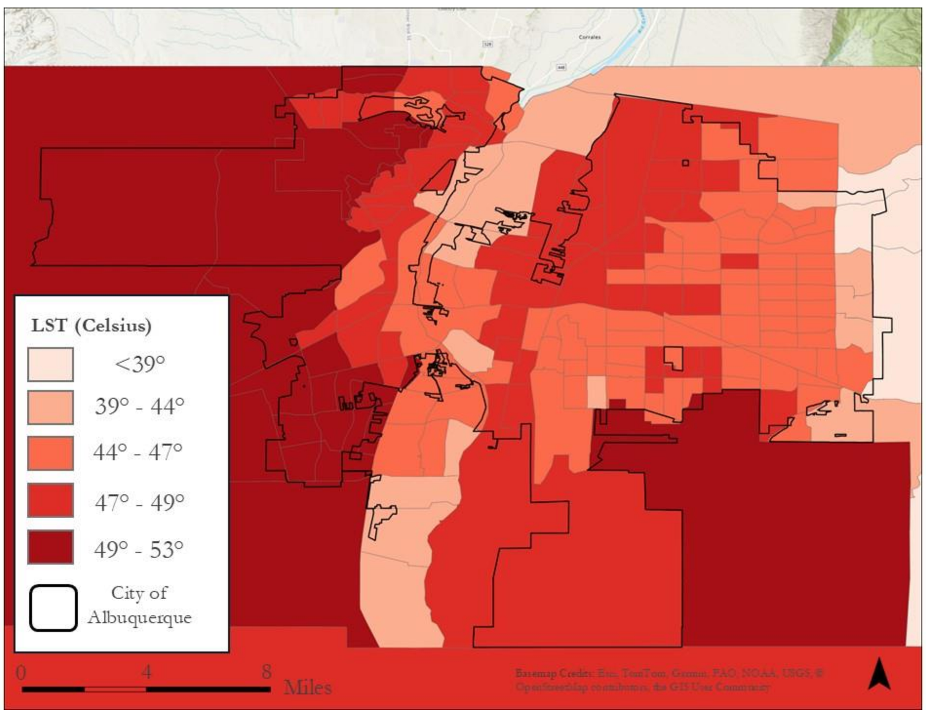

Figure 3. Mean LST (ºC) by census tract for the months of May, June, July, and August from 2014-2024 in Albuquerque, New Mexico

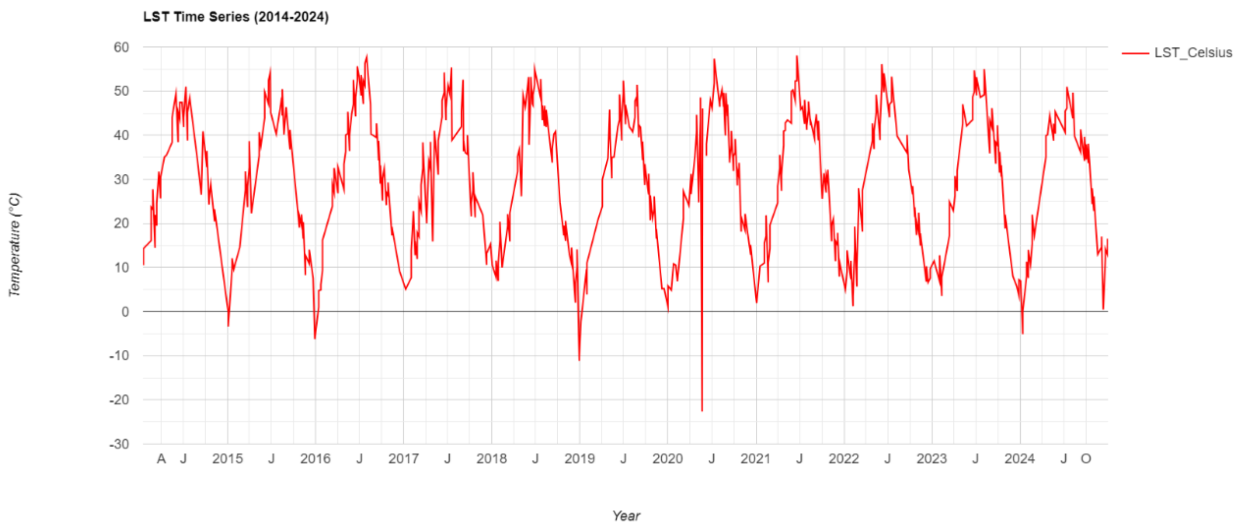

Figure 4. Mean LST (ºC) from 2014-2024 in Albuquerque, New Mexico

Vegetation

The mean NDVI map for the summer months from 2014-2024 shows how vegetation varies throughout the city and surrounding areas (Figure 5). Areas with high vegetation greenness, a proxy for vegetation health, are shown in dark green, while areas of low vegetation greenness or non-vegetative areas are shown as yellow. The data shows that there is higher vegetation greenness near the Rio Grande in riparian zones, as well as in the Sandia Mountains east of the city. Green spaces and parks are also shown as small areas of dark green throughout the city. The mean NDVI by census tract map (Figure 6) shows the average vegetation greenness for summer months within the census tracts in Bernalillo County. Census tracts near the Rio Grande and mountains also show higher vegetation greenness. The time series plot (Figure 7) shows how NDVI changes across season from 2014 – 2024 with the peak vegetation greenness occurring between May and July every year. When comparing with LST

(Figure 8), there is a negative relationship between LST and NDVI, with an R^2 value of 0.56.

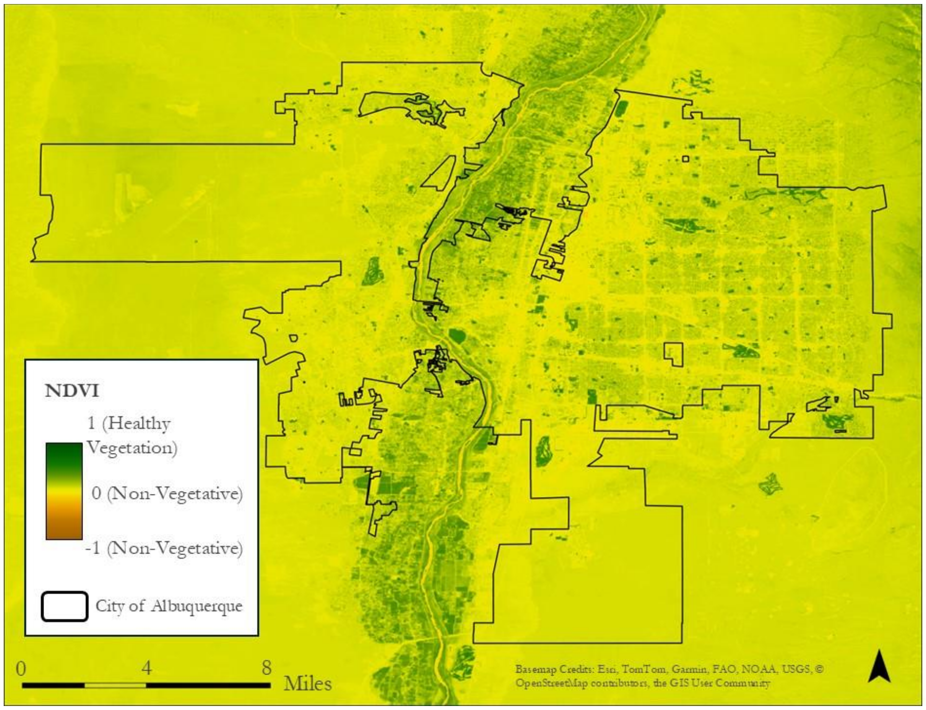

Figure 5. Mean NDVI for the months of May, June, July, and August from 2014-2024 in Albuquerque, New Mexico

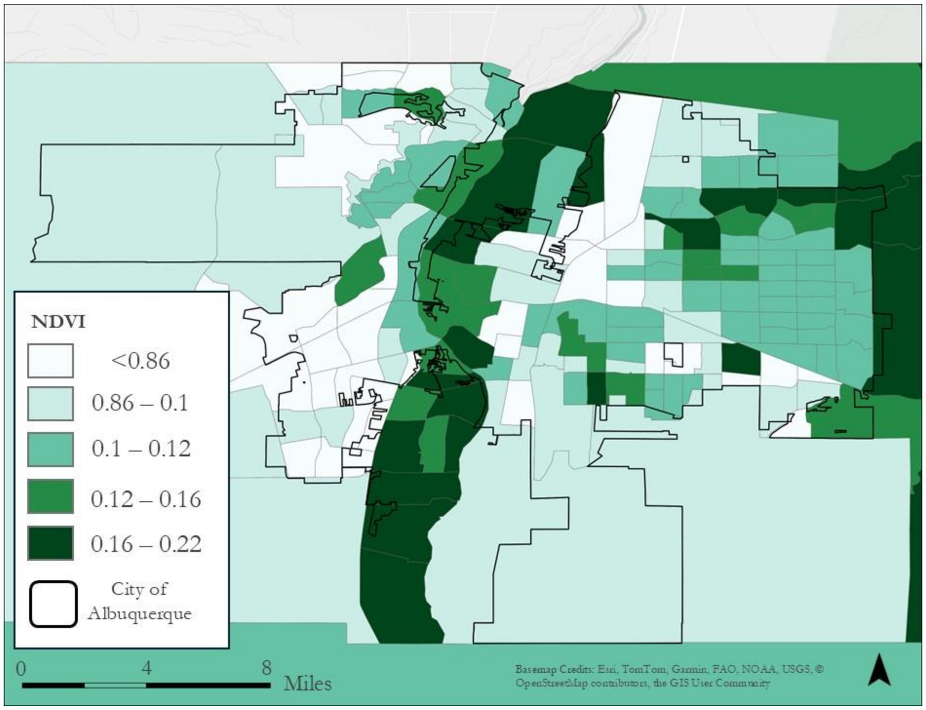

Figure 6. Mean NDVI by census tract for the months of May, June, July, and August from 2014-2024 in Albuquerque, New Mexico

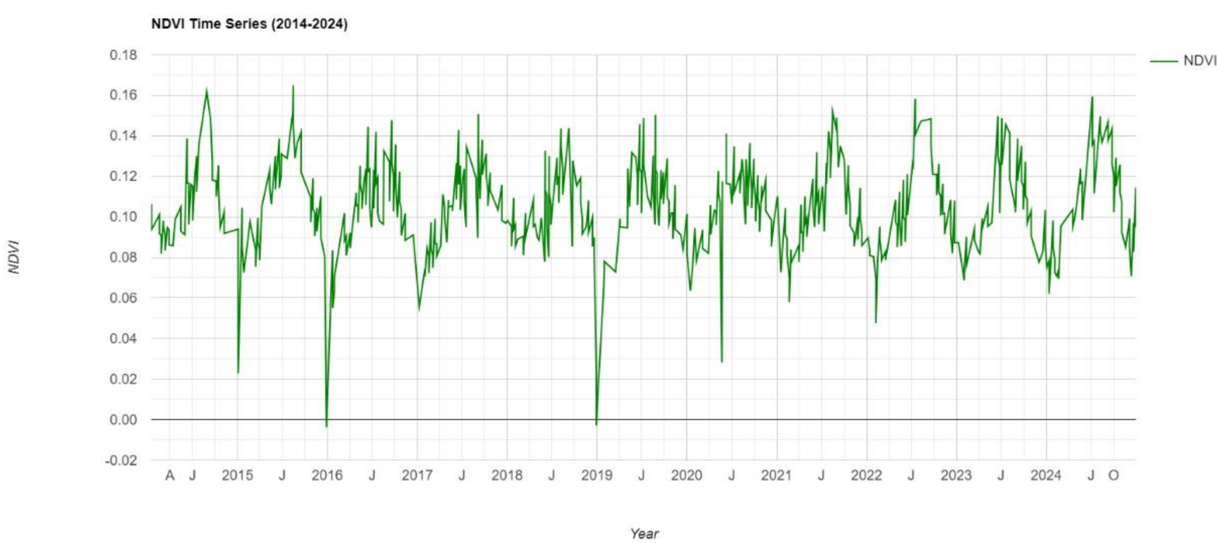

Figure 7. Mean NDVI from 2014-2024 in Albuquerque, New Mexico

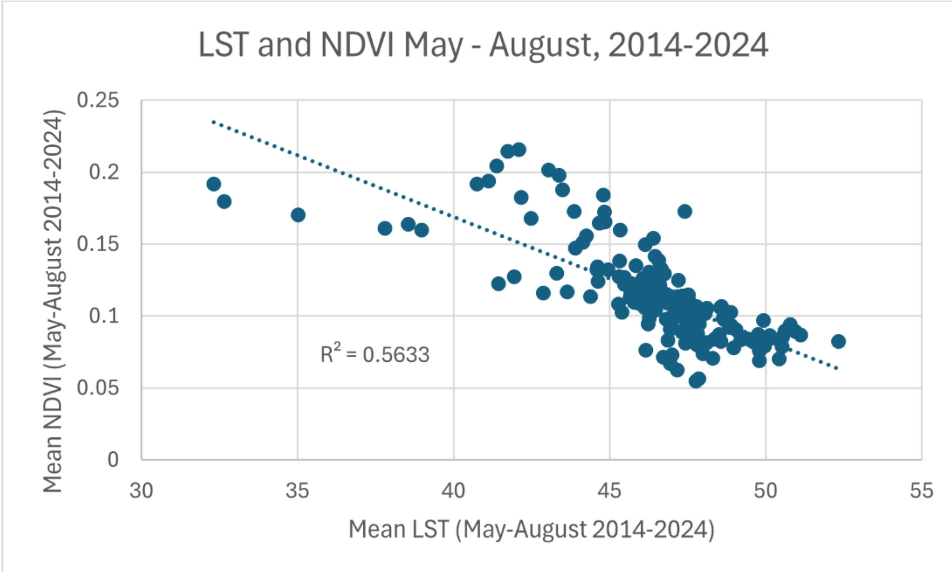

Figure 8. Mean LST and NDVI by census tract for the months of May, June, July, August from 2014-2024

Social Vulnerability

The social vulnerability map (Figure 9) shows social vulnerability for census tracts in Bernalillo County, with Albuquerque city limits indicated. Census tracts with higher vulnerability are indicated with dark red, and areas of lower social vulnerability are indicated as light pink. Vulnerability varies throughout the city, with lower risk in the northeastern portion of the city as well as near the northern portion of the Rio Grande. Areas near the southern and western side of the city have higher vulnerability values. Social vulnerability did not have a strong relationship with LST or NDVI. There is a small positive trend with LST (Figure 10), and small negative trend with NDVI (Figure 11), however the results are inconclusive.

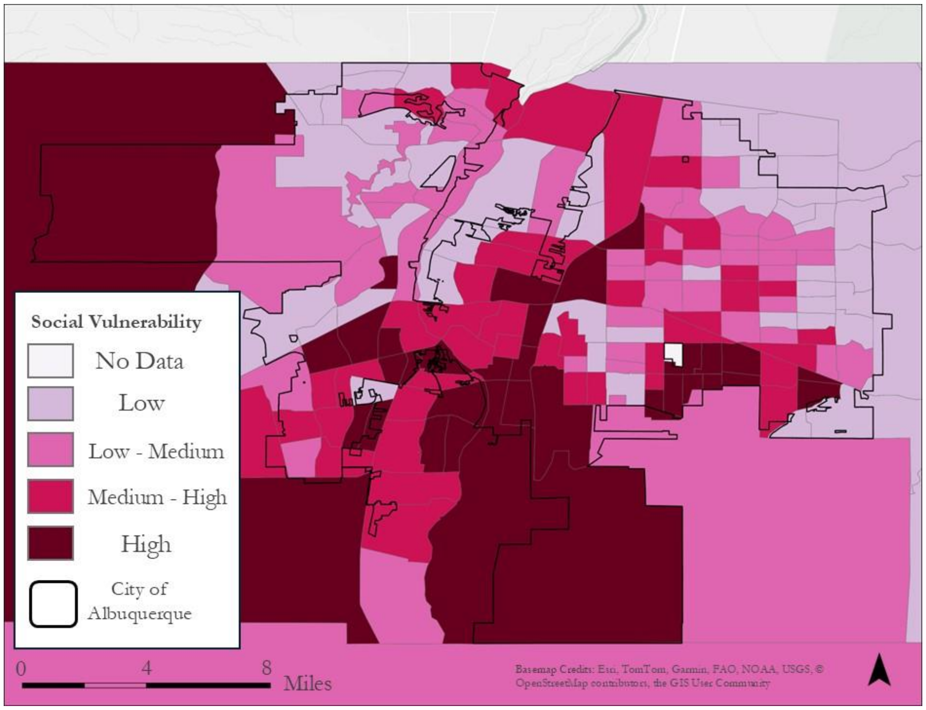

Figure 9. Social Vulnerability and Mean LST (ºC) for the months of May, June, July, and August by census tract from 2014-2024 in Albuquerque, New Mexico

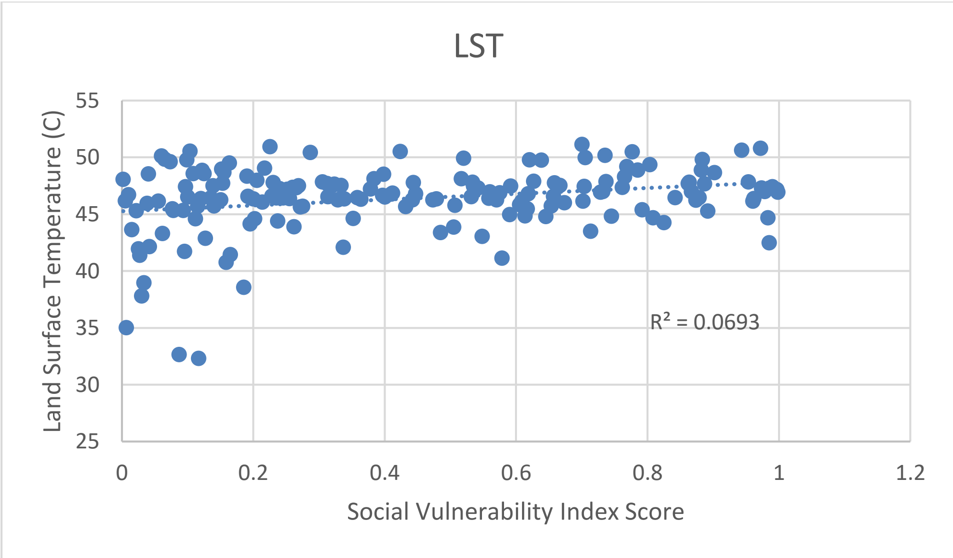

Figure 10. Social Vulnerability and Mean LST (ºC) for the months of May, June, July, and August by census tract from 2014-2024 in Albuquerque, New Mexico

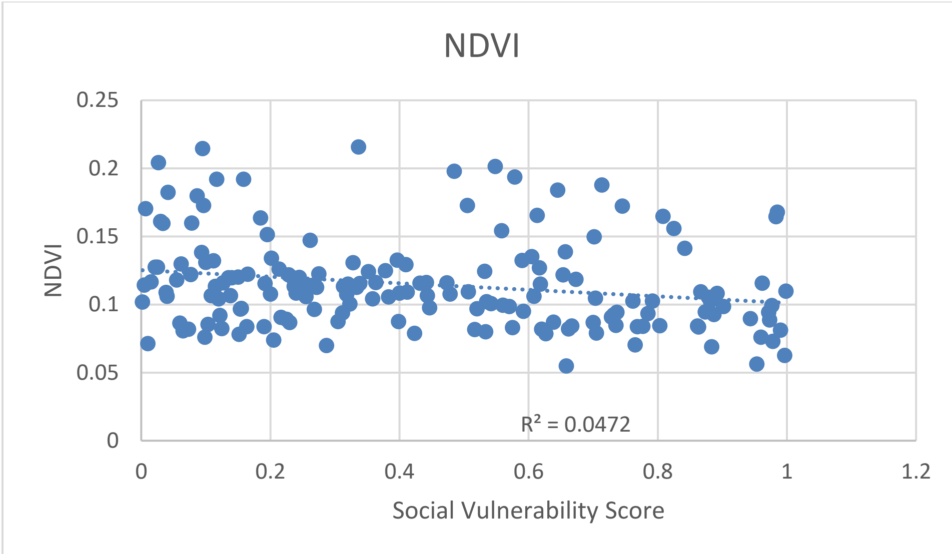

Figure 11. Social Vulnerability and Mean NDVI for the months of May, June, July, and August by census tract from 2014-2024 in Albuquerque, New Mexico

Errors & Uncertainties

By applying a filter on cloud cover for images used in the calculations for LST and NDVI, the number of images per month were limited and dependent on conditions during Landsat 8 overpasses. This caused variation in data availability. This study also used mean to calculate LST and NDVI across the study period, however adding median calculations could provide a good comparison to see if outliers are over-represented.

This study only used the CDC's social vulnerability index to compare the environmental factors with. Other indices, including heat specific ones, could be more representative of vulnerabilities and provide interesting comparisons. Albuquerque's city boundaries do not fully encompass all the census tracts that overlap it. This provides a dilemma in the best ways to represent the environmental and social data as census tracts that have area outside of the boundaries are influenced by those external areas.

CONCLUSION

Interpretation of Results

This study found that heat is lower in the riparian zones near the Rio Grande, and in areas near the Sandia Mountains. It also found that there is a relationship between LST and vegetation greenness, and that vegetation is also higher in those areas. The social vulnerability index shows lower vulnerability in some areas near the Rio Grande and Sandia Mountains where heat is lower and vegetation health is higher, however this was not consistent throughout riparian zones near the Rio Grande.

Understanding where LST is higher, and vegetation greenness is lower, provides urban planners and city government officials with important data to inform where they plant new trees and create more green spaces. This study identified that areas between the Rio Grande and Sandia Mountains would benefit from receiving new trees and showed certain census tracts that have a higher social vulnerability and should be considered a priority for receiving these resources.

This study aimed at assessing how easy Google Earth Engine is to use and see if it is a reasonable tool for city officials in midsize or small cities to use. Some agencies do not have dedicated GIS teams, so officials are interested in information like where to allocate new trees work to run analyses like these on their own. GEE is a straightforward tool that users with basic GIS knowledge can run, especially when provided with scripts to modify as opposed to starting from scratch. This study found that GEE is a great tool for government officials to use for analyses like these.

Future Research

A potential direction for future research includes using different social vulnerability indices that incorporate different social factors. The US Census' Heat

Vulnerability Index provides users with a tool designed specifically for heat and could be an interesting comparison with the CDC's social vulnerability index. Land cover classification is another valuable tool that gives important context to urban heat and vegetation. The National Land Cover Database (NLCD) classifies land based on use and type. Change in land cover throughout time can be tracked and researching how land cover changes affected urban heat in Albuquerque has value. Canopy cover is another incredibly valuable tool for assessing urban vegetation. Light Detection and Ranging (LiDAR) is a remote sensing method that uses laser pulses to create 3D images. It is more expensive and harder to use than other remote sensing techniques but gives a more accurate assessment of canopy cover. If there is data accessibility and capacity within the agency or organization looking at urban heat and vegetation, this is a great potential future research direction.

A major next step for this project would be to create a tutorial and resource library for city officials to replicate this process in their cities. This would include instructions for how to use GEE, import a script with NDVI and LST calculations set up, and how to change the study period and study area. It would also include how to bring it into another GIS software, either ArcGIS Pro or QGIS, and create maps and integrate socioeconomic data.

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APPENDIX

METADATA TABLES

Table 2. Landsat 8

Dataset:	Landsat 8
Last Updated:	2025-05-01
Owner:	NASA/USGS
Description:	This project used the Red (4), NIR (5), and surface temperature (10) bands to complete the analysis.
Coordinate System:	World Geodetic System 1984 (WGS 1984)
Projection:	Geographic Coordinate System
Type of Geometry:	Raster

Table 3. CDC Social Vulnerability Index

Dataset:	CDC Social Vulnerability Index
Last Updated:	2022
Owner:	CDC
Description:	Social vulnerability index created from US Census data from the American Community Surey
Coordinate System:	World Geodetic System 1984 (WGS 1984)
Projection:	Geographic Coordinate System
Type of Geometry:	Vector