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Creating Cool and Equitable Communities: A Comprehensive Study on Urban Heat Island Mitigation and Health Equity in Birmingham, Alabama

Bhuvana Sai Kumar Yandra
University of Alabama at Birmingham

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CREATING COOL AND EQUITABLE COMMUNITIES: A COMPREHENSIVE STUDY ON URBANHEAT ISLAND MITIGATION AND HEALTH EQUITY IN BIRMINGHAM, ALABAMA

by

BHUVANA SAI KUMAR YANDRA

ROUZBEH NAZARI, COMMITTEE CHAIR

MD GOLAM RABBANI FAHAD

WESLEY C. ZECH

A THESIS

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CIVIL ENGINEERING

ABSTRACT

Urban Heat Islands (UHIs) are a major source of concern for urban populations' health and well-being, particularly in densely populated and vulnerable locations. The integrative research, which is being undertaken in Birmingham, Alabama, intends to reduce the burden of UHIs induced by climate change, as well as to mitigate associated health risks and inequities. The study identifies the locations most affected by UHI effects and vegetation loss and offers solutions to these problems.

Furthermore, the study expands to identify socioeconomically disadvantaged and health-vulnerable groups in need of assistance to improve their quality of life. During urban heatwaves, UHIs trap heat, modify local climates, and increase health risks. The study identifies Jefferson County's Urban Heat Islands (UHI) and sensitive locations. The primary goal of the study is to quantify the impact of various types of vegetation cover on the microclimate in specific parts of Birmingham City. The goal is to improve thermal comfort on the street and reduce heat-related disorders. To attain these goals, one of the solutions investigated in this study is the augmentation of vegetative canopy. The study will also look into the effect of urban morphology on the heating or cooling rate experienced by street tree canopies. The major goal is to assess the amount to which trees planted along streets in Birmingham, AL contribute to cooling effects while considering various morphological aspects.

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The study acknowledges the considerable impact of thermal well-being on urban dwellers' involvement, especially in places with hot summers. It aims to investigate many aspects that influence thermal conditions in urban streets and to provide strategies including albedo (reflectivity) and vegetation. The ENVI-met program will be used to undertake this detailed analysis.

The study's goal is to assess environmental factors such as air temperature (Ta), surface temperature (Ts), albedo, wind speed (WS), sky view factor (SVF), and mean radiant temperature (Tmrt). A thorough investigation of these variables will result in a better understanding of the thermal environment and will inspire methods for improving outdoor thermal comfort in street areas.

Keywords: Urban Heat Island, Socioeconomically, Albedo, Surface temperature, Sky view factor

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DEDICATION

I express my deepest gratitude to my Mother Mrs. Yandra Sridevi and my beloved family. Lastly, I amindebted to my dear friends whose constant encouragement has been instrumental in shaping this work.

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CHAPTER 1

TACKLING URBAN HEAT ISLANDS AND HEALTH INEQUALITIES: AN INTEGRATIVE STUDY IN BIRMINGHAM, ALABAMA

Abstract: Urban Heat Islands (UHIs) represent a severe hazard to people's health and quality of life, particularly in areas of cities with dense and at-risk populations. This integrative research aims to reduce the burden of UHIs caused by climate change and mitigate associated health risks and inequalities in Birmingham, Alabama. The study identifies areas most impacted by UHI effects and loss of vegetation and provides remediation strategies to combat these issues. In addition, the research expands to identify socioeconomically disadvantaged and health-vulnerable communities needing intervention to improve their quality of life. Urban Heat Islands (UHIs) trap heat, alter local climates and raise health hazards during heat waves in urban areas. A multidisciplinary team from the University of Alabama at Birmingham collaborates with the city of Birmingham to implement advanced technical analytics and policies to address the areas that most need environmental remediation to counter extreme heat events and associated damages. This project utilizes a technical approach to develop a framework to identify the impact of UHIs on human health and communities in Birmingham, considering both physical and social indicators. The city of Birmingham also faces significant healthcare challenges due to pollution exposure, exacerbating underlying health conditions, and increasing hospitalizations without health insurance coverage. The study identifies that areas predominantly populated by African Americans are more vulnerable to adverse health

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effects caused by acute and long-term air pollution exposure due to their proximity to industrial facilities. The proposed study provides a unique opportunity for the city of Birmingham to address UHI-related health inequalities and improve the overall well-being of its residents.

Keywords: Urban Heat Island; Health Vulnerability; Hospitalization; Extreme Heat events.

1.1.Introduction:

Climate change has noticeable adverse impacts on cities worldwide [1], and Urban Heat Islands are a specific problem that is made worse by global warming. The phenomenon known as an "Urban HeatIsland" (UHI) is the air temperature difference between an urban region and adjacent regions. UHIs areformed because of land use changes, which result in changing physical properties, such as albedo, surface roughness, evapotranspiration, and energy flux, which change climate systems.

The impact of UHIs can be significant within city blocks, as Karimi et al. (2014) showed that up to 10^{o}C could be observed between blocks [2]. In addition, UHIs significantly impact mesoscale air circulation and can result in convection and precipitation [3-11]. Recently, there has been a heat-related illness and death incident in Alabama. In 2007, a severe heatwave caused many people to gethospitalized, and 13 died due to heat-related illness.

UHIs are a concern for several reasons, including increased human mortality and disease [12&13], poor air/water quality, changes in frequency and duration of precipitation, damage to ecosystems and infrastructure, and increased energy consumption. The end outcome of exposure to heat includes increased hospital admissions, asthma attacks, and

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acute respiratory symptoms. The National Weather Service has published online statistics of nationwide deaths due to naturalhazards since 1996 [14].

During this period, extreme temperature has been the leading cause of mortality for 10 out of 17 years and the second leading cause for four years. Since adequate heating is necessary, while air conditioning is not, deaths due to heat waves are many times higher than those due to cold. It has been demonstrated that when temperatures increase above a certain threshold, mortality becomes increasingly sensitive to small temperature changes. Currently, comparable analyses in the literaturequantify the exposure of people at risk to excessive temperatures using data from a central site's temperature. Temperature and a population's sensitivity to temperature vary locally and are factors inacute respiratory illness. Three primary components comprise the risk of injury from a UHI: occurrence, exposure, and vulnerability [15&22]. Since the extent and intensity of a certain UHI are very localized, localized research must be carried out to identify UHIs and their effects on communities[15&16].

1.2.Materials and Methods

1.2.1Study Area:

The study area of Birmingham, AL (population 209,880; 151.9 sq. miles land area) is one of the most populated cities in Alabama, with some economically distressed areas throughout the metropolis. Birmingham's reported median household income is $33,770, with 28.1% of persons living in poverty. The city has a predominantly minority population (71.6 % Black or African American, 3.8% other) with an unemployment rate of 2.6% (The estimated percentage of its total vulnerable population, children under the age of 5 and

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adults 65 years and older, affected by acute respiratory symptoms is over 20.3%. Heavy commercial and industrial land use is in African-American and low-income neighborhoods, putting them at higher risk of environmental exposures and adverse health effects. There is significant contamination of air, soil, and water in Birmingham due to the past and current production of iron and steel. Manufacturing and industrial businesses account for most of Birmingham's land use, and Brownfields constitute more than half of all industrial sites in the city [17]. Hazardous substances in industrial sites pose a considerable risk to public health [18]. The adverse effects of these contaminants have been particularly noticeable North Birmingham area due to the presence of various coke plants. The manufacturing process of coke plants involves the combustion of coal, and the pollutants emitted during this process vary depending on the source of the coal. The resulting emissions may contain various harmful substances, including formaldehyde, carbon monoxide, phenol, arsenic, cadmium, mercury, polycyclic aromatic hydrocarbons (PAHs), and aliphatic aldehydes [19]. The pollutants from these industrial sources can cause and/or intensify adverse health effects such as asthma, chronic obstructive pulmonary disease (COPD), cancer, and skin irritations. The families in these communities are, in turn, significantly impacted regarding their employment and health status.

1.2.2. Data Collection:

For this project, we collected data from various sources, such as the United States Geological Survey (USGS), the Center for Diseases Control (CDC), and the United States Census. We have collected the Land Sat 8 data, a remote sensing satellite operated by the United States Geological Survey (USGS). The data collected by Landsat 8 is used for a wide range of applications, including mapping, land use, and land cover classification, monitoring natural resources and studying the land surface and atmospheric processes (Science). The Land-Sat 8 has different bands from 1 to 11;each band is of a different wavelength, and if two or more bands are combined, it gives different information about that land or area. We have used these bands to make separate maps for the city of Birmingham and we developed Maps for Land Surface Temperature (LST), Normalized DifferenceVegetation Index (NDVI), Normalized Difference Water Index (NDWI) (as shown in Figure 1.1), Proportionate Vegetation (Pv).

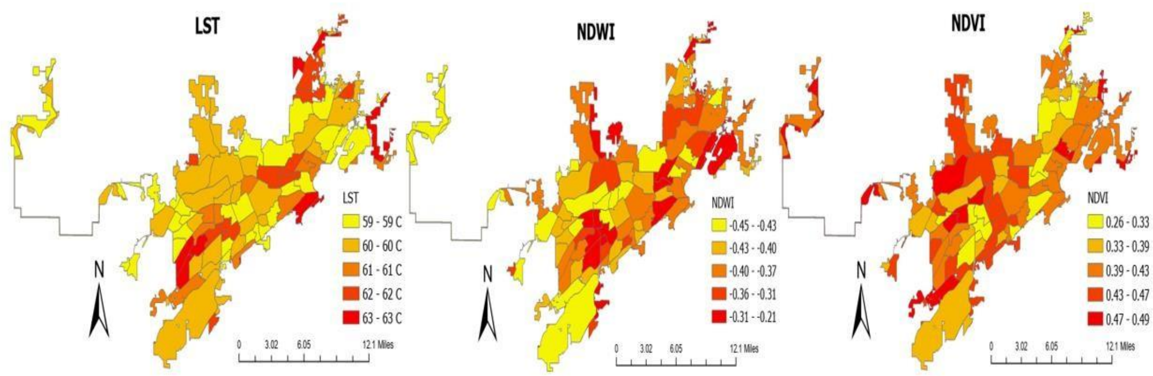

Figure 1.1. *Environmental Parameters Mapped over Birmingham City 1. LST, 2. NDWI and 2. NDVI*

We have also collected the Digital Elevation Mean (DEM) and Imperviousness of the land (%Impv) (as shown in Figure 2). The satellite images are acquired from Landsat8 [20], with >10% cloud cover, between April and August (Summer season) from 2016 to 2020. The Census tract datafor Jefferson County was obtained from the U.S. Census Bureau, and the data file was extracted using the R programming language for a period of 5 years from 2016 to 2020 for the summer months (April to August)

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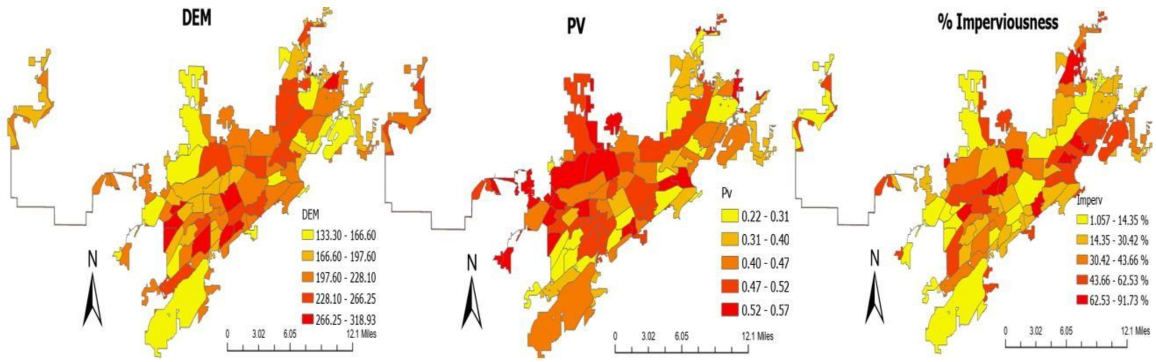

Figure 1.2. *Environmental Parameters Mapped over Birmingham City 1. DEM, 2. PV and 3. Imperviousness.*

The census data provides comprehensive information on individual segments, including but not limited to Population Density, Disability Rate, Ethnicity (Black and Hispanic), Proportion of the Elderly Population (above 65 years), Elderly Population Living Alone, Poverty Rate, Unemployment Rate, and the Percentage of Households without a Vehicle (Figure 1.3).

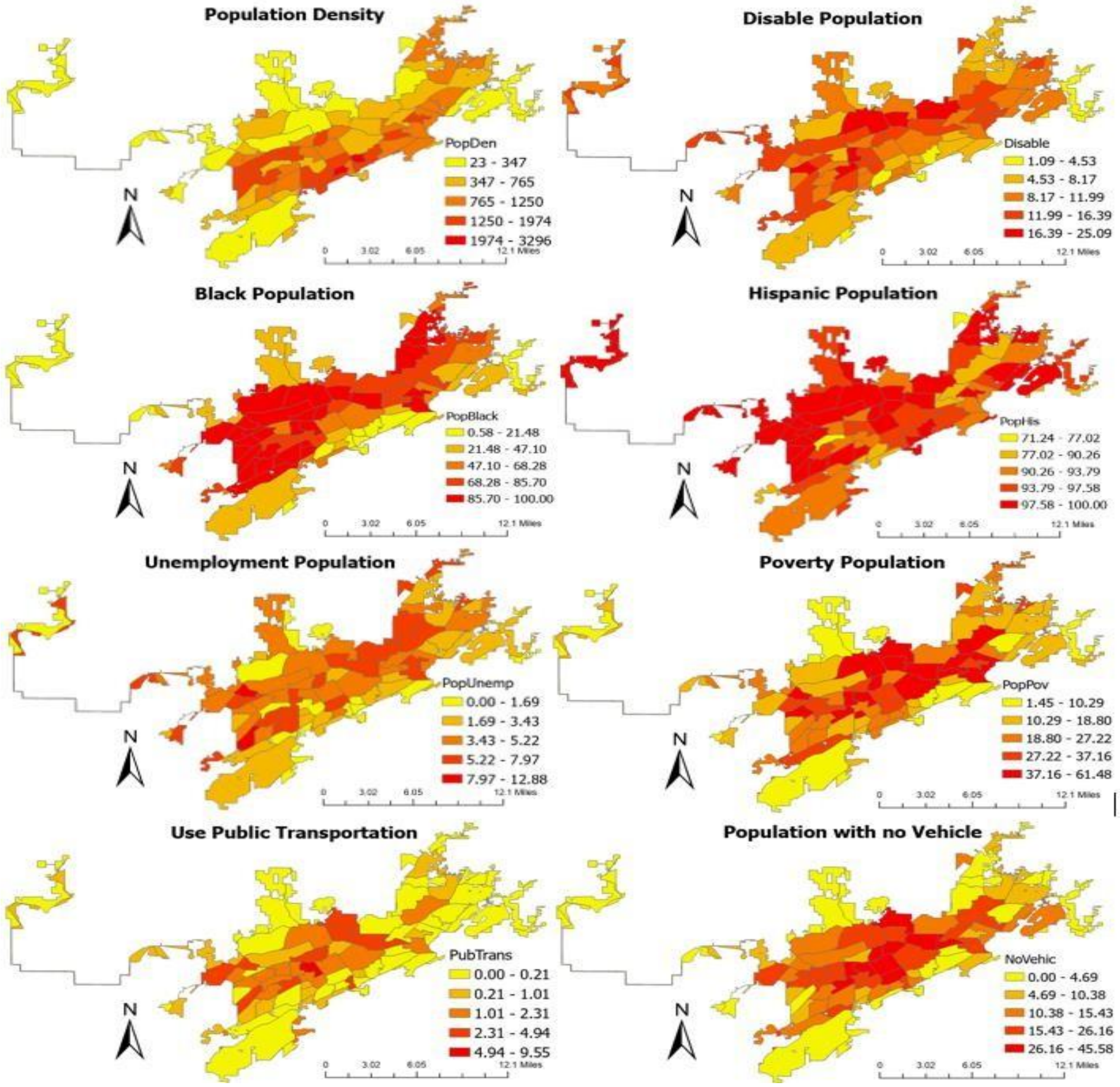

***Figure 1.3**. Social Parameters Mapped over Birmingham City Population with Disability, Population over 65, Population Density, Hispanic Population, Population over 65 Lives Alone, Black Population,Unemployment, People Without Vehicle, and Population below Poverty.*

This information provides an in-depth understanding of the demographic, socio-economic, and geographic characteristics of Birmingham City [21]. We collected health-related data for the study area from the Centers for Disease Control and Prevention (CDC) in the United States. The dataset comprises various parameters for each segment of the study area,

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including but not limited to the prevalence of obesity, stroke, high blood pressure, asthma, and chronic obstructive pulmonary disease (COPD) (Figure 1.4). These parameters provide vital insights into the health status of the study area and enable us to identify potential health risks and concerns in the community.

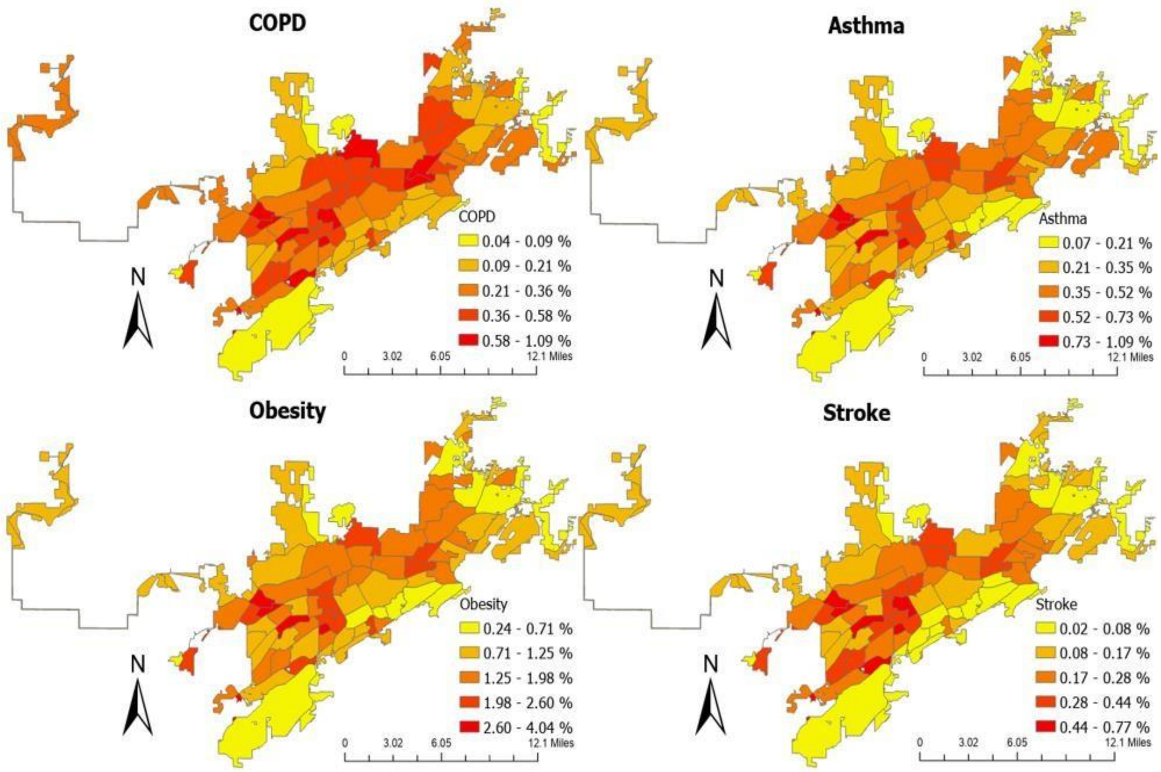

Figure 1.4. *Health Parameters Mapped over Birmingham City COPD, Asthma, Obesity and Heart Stroke*

1.3. Methodology:

For the methodology part, three different models have been prepared using data collected from various sources; the models are as follows: **1. PCA Index** (Principal Component Index), **2. Exposure risk Index** (E) and, 3. **Heat Risk Index (R) (Figure 1.6).**

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The Exposure risk (E) model was made by considering the risk factor of exposure to environmentaleffects such as Land Surface Temperature (LST). The Principal Component Analysis (PCA) model is made by assessing the underlying socio-demographic and health vulnerability, calculated by combining the six health indicator components and the 16 socioeconomic census components health parameters.

Principal Component Analysis resolution reduces people's capacity for adaptation (PCA). Combining these factors with the dimensionality of big datasets makes variables simpler to comprehend (Figure 1.5). Finally, the Exposure risk and PCA index are combined to get the Heat Risk Index (R), which shows the population affected by heat risk due to their social, dimorphic, and health parameters.

For calculating the Risk Index as follows:

Equation 1.1. Heat Risk (R) = Exposure Risk (E) $*$ Social and Health

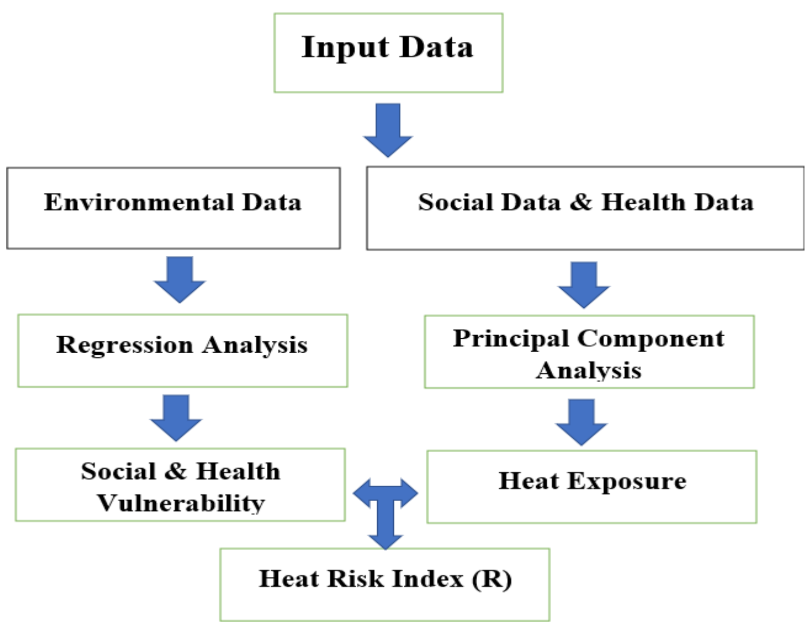

Figure 1.5. *Methodology*

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By considering relevant environmental indicators and by using Ordinary Least Squares (OLS) analysis, one can evaluate the exposure risk to Land Surface Temperature (LST) and determine the relationship between each environmental variable and LST. We performed several multicollinearitytests and removed dependent variables like NDVI and Albedo [23]. We used an R script to conduct regression analysis on the data in the shapefile provided in the previous section. We also tested the spatial autocorrelation using Moran's I test to see if a spatial regression model would enhance our findings. We used a global geographical model for the study called Spatial AutoRegression (SAR), which accounts for the spatial effects of dependent variables and independent variables like Land Surface Temperature (LST). This method enables us to take into account these aspects of worldwide interdependence. This SAR model covered all census block groups in Jefferson County. The SAR method was utilized to get broad effect values, which were then used to identify anomalies in each variable based on the statistically significant aspect of each variable. It was discovered that these impact values, which were computed as index weights, helped describe the connection between LST and the variables that are affected.

1.4.Result:

1.4.1. Calculating Health Social Vulnerability via V index:

The data collected for the Census tract variables in Jefferson County were subjected to Principal Component Analysis (PCA) to decompose socio-economic and health characteristics into smaller independent components that are most crucial for heat vulnerability. The most crucial informationis taken from the original variables using PCA and combined into several independent components.The methods were incorporated into

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R Studio to do an extensive PCA evaluation. For this, the stats package's 'prcomp' function (version 3.6.2) was employed. It was necessary to compute index values that could accurately represent and indicate social and health risks among the constituent elements of each census tract.

To better understand social vulnerability in Birmingham City, the study used principal component analysis to identify the variables most strongly associated with vulnerability. The examination revealed that the initial principal component exhibited significant associations with various health conditions, namely diabetes, high blood pressure, obesity, stroke, the absence of health insurance, and asthma. Additionally, other contributing factors encompassed proficiency in English language usage, population density levels, and the proportion of elderly individuals within the Hispanic community as well as minors in general.

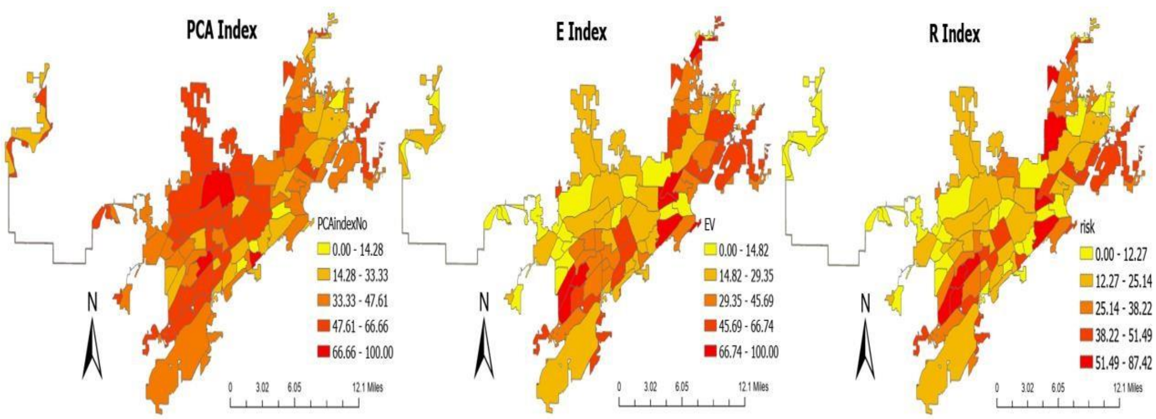

Figure 1.6. *Final 3 Models Mapped over Birmingham City PCA Index, E Index, and R Index*

Furthermore, identified were characteristics such as racial identity (specifically Black), limited access to vehicles, and disability status which also played a role in determining vulnerability. In order to ascertain the vulnerability index for Birmingham City accurately; we proceeded by computing an average value derived from the first ten principal elements

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across all available data points. The values obtained underwent normalization procedures resulting in their conversion ontoa standardized scale ranging between 0 and 100 units. This index was then used to create a map depicting the county's social and health vulnerability. Figure 1.6. illustrates the vulnerability index at the census tract level using a color scale to indicate the degree of vulnerability. An assorted coloror shade represented each census tract, and the map displayed the boundaries of each city and its corresponding census tracts. The color scale ranged from low to high vulnerability, with higher values indicating greater vulnerability and lower values indicating lower vulnerability. By comparingthe vulnerability index values across different census tracts, the map visually represented each area'srelative social and health vulnerability levels. This information is vital for policymakers andresearchers to understand the specific needs and challenges different communities in Birmingham City face. The figure 1.7. shows the graphical representation of all the 10 principal components utilized for the PCA

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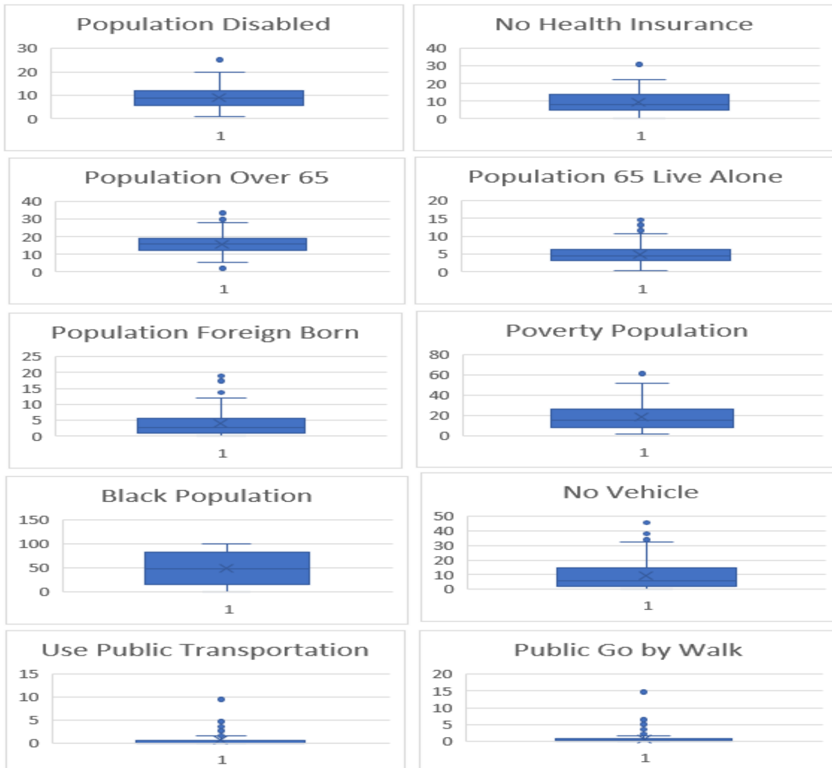

Figure 1.7: *Comparing Scores of 10 Principal Components for Birmingham City.*

1.4.2. Heat Exposure Risk (E index):

To understand the connection between heat exposure and environmental factors, such as fractional vegetation, NDWI, % imperviousness, and elevation, LST was used as a reference for the actual temperature of the air. All of the selected ecological variables together strongly describe LST, as demonstrated by an OLS model that yielded an adjusted R-square value of 0.358 with a significant F-value (p-value 0.05). The coefficients for Pv (-5.20), NDWI (-5.54), elevation in meters (0.0037),and percent imperviousness (0.0049) were all present in terms of statistical significance (p-value 0.05). Additionally, it was shown that there were significant correlations between LST and NDWI (-0.88), percent imperviousness (-0.887), and Pv (-0.859). Because percent imperviousness also exhibits

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substantial association with Pv and NDWI, a multicollinearity test was conducted utilizing the 'imcdiag' function from the ''mctest' library in R. The OLS model revealed that NDVI and albedo were multicollinear, therefore just four explanatory variables—Pv, NDWI, elevation, and % imperviousness—were employed to construct the final model that was used. Interesting results from the statistical analysis known as the Moran's I test showed a significant Moran's I statistic (p-value 0.05). This implies that the ordinary least squares (OLS) model has residuals that are spatially linked. Lagrange Multiplier diagnostics were used to examine and assessthe spatial connection in linear models in more detail. These diagnostics showed how adding spatialmodels, like a spatial delay or spatial inaccuracy model, can improve upon what the original linear algorithm produced. To comprehend the direct and indirect effects of the explanatory factors on LST, the SLX model was ultimately chosen. All explanatory variables, except for DEM, have statistically significant correlation coefficients with LST (-5.2, -5.4, -0.0037, and 0.0049, respectively) (Table. 1.1.). The SLX model suggests that all explanatory variables, except for DEM which is a notable outlier, significantly account for variations in LST. Unlike other parameters, the relationship between imperviousness and LST seems to oscillate between positive and negative associations. A subsequent impact analysis on the SLX model provided insight into each variable's direct, indirect, and total effects through their respective coefficients. Table 1 below presents these coefficient values along with the statistical significance of every parameter’s overall influence as well as its separate direct and indirect impacts on LST. It appears that only imperviousness has a favorable effect on LST while NDWI negatively influences it substantially. The exposure risk (E index) was then calculated using the global impact coefficients, and the values were standardizedon a 0–100 scale

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Equation 1.2. $\text{E index } (\mathrm{E}_X) = \sum_{(i=P_v, NDWI, DEM, \%\ \text{imperviousness})} (X_i \times G_i)$

The letters X and G represent a specific census block group and its worldwide impact on a given variable. The letter 'i' stands for one of four X, while G stands for a specific census block group andits global implications for a given variable. In our SLX model, the letter i represents one of four variables, with Xi denoting the specific value of that variable for a given census block group.

Figure 1.6 depicts an E-index map constructed at the census block-group level utilizing the SLX model's global effect coefficients. Applying the Jenks natural break classification method, the mapsdivide the E index spectrum into five categories. Block groupings around city centers have a significant risk of heat exposure. The highly vulnerable blocks all tend to the north and near Birmingham; these areas mainly consist of the vulnerable black and Hispanic populations. And if we look at the other parts of Jefferson County with lower E Index values, the areas are less vulnerable due to their economic status.

Table 1.1: *Direct, Indirect, and Total impact of explanatory variables resulting from the SLX model.*

Variable	***Direct Impact***	***Indirect Impact***	***Total Impact (G)***
Pv	*-5.203*	*-3.609*	*-8.812*
NDWI	*5.542*	*3.690*	*9.233*
DEM	*-0.003*	*-0.004*	*-0.008*
% Imperviousness	*0.004*	*-0.002*	*0.001*

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1.4.3. Distribution of Exposure Risk and Socio-demographic-health Vulnerability Index:

The E and V index are shown below graphs (Figure1.8.); the data distribution of the V index is almost all over Birmingham with a median of 40 and does have a peek in certain census tracts that are much more vulnerable compared to other areas. The E Index has a variation in thedistribution of data census tracts 90 to 163 are much more affected the areas 1 to 89, which is dueto the difference in the land cover, as much of the city is covered by concrete and roads which results in more risk in higher values.

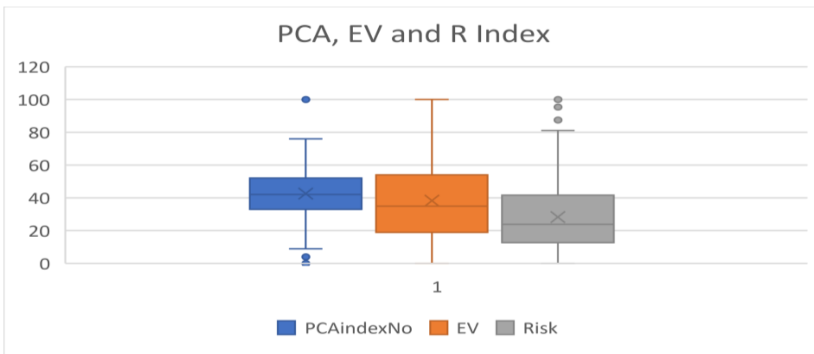

Figure 1.8. Distribution of PCA, E and V index values resulted for Birmingham city Census tracts.

1.4.4. The Heat Risk Index (R):

The result was used to calculate the Heat Risk Factor in Equation 1, which combined exposure and underlying city vulnerability. Figure 6 depicts thermal risk maps for Birmingham City at Census block group solution, generated with the E Index (1-100), V Index (1-100), and Jenks natural break categorization methods. The Birmingham city center is surrounded by a high heat risk cluster. The lower heat-risk groups, like the low E index clusters, are located on the outer limits of the city. Figure 8 depicts a graph chart of the estimated heat dangers for Jefferson County census block groups. According to the distribution and data of such hazards, most census block groups in Birmingham City have

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high heat risks. Therefore, heat mitigation techniques should concentrate on high-risk block groups in cities with wide R-index dispersion.

1.5.Limitations:

While our study provides valuable insights into the impacts of heat islands, it is important to acknowledge its limitations. One such limitation is using surface temperature as a proxy for air temperature to explore the effects of heat islands. While commonly used in similar studies, this approach may not fully capture the complexity of air temperature variations in urban areas.

Additionally, our analysis is based on Landsat 8 imagery, which provides only a limited number of monthly surface temperature samples. Furthermore, the imagery is captured at specific times and days during the summer months, which may not represent the overall temperature conditions in the study area. Despite these limitations, our study employed a census tract-level resolution for computing the V index. This decision was made because the sociodemographic data required to construct the index are mainly unavailable at the census block and block group level. By utilizing the census tract level, we were able to analyze the vulnerability of communities in a more granular manner, providing valuable insights for policymakers and researchers.

1.6.Conclusion:

The study conducted a spatial analysis to examine the impact of urban heat on the physicallandscape of Birmingham and assess the vulnerability of communities to these effects. The results showed that individuals from economically weaker sections,

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particularly those from minority and foreign-born communities, children, and individuals above 65, are more susceptible to heat risks. The study identified a pattern in the PCA, EV, and Risk Indexes that indicates a higher risk in these areas. The findings indicate that poverty and unemployment contribute to economic vulnerability and increased susceptibility to heat risk, which is particularly prevalent in black neighborhoods. The study suggests implementing green infrastructure (GI) to enhance air quality and promote community well-being. Climate and temperature data, vegetation coverage, and infrastructure location were the physical indicators used to develop maps that will assist city planners in better planning and development for the City of Birmingham. The generated data and maps are available on an informative webpage hosted through UAB, allowing for rapid dissemination. Overall, this study highlights the need for community-based strategies that target themost vulnerable populations and demonstrates the potential of GI as a means of mitigating the impact of urban heat on vulnerable communities.

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CHAPTER 2

"URBAN HEAT ISLAND MITIGATION IN BIRMINGHAM, AL: ASSESSING COOLING STRATEGIES THROUGHENVI-MET SOFTWARE."

2.1. Abstract:

This Paper identifies the Urban Heat Islands (UHI) and vulnerable areas across Jefferson County. The objective of this research is to assess the quantitative influence that different types of vegetation cover have on the microclimate within distinct areas in Birmingham City. The aim is to enhance thermal comfortat street level and alleviate heat-related issues. One of the strategies explored in this research is the additionof vegetation canopy to achieve these goals. This study aimed to investigate the impact of urban morphology on the rate at which street tree canopies experience heating or cooling. The primary objective was to evaluate the extent to which trees planted along streets in Birmingham, AL contribute to cooling effects, taking into account different morphological factors.

Considering the significant impact of thermal well-being on urban dwellers' engagement, there isa growing interest in investigating outdoor thermal comfort within street environments, particularly in regions experiencing scorching summers. The main aim of this study is to examine the various factors that impact the thermal conditions within an urban street and propose strategies pertaining to albedo (reflectivity) and vegetation. To achieve this, a comprehensive analysis will be conducted using the ENVI-met software. The objective of the research encompasses evaluating environmental attributes such as air temperature (Ta), surface temperature (Ts), albedo, wind speed (WS), sky view factor

(SVF) and mean radianttemperature (Tmrt). By thoroughly investigating these variables, a more profound comprehension of the thermal environment can be attained. For the study 3 different scenarios for Envi-Met models, they are 1. Area with Existing vegetation, 2. Area with Existing Vegetation with Albedo and, 3. Area with additional Vegetation and Albedo. The study's findings demonstrate that the degree of temperature relief sensed by pedestrians, during the daytime is influenced by the types and characteristics of trees. This comfort level is measured using parameters such as Mean Radiant Temperature (Tmrt), Physiological Equivalent Temperature (PET), and Universal Thermal Climate Index (UTCI). The research will offer, valuable insights into effective green cover scenarios that can be implemented to ensure a more comfortable pedestrian environment. The study produced the anticipated results, demonstrating that the combination of various types of vegetation with albedo has the potential to effectively lower temperatures and create a more favorable and conducive environment. These insights will guide future interventions to maintain optimal thermal conditions for pedestrians.

Keywords: Envi-Met, Physiological Equivalent Temperature (PET), Mean Radiant Temperature (Tmrt), Universal Thermal Climate Index (UTCI), Albedo, Sky View Factor (SKV), and Surface Temperature (Ts).

2.2. Introduction:

The Urban Heat Island (UHI) phenomenon has emerged as a significant challenge in the 21st century, primarily resulting from the rapid urbanization and industrialization of human civilization. With the projected global temperature rise, it is anticipated that the climate will become more uncomfortable, particularly during the summer season, leading to an

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escalation in heat stress. The aggravation of heat stress induced by a condition known as heat islands in urban areas (UHI) will have even more severe repercussions for urban areas. The environment of a city has a considerable impact on how its open spaces are used. Public spaces designed for cycling and walking, such as gardens, squares, housing and commercial districts, and foot- and cycling routes, are more likely to be used and appreciated often when they provide a warm and healthy atmosphere (Laura Kleerekoper, 2012).

Due to the UHI effect, urban areas frequently have greater temperatures than adjacent countryside, caused by buildings and paved surfaces' absorption and re-emission of heat. Plants and vegetation help counteract this effect by providing shade, evaporative cooling through transpiration, and reducing the surface temperature of urban areas. Being in the presence of plants and green spaces has been shown to have a calming effect on people and reduce stress levels. The sight and proximity of nature can help improve mood, promote relaxation, and provide psychological well-being, which is particularly beneficial urban settings where stress and mental health issues are prevalent (Peschardt K.K., 2012).

Zheng, (2016) found that the type of green space also significantly improves thermal comfort and energy savings. Different vegetation types, such as trees, shrubs, or green roofs, have varying effects on shading, evapotranspiration, and air movement, influencing thermal conditions in urban environments. As urbanization progresses and the climate changes, the emergence of heat pockets in cities becomes more pronounced. Consequently, it has become imperative to intervene or design the built environment with a specific focus on reducing air temperatures, especially during heat waves. Taking measures to mitigate heat and create cooler urban spaces is essential for the well-being and comfort of urban

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residents in the face of rising temperatures (Jens Hesselbjerg Christensen, 2013). Overall, incorporating plants and greenery into urban environments offers a wide range of benefits, including noise reduction, stress reduction, improved air quality, enhanced social interactions, mitigation of the UHI effect, and improved outdoor thermal comfort. These effects create healthier, more sustainable, and enjoyable cities for residents.

A surface's capacity to reflect sunlight is referred to as albedo. It depends on things like color and brightness. A modification in the building/pavement material albedo can either have an advantageous (cooling) or unfavorable (warming) impact on the environment (Hannes P. Schwaiger, 2010). Cities worldwide have shown great interest in cool pavements as they actively work to tackle the combined problems of heatwaves and urban heat islands (UHIs). Global warming projections, which predict a rise in such occurrences and their associated repercussions, contribute to this growing awareness (Hendel, 2020).

2.3.Materials and Methods:

2.3.1. Urban Microclimate and Thermal Comfort:

Changes in urban temperatures have a profound impact on the living environment of society and the way people engage in outdoor activities. This environment can be defined as a microclimate, which encompasses a limited volumetric space extending just a few meters above and below the earth’s surface. This microclimate includes various elements such as the spaces within vegetation canopies, where temperature variations, airflow patterns, and other factors shape the unique conditions experienced within these urban spaces (Evyatar Erell, 2012).

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Understanding and managing the microclimate within urban areas is crucial for creating comfortable and sustainable environments that promote the well-being and activities of those who inhabit and interact with these spaces. Seven important factors influence a person's energy budget in outdoor spaces: air humidity, ambient temperature, air circulation, radiation from the sun, terrestrial radiation, body heat, and garment protection. These parameters, when considered collectively, establish the balance between heat absorbed from the environment and heat lost by the individual, and hence play an important part in thermal comfort and overall energy exchange (Naveed Mazhar, 2015). Researchers prioritize studying and assessing microclimatic circumstances, physiological factors (including aspects such as respiratory rate), and personality characteristics in thermal comfort in outdoor studies. These three aspects are crucial in evaluating and comprehending the thermal comfort experienced by individuals in outdoor environments. By considering the complex interplay between microclimatic factors, physiological responses, and human behavior, researchers can gain insights into the factors influencing thermal comfort and develop strategies to enhance outdoor environments for optimal comfort and well-being (S.Y. Chan, 2017).

In assessing local thermal comfort, human biometeorological parameters play a vital role. Parameters such as mean radiant temperature (Tmrt), physiological equivalent temperature (PET), and universal thermal climate index (UTCI) are commonly utilized to evaluate thermal comfort levels (Samain Sabrin,2021). These parameters consider meteorological conditions and human physiological responses to comprehensively understand the thermal environment. By considering these biometeorological parameters, researchers and practitioners can better access and analyze the perceived thermal comfort experienced by

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individuals in specific locations and optimize urban planning and design strategies accordingly. This study will enhance the analysis by examining the spatial distribution of Tmrt and PET. Tmrt specifically focuses on exchanging radiant heat between the environment and occupants with radiation serving as the primary heat source. By investigating the spatial distribution of Tmrt, researchersaim to gain a more comprehensive understanding of how urban vegetation configurations impactthermal comfort in different areas (Sabrin, 2022).

The ENVI-met microclimate simulating software based on computational fluid dynamics or CFD will be used in the study to simulate and evaluate the microclimatic circumstances (Sabrin, 2022). This studywill use an integrated analytical method to analyze the combined influence of plant and pavement reflectivity on thermal comfort in the outdoors. It seeks to investigate how different scenarios involving changes in plant species and surface albedo can collectively impact outdoor spaces' microclimate and thermal conditions. This holistic approach will provide a comprehensive understanding of the interplay between vegetation, surface materials, and thermal comfort, allowing for more informed decisions in urban planning and design (Alireza Karimi, 2020).

2.3.2. Study Area:

For the study area, I have already selected the city of Birmingham, AL, with a population of 209,880 and a land area of 151.9 square miles, which is among the most populated cities in Alabama. However, it faces economic challenges, including economically distressed areas scattered throughout the metropolis. This study investigates the microclimatic thermal conditions within an underserved neighborhood, specifically the city blocks in Birmingham, Alabama.

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According to the Koppen-Geiger climate classification, Birmingham, Alabama has a humid subtropical climate with no clearly defined dry season and mild average temperatures (Hylke E. Beck, 2018). Due to yearly rains, the area experiences constant dampness throughout the year. In Birmingham, summers are often warm and muggy, with lots of thunderstorms. The winters are moderate, and mid-latitude cyclones are mostly responsible for the precipitation. In Birmingham, the seasonality is moderate (States,1977). Due to ongoing environmental issues, the North Birmingham neighborhood has been chosen as the study area. Residents of this neighborhood have been enduring environmental pollution from industrial emissions in the surrounding areas (Letwin, 1991). It is worth noting that heavy commercial and industrial land use is concentrated in African American and low-income neighborhoods, resulting in a higher risk of environmental exposure and associated health consequences (Schwartz, 1993). Birmingham generally has a significant history of air, soil, and water contamination due to past and present iron and steel production. Manufacturing and industrial activities constitute a significant portion of Birmingham's land use, and a substantial number of industrial sites are classified as Brownfields, posing a considerable health risk to the public due to hazardous substances (Chaney, 2002).

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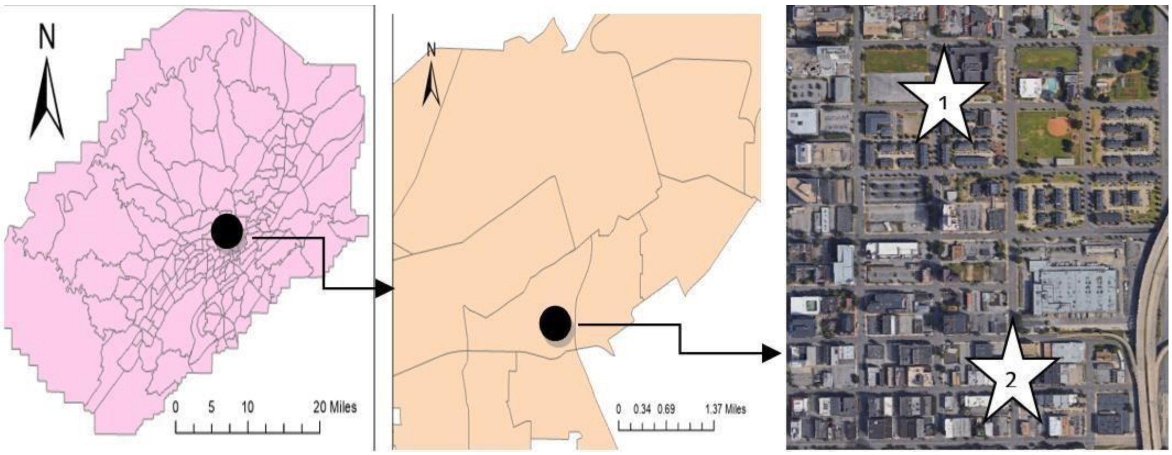

Figure 2.1. *Jefferson County (Left) selected study areas are stars 1&2 shows the study area block in the City of Birmingham.*

In Chapter 1 of my thesis, the areas with more vulnerability in the city were identified, and for this study, two city blocks have been selected, which are shown in the Figure.2.1. The selected city blocks are near the northeast side of the city. Both areas' ground was mostly covered with paved roads or buildings, resulting in more solar radiation and less vegetation increasing radiation absorption and directly affecting the people on these streets. Given the neighborhood's ongoing challenges in safeguarding the health of its residents from various environmental exposures, this study focuses on the heat-stressed areas within the neighborhood. These areas have been identified for analysis to determine the most effective strategies, with a particular emphasis on interventions through vegetation planting and albedo.

2.4. Methodology:

In this research, the study employed ENVI-met (version 5.5) to simulate thermal comfort techniques. ENVI-met is a renowned multidimensional software extensively utilized in

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various microclimate simulation studies. With its extensive capabilities, ENVI-met enables the modeling of urban climates by considering diverse parameters including radiation emissions from structures and vegetation such as short-wave and long-wavelength radiations (Michael Bruse, 1998). The software incorporates all relevant physical vegetation characteristics, allowing for accurate modeling and analysis of the urban environment (Ferdinando Salata, 2016). By utilizing ENVI-met, this study was able to simulate and assess the effectiveness of different thermal comfort strategies. The utilization of this software provides researchers with valuable and profound insights into the intricate dynamics between structures, flora, and their surrounding environment. It enables them to delve deeply into the investigation of various factors that impact climatic conditions in a meticulous manner. ENVI-met encompasses all crucial elements contributing to thermal comfort including wind velocity, mean radiant temperature (MRT), ambient temperature, and moisture levels (Lenzholzer, 2012). To conduct simulations using this computer program requires an extensive input directory encompassing multidimensional data such as building types, pavement materials utilized, tree dimensions, and species present along with geographic and climatic information (Figure 2.2.).

The physiological equivalent temperature (PET) was computed by utilizing, the Biomet. Its initials stand for "Biometeorological Models." Envi-Met's Biomet models simulate and examine how the urban environment and human biometeorology interact (Ouali, et al., 2018). Biomet models can offer important insights into people's outdoor thermal comfort and well-being in various urban design scenarios by simulating the microclimate and environmental conditions within an urban region (Manat Srivanit, 2020). These models determine how the urban environment affects people's thermal comfort, their perception

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of the temperature outside, and other biometeorological characteristics. The calculation of PET considers factors including air temperature, relative humidity, wind speed, MRT, human activity, and apparel (AndreasMatzarakis, 2006).

The ENVI-met model relies on primary inputs received from many datasets, including information about the built environment and meteorological conditions. These inputs are necessary to run reliable simulations, produce insightful results, and inform design decisions and strategies for thermal comfort in urban locations (Sabri

n, 2022). The climatic information was taken from the closest forecasting facility in the city and had chosen the 9th of May, one of the hottest days inthe month of May 2021. The physiological equivalent temperature (PET) was evaluated andcalculated by using the Zahakis model. In this simulation, the height has been set at 1.5 meters above the surface. Air temperature, relative humidity, wind speed, MRT, human activity, and apparel are used in the calculation of PET (Andreas Matzarakis, 2006). The parameters required to calculate are shown in table no.2.4.

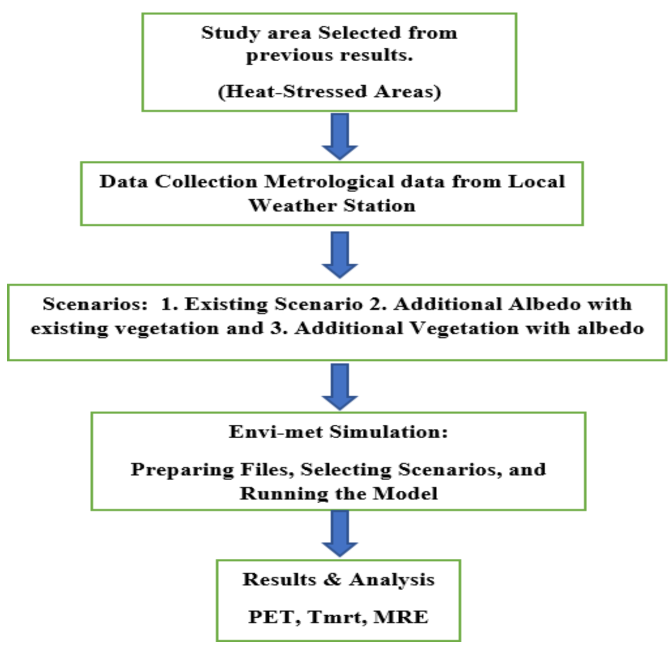

Figure 2.2. *Methodology*

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For the different vegetation and albedo strategies, we have created three different scenarios. They are:

1. Existing vegetation and Albedo (No changes)
2. Change in Albedo with the same vegetation and
3. Change in Albedo with additional vegetation.

Scenario 1. In this scenario, the weather data has just been gathered from the nearby weather stationand high-resolution images have been used from Google Earth Pro. The PNG images have been converted into Bitmap to be utilized in Envi-met spaces. The default concrete has been used as the building material, with an absorption value of 0.5 and a reflection value of 0.5. For surfacepavements, a black asphalt road with an albedo value of 0.2 and concrete pavement with an albedo coefficient of 0.2 have been used (Table 2.1.). For grass, an average dense grass of 25 cm has been used as the existing vegetation, and for 3D plants, the Tulip Polar of medium age has been chosen (Figure 2.3.).

Table 2.1. ENVI-met input data for Scenario 1.

Simulation days	9th–10th May 2021
Starting time	6:00 a.m.
Simulation period	24 h
Number of grids (x, y, z)	100, 100, 60
Size of x and y grid cells	2 m
Size of z-grid cells	1 m
Albedo of walls & roofs	0.5 (default value)
Building and Pavement material	Dense concrete & Black asphalt road
Albedo of Pavements	0.2
Green Covering	25 cm avg grass cover
Tree Species	Tulip Polar

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Scenario 2. All the data gathered in the first scenario has been used in this scenario. Still, with modifications for the building material and surface material (Table 2.2.). For the building material, an albedo value of 0.7 has been chosen, which can be changed by adding a white paint coating on the rooftops of the building (Figure.3). For roads, asphalt road with a red coating has an albedo of 0.5, and for pavement, light-colored concrete with an albedo value of 0.8 has been used.

Table2.2. ENVI-met input data for Scenario 2.

Simulation days	9th–10th May 2021
Starting time	6:00 a.m.
Simulation period	24 h
Number of grids (x, y, z)	100, 100, 60
Size of x and y grid cells	2 m
Size of z-grid cells	1 m
Albedo of walls & roofs	0.7 (default value)
Building and Pavement material	Light concrete & asphalt road with red pigment
Albedo of Pavements	0.5
Green Covering	25 cm avg grass cover
Tree Species	Tulip Polar

Scenario 3. In the third and final scenario, the albedo and the tree species for the study area have been modified (Table 2.3.). The same albedo values and material as in the second scenario have justbeen used. For vegetation, Bold Cypress, Tulip Polar, and Green Ash three species have been used, and the 25 cm average dense grass has been spread across the footpath (Figure 2.3.).

Table 2.3. ENVI-met input data for Scenario 3.

Simulation days	9th–10th May 2021
Starting time	6:00 a.m.
Simulation period	24 h
Number of grids (x, y, z)	100, 100, 60
Size of x and y grid cells	2 m
Size of z-grid cells	1 m
Albedo of walls & roofs	0.7 (default value)
Building and Pavement material	Light concrete & asphalt road with red pigment
Albedo of Pavements	0.5
Green Covering	25 cm average grass cover
Tree Species	Tulip Polar, Bold Cypress, and Green Ash.

The tree plantation has been carried out every 15 meters distance along the pavement on both sides,increasing in green shading areas.

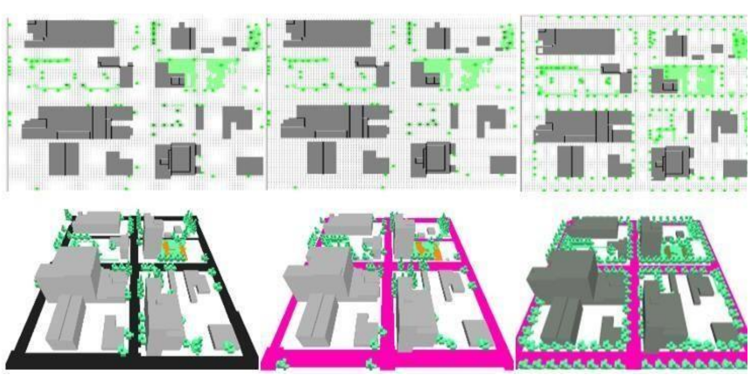

Figure 2.3. *Shows the three scenarios of the study area in 2D and 3D in Envi-met.*

Table 2.4. Biomet input data for calculating thermal comfort.

Personal data	Height	1.65 m
	Weight	70 kg
	Age	30 years old
	Sex	Male

2.5. Results:

2.5.1. Temporal profile of the microclimatic conditions:

An initial analysis was conducted to assess the microclimatic conditions in each scenario by examining the temporal variation of meteorological data. The objective was to gain insights into the thermal comfort level experienced during different periods. Specifically, the focus was on the warmest hours, from 12:00 p.m. to 8:00 p.m. Hourly profiles of various parameters were investigated during this time frame, including potential air temperature, relative humidity, radiative heating, or air-cooling rate, and three thermal comfort indices (Tmrt, PET, and UTCI). These profiles provided valuable information on how these parameters fluctuated throughout the afternoon and early evening. To comprehensively view the temporal variation, average values for each hour were calculated for the entire block area. This allowed for the creation of temporal profiles that illustrate the trends and patterns exhibited by these parameters. Figure 4 presents these profiles, specifically demonstrating the gradual increase in air temperature until it peaked between 4 and 5 PM, followed by a rapid decrease until 6:00 PM. By analyzing these temporal profiles, researchers can better understand the microclimatic circumstances and the accompanying thermal well-being observed in the tested scenarios. These findings lead to a more thorough assessment of the influence of various factors on the climate and aid in the development of methods to improve comfort during the identified warmest hours. The existing scenario, characterized by limited vegetation and lower albedo for buildings and pavements, exhibited the highest temperatures among the studied scenarios.

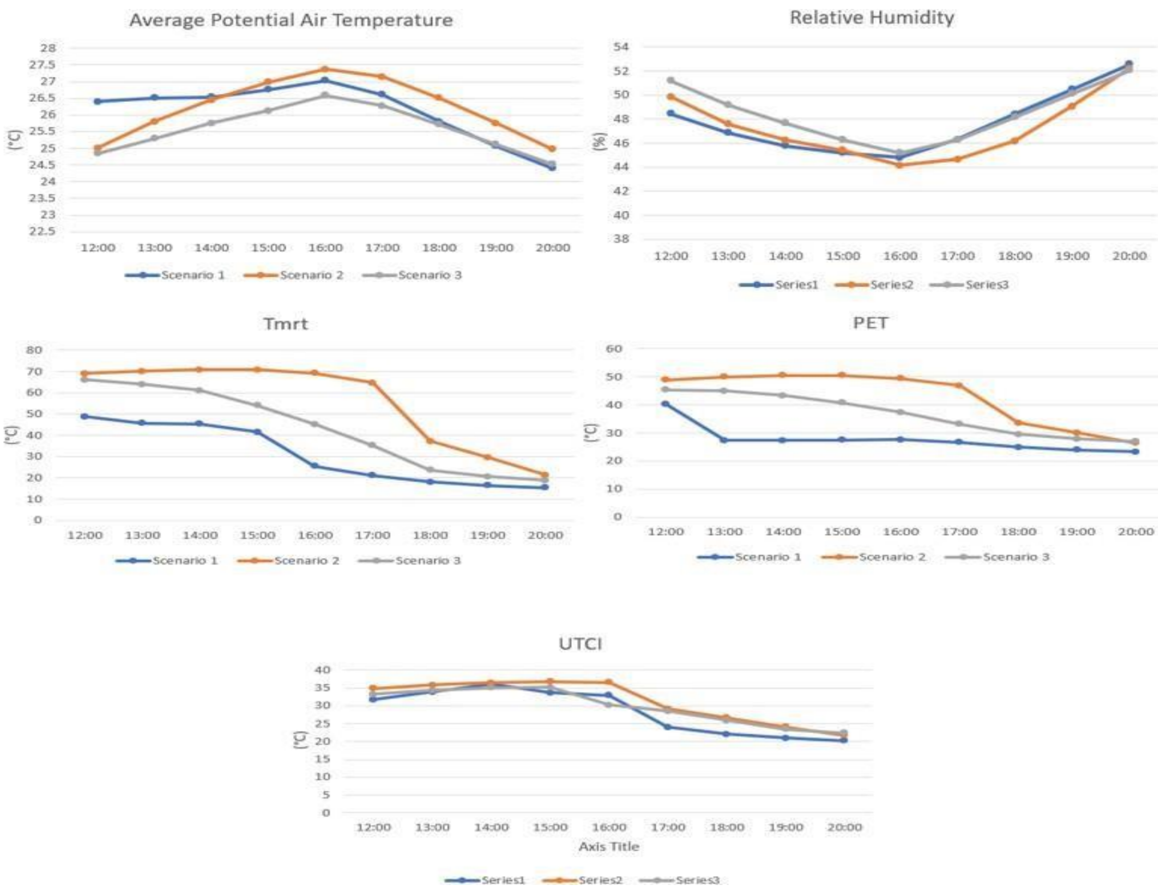

Figure 2.4. *Temporal Profile for the study area from 12 pm to 8 pm for 5 parameters (Average Potential Air Temperature, Relative Humidity, Mean Radiant Temperature (Tmrt), Psychological equivalent temperature (PET), and Universal Thermal Comfort Index (UTCI))*

Following that, scenarios involving the addition of higher albedo surfaces and the combination of higher albedo and vegetation showed slight temperature variations. During the coolest hour, a contrasting behavior was observed in the scenarios. This was attributed to the presence of shade trees, which have a heat-absorbing nature and slower heat dissipation. Consequently, the Tulip Poplar trees resulted in the highest air temperature at 8:00 PM.

In terms of relative humidity, a different pattern emerged compared to air temperature. The hourly relative humidity profile displayed a decreasing trend until 4:00 PM, followed by a gradual increase and reaching its peak value in the evening. Notably, at 4:00 and5:00 PM, the existing scenario exhibited the lowest humidity levels among the scenarios studied. These findings highlight the influence of vegetation, albedo, and shading effects on the microclimatic conditions.

2.5.2. Spatial distribution of the microclimatic conditions:

The spatial distribution of several important characteristics has been investigated to look at the microclimatic conditions. These variables include the sky-view factor, albedo, the properties of the soil, the surface temperature, and the weather. These elements play a vital role in shaping the built environment and impacting the regional climate. Their regional distribution was investigated by evaluating hourly profiles of weather information such as ambient temperatures, humidity levels, and the rate of radiative heating or cooling due to longwave radiation. This research offers insightful information on the variances and trends of these variables throughout the study area, enabling a thorough comprehension of the microclimatic conditions.

The metrics have been regionally distributed and averaged overtime over the full study period of 24 hours to offer a thorough analysis. This method enables an in-depth understanding of their changes and patterns throughout the studied region. The regional distribution of important characteristics, such as the albedo, Sky-View factor, and time-averaged microclimatic conditions, is shown in Figure 2.5. Soil temperature, surface temperature, potential temperature in degrees Celsius, relative humidity in %, and heating/cooling rate in degrees Celsius per hour is the microclimatic factors considered in the analysis. The left six columns of the picture visually represent these factors. The average SVF value for the third scenario, determined by averaging the SVF values of every grid cell in the computational domain, is the lowest among the methods considered.This shows a very small amount of clear space for the sky due to the presence of Tulip Poplar trees and the albedo effect combined. Unlike the third scenario, the scenario with existing trees and lower albedo showed a greater SVF value. This shows that the shade and reflection of radiation produced by the existing trees and pavements were substantial, resulting in a reduced SVF score.

The difference in SVF values between the various scenarios illustrates the impact of different vegetation kinds and the size of their crowns on the amount of shading and sky obstruction. The lower SVF values associated with tree situations indicate a greater shade, which may affect the research area's microclimate and thermal comfort.

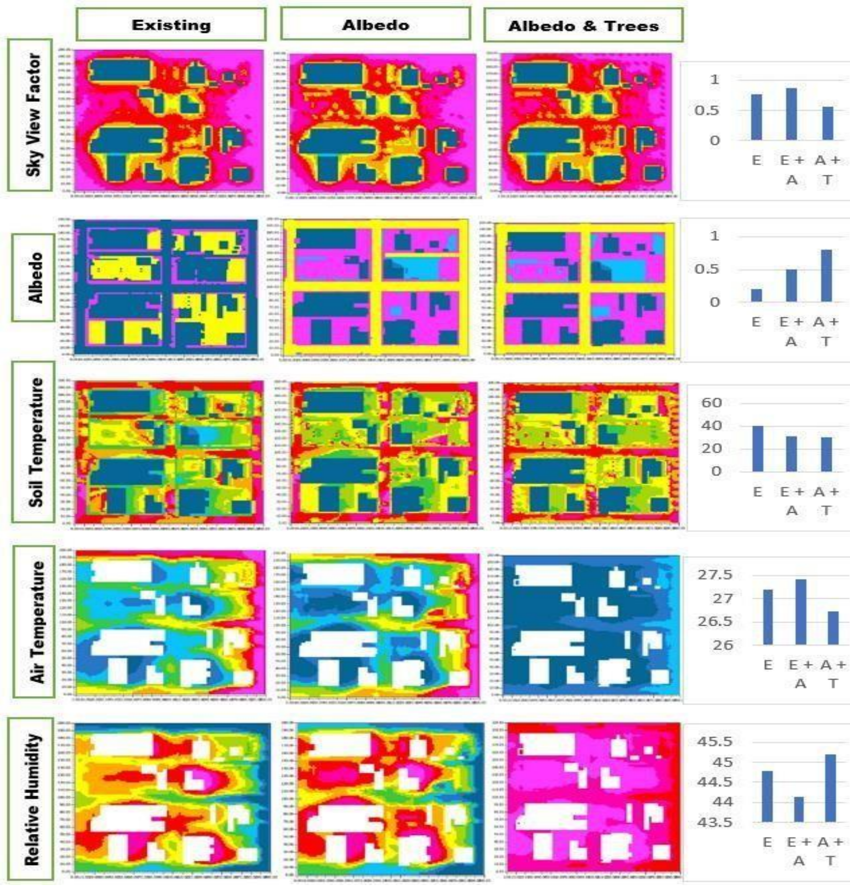

Figure 2.5. *Shows the Sky view factor (°C), Albedo(°C), Soil Temperature (°C), Air temperature (°C) and Relative humidity (%) for three different scenarios 1. Existing, 2. With Albedo and 3. Albedo & Trees.*

The surface and soil temperature were measured at a height of 1.5 meters, as we can see in the graphs beside each parameter that the existing scenario has more temperature and higher values in all factors and the combined effect of albedo and trees gives the best results with lower temperature values.

2.5.3. Spatial distribution of thermal comfort at the warmest hour:

The spatial distribution of various vegetation type's effects on thermal comfort around the hottest portion of the day was investigated in this section. The comfort indices were compared among several scenarios, which included the hottest event in the warmest hourly rate, to determine the unique advantages of the three scenarios.

Based on the results, it was determined that 4:00 PM was the warmest time when all comfort indices peaked. Because of the extreme warmth from longwave radiation in the afternoon, the scenario with grass as the only vegetation showed the highest air temperature. Figure 2. 6. compares the physiological equivalent temperature (PET), universal thermal climate index (UTCI), and mean radiant temperature (Tmrt) for the existing scenario and other situations. This comparison shows how comfortable each vegetation setting is. The findings imply that the east side of the research region, where building density is relatively low, saw the greatest temperature reduction because of the inclusion of specific vegetation scenarios. These results demonstrate the potential of various vegetation kinds to improve thermal comfort. It is feasible to achieve large temperature decreases and raise overall comfort levels by adding adequate vegetation in urban environments, especially in areas with lower building density.

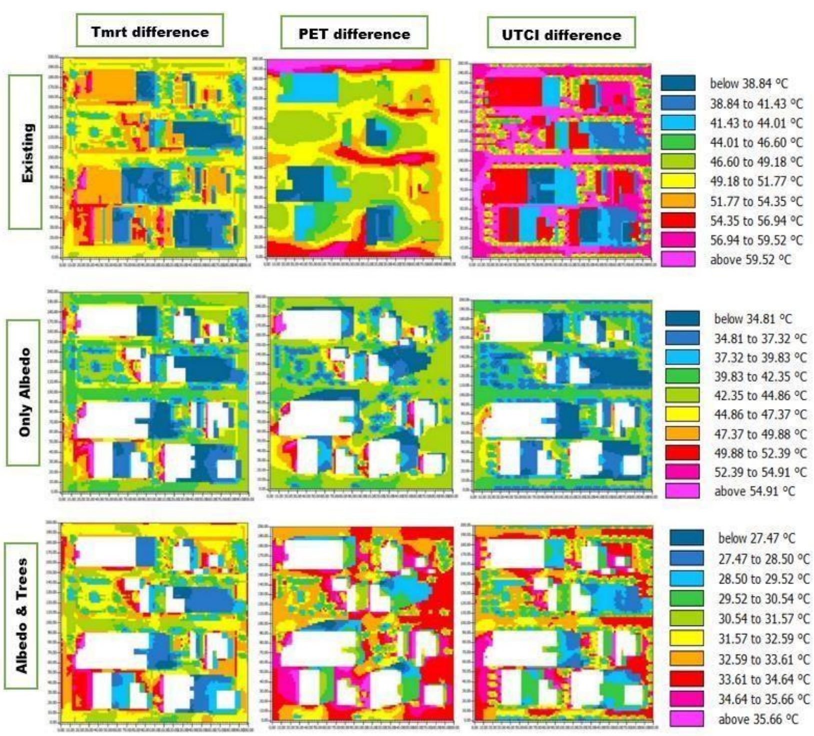

Figure 2.6. *Spatial Distribution differences between Tmrt, PET, and UTCI among thethree different Scenarios (Existing, With Albedo & Albedo + Trees)*

2.5.4. Overall thermal comfort observed in each scenario:

The physiological equivalent temperature (PET), universal thermal comfort index (UTCI), and time-averaged mean radiant temperature (Tmrt) were calculated to assess theoverall thermal comfort across each case scenario over the course of the whole study period. From 12:00 PM to 8:00 PM, an 8-hour study period, this examination was completed. Additionally, the average values of these indices for the whole researchdomain were determined, giving an expected value for each of the three scenarios. Because they had the highest air temperature and index values in the previous sections,the average index values of the future scenarios were contrasted to those of the present situation.

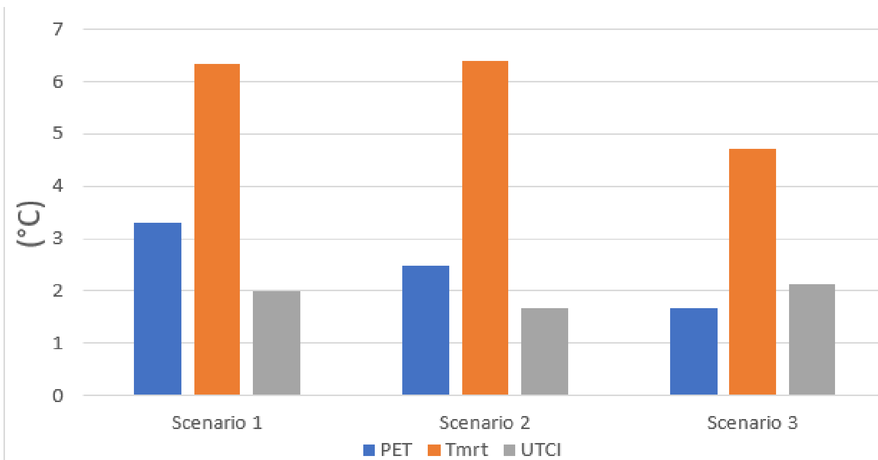

Figure 2.7. *Time-averaged values for the three 3 scenarios (scenario 1 = Existing, scenario 2 = with Albedo& scenario = Albedo & Trees) of PET, Tmrt & UTCI*

A two-sample T-test was used for this comparison under the assumption of unequal variances. As you can see from the variations in the three different scenarios (Figure 2.7.), Scenario 3 has a lower temperature and high UTCI values. It is possible to determine whether there are appreciable changes in thermal comfort between the grass scenario and the other situations by performing this statistical study. This aids in determining the utility of various vegetation coverings, albedo, and their influence on the level of thermalcomfort in the study area.

2.6. Discussion and Conclusion:

This study aimed to improve overall thermal comfort at the neighborhood block level of disadvantaged communities in Birmingham, Alabama, by reducing thermal stress. The community's social disparity and higher prevalence of chronic diseases make it more difficult to adjust to climate change's effects. People's health is being negatively impacted by the consequences of the city's growing number of long, hot summer days, and the community is having a difficult time coping with these conditions. This research concentrated on investigating a natural remedy that uses local shade trees and the albedo effect to improve local thermal comfort to address these problems. To find a suitable scenario or species that can help to create a comfortable microclimate in the area's humid subtropical environment, the effectiveness of several native tree species as well as the current tree conditions were examined. And different albedo values and their effects on thermal comfort. The determinants of the entire built environment are strongly related to the built environment factors, such as the air heating or cooling rate and potential air temperature. These elements significantly influence how a city's thermal environment is shaped. The rate of evapotranspiration and the sort of plant present in the atmosphere also have a direct influence on the amount of moisture in the air. Urban designers and planners can carefully choose and include plant varieties and construction materials with high albedo to develop the appropriate microclimate while considering the preferred amount of humidity. Urban planners can choose vegetation more effectively to create the ideal humid conditions in each region by understanding how various vegetation kinds and their related evapotranspiration rates affect the moisture content in the air and the reflection rate of the building and pavements to reduce the absorption rate of solar radiation. This emphasizes how crucial it is to consider both temperature and moisture when constructing and planning urban areas.

In conclusion, variables like the width of tree canopies, the level of tree covering, and the overall amount of greenery present directly impact how comfortable it is to be outside. The amount of overall comfort is significantly influenced by the shade that trees provide and the trees' placement (at frequent intervals on both sides of the sidewalks), and orientation must be considered, especially considering the width of their canopies. In addition, albedo affects solar radiation absorption and reflection which plays a major role in the development of urban heat islands. Smaller to moderate-sized tree species can contribute to thermal comfort by providing shade on sidewalks or roadside areas in regions with limited space or special design limitations. Smaller trees can be placed carefully to maximize comfort in confined urban situations, even if larger trees with greater canopies might provide more extensive shade coverage.

2.7. Study Limitations:

This study had a few drawbacks that offer room for further development. One drawback was that the analysis's meteorological data was only available for one day, especially the hottest day of 2021. Future research might consider averaging the climatic conditions from several years' worth of the warmest days to improve the precision and reliability of the findings. Considering the inherent diversity in weather patterns and climatic circumstances, this would offer a complete and more representative dataset for analysis. The study results would probably provide a more trustworthy picture of the thermal comfort dynamics in the study area if data from a wider time range had been included which can improve the accuracy of the results.

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