SOCIAL DISPARITIES IN EXPOSURE TO HEAT IN ATLANTA USING DATA FROM CDC'S ENVIRONMENTAL PUBLIC HEALTH TRACKING NETWORK AND NASA'S ECOSTRESS SATELLITE

by

Aishwarya Javali

A thesis submitted to Johns Hopkins University in conformity with the requirements for the degree of Master of Science

Baltimore, Maryland

April 2022

Abstract

Globally, extreme temperature events are observed to be increasing in their frequency, duration, and magnitude. As global warming and climate change have become increasingly prevalent phenomena, the intensity and frequency of extreme heat events has also seen an upward trend. Heat from these high temperatures represents a natural hazard that adversely affects human health. Accounting to approximately 650 deaths per year in the United States, extreme heat events cause more fatalities than any other weather hazard.

The physiological responses to extreme heat depend on whether these changes are short term or long term. Acclimatization can only occur in case of long-term and slower changes. It is therefore essential for us to identify the populations that are most vulnerable and enforce effective policy changes to either prevent catastrophic events, or prepare the communities for extreme events.

What makes heat stress different is that it is readily perceived by individuals, unlike most other environmental exposures. Socioeconomic factors play a major role in increasing an individual's susceptibility to heat stress. Heat stress has been said to disproportionately impact people with low median household income and people of color, raising issues such as health equity and environmental injustice. It has been a challenge to study the effects of heat on health with respect to racial and socioeconomic disparities because these characteristics are often correlated. By understanding disparities, public health can better target interventions that prevent the health effects of heat stress illness.

The purpose of this project was to firstly understand variation of heat trends in the counties of Fulton and DeKalb, Atlanta Metropolitan Area. Secondly, it looked for patterns of correlation between heat trends and social determinants of health or SDHs (racial distribution, median household income, level of educational attainment). This was done using NASA-ECOSTRESS satellite raster data for high resolution land surface temperatures and U.S. Census Bureau data for census data corresponding our SDH's of interest. Although studies of this type have been conducted before, they have never been at the census tract level.

Primary reader and advisor: Dr. Megan Latshaw

Secondary reader: Dr. Benjamin Zaitchik

Table of Contents

Tables

Figures

1. **Introduction**

As global warming and climate change have become increasingly prevalent phenomena, the intensity and frequency of extreme heat events has also seen an upward trend. Heat from these high temperatures represents a natural hazard that adversely affects human health. Accounting to approximately 650 deaths per year in the United States, extreme heat events cause more fatalities than any other weather hazard (Schmeltz, Sembajwe, Marcotullio, & Grassman, 2015).

What makes heat stress different is that it is readily perceived by individuals, unlike most other environmental exposures. Socioeconomic factors play a major role in increasing an individual's susceptibility to heat stress. Factors such as racism, income, occupation and education can lead to vulnerability (Gronlund, 2014). By understanding disparities, public health can better target interventions that prevent the health effects of heat stress illness.

The purpose of this project was to firstly understand variation of heat trends in the counties of Fulton and DeKalb. Secondly, it looked for patterns of correlation between heat trends and sociodemographic characteristics of the community. This study used population data from CDC's Environmental Health Tracking Network and heat data from NASA's ECOSTRESS satellite.

2. **Background- literature review**

2.1 Heat stress illness (HSI)

In extreme heat conditions, internal body heat rises as a result of overwhelmed homeostatic mechanisms, bringing about heat stress illness (Hanna & Tait, 2015). A range of disease states exist when it comes to heat stress illnesses. At the most minor stage they are experienced as an inconvenience, but at the most severe stage they are life threatening (Sankoff, 2015).

Regulation of body temperature usually takes place through the skin, where heat is lost to the surrounding air by radiation and evaporation. Sweat glands also excrete a concentrated salt solution to enhance the heat transfers. Ultimately blood vessels of the skin dilate, thereby increasing cardiac output and enhancing blood flow to the skin to increase heat transfer, and cool the body. This blood redirection from the core to the periphery results in lack of blood flow to other organs, potentially causing hypoxia and eventual cell death (Mora, Counsell, Bielecki, & Louis, 2017).

Heat stress illnesses disproportionately impact the poor and people of color, raising issues such as health equity and environmental injustice. The challenge when it comes to studying the effects of heat on health with respect to racial and socioeconomic disparities is that these characteristics often correlate with each other. For example, in Detroit, Michigan, the census tract percentages of individuals of non-white race, living below the poverty level, disabled, with less education, and proximity to impervious surfaces (i.e., heat-retaining surfaces impervious to water) moderately correlate with each other (Gronlund, 2014). This makes it problematic to identify the mechanisms of heat vulnerability and understand the magnitude of the effects on heat-related morbidity and mortality (Gronlund, 2014). Thus, these factors must be controlled for in the analysis model to identify the true relationship between individual factor and heat exposure.

Occupational heat stress particularly impacts outdoor workers' health, safety, productivity and social well-being, and can cause significant harm. Workers at risk of heat stress include firefighters, farmers, construction workers, miners, environmental scientists, and survey technicians. Heat stress among these workers can result in heat stroke, heat exhaustion, heat cramps, or heat rashes. It can also increase the risk of injuries as it may result in sweaty palms, fogged-up safety glasses, and dizziness. Currently there are a few options to manage occupational heat exposure in outdoor workers, for example:

- reducing time in the heat
- training about the importance of acclimatization (gradual increased exposure to hot environments that is conducive to physiological adaptation)
- policy governing hydration and rest breaks (NIOSH, 2016)

The WHO, 2018 report on health effects of extreme heat reports the direct and indirect effects of heat exposure (see Figure 1 below). This research refers to the direct impacts of heat exposure such as heat illness.

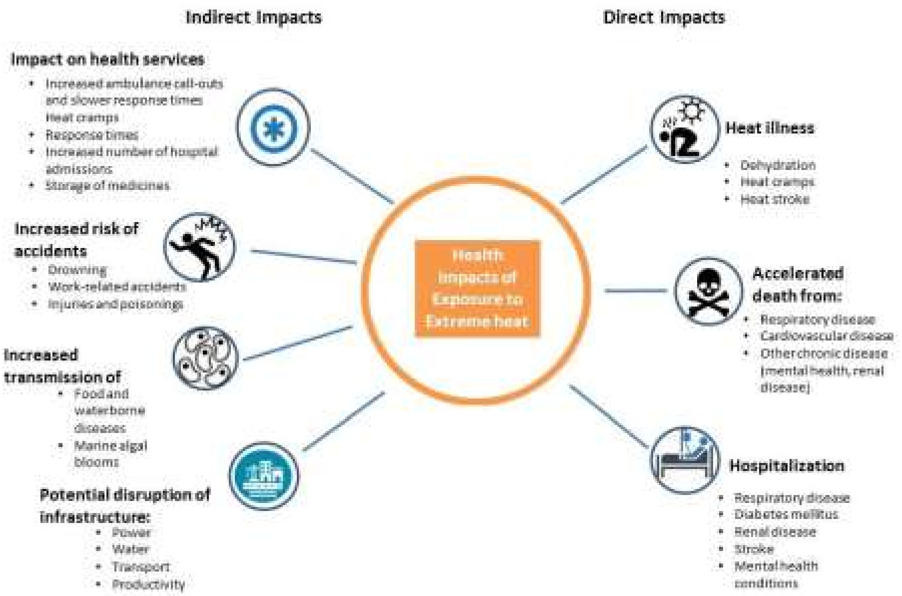


Figure 1: Health effects of extreme heat *(WHO, 2018)*

In summary, changes to physiological thermoregulation mechanisms in the body makes heat a health concern. With high heat days predicted to increase over the coming years as an effect of climate change, heat-related health effects will become increasingly common.

Globally, extreme temperature events are increasing in their frequency, duration, and magnitude. Between 2000 and 2016, the number of people exposed to heat waves increased by around 125 million. In 2015 alone, 175 million additional people were exposed to heat waves compared to the previous year. The impact of heat stress will be felt on a large scale, distributed among large populations, and inequitably experienced by marginalised communities. The number of people affected and the inequity in how the community perceives these effects makes heat stress illness a public health concern. The negative health impacts of heat are predictable and largely preventable, with actions to help keep homes and bodies cool (WHO, 2018).

Of all other environmental exposure-related injuries treated in US emergency departments (ED), heat-related illnesses (HRI) are the most frequent. Additionally, they have seen an increasing trend in the last decade. According to CDC's fact sheet on Heat-Related Illnesses, in the decade up to 2010:

- 8,081 heat-related deaths were reported in the United States.
- 5,783 (72%) of these deaths were due to exposure to excessive heat
- the remaining 2,298 (28%) of the deaths had heat as a contributing factor.

These numbers could increase exponentially over the next decades. Communities should therefore identify high risk populations and aim to form adaptive and resilient techniques to prepare (CDC, 2013).

2.2 Social determinants of health and demographic disparities of heat stress

The conditions in the environments in which people are born, live, learn, work and age can be known as the social determinants of health. These factors affect a range of health, functioning, and quality of life. The factors can be characterized into five domains: economic stability, education access and quality, health care access, neighborhood and built environment, and social and community context. These determinants cause health disparities and inequities (U.S. Department of Health and Human Services); they also play a vital role in the disparity in effects of heat exposure on populations.

A study conducted in Georgia (Pillai, et al., 2014) analysed data regarding Emergency Department (ED) and hospital discharges for HRI from 2002 through 2008 using extreme heat event (EHE) and temperature data from CDC's Environmental Public Health Tracking

Network. This study used a multivariable logistic regression model to predict hospitalizations versus ED discharge. A unique feature of this analysis was the investigation of potential predictors such as demographic characteristics, socioeconomic status, and district of residence associated with hospitalization versus discharge. The study found that men were more prone to ED visits and hospitalizations. Additionally, odds of hospitalization (versus routine discharge from emergency departments) due to heat stress illnesses were higher for those in the older age group. No significant differences were identified among the different races in terms of hospital admissions versus routine discharge. A univariable analysis on heat related illness showed significantly higher odds of hospitalization versus discharge from ED among middle, lower-middle and lower socioeconomic groups. A limitation was that the tracking data was ecological data and not an accurate indicator of individual heat exposure.

A systematic review by Gronlund et. al., studied the disparities in heat-related health effects based on racial and socioeconomic factors. The author concluded that many racial and socioeconomic characteristics correlated with increasing susceptibility to heat-associated health effects. For example, socially-vulnerable populations (those experiencing poverty or racial discrimination) are at higher risk in heat events for hospitalizations compared to other groups (Gronlund, 2014).

The Gronlund paper brings to light that differences in heat-associated health outcomes by educational completion levels are frequently confounded by related factors, such as income disparities, occupational opportunities, unemployment, or cognitive deficits. Social programs and public health measures targeting these more proximate factors are more likely to create an impact and be effective.

Figure 2 below outlines some of the major pathways by which racial ethnic minorities or individuals of low socioeconomic status might have increased vulnerability as suggested by heat-health research. A precise understanding of who is more vulnerable to extreme heat is important for developing strategies to adapt to extreme heat and the Gronlund paper helps with understanding these factors in much greater detail.

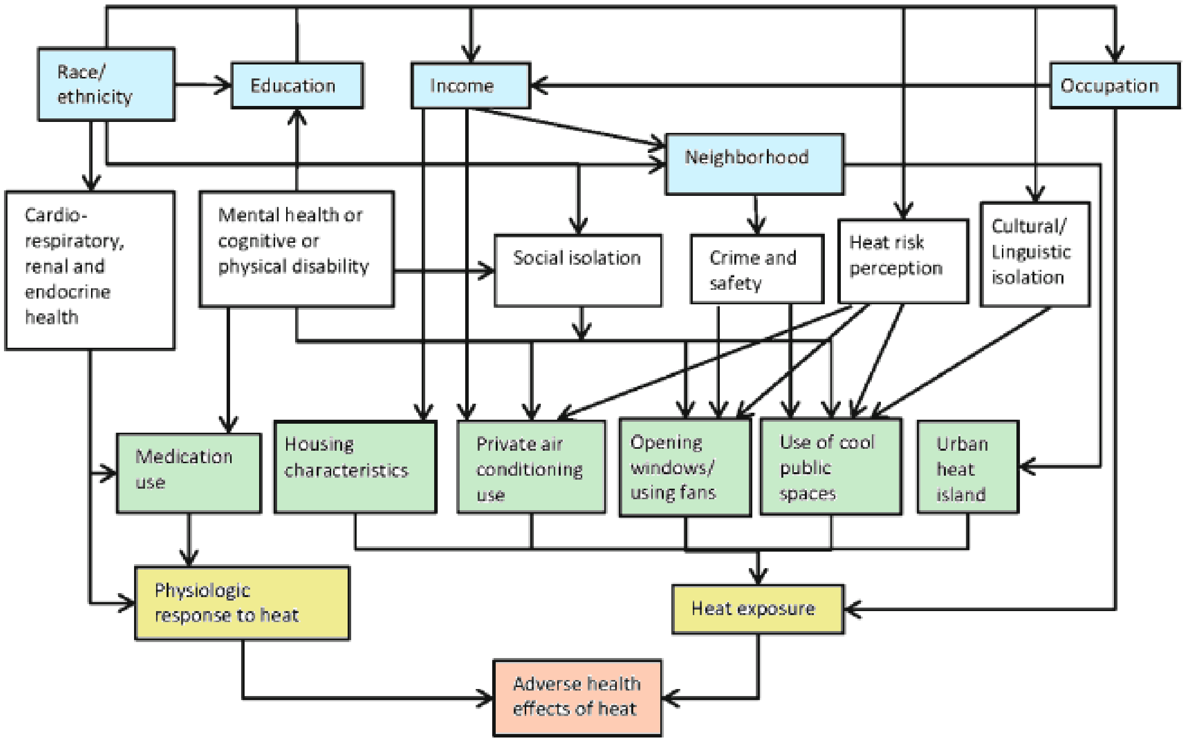


Figure 2: Associations between racial and socioeconomic characteristics and more proximal determinants of adverse health effects of heat *(Gronlund, 2014)*

Another systematic review (Nunfam & Fannam, 2018) discusses the social impacts of occupational heat stress and brings to light adaptive strategies to deal with susceptible workers. It aggregates 121 findings into eight categories and three syntheses based on patterns of significant similarities and differences. These include (1) awareness of occupational heat stress, (2) social impacts of occupational heat stress and (3) workers' adaptation to occupational heat stress due to changing climate.

The review found a clear but varied awareness among workers about the magnitude of workplace heat exposure and the role that awareness plays in improving:

- occupational health and safety policies
- heat exposure risk management.

It reported a range of social impacts from occupational heat stress on workers, including physical, mental, behavioral, health and safety, socioeconomic, and productivity consequences.

Occupational exposure to heat is also a leading risk factor for heat stress illness. Exposure to heat in outdoor workers, like farmers and those involved in construction, affects their productivity and ability to work due to dehydration. The projected rise in temperature will likely exacerbate loss of productivity, absenteeism, reduced work pace and performance efficiency.

In summary, multiple social factors play a role in heat stress illnesses and need to be kept in mind while formulating policies. Social factors that act as barriers to optimal decision making when implementing occupational health policy change include inadequate resources, lack of awareness, absence of management commitment, lack of prevention training, low compliance, lack of heat stress guidelines, and limited access to shade or medical attention.

2.3 CDC’s Environmental Public Health Tracking Network

The US Centers for Disease Control and Prevention's (CDC's) National Environmental Public Health Tracking Program is a

Figure 3 CDC: Climate change and extreme heat flyer

multidisciplinary collaboration that involves the “ongoing collection, integration, analysis, interpretation, and dissemination of data from environmental hazard monitoring, human exposure surveillance, and health effects surveillance” (Eatman & Strosnider, 2017). With a focus on data-driven decision-making, CDC's Tracking Program emphasizes the distribution of data to public health practitioners, policy makers, and communities. The Tracking Network, a web-based system with components at all levels of government, houses the above-mentioned data and can be used to inform public health actions to improve community health (Eatman & Strosnider, 2017).

The primary goal of the Tracking Network is to allow the exploration of data on health effects, environments, and demographics (Wall & Kassinger, 2017). For information related to heat-related mortality or heat vulnerabilities, the Tracking Network’s data explorer can be used to evaluate multiple indicators. By selecting content area as Climate Change or Heat Stress Illness, relevant indicators include:

- Heat stress emergency department visits
- Heat stress hospitalizations
- Heat vulnerability based on adaptive capacity, exposure and sensitivity
- Heat related mortality
- Historical extreme heat days and events
- Temperature distribution

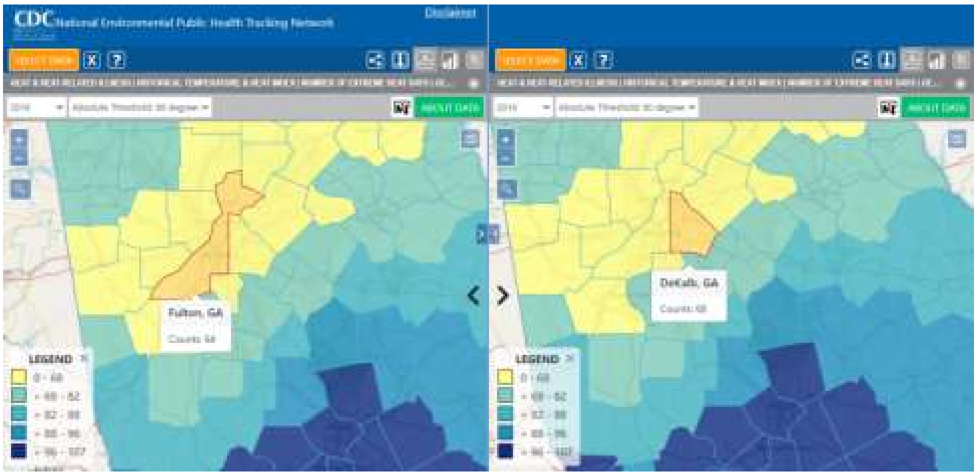


Figure 4: Representation of CDC Environmental Health Tracking Network used to track heat extreme heat days in Fulton County and DeKalb County, Georgia

Once the content area and indicator are selected, a measure (for example age-adjusted rate, crude rate, or number of emergency department visits) can be selected. This study used the Tracking Network for population-level data required for the study in our project.

2.4 NASA satellite ECOSTRESS data

The ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS) instrument was installed onboard the International Space Station (ISS) on June 29th, 2018. By allowing the structural and functional classification of ecosystems, this established the National Aeronautics Space Administration (NASA) in ecology and climate research (Hulley, Shivers, Wetherley, & Cudd, 2019).

The key science questions that ECOSTRESS addresses include:

1. how terrestrial biosphere is responding to changes in water availability
2. how changes in diurnal vegetation water stress impacts the global carbon cycle and

3. if agricultural vulnerability can be reduced through advanced monitoring of agricultural water consumptive use and improved drought estimation (ECOSTRESS Maps LA's Hot Spots, 2018)

The ECOSTRESS mission provides both land surface temperature (LST) and emissivity[1] at a spatial resolution of ~70 m × 70 m. To study processes at the land-atmosphere interface, LST is an essential parameter which measures Earth's surface temperature rather than air temperature. Surface temperature, which is what you would feel if you touched the surface of something, differs from air temperature, which is typically reported by weather stations. Currently, no other satellite sensors have such sufficient spatiotemporal resolution to reliably monitor LST at the local to global scale over the diurnal cycle. The images represent the most detailed temperature images of the surface ever acquired from space, also known as **data scenes**. (Hulley, Shivers, Wetherley, & Cudd, 2019).

ECOSTRESS is uniquely well-suited for observing the urban environment because:

1. it has a high spatial resolution of 70 m × 70 m (≈1.2 acres, or the size of a football field);
2. it samples the diurnal cycle of temperatures and heat stress at different times of day;
3. five thermal bands allow for implementation of multispectral temperature/emissivity separation approaches to retrieve the most accurate LST over urban areas (Oltra-Carrió, Sobrino, Franch, & Nerry, 2012).

ECOSTRESS data has a wide variety of applications and applied science investigations which include land management (evaluating and assessing restoration efforts), urban heat island detection and mitigation, drought, aquatic ecosystem and habitat assessment,

[1] Emissivity is a term used to explain the ratio between the energy radiated by an object to energy radiated by an ideal emitter such as a blackbody. A black body is a physical object that emits all incident radiation when at a constant temperature.

thermal pollution from power plants, shellfisheries and coastal vegetation stress and risk, wildfires, public health, and geothermal and geology hazards. ECOSTRESS also has an international footprint through engagements with Brazil, Costa Rica, Portugal, Spain, and Cambodia (NASA, n.d.).

This study filtered data scenes, using only cloud-free LST raster data[2] evaluate heat patterns.

2.5 Atlanta, Georgia and the Counties of Fulton and DeKalb

This study looked at ECOSTRESS data with respect to Atlanta including Fulton County and DeKalb County. Atlanta is the capital of Georgia. According to United States Census Bureau, with a population of 488,800, it is the most populous city in Georgia and the 37th most populous in the United States. The city has geographic disparities in socio-economic status as well as a legacy of segregation that could lead to disparities in heat exposure (see below). It overlaps two counties: mainly Fulton, while also extending into DeKalb. Fulton County is 1.1 percent rural whereas DeKalb County is 0.3 percent rural (Hambrick, 2016). With a median household income of $59,948, Atlanta has a poverty rate of 20.8 percent. Racial composition as of 2010 in Atlanta constituted 54 percent blacks, 38 percent whites and 8 percent other races. More than 51.8 percent of the population has a Bachelor's degree or higher (United States Census Bureau, 2019).

[2] Raster data constitutes a spatial dataset of rows and columns where each pixel represents a geographical area. This pixel can contain continuous data such as heat.

Demographics	DeKalb County, Georgia	%	Male	Male%	Female	Female%
Total population	759297		357937		401360	
Age						
Under 5 years	52559	6.9	26650	7.4	25909	6.5
5 to 9 years	44834	5.9	22712	6.3	22122	5.5
10 to 14 years	50416	6.6	25772	7.2	24644	6.1
15 to 19 years	43454	5.7	21933	6.1	21521	5.4
20 to 24 years	46479	6.1	21655	6	24824	6.2
25 to 29 years	64896	8.5	31052	8.7	33844	8.4
30 to 34 years	62846	8.3	30178	8.4	32668	8.1
35 to 39 years	55758	7.3	25375	7.1	30383	7.6
40 to 44 years	52532	6.9	26152	7.3	26380	6.6
45 to 49 years	50424	6.6	23919	6.7	26505	6.6
50 to 54 years	47100	6.2	22043	6.2	25057	6.2
55 to 59 years	49242	6.5	22929	6.4	26313	6.6
60 to 64 years	41058	5.4	17545	4.9	23513	5.9
65 to 69 years	35463	4.7	16163	4.5	19300	4.8
70 to 74 years	25530	3.4	9853	2.8	15677	3.9
75 to 79 years	18353	2.4	7354	2.1	10999	2.7
80 to 84 years	8528	1.1	2964	0.8	5564	1.4
85 years and over	9825	1.3	3688	1	6137	1.5
Median income						
Household	63652	27.6				
Family	85420	31.2				
Nonfamily	43377	21.9				
Race						
White alone	256943					
Black or African American alone	409327					
American Indian and Alaska Native alone	11330					
Asian alone	47162					
Native Hawaiian and Other Pacific Islander alone	329					
Some other race alone	15189					
Two or more races:	19017					
Educational Attainment	521555		239215		282340	
High school graduate (includes equivalency)			57920		53446	
Some college, less than 1 year			9447		11292	
Some college, 1 or more years, no degree			27726		35122	
Associate's degree			17003		23409	
Bachelor's degree			59415		73651	
Master's degree			26520		41489	
Professional school degree			9608		9610	
Doctorate degree			6513		7473	

Table 1 Demographics for DeKalb County including Age, Income, Occupation, Race and Educational attainment *(United States Census Bureau, 2019)*

Demographics	Fulton County, Georgia	%	Male	Male%	Female	Female
Total population	1063937		514901		549036	
Age						
Under 5 years	61084	5.7	31029	6	30055	5.5
5 to 9 years	60180	5.7	29977	5.8	30203	5.5
10 to 14 years	67278	6.3	34704	6.7	32574	5.9
15 to 19 years	72060	6.8	35891	7	36169	6.6
20 to 24 years	74294	7	37936	7.4	36358	6.6
25 to 29 years	96369	9.1	47169	9.2	49200	9
30 to 34 years	87402	8.2	43101	8.4	44301	8.1
35 to 39 years	79641	7.5	36338	7.1	43303	7.9
40 to 44 years	70973	6.7	35776	6.9	35197	6.4
45 to 49 years	76114	7.2	36811	7.1	39303	7.2
50 to 54 years	69491	6.5	34609	6.7	34882	6.4
55 to 59 years	67289	6.3	32387	6.3	34902	6.4
60 to 64 years	54006	5.1	25418	4.9	28588	5.2
65 to 69 years	46168	4.3	18871	3.7	27297	5
70 to 74 years	32696	3.1	16080	3.1	16616	3
75 to 79 years	20164	1.9	9002	1.7	11162	2
80 to 84 years	13160	1.2	4123	0.8	9037	1.6
85 years and over	15568	1.5	5679	1.1	9889	1.8
Median income						
Household	80013	32.7				
Family	109818	36.2				
Nonfamily	55624	27.6				
Race						
White alone	469465					
Black or African American alone	472625					
American Indian and Alaska Native alone	2068					
Asian alone	76786					
Native Hawaiian and Other Pacific Islander alone	673					
Some other race alone	17248					
Two or more races:	25072					
Educational Attainment	729041		345364		383677	
High school graduate (includes equivalency)			58358		53803	
Some college, less than 1 year			12147		16560	
Some college, 1 or more years, no degree			34574		46974	
Associate's degree			19217		23334	
Bachelor's degree			113909		131646	
Master's degree			58213		68582	
Professional school degree			17307		13094	
Doctorate degree			9208		7571	

Table 2: Demographics for Fulton County including Age, Income, Race and Educational attainment *(United States Census Bureau, 2019)*

2.6 Legacy of segregation in Atlanta

Atlanta is the most segregated city in the South and the second-most segregated in the country. With a population that is 54 percent black and 38 percent white, it has a citywide diversity index of 56.8 percent. But its neighbourhood diversity index is just 30.7 percent (Yee, 2015) reflecting historically redlined neighborhoods.

In the 1960's efforts were made to distinguish Atlanta from racial violence occurring as part of the Civil Rights Movement and promote it as a racially progressive city by marketing it as the “city too busy to hate”. Despite these efforts racial inequality was apparent in the deeply embedded segregation laws, policies and practices (Robert W. Woodruff Library, 2018).

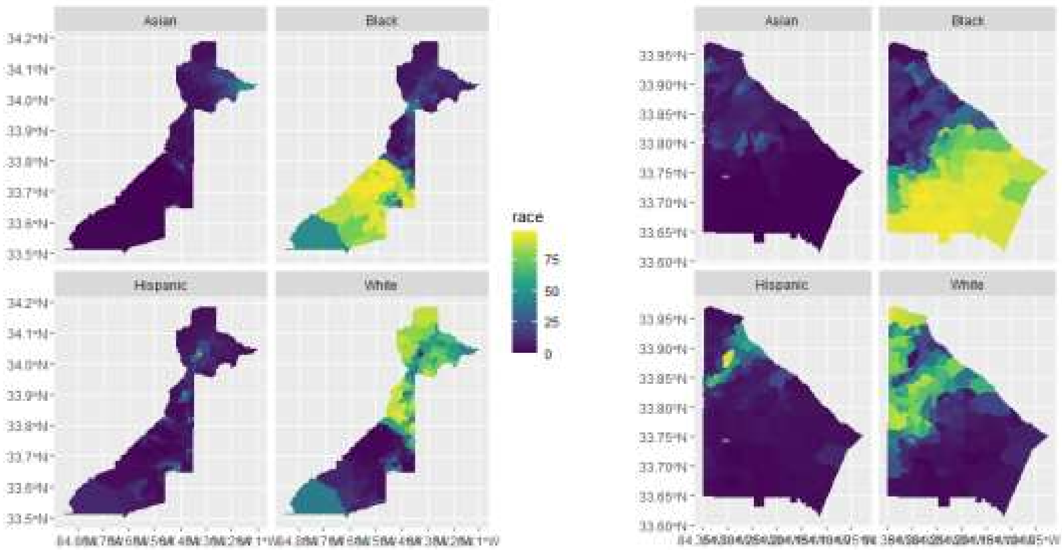


Figure 5: Racial distribution of population in Fulton and DeKalb County

Legal segregation based on race in Atlanta continued until the signing of the Civil Rights Act in 1964. City planners and corresponding private organizations and companies planned separate sections, centralizing the black population in Atlanta. Along with the city planners, the federal governments and banks’ discriminatory mortgage insurance and loan policies also played vital roles in the cultivation of residential segregation of minorities and the concentration of poverty in Atlanta (Hayes, 2006)

The practice of ‘redlining’ or the refusal to serve a particular area or community because of the residents’ income or race greatly disadvantaged the black race in Atlanta. Even after anti-segregation legislation through the Civil Rights Act attempted to integrate the populations there has not been much progress. Residential segregation also led to inequality in the availability of resources, such as education, health care, jobs, green space, and more (Hayes, 2006). These factors could also be linked to a disparity in the effect of heat exposure, leading to the aim of our study.

2.7 Disparity in effect of heat exposure between urban and rural neighbourhoods

Due to the Urban Heat Island effect, it is generally assumed that urban dwellers are at a higher risk of exposure to extreme heat. This results from a combination of many factors observed in urban areas such as:

- The replacement of trees and natural vegetation with hard and dry surfaces such as rooftops, asphalt roads and parking lots, and buildings.
- The impervious nature of man-made construction material that prevents the absorption of water, which would otherwise cool down the surroundings.
- Higher density and intensity of human activities leading to vehicular and industrial emissions
- Obstruction of wind flow as a result of urban geometry[3]
- Inability of urban materials to absorb and release solar energy (EPA, 2020).

[3] Urban geometry can be explained as the relationship between building volume and open space and their spatial configuration (urban layout)

3. **Research question and specific aims**

3.1 Aim 1: Explore the high resolution ECOSTRESS heat data to identify patterns across Fulton and DeKalb counties

We used scenes captured by the ECOSTRESS satellite from 2019 and 2020 of Fulton and DeKalb counties to explore evidence of heat patterns across the counties. Cloud masked data was treated as a missing value. We used R studio (version 4.1.0) to analyse raster data provided by the NASA-ECOSTRESS team.

3.2 Aim 2: Conduct exploratory data analysis to assess whether there is an association between exposure to heat and the social determinants of health in Atlanta

Using census data and CDC's Environmental Health Tracking Network we developed a detailed description of disparities with respect to social determinants of health across the two counties of interest. Although performed previously on a state/county level such an analysis has never been conducted at a high-resolution census tract level. We aimed to identify if an association exists between populations' exposure to heat across and social determinants of health.

4. **Research strategy**

4.1 Significance

Although risk factors for heat stress illness include physiologic elements such as age and sex, it also greatly depends on socioeconomic factors. Socioeconomic factors such as level of education, housing characteristics, neighborhood- urban or rural, income, racism and access to healthcare are all factors that contribute to occurrence of these illnesses as the years progress. Figure 6 shows not only how the heat-related emergency department visits changed over time, but also how the effect varied by race/ethnicity.

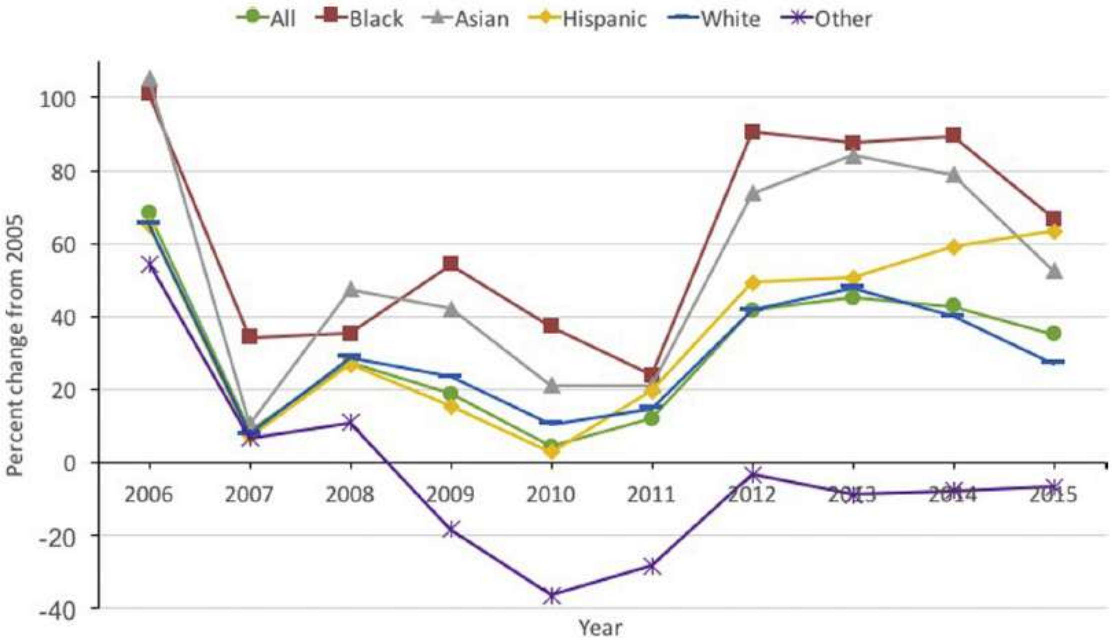


Figure 6: Percent change in heat-related emergency department visits calculated using visits from the year 2005 as the baseline stratified by ethnicity *(Abualsaud, Ostrovskiy, & Mahfoud, 2019)*

Increased understanding about the need for mitigation, adaptation and social protection policies may help reduce vulnerability and sensitivity to heat stress. Future generations may see a shift in economies to non-outdoor work or compensation to workers for productivity losses due to extreme heat. The Nunfam & Fannam (2018) study provided recommendations to policy analysts, industrial hygienists, social risk and environmental health scientists to improve heat-related occupational safety and health administration and policies. The current study looked at neighborhoods with higher susceptibility to extreme heat with the idea that precautions can be implemented for people living and working in these neighborhoods.

4.2 Innovation

For this analysis we used data from the NASA satellite ECOSTRESS. The data came from the space-ready Prototype HyspIRI Thermal Infrared Radiometer (PHyTIR) on the International Space Station. It provided data with 38-m in-track by 69-m cross-track spatial resolution (science requirement is 100 m)[4] and predicted temperature sensitivity of ≤0.1 K. Such high-resolution data had never been used for an analysis by CDC's Environmental Health Tracking Branch before. The analysis will therefore be able to give very localised findings where disparity analysis can occur at a community level or even between two neighborhoods.

4.3 Approach

4.3.1 Study population

The population of the Atlanta Metropolitan Area including Fulton County and DeKalb County in the years of 2019-2020 served as the study population. The data from Table 1 and Table 2 includes statistics about our study population such as total population, and demographic breakdown.

[4] Spatial resolution is the ground area imaged for the instantaneous field of view (IFOV) of a sensor on the satellite. The usual requirement for use in science is precision or resolution up to 100m. ECOSTRESS exceeds requirements by providing ~70 m resolution.

4.3.2 Independent variable

Data from US Census Bureau's decennial census datasets along with American Community survey datasets were used. This data was accessed using the 'tidycensus' package in R which allowed us to interface between these datasets and return tidyverse-ready data frames. It also provided options for simple geometry such as shapefiles for County/Census tracts of interest. This made it easy to visualize the data. Therefore, de-identified sociodemographic characteristics such as racial distribution, median household income and level of educational served as the independent variables for the census tract.

4.3.3 Dependent variable

The hypothesis for this study was that an association exists between the heat experienced by a population and social determinants of health at the fine scale of blocks within neighborhoods due to presence of microclimates. Therefore, the null hypothesis was that no difference exists in population exposure to heat between groups categorized on various social determinants of health in the Atlanta Metropolitan Area.

The dependent/response variable is the average ΔLST of a census tract in comparison to the other tracts. First, our collaborators at NASA identified 23 cloud-free scenes (from among many) containing land surface temperature in degrees kelvin captured by the ECOSTRESS mission. For each scene, LST was then converted to ΔLST by subtracting the temperature at each pixel from the mean temperature of the entire scene. Next, scenes were grouped based on when they were captured; during the day (5am to 9pm) or night (9pm to 5am). Finally, separate day and night composite rasters were created by taking the average ΔLST across all day and night scene respectively. This was used to test the presence of significant difference between varying census tracts and its association to social determinants of health.

We expected to identify an association between SDH and heat experienced by the population. Exploring the possibility of a geographic pattern or relationship between these factors is also something we looked to identify as a desired outcome.

4.3.4 Statistical modelling

To conduct statistical analysis in this study R (version 4.1.0) was used.

Descriptive analysis: Data analysis explored the distribution of the social determinants of health to look for existing patterns. Visualization tools in R software such as mapview and ggplot allowed exploration of the high-resolution heat data captured by the ECOSTRESS satellite. This identified patterns of heat distribution over Fulton County and DeKalb County using the variable ΔLST to examine diurnal changes in heat patterns.

Statistical analysis: Originally, the plan involved a simple linear regression or Analysis of Variance (ANOVA) model to look for association between exposure to heat and categorical variables (race, income and educational attainment). A *post hoc* ANOVA multiple comparisons test or the Tukey's Honest Significant Differences (HSD) test using studentized range distribution would have then been applied.

However, this statistical model could not be used as there were high levels of correlations between the variables in our model. Instead, three separate multivariate linear regression models for each determinant of health (racial distribution, median household income and level of educational attainment) were created. Each of these models accounted for high levels of correlation (for e.g., between White and Black population).

4.4 Results

The maps in this section used for descriptive analysis were visualized using the mapview package in R studio.

4.4.1 Descriptive analysis

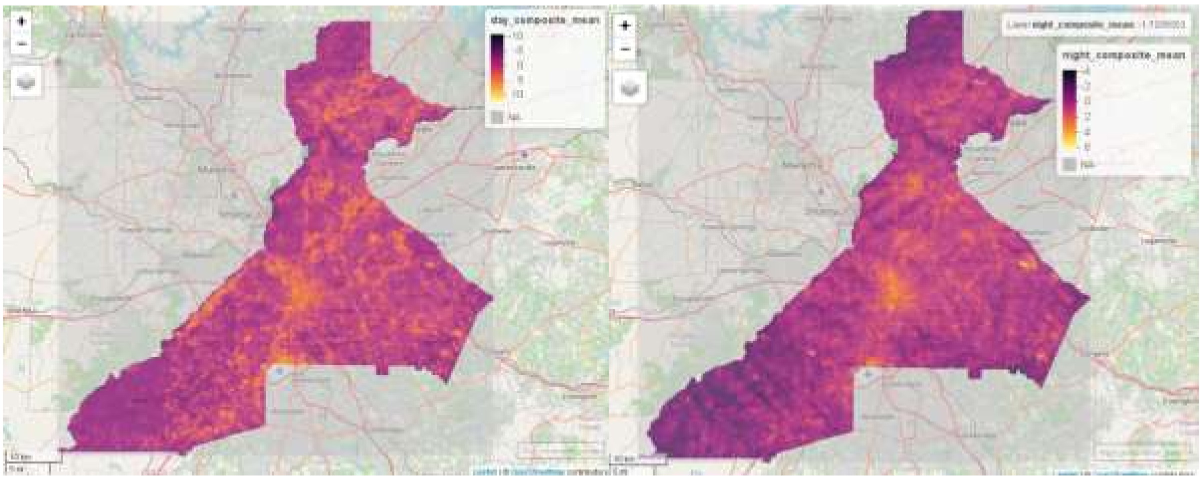


Figure 7: Day and night time ΔLST distribution composite raster choropleths across Fulton and DeKalb County

The ΔLST composite raster choropleths show similar patterns across both day and night time distributions. It is observed that higher temperatures are concentrated around downtown Atlanta and cooler land surface temperatures closer to the suburbs. Certain suburban areas however also appear warmer than others.

Social Determinants of Health such as racial distribution, median household income, level of educational attainment across Fulton and Dekalb counties on a census tract level were then visualized. The red dots on maps depict point of reference from where values arise. These values can be typically visualized on the top right corner of the map and usually correspond with ΔLST of that particular point. The values on each map refer to the same point during day and night.

Racial distribution

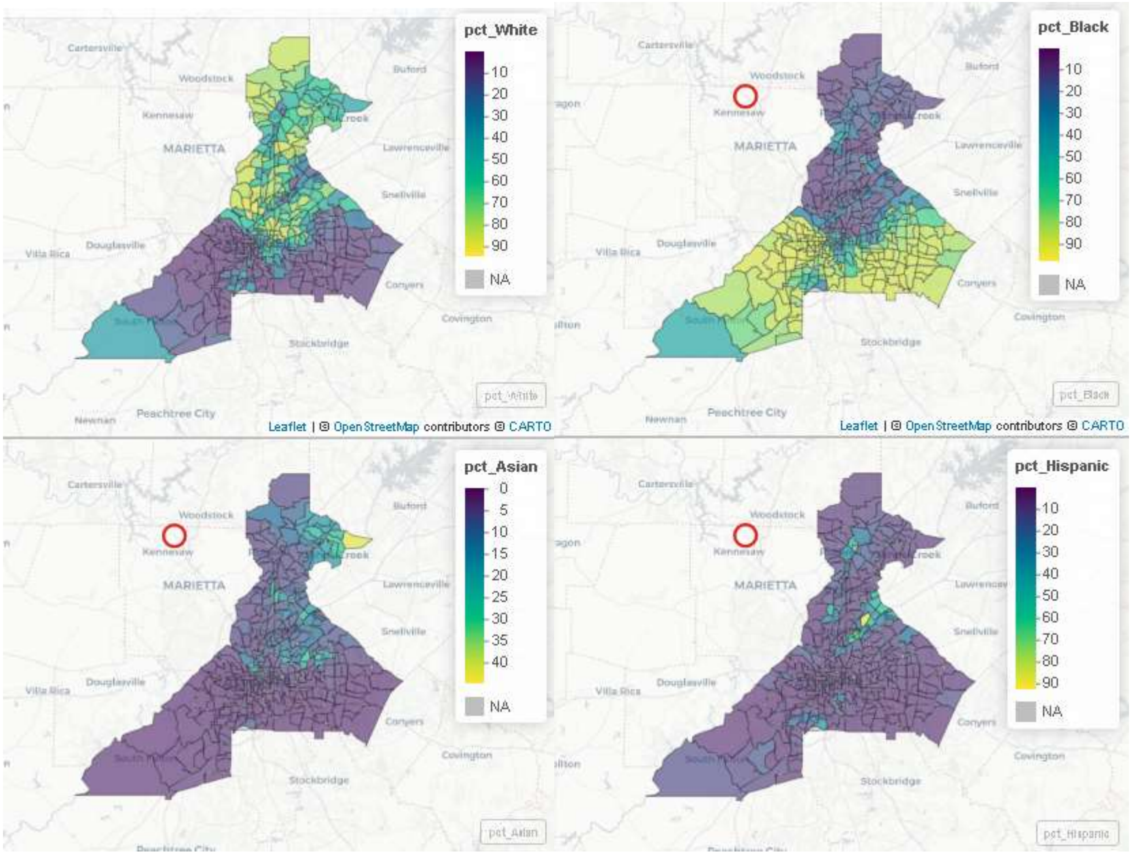


Figure 8 Racial distribution across Fulton and DeKalb County (L-R and Top-Bottom) Percent White, Percent Black, Percent Asian and Percent Hispanic

The legacy of segregation is still evident from the above spatial representation of percent population distribution across the two counties. We see that the White population is predominantly concentrated towards the North, and the Black population in the South of the two counties. Asian and Hispanic populations are concentrated in pockets and limited to very few census tracts.

Income distribution

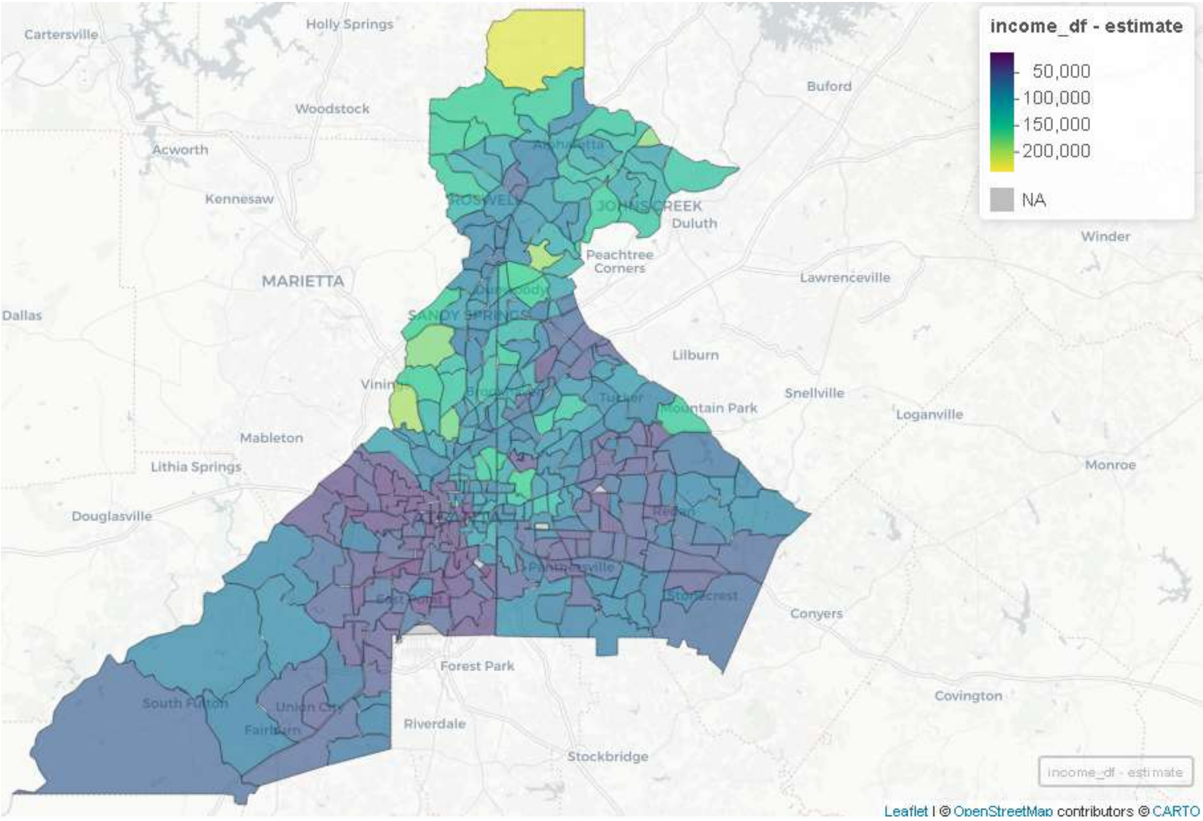


Figure 9 Income distribution across Fulton and DeKalb County

The median household income distribution map above shows clear concentration of wealth in the census tracts to the North. We have earlier seen that these census tracts are occupied predominantly by White population.

Level of educational attainment distribution

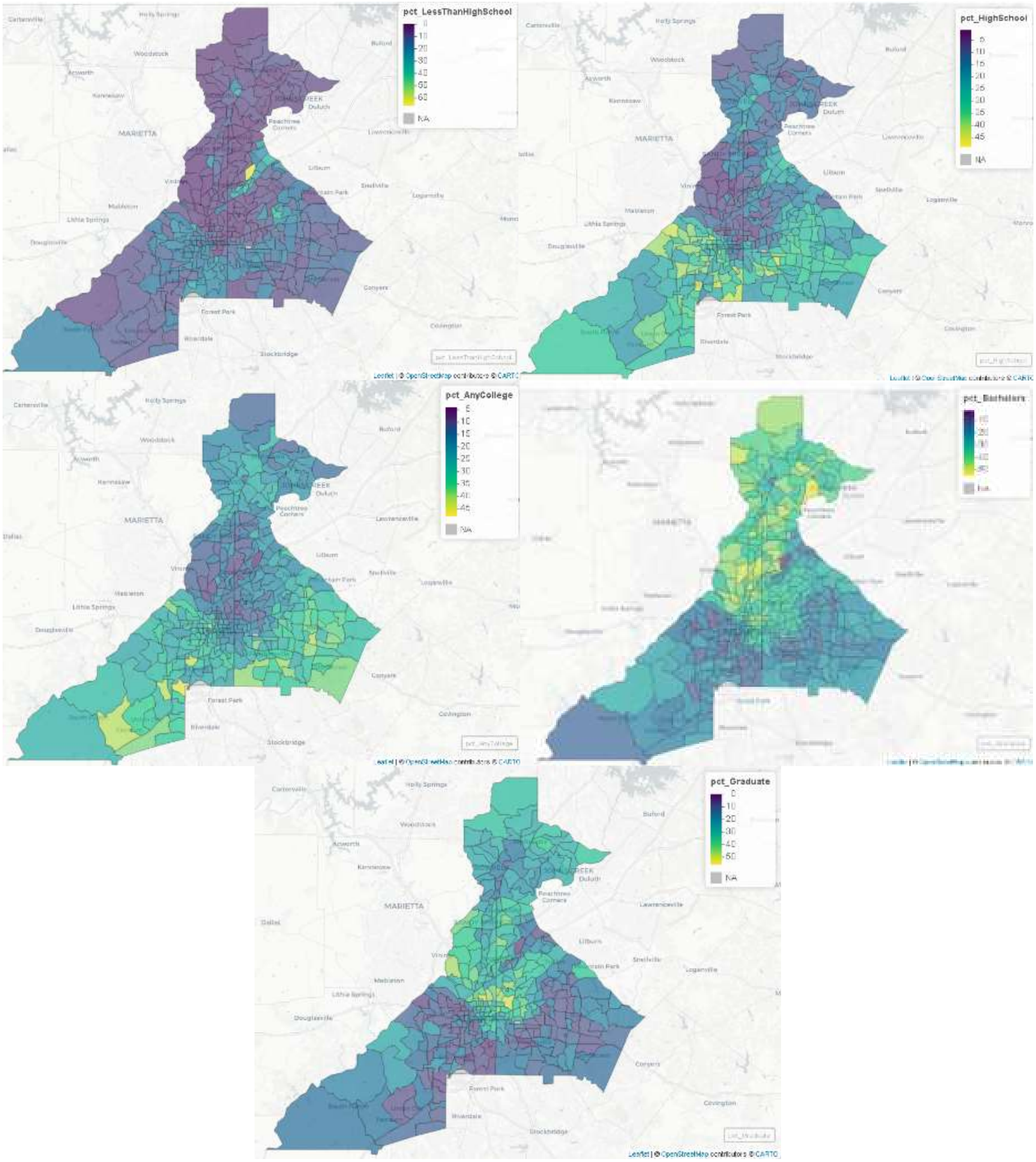


Figure 10 Distribution of level of educational attainment (L-R and Top-Bottom) Less than High School, High School, Any College, Bachelor, Graduate

Distribution of level of educational attainment has been displayed above in 5 categories; Less than High School, High School, Any College, Bachelor and Graduate degree holders. Here we see some similar coinciding patterns as previously visualized SDH's. We see a concentration of Bachelor and Graduate degree holders in the census tracts that are centrally located and extending towards the North, which as previously shown is predominantly white and a concentration of High School and Any College to the south which is predominantly black. One interesting observation is the high concentration of Less that High School population in just one census tract which also corresponds to the census tract with the highest percent Hispanic population and this is investigated further below.

Day and night contrast findings

The maps in this section have been visualized using sync mapview function where the same census tracts make up for adjacent maps in day and night contrast findings which are on the same scale.

The areas of interest for this section were found through exploratory analysis of our geographic limit. Areas that showed highest contrasts between day and night ΔLST were selected with decreasing level of difference. Corresponding social demographics of health for some of these areas were examined.

1. QTS Atlanta Data Center in the Bankhead neighborhood

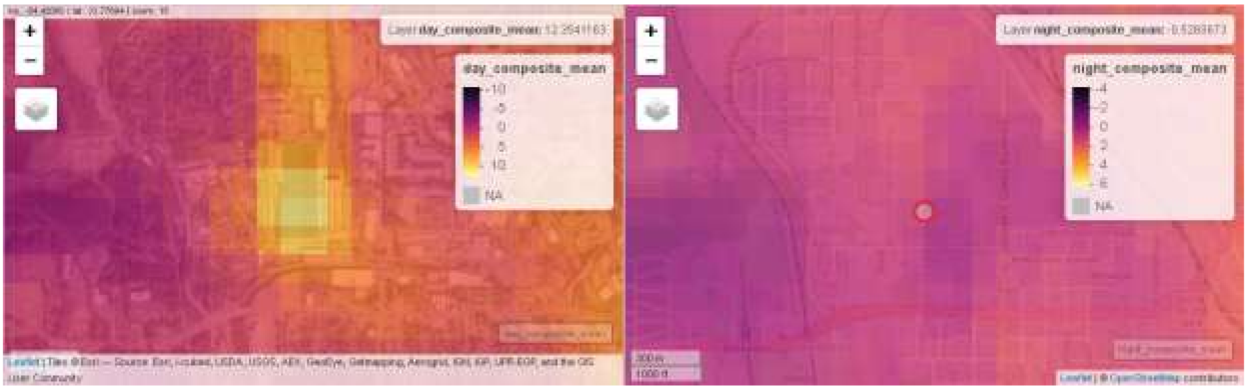


Figure 11: Contrast between day and night ΔLST for QTS Atlanta Data Center

It was noticed that ΔLST day was 12.35 and ΔLST night was -0.53 for the same point which is located at the QTS Atlanta Data Center identified by using OpenStreetMap feature on mapview. However, the surroundings census tracts do not follow the same pattern of extreme heating and cooling. The Westside Reservoir Park situated on the west of the Data Center doesn't seem to have a cooling effect during the day.

2. Georgia World Congress Center north of Mercedes Benz Stadium

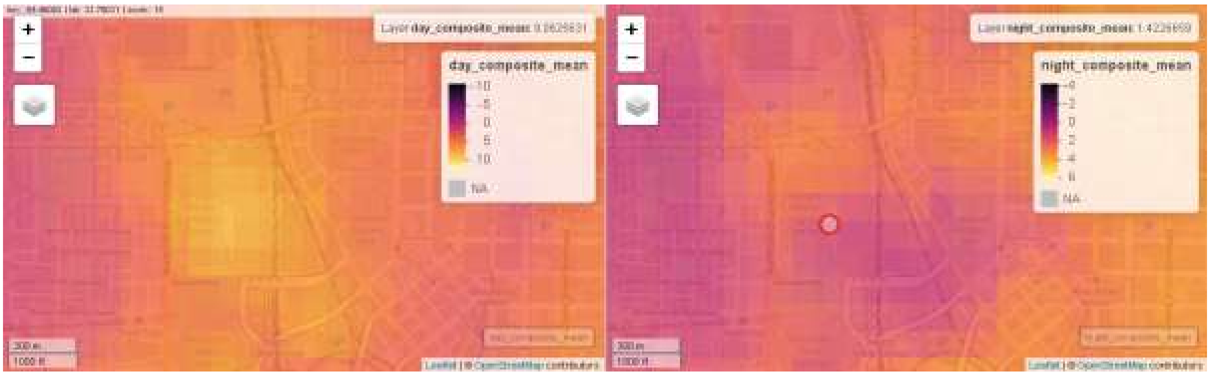


Figure 12: Contrast between day and night temperatures at the Georgia World Congress Center

The Georgia World Congress Center is the world's largest LEED certified convention center and features 1.5 million square feet of exhibit space. It stands at the heart of downtown Atlanta. Here it was noticed that ΔLST day was 9.06 and ΔLST night was 1.42 for the same point on the composite rasters.

One interesting observation for this area is also the racial distribution between populations in neighboring census tracts. We see a striking difference between the percent White and percent Black population composition in the census tract to which the Georgia World Congress center belongs. It contains 92.78 % Black population in comparison to the 2.2% White population. Whereas the neighboring tract to the east, has 59.48 % Black and 26.90 % white.

Figure 13 Distribution of White and Black populations around Georgia World Congress Center

3. DeKalb-Peachtree Airport

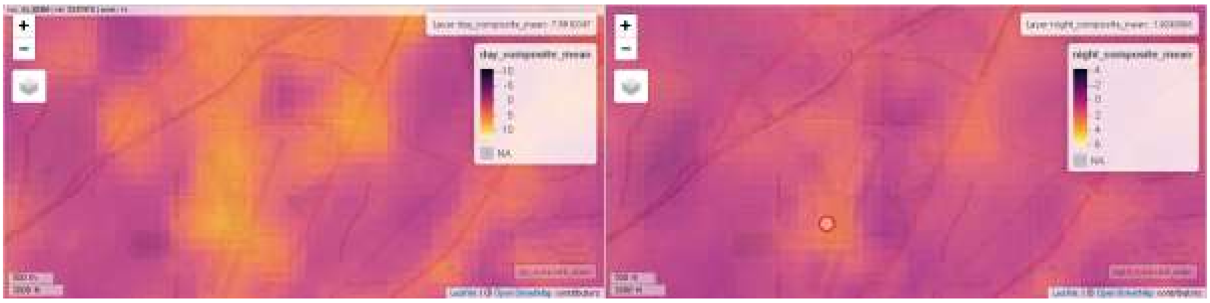


Figure 14: DeKalb-Peachtree airport day and night ΔLST choropleth

This census tract containing the DeKalb- Peachtree airport shows similar patterns of heat distribution between the day and night rasters with evidently and expected lesser values of ΔLST during the night. However, it has an overall higher ΔLST value in comparison to the rest of our area of interest, reaching daytime maximum ΔLST of 7.72. Other interesting features with respect to this particular census tract include racial composition and level of educational attainment, displayed below.

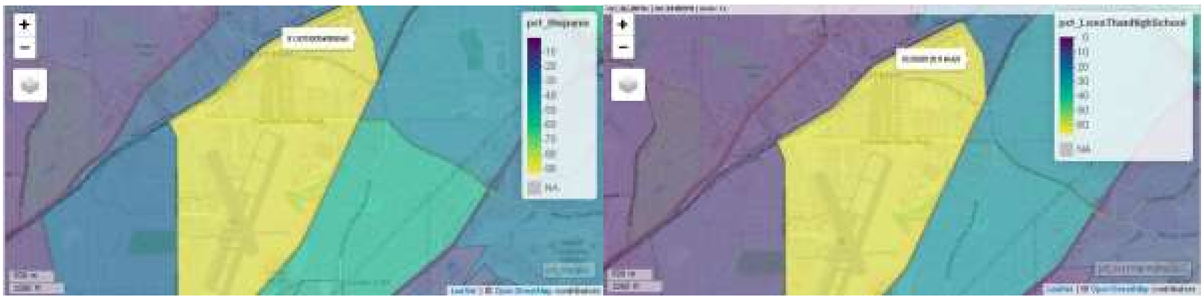
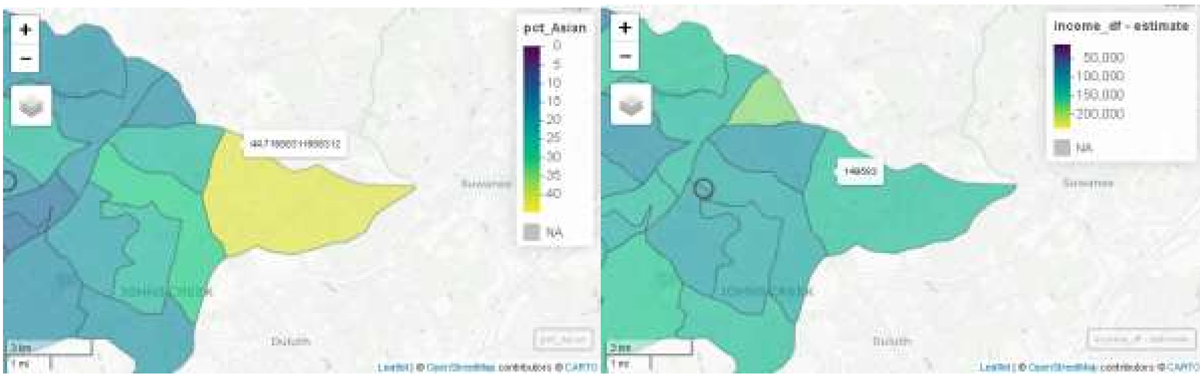


Figure 15: Distribution of percent Hispanic and percent with Less than High School level of educational attainment

The distribution shows 91.9% Hispanic population concentrated in this particular census tract compared to all other races. The same census tract also has a majority (65.86%) of the population with an educational attainment of Less than High School.

4. Census tract with highest percent Asian population

On observation of racial distribution maps, it becomes evident that the Asian population is very concentrated to only one census tract and even within that tract they compose 44.72% of the population.



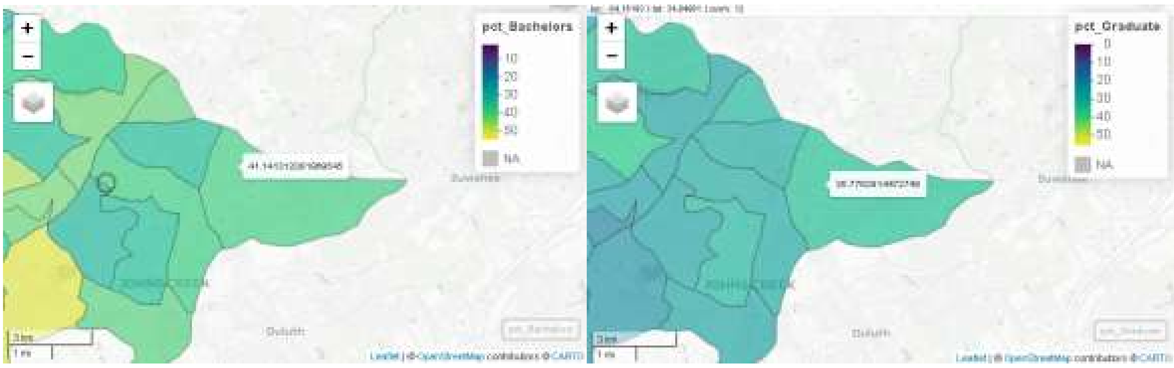


Figure 16: (L-R and Top-Bottom) Census tract with majority Asian population along with income, percent Bachelors and Graduates in corresponding census tract

This census tract belongs to a higher category of median household income with value of $149583. It also has a higher composition of population with Bachelors (41.14%) and Graduate (35.78%) level of educational attainment. No extreme temperature conditions identified within the census tract with a maximum day time ΔLST of 5.69 and night time ΔLST of 2.25.

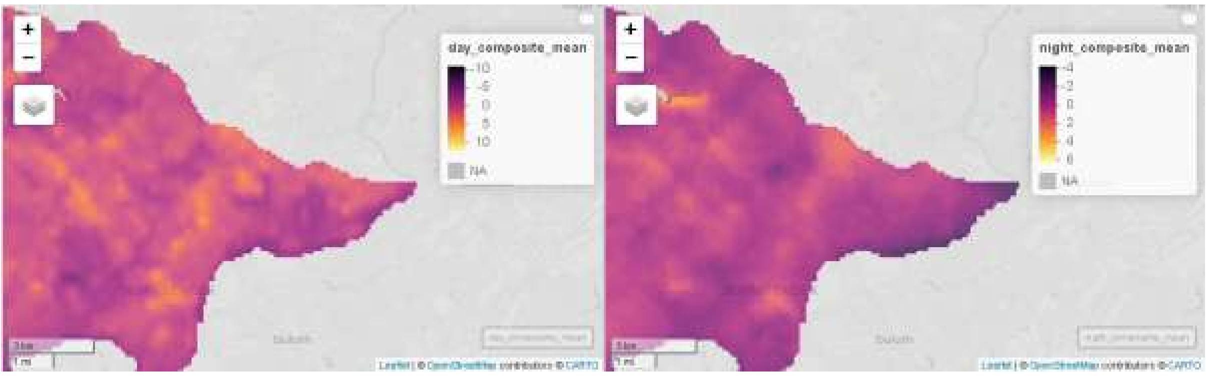


Figure 17: Day and night time ΔLST in census tract with maximum Asian population

4.4.2 Statistical analysis

Model 1:

		LSTday			LSTnight	
Predictors	*Estimates*	*CI*	*p*	*Estimates*	*CI*	*p*
(Intercept)	0.1369153	-0.2841851 – 0.5580157	0.523	0.7518105	0.5243733 – 0.9792478	**<0.001**
pct_Black	0.0083794	0.0030739 – 0.0136849	**0.002**	-0.0029995	-0.0058650 – -0.0001340	**0.040**
pct_Hispanic	0.0322251	0.0193818 – 0.0450683	**<0.001**	0.0048549	-0.0020817 – 0.0117916	0.170
pct_Asian	0.0494217	0.0219734 – 0.0768699	**<0.001**	0.0106163	-0.0042086 – 0.0254411	0.160
Observations	346			346		
R^2 / R^2 adjusted	0.090 / 0.082			0.052 / 0.043		

Multivariate linear regression of ΔLSTday on racial distribution

In this statistical model we regress the dependent variable of ΔLSTday on the variables containing values of percent composition of different races (White, Black, Asian and Hispanic). On examination we identify high a correlation coefficient between percent White and percent Black (-0.91) the absolute value of which is higher than the cut-off of 0.70 and thus unacceptable in the model.

The model then contained only percent Black, percent Asian and percent Hispanic (the minority populations). The results of these show us that with percent increase in Asian, Hispanic and Black there is a statistically significant increase in land surface temperature:

For every degree increase in temperature the percent Asian goes up 0.049%, percent Hispanic goes up 0.032% and percent Black goes up 0.008%. Approximately 10% of the variation in day time temperature is explained by patterns in racial distribution which is given to us by the R squared.

Multivariate linear regression of ΔLSTnight on racial distribution

We repeated the same technique for night time temperatures and see that with percent increase in Asian, Hispanic and Black population there is a statistically insignificant:

- increase in land surface temperature for Asian (0.010) and Hispanic (0.004) populations
- decrease in LST for percent Black population (-0.003).

Approximately 5.2% of the variation in night time temperature is explained by patterns in racial distribution given by R squared.

Model 2:

		LSTday			**LSTnight**	
Predictors	*Estimates*	*CI*	*p*	*Estimates*	*CI*	*p*
(Intercept)	1.9251247	1.6100806 – 2.2401687	**<0.001**	0.8828722	0.7081453 – 1.0575991	**<0.001**
income	-0.0000120	-0.0000157 – -0.0000082	**<0.001**	-0.0000026	-0.0000046 – -0.0000005	**0.015**
	345			345		
R^2 / R^2 adjusted	0.104 / 0.101			0.017 / 0.014		

Univariate linear regression on ΔLSTday on income

In this statistical model we regress the dependent variable of ΔLSTday on the variable of income. The results show a statistically significant decrease of 1.2 °C per $100,000 increase in income. This can also be visually explained by the above created maps.

Univariate linear regression on ΔLSTnight on income

In this statistical model we regressed the dependent variable of ΔLSTnight on the variable of income. The results show a statistically significant decrease of 0.25 °C per $100,000 increase in income. This can also be visually explained by the above created maps.

Model 3:

		LSTday			**LSTnight**	
Predictors	*Estimates*	*CI*	*p*	*Estimates*	*CI*	*p*
(Intercept)	1.9473009	-0.1438560 – 4.0384577	0.068	3.0425932	1.9822225 – 4.1029639	**<0.001**
pct_LessThanHighSchool	0.0404917	0.0114495 – 0.0695339	**0.006**	-0.0019556	-0.0166821 – 0.0127710	0.794
pct_HighSchool	-0.0260027	-0.0560974 – 0.0040920	0.090	-0.0289811	-0.0442414 – -0.0137209	**<0.001**
pct_College	-0.0142396	-0.0432160 – 0.0147368	0.334	-0.0358882	-0.0505813 – -0.0211950	**<0.001**
pct_Bachelors	-0.0162150	-0.0548706 – 0.0224407	0.410	-0.0336964	-0.0532977 – -0.0140951	**0.001**
Observations	347			347		
R^2 / R^2 adjusted	0.062 / 0.051			0.138 / 0.127		

Multivariate linear regression of ΔLSTday on level of educational attainment

In this statistical model we regress the dependent variable of ΔLSTday on the variables containing values of percent composition of different levels of educational attainment (Less than high school, high school, any college, bachelors, graduate). On examination we identify high correlation between percent Graduate with all other variables and thus will exclude it from our model. For this model we accept a correlation of less than 0.70.

When we run the regression with the remaining variables, we see that there's a statistically insignificant decrease in LST for unit increase in percent High School, Any College and Bachelors. However, we see a statistically significant increase of 0.04°C for unit increase in percent Less than High School population. Approximately 6.1% of the variation in day time temperature is explained by patterns in racial distribution given by R squared.

Multivariate linear regression of ΔLSTnight on level of educational attainment

In this statistical model we regress the dependent variable of ΔLSTnight on the variables containing values of percent composition of different levels of educational attainment (Less than high school, high school, any college, bachelors, graduate). On examination we identify high correlation between percent Graduate with all other variables and thus will exclude it from our model. For this model we accept a correlation of less than 0.70.

When we run the regression with the remaining variables this time around, we see that there's a statistically significant decrease in LST for unit increase in percent High School (0.029°C), Any College (0.036°C) and Bachelors (0.034°C). However, we see a statistically insignificant decrease of 0.002°C for unit increase in percent Less than High School population. Approximately 13.75% of the variation in night time temperature is explained by patterns in racial distribution given by R squared.

4.5 Discussion

Results from the study confirm our understanding about the complexity of looking into association of social determinants of health with land surface temperature as there exists a correlation between each of these latter factors.

There seems to be a clear inverse association of income with land surface temperature. This implies that communities with lower median household income are exposed to higher land surface temperatures and might be inadequately equipped to handle these temperatures. This was similar to what was discussed in detail in the study by Gronlund et.al. where they concluded that racial and socioeconomic factors correlate with exposure to extreme temperatures in this study. Gronlund also discussed the complexity of conducting such an analysis due to the high degrees of correlation between each factor which is also something we experienced in our study as well.

It stood out that the one census tract with highest percent Hispanic population also happened to be the tract with the highest percent population with Less than High School level of educational attainment. It was interesting to identify that the same census tract also corresponded with the DeKalb-Peachtree airport. This could imply that the Hispanic community that had a low level of education, and comparatively lower median income, perhaps only able afford to live in less desirable neighborhood, such as near an airport. Not only are they constantly exposed to noise from all the road and air traffic, but this environment also showed higher temperatures in the study. Many of them could also be outdoor workers, with construction being one of the more popular occupations among Hispanics (Somoza, 2015), in which case prolonged periods of time in the sun could cause severe thermoregulation disorders and lead to heat stress illnesses. These factors will make them the populations of interest for extreme heat events with limited means to deal with it appropriately.

The comparatively lower estimate of Black population (0.0084% increase in LST) than Asian (0.0494% increase in LST) and Hispanic (0.0322% increase in LST) can be attributed to the larger population spread over most of the south of Atlanta Metropolitan Area. Therefore, although a large percentage of Black population experiences high LST's the population size for this category is much larger and is also spread over a larger area in our study. This is also highlighted by the observation above where the census tract with highest Asian population only went up to 45% and was the only tract with a majority Asian population.

It is also important to mention the high correlation between temperatures across Black and White population distribution. This corresponds to findings in the Pillai et al. study which found no significant differences between Whites and African-Americans or Whites and other races in terms of the proportion of cases resulting in hospital admissions versus routine discharges due to heat stress.

The day and night contrast findings on a high resolution were interesting and could have important implications. The diurnal dynamics of surface urban heat island (e.g., the timing of the maximum and minimum values of the surface urban heat island (SUHI) intensity for each day/night) has been thought out as a vital indicator of climate change, and is of great value for heat island mitigation and city planning efforts (Yue Chang, 2022). The striking difference between day and night time LST at the QTS Atlanta Data Center could have resulted from its black roof which absorbs more heat (T. Susca, 2011). The extreme heating and cooling could adversely impact surrounding communities especially considering the Westside Reservoir Park location situated to the west as it could affect diurnal patterns followed by certain plants and animals in the neighborhood. Plant growth is altered by environmental cues such as light, temperature, and humidity which enables the maintenance of their circadian rhythms with diurnal cycles. Temperature variations between day and night affect the time lag to light cycle in plants and thereby affect growth. (Masuda K, 2021). Therefore, the additional heat being generated by buildings like this might be of concern.

The location of Georgia World Congress Center should also be noted as it is not only related to significant difference between day and night LST, but also with a stark difference in population composition from its neighboring census tract. This once again gives rise to our hypothesis of association of LST with racial distribution.

Limitations of the study includes the fact that EPHT data is ecological. There is also scope for further research by looking at not only land surface temperature but also corresponding air temperatures. This can make the study more understandable to general population. Future research could also look into Social Vulnerability Index (SVI) as a combination of most of the social determinants of health as and index and look at the association with LST. Another addition to the project could be to include land use characteristics into each model to look for the effect and role it has to play with heat exposure.

4.6 Conclusion

Globally, extreme temperature events are observed to be increasing in their frequency, duration, and magnitude. The dynamic nature of surroundings has led humans to evolve to have a higher effective capability to acclimatize to changing climates. The physiological responses to extreme heat depend on whether these changes are short term or long term (Hanna & Tait, 2015). Acclimatization can only occur in case of long-term and slower changes. With short term rises in temperature and extreme weather events, physiological thermoregulation sets in which eventually leads to heat stress illnesses. It is therefore essential for us to identify the populations that are most vulnerable and enforce effective policy changes to either prevent catastrophic events, or prepare the communities for extreme events.

Heat stress has been said to disproportionately impact people with low median household income and people of color, raising issues such as health equity and environmental injustice. It has been a challenge to study the effects of heat on health with respect to racial and socioeconomic disparities because these characteristics are often correlated.

This study set out to look for an association between land surface temperatures and the social determinants of health or SDHs (racial distribution, median household income, level of educational attainment). This was done using NASA-ECOSTRESS satellite raster data for high resolution land surface temperatures and U.S. Census Bureau data for census data corresponding our SDH's of interest. Although studies of this type have been conducted before, they have never been at the census tract level.

A significant association between LST and median household income was established by the study. Although significant association was found between racial distribution and LST for Black, Hispanic and Asian population, the values were small. Interestingly, Asian and Hispanic neighborhoods were more likely to see hotter temperatures. There was also a significant increase in LST associated with an increase in the percentage of population with Less than High School level of educational attainment.

The high correlation between involved covariates have always made it difficult to understand the relationship between socio-demographic associations and heat stress. This is one of the main limitations of the study. However, certain general understanding can be derived from the study that minority populations would require better emergency preparedness to deal with extreme events of heat stress. Once these communities have been identified, steps can be taken towards improving preparedness.

The urban heat island effect that is evident with high day and night time temperatures concentrated towards downtown Atlanta requires attention. In the recent years this increase in temperature has been so evident that the term 'Hotlanta' is finding its way into news reports and social media (Derek Van Dam, 2021). Measures could be taken to reduce the effect of heat by increasing green space, encouraging the practice of green-roofing and painting of concrete and asphalt with reflective paint to prevent heat absorption. It is also essential to establish a comprehensive heat warning system for extreme heat days (>100°F) in which case an advisory or warning may be issued.

The highest association (13.8%) between the variable and heat was of educational attainment in the night time raster. This educational model also had the highest average R squared for day and night among the three models which implies that 13.8% of the variation in night time temperature was explained by patterns in educational distribution.

As projected, there is a constant increase in heat stress and number of extreme heat days. This study brings out vital inequities in the way different members of the population will be affected in case of extreme events. It brings to light how certain communities bear the brunt of climate change and extreme heat events more than others. Steps need to be taken towards policy translation and emergency preparedness to ensure that especially vulnerable communities are better equipped to handle these.

This project explored the possibility of a relationship between exposure to heat and sociodemographic characteristics in Atlanta. Based on the results, evidence-based policy changes could better target limited resources to protect vulnerable populations from undue exposure to heat, thereby reducing number of illnesses, hospitalizations, and death due to extreme heat exposure.

Due to increasing frequency of extreme heat events as a result of climate change, the findings of this study are of more importance than ever. These findings can be communicated to those communities most impacted by the health effects of heat. Such communication may include educational campaigns and outreach on efficient adaptive and resilience strategies.

The research can also be used as a reproducible model in other cities for which ECOSTRESS data is available. It can be incorporated as an additional tool in the Environmental Public Health Tracking Network. Lastly, it can also help prepare communities, first responders, and health workers for extreme heat exposure.

References

1. Abualsaud, R., Ostrovskiy, G., & Mahfoud, Z. R. (2019). Ethnicity-Based Inequality in Heat-Related Illnesses is on the rise in California. *Wilderness and Environmental Medicine*.

2. CDC. (2013). Climate change and Health; Heat Waves.

3. Charleston, A. E., Wilson, H. R., Edwards, P. O., David, F. M., & Dewitt, S. B. (2015). Environmental Public Health Tracking: Driving Environmental Health Information. *Journal of Public Health Management and Practice*.

4. Derek Van Dam, H. B. (2021 , October 2). *'Hotlanta' is even more sweltering in these neighborhoods due to a racist 20th-century policy.* Retrieved from CNN Weather: https://www.cnn.com/2021/09/18/weather/extreme-urban-heat-environmental-racism-climate/index.html

5. Dwivedi, A., & Mohan, B. K. (2018). Impact of green roof on micro climate to reduce Urban Heat Island. *Remote Sensing Applications: Society and Environment*, 56-69.

6. Eatman, S., & Strosnider, H. M. (2017). CDC's National Environmental Public Health Tracking Program in Action: Case Studies From State and Local Health Departments. *Journal of Public Health Management and Practice*.

7. *ECOSTRESS Maps LA's Hot Spots.* (2018, September 18). Retrieved from Jet Propulsion Laboratory: ecostress.jpl.nasa.gov

8. *ECOSTRESS Maps LA's Hot Spots.* (2018, September 18). Retrieved from Jet Propulsion Laboratory: ecostress.jpl.nasa.gov

9. EPA. (2020, July 30). *Heat Islands*. Retrieved from Learn about heat islands: https://www.epa.gov/heatislands/learn-about-heat-islands

10. *Geography Program.* (n.d.). Retrieved from United States Census Bureau: https://mtgis-portal.geo.census.gov/arcgis/apps/MapSeries/index.html?appid=49cd4bc9c8eb444ab51218c1d5001ef6

11. Gronlund, C. J. (2014). Racial and Socioeconomic Disparities in Heat-Related Health Effects and Their Mechanisms: a Review. *Current Epidemiology Reports*.

12. Hambrick, G. (2016). *Urban vs. Rural: Counties Ranked in Atlanta Metro.* Retrieved from https://patch.com/georgia/eastcobb/urban-vs-rural-counties-ranked-atlanta-metro

13. Hanna, E. G., & Tait, P. W. (2015). Limitations to Thermoregulation and Acclimatization challenge Human Adaptation to Global Warming. *International Journal of Environmental Research and Public Health*.

14. Hayes, M. M. (2006). The Building Blocks of Atlanta: Racial Residential Segregation and Neighborhood inequity. *Thesis, Georgia State University*.

15. Hu, K., Guo, Y., Hochrainer-Stigler, S., Liu, W., See, L., Yang, X., & Zhong, J. (2019). Evidence for Urban–Rural DisparityinTemperature–Mortality Relationshipsin. *Environmental HealthPerspectives*.

16. Huang, Z., wu, C., Teng, M., & Lin, Y. (2020). Impacts of Tree Canopy Cover on Microclimate and Human Thermal Comfort in a Shallow Street Canyon in Wuhan, China. *Atmoshpere*.

17. Hulley, G., Shivers, S., Wetherley, E., & Cudd, R. (2019). New ECOSTRESS and MODIS land surface temperature data reveal fine-scale heat vulnerability in cities: A case study for Los Angeles County, California. *Remote Sens*.

18. Masuda K, Y. T. (2021). Time Lag Between Light and Heat Diurnal Cycles Modulates CIRCADIAN CLOCK ASSOCIATION 1 Rhythm and Growth in Arabidopsis thaliana. *Frontiers in Plant Science*, PMID: 33643331.

19. Mora, C., Counsell, C. W., Bielecki, C. R., & Louis, L. V. (2017). Twenty-Seven Ways a Heat Wave Can Kill You: Deadly Heat in the Era of Climate Change. *Circ Cardiovasc Qual Outcomes*.

20. Na, J.-Y, J., K.E, L., H, K., B, J., J.-W, K., & S.-N, J. (2013). The effects of temperature on heat-related illness according to the characteristics of patients during the summer of 2012 in the Republic of Korea. *Journal of Preventive Medicine and Public Health*, 19-27.

21. NIOSH. (2016). *Criteria for a Recommended Standard: Occupational Exposure to Heat and Hot Environments.* U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS.

22. Nunfam, & Fannam, V. (2018). Social impacts of occupational heat stress and adaptation strategies of workers: A narrative synthesis of the literature. *Science of Total Environment*.

23. Oltra-Carrió, Sobrino, R., Franch, J., & Nerry, B. (2012). Land surface emissivity retrieval from airborne sensor over urban areas. *Remote Sensing of Environment*, 298–305.

24. Pillai, S. K., Now, R. S., Murphy, M. W., Vaidyanath, A., Young, R., Kieszak, S., . . . Wolkin, A. F. (2014). Heat Illness: Predictors of Hospital Admissions among Emergency Department Visits- Georgia,2002-2008. *J Community Health*.

25. Robert W. Woodruff Library. (2018). Segregation in the City Too Busy to Hate. *Archives Research Center*, https://digitalexhibits.auctr.edu/exhibits/show/seekingtotell/segregation.

26. Sankoff, J. (2015). Heat illnesses: a hot topic in the setting of global climate change. *Australian Family Physician (Vol 44): Focus Environment*.

27. Schmeltz, M. T., Sembajwe, G., Marcotullio, P. J., & Grassman, J. A. (2015). Identifying Individual Risk Factors and Documenting the Pattern of Heat-Related Illness through Analyses of hospitalization and Patterns of Household cooling. *PLoS ONE 10(3): e0118958*, 2.

28. Services, U. D. (n.d.). *Social Determinants of health*. Retrieved from Office of Disease Prevention and Health Promotion: https://health.gov/healthypeople/objectives-and-data/social-determinants-health

29. Smargiassi, MS, G., C, P., M, F., Y, B., & T, K. (2009). Variation of daily warm season mortality as a function of micro-urban heat islands. *J Epidemiol Community Health*, 63(8):659–64.

30. Somoza, L. (2015). *A Changing Composition: Hispanics in the Southeast.* Retrieved from Federal Reserve Bank of Atlanta: https://www.atlantafed.org/economy-matters/2015/10/15/hispanics-in-the-southeast

31. T. Susca, S. G. (2011). Positive effects of vegetation: Urban heat island and green roofs. *Environmental Pollution, Volume 159, Issues 8–9*, 2119-2126.

32. Toparlar, Y., Blocken, B., Maiheu, B., & Heijst, G. J. (2017). The effect of an urban park on the microclimate in its vicinity: a case study for Antwerp, Belgium. *The International Journal of Climatology*.

33. Ulaszewski, B. (2007). Microclimate of a parking lot. *the HiLo*.

34. *United States Census Bureau.* (2019). Retrieved from Atlanta City, Georgia profile : https://data.census.gov/cedsci/profile?g=1600000US1304000

35. Wall, P., & Kassinger, C. (2017). Multiple measures on the Environmental Public Health Tracking Network. *Journal of Public Health Management and Practice*.

36. WHO. (2018). *Information and public health advice: heat and health.*

37. Yee, A. (2015). The most racially segregated cities in the South.

38. Yue Chang, J. X. (2022). Combining GOES-R and ECOSTRESS land surface temperature data to investigate diurnal variations of surface urban heat island. *Science of The Total Environment*, ISSN 0048-9697.