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**Final Report: Calculating Extreme Heat Vulnerability for Los Angeles**

**Introduction:**

According to the United States Environmental Protection Agency, extreme heat events are the deadliest form of climate hazard, constituting close to a quarter of all hazard-related deaths (1130 fatalities) between the years 2006 and 2015; although the number is definitely more since some cases go unreported (*EPA*, 2021). In 2020 alone, we lost 8,500 people as a result of daily temperatures being over 90 °F, and by 2050, this figure is expected to increase to 60,000 people per year (Visram, 2021).

Chart, bar chart

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Extreme heat events are characterized by “periods of summertime weather that are substantially hotter and/or more humid than typical for a given location at that time of year.” Besides being the most deadly natural disaster, extreme heat events are also considered to be the second most costly. After hurricanes, which cause the most economic damage, extreme heat events led to the loss of close to 80 billion dollars between the years 2004 and 2013 (*U.S. Climate Resilience Toolkit*, 2016).

Chart, bar chart, histogram

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Furthermore, it is important to consider how extreme heat events relate to other types of climate hazards. For example, depending on its extent and magnitude, an extreme heat event can lead to wildfires or even a prolonged period of drought. This would contribute to said event’s economic, environmental, and human health implications and thus leave some areas especially vulnerable to the effects of climate change. Within the context of increasing temperatures as a result of climate change, extreme heat events will only become more devastating in the future, so identifying the communities that are most at-risk is of the utmost importance in terms of climate mitigation and adaptation.

**Motivation and Literature Review:**

As a native Angelino, I have high stakes in the health of the environment and the people of Los Angeles. Pursuing my Bachelor’s at Cornell University, I studied Environment and Sustainability, hoping to learn of a more practical way to assist my community in terms of climate change adaptation. This led me to the complex world of Geographic Information Systems (GIS) and data science, where I currently reside – rendering visualizations that reveal deeper insights into data and the complexities of systems.

To begin with, I’d first like to discuss Los Angeles’ unique social context. The City’s demographic makeup is extremely diverse and varies greatly in terms of space; of the 4 million Angelinos, 26% are White, 8% are Black, 50% are Hispanic/Latino, 16% are Asian, 1% are Native American, and the rest are two or more races. Within this huge group of people, 12.8% do not have access to health insurance and 18% are living below the Federal Poverty Level (*U.S. Census Bureau*, 2022). This is generally why climate change yields harsher impacts for people of color than for white people; people of color, on average, have increased rates of genetic health predispositions – such as asthma and diabetes – and are less likely, statistically speaking, to have the money and resources necessary to flee from or mitigate their conditions (Fears & Grandoni, 2021). With this, and the spatial components within Los Angeles’ demographic data, it can be safely assumed that certain populations and areas within the City will be disproportionately affected by extreme heat events. This idea will be further explored throughout this section and considered when calculating Social Vulnerability to heat.

According to a report published by the EPA just last year, the United States – as a whole – has experienced a drastic increase in heat wave frequency, duration, and intensity over the past 50 years (*EPA*, 2021). In this same report, Los Angeles was also identified as an area of significant concern due to its relative change in its heat wave season length; 25-50 additional days of extreme heat per year. Additionally, when observing the differences between historic, current, and projected temperature data for the City, it is clear to see that Los Angeles is no exception to the global trend in increasing temperatures. More specifically, the City’s average summer temperature has increased by over three degrees Fahrenheit since 1970 and is projected to increase by another five to nine degrees by the end of the century (*ClimateStations.com*, 2022).

Chart

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This issue becomes even more bleak when one begins to consider mitigation strategies. Even if Los Angeles were to reduce its emissions to be in accordance with the level designated in the Intergovernmental Panel on Climate Change’s “Global Warming of 1.5 °C” report –which will never happen because of the amount of emissions already accumulated in the atmosphere and the lack of perceived incentive for current mitigation strategies – the City would still experience a steady increase in temperatures and rate of extreme heat events (*Climate Explorer*, 2022). In fact, by 2050, climate scientists expect the frequency of heat waves in Los Angeles to increase tenfold- equating to over 5 distinct heat waves throughout the year, compared to the historic average of less than one per year.

Chart

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Figure showing historic vs projected temperature data for Los Angeles

Something that most people fail to mention when assessing Los Angeles’ status in dealing with climate change adaptation is the fact that the City is entirely fossil fuel reliant. Speaking as an Angelino, you really cannot get anywhere in the City unless you have a car or someone who is willing to drive you; the public transportation is highly inefficient and undeveloped. Because of this, Los Angeles is riddled with smog and impervious surfaces, which both contribute to the impact of extreme heat events; the amount of impervious surfaces and smog in an area contribute to the relative prevalence of heat-related illnesses and to that area’s ability to deal with heat (Grifman et al, 2015). Air pollution also varies depending on one’s location within the City (i.e. how many cars are driving through your neighborhood, wind and elevation conditions), eluding to the idea that some communities may be more socially vulnerable to heat than others.

The effects of extreme heat events present challenges for all the systems within Los Angeles, including the social, economic, and environmental. The most obvious effect that extreme heat events will have on the City is in terms of public health. In 2020, State of California officials released a report saying that, between the years 2000 and 2019, there were 599 deaths attributed to heat. However, the Los Angeles Times’ Environmental Policy Reporter, Anne Jacobs, found that the true number was closer to 3,900 deaths- which is about six times that of the original count (*KERO*, 2021). While this number may seem like a lot, the number of people who are hospitalized or otherwise afflicted by heat is far greater, and will only continue to increase; the discrepancy between the reported and true count also reveals that the City and State are not doing a good job at establishing extreme heat metrics and procedures.

For one, the human body physically cannot withstand temperature elevations above normal (4.5 °C, 9.0 °F) without some sort of systematic dysfunction or multi-organ failure. We can dissipate heat through four different types of naturally occurring processes: 1) evaporation through the skin or respiratory tract, 2) radiation (transfer of heat through contactless electromagnetic waves), 3) convection (transfer of heat to gas or liquid surrounding), and 4) conduction (direct transfer of heat through contact with colder, adjacent object). The problem with this is that when the surrounding air outside is hotter than our core body temp, the processes of radiation, convention, and conduction are rendered ineffective at reducing one’s temperature. Additionally, our last option of evaporative cooling also becomes ineffective with high humidity (> 75%), as it requires a water vapor pressure gradient for sweat to evaporate and release heat. The table below shows the relationship between humidity, temperature, and human health:

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When the heat is too much for our bodies to naturally process (in excess of 40.5 °C, or 105 °F), we succumb to one, if not several, of many heat-related illnesses: including heat stroke, heat exhaustion, renal disease, respiratory and cardiac dysfunction, death, etc. Heat stroke is divided into two separate categories: 1) classic heat stroke and 2) exertional heat stroke. Classic heat stroke affects individuals with physiological/anatomical predispositions or underlying chronic medical conditions that impair thermoregulation, impede removal from hot environments, or interfere with the access to attempts at cooling or hydration; most of the people affected are people over 65 and infants who are mistakenly locking in cars. Exertional heat stroke can affect any individual that is participating in exertional activities – like sports, lifting weights, gymnastics, farming, construction, etc. – during periods of high temperatures and humidity; these are otherwise healthy individuals, and predominantly younger. Regardless of which type of heat stroke one faces, 21-63% of all hospitalized individuals die (*CDC*, 2017). However, there are commonalities amongst the victims: extremes of age spectrum (individuals less than 5 years of age and more than 65 years of age), pregnant and obese individuals, individuals without air- conditioning, individuals in social isolation (live by themselves), and individuals with underlying conditions like cardiovascular disease, diabetes, and drug addiction. Disheartening to say, but the majority of these shared risk factors are derived from one’s socioeconomic and genetic background – contributing to the idea that some populations and areas are more vulnerable to heat events than others. Besides the threat of death, heat stroke can also come with it temporary and lifelong health complications, including respiratory and cardiac dysfunction, hypotension, seizures, neurological damage, blood clots, and kidney injury.

Cases of heat exhaustion, although most never lead to death, is also a concern in terms of extreme heat events. Heat exhaustion boils down to individuals either exerting too much energy – whether it be exercisers or outdoor laborers – or not drinking enough water during hot days. If the case is serious enough, heat exhaustion can escalate to “heat injury,” or hyperthermia, where the individual’s core temperature is over 104 °F and organ damage ensues.

Lastly, recent research has been done regarding a type of renal or kidney disease that has ties with climate sensitivity. The name of the broad-term disease is “chronic kidney disease of unknown cause,” or CKDu, and is widely prevalent in the low-altitude, coastal regions of El Salvador, Nicaragua, Guatemala, and Costa Rica – although other research is being done in India and Sri Lanka. The symptoms of the disease include blood in urine, cramps, and elevated levels of serum creatinine (indicator of poor kidney function) and are found mainly in migrant and farm workers who work in extreme heat for extended periods of time on a regular basis. CKDu is suspected to be a form of heat stress disease and its prevalence increases according to the increase in the environmental exposures of humidity and temperature. The problem with this is that CKDu primarily affects socially and economically vulnerable people who either lack access to quality healthcare or essential heat-dissipating utilities (Sorenson, 2019). With the majority of victims being farm workers – who are often times the primary earners for their family – the disease acts as a means of exacerbating the social preconditions of poverty. Not only do these heat-related diseases and illnesses come with individual health and socioeconomic complications, but they also come with cascading implications for global food security and local and state GDP. In 2017 alone, an estimated 153 billion hours of labor in service were lost (80% within agriculture, the rest in “industry”), which is a 60 billion hour increase since 2000; with the absence of adaptation, heat exposure and its respective health effects will continue to have a dramatic effect on labor productivity (Sorenson, 2019).

In terms of the economic side of things, the City stands to lose a lot within the context of more frequent extreme heat events. In general, extreme heat events have profound effects on federal and local economies. According to a report published last year by the Washington D.C-based thinktank, the Adrienne Arsht-Rockefeller Foundation Resilience Center, productivity losses due to heat currently cost the U.S. an estimated 100 billion dollars per year - with this figure projected to double by the year 2030 as a result of increasing temperatures (Nugent, 2021). While most of this national loss is expected to come from the southeastern part of the country, the effects are currently being felt nationwide, with 62% of all U.S. counties experiencing an annual GDP loss of at least 0.5%.

As stated previously, the industry most affected by heat is agriculture, as productivity is especially reliant on climate conditions and most of the jobs within this industry require strenuous, outdoor labor (Visram, 2021). This looks bad for California, considering the facts that it is the leading state in terms of income derived from agricultural activities, 10% of the State’s population works within the industry, and more than 25% of the land in the State is allocated for agricultural use (Omondi, 2019). The relative success of California’s agriculture sector is a result of the State’s historically long growing season and fertile soil, however climate change and increasing temperatures will lead to drier, less fertile soil and shorter growing seasons – putting a large portion of the State’s economy at risk and contributing to local and national food shortages. Los Angeles is also home to the entertainment industry, which pours close to 50 billion dollars into the City’s economy on a yearly basis and directly employs over 420,000 people (Navarro, 2021). Because of Hollywood’s presence within the City, Los Angeles also has a booming tourist industry; it is both California’s and Los Angeles’ third largest industry after agriculture and entertainment. The City is heavily reliant on beach and entertainment tourism, as they help to rake in over 42 million people per year and constitute over 17 billion dollars generated (Grifman et al, 2015). However, as Los Angeles gradually gets hotter - and thus becomes less habitable and aesthetically pleasing for people – tourism will decrease and the entertainment industry might decide to uproot itself and establish a new base elsewhere; both of which would have unprecedented economic and social consequences.

The health of the City’s natural resources and environment is also put at risk due to extreme heat and its associated effects. As was discussed earlier, Los Angeles is extremely fossil-fuel and impervious surface reliant, meaning that the City lacks quality green space and that air pollution and other types of urban waste are prevalent. During the case of an extreme heat event, the amount of green space and tree canopy in an area contributes to that area’s heat resiliency, as green areas help to shade surfaces, deflect radiation from the sun, and release moisture into the atmosphere – purifying the air (*EPA*, 2022). However, when temperatures get too hot and the soil begins to dry up and erode, these green spaces become far less efficient at dissipating heat and can even turn vulnerable to wildfires. The threat of wildfires in Los Angeles has become increasingly alarming over the past decade since climate change has contributed to wildfire magnitude and frequency. While Los Angeles’ vulnerability to wildfires could be discussed as the main topic of an entirely separate paper, it is important to keep in mind how extreme heat events can be exacerbated by other climate hazards. For example, the problems of extreme heat, lack of green space, and wildfires in the City are all related to one another and contribute to the same positive feedback loop; as temperatures increase, green space increasingly dries up and becomes more vulnerable to wildfires, and when wildfires destroy the green space, there is less green space to help deal with increasing temperatures, and the cycle starts again. This environmental degradation goes even further to affect native biodiversity. The World Health Organization states that this decline in biodiversity has implications on humans as well, “affecting livelihoods, income, local migration, and political conflict” (*World Heath Organization*, 2015). In consideration of the goal of this paper being to highlight the areas of the city that are most vulnerable to extreme heat, I will thus be using percent green space and proximity to closest park as features in my physical vulnerability model.

Due to the aforementioned reasons, it is plain to see that Los Angeles is on the precipice of environmental, social, and economic collapse. Not only this, but extreme heat has disproportionate impacts on certain neighborhoods based on their respective social and physical characteristics, inherently making some of the City more at-risk than others. Extreme heat already poses a clear and present threat to Los Angeles, and thus will only continue to worse in the decades to come unless immediate action is undertaken by the City to adapt to or mitigate the effects of climate change. In order to optimize where this action should take place, I will consult expert literature regarding extreme heat and social vulnerability to inform a model that calculates Heat Vulnerability (Index) for each Census tract in Los Angeles. This model will attempt to be as holistic as possible, taking into consideration the multi-faceted impacts of heat. Using a plethora of open data sets – including ACS demographic data, historic and current sea level rise data, proximity/point data, and land use data -, as well as R, I will create three separate maps to support my argument: 1) map of physical vulnerability to extreme heat (i.e. % tree canopy/green space/impervious surface, proximity to emergency medical locations or cooling centers, difference between tract temperature and average city temperature), 2) map of social vulnerability to extreme heat (i.e. racial composition, income, genetic health predispositions, % people without air-conditioning, etc.), and 3) a classification map that splits Census tracts into different “priorities” for intervention based on the Social and Physical Vulnerability calculations (i.e. high social and physical vulnerability, high physical but low social vulnerability, high social but low physical vulnerability, and low physical and social vulnerability). The final deliverable will be in the form of an executive-style brief in which I will explain my motivation, methods, and findings to the City of Los Angeles and persuade them to implement a particular strategy (ex. Put in more green space/plant more trees, reconvert abandoned City-owned buildings into community cooling centers, tax write-offs for installing air-conditioning units/green roofs) in an area that I highlight as being the most vulnerable to extreme heat events.

**Methods:**

As discussed in **Motivation and Literature Review**, I will be using a variety of open data sources to produce features that I think - based on my experience as an Angelino and review of expert literature - contribute most to a neighborhood being labeled as “vulnerable” to extreme heat events. Using these features, I will calculate each Census tract in Los Angeles’ social, physical, and overall vulnerability to extreme heat. In order to better delineate between these features and what they represent, I have included my definitions of social vulnerability and physical vulnerability.

**Social Vulnerability:** the susceptibility of an individual or social group to the negative impacts of natural hazards and disasters due to characteristics that influence one’s ability to prepare, respond, cope, or recover from a disaster (*FEMA*, 2020). These characteristics include financial situation, health, age, communicative abilities, and lack of access to life necessities. Historically discriminatory and racist policies, like redlining, also place low-income and minority communities more at risk of experiencing disasters. According to the Federal Emergency Management Agency’s *Guide to Expanding Mitigation*, these are the populations who will be disproportionately affected by extreme heat:

* Underserved communities with a low socioeconomic status
* People of color
* Tribal and first nation communities
* Women
* Members of the LGBTQ+ community
* Individuals experiencing homelessness or displacement
* Populations over the age of 65 and under the age of 5
* Populations with limited English proficiency
* Service workers or migrant laborers
* Populations with limited cognitive or physical abilities
* Institutionalized populations, such as those in prisons and nursing homes, or individuals going through reentry

The Centers for Disease Control and Prevention also has its own way of calculating Social Vulnerability, in which it uses United States Census data to examine social vulnerability at the Census tract level for 15 social factors (broken up into four groups), including:

1. Socioeconomic status

* Below poverty
* Unemployed
* Per capita income
* Educational attainment (% over 25 without high school diploma)

1. Household Composition and Disability

* 65 years old or older
* 17 years old or younger
* Older than 5 years old and with a disability
* Single-parent households

1. Minority Status and Language

* Minority
* Speaks English “less than well”

1. Housing Type and Transportation

* Multi-unit structures
* Mobile homes
* Crowding
* No vehicle
* Group quarters/co-ops

Rather than just assuming that areas with more people of color will have more people with genetic predispositions, I also want to factor in “health status” features, including (% of adults with):

* Asthma
* Chronic Obstructed Pulmonary Disease
* Coronary Heart Disease
* Diabetes
* Obesity
* Hypertension

Using the FEMA and CDC models for social vulnerability as inspiration, and based on Los Angeles’ unique context, I decided to use the following social factors in my social vulnerability calculation:

* Racial context
* Immigrants and migrant laborers
* Populations with limited English proficiency
* Single-parent households
* Educational attainment
* Unemployment
* Per capita income
* Poverty
* Individuals experiencing homelessness or displacement
* Populations over the age of 65 and under the age of 5
* Populations with limited cognitive or physical abilities
* Institutionalized populations, such as those in prisons and nursing homes, or individuals going through reentry
* Individuals with lack of vehicle access
* Redlining
* Health status

**Socio economic**

Poverty

Unemployed

Educational attainment

**Household composition**

Single parent

Populations over 65

Populations under 5

Populations with disabilities mental and phys

**Minority status**

Racial context

Immigrants and prior immigrants

Limited English proficiency

**Health status**

Asthma

Low birth weight

Cardiovascular

**Housing status and transportation**

Homeless

Institutionalized

Lack of vehicle access or uses public transportation

Housing burden

**Physical Vulnerability:** the susceptibility of an area to the negative impacts of natural hazards and disasters due to characteristics that influence the environment’s ability to prepare, respond, cope, or recover from a disaster. Besides the physical vulnerability features that I outlined in **Motivation and Literature Review,** the City of Philadelphia’s own Heat Vulnerability Index map includes several other features that contribute to a neighborhood’s physical vulnerability, including:

* Difference between City average temperature and Census tract temperature
* Proximity to public pools, spraygrounds, and cooling centers
* Proximity to public schools (serve as neighborhood centers and assist in preparing for extreme heat events)
* Proximity to federally qualified health centers
* Air-conditioning prevalence
* Air quality

Using these variables as my initial physical vulnerability framework, I made a new model to calculate Physical Vulnerability, including the following factors:

* % green space ? (parks and available green spaces)
* Proximity to closest park
* PM 2.5 concentration ?
* Air-conditioning prevalence
* % tree cover (tree people data incoming)
* Current/historical surface temperature ?
* Projected surface temperature ?
* Proximity to public pools, spraygrounds, and cooling centers ?
* Proximity to public schools ? (elementary, middle, and high school)
* Proximity to urgent cares and hospitals ?
* % impervious surfaces (if not reciprocal of % green space feature)

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