HEAT WAVES AND HOMELESSNESS: ANALYSIS OF SAN DIEGO AND RECOMMENDATIONS

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INTRODUCTION

CLIMATE CHANGE, HEAT, & HEALTH

CLIMATE CHANGE

According to the Intergovernmental Panel on Climate Change (IPPC), the "scientific evidence for warming of the climate system is unequivocal." Atmospheric concentrations of carbon dioxide (CO_2) have been rising for decades primarily due to the burning of fossil fuels for energy (Lindsey 2018). Combustion of fossil fuels is well known to be the leading explanatory variable of climate change due to the release of CO_2 and other pollutants. CO_2 is a greenhouse gas, and absorbs heat infrared radiation from the Earth's surface, effectively trapping the heat. The more CO_2 in the atmosphere, the more warming is expected at the surface. The increased warming at Earth's surface is likely to cause changes in the climate systems that are responsible for global weather patterns. Global average temperatures are projected to increase between 1.4 and 5.8 °C by the end of this century (IPCC). Climate change exacerbates existing weather conditions and creates unprecedented situations through the altering of weather systems for extended periods of time (NASA). These alterations also change the distribution of risk factors to extreme weather events. Changes in precipitation, temperature, and other environmental factors will put pressure on communities that are not yet well adapted, especially to rare or uncommon extremes. Although many studies explore evidence of the associations between daily temperatures and mortality, additional tools are needed to predict and prepare for the future effects of climate change on ambient outdoor temperatures and mortality.

EXTREME WEATHER: HEAT

Under a scenario where CO_2 emissions keep increasing, climate change is projected to increase the frequency, intensity, and duration of heat waves, meaning events will generally occur more often, last longer, and be hotter (Anderson 2011). According to the most recent IPCC AR5 report, it is likely that human influence on the climate has more than doubled the probability of heat waves in some locations. Extreme heat events (EHEs) have been described in literature as lingering warm air masses that lead to consecutive nights of high minimum temperatures and are associated with temperature extremes (Luber & McGeehin 2008). About 30 percent of the world's human population (~2.3 billion as of May, 2019) lives in areas experiencing extreme heat conditions that contribute to mortality (Mora et al. 2017). The global population is continuing to rise, and emissions have not decreased by enough to change the trajectory. In a warming climate, heat-related mortality is expected to increase and the zone of vulnerability will expanding (Patz et al. 2005). Extreme heat poses a threat to humans and other mammal species by changing the immediate environment in which they are exposed to on a regular basis. Mammal species are warm-blooded and research has shown that there are upper boundaries to the maximum temperature that they can tolerate before it becomes fatal (Sherwood & Huber 2010). At the national level, extreme heat is responsible for more deaths in the United States than any other weather-related events combined (Davis et al. 2003). Extreme heat can be dealt with more comprehensively because it is something that can be felt through the human body's responses, such as sweating and increased breathing.

HEAT & HEALTH

Vulnerability to extreme heat is a function of the social complexities experienced by an individual as well as the environmental conditions they are subjected to (Johnson et al. 2012). Extreme heat events raise the outdoor ambient temperature that a population is exposed to. This means that during a heat event, every single person is at some level of risk. Individual susceptibility to a heat wave depends heavily on the body's thermoregulatory capacity (Mora et al. 2017). The human body, through all of the physiological mechanisms, balances core temperature at approximately 37ºC (98.6ºF). During an EHE, the heart works harder to increase sweat production. Respiration and perspiration allow for heat to leave the body consequently cooling a person down. Serious health issues and death can occur after a relatively short amount of time if core body temperature goes above 42ºC (107.6ºF) (Kjellstrom 2009). When blood is pumped to the skin to rapidly cool the body, other organs do not receive adequate blood supply. Most of the heat-related mortality has been attributed to changes in these physiological processes due to extreme heat. A recent epidemiological study found that extreme heat critically impacts 7 vital organs through 27 different physiological pathways (Mora at el. 2017). Negative health effects of heat wave exposure can include cramps, fainting, heat exhaustion, heatstroke, dehydration, existing disease exacerbations, thermoregulatory process disruption and ultimately, death (Lowe et al. 2011). Well-known risk factors for mortality during a heat wave event include medical conditions and being elderly, as well as living alone, being exposed to environmental pollution, being socially isolated, lacking access to air conditioning, drug abuse, and mental health issues (Ramin et al. 2009).

OBJECTIVES

UNITED STATES HEAT IMPACTS

In discussing the effects of extreme heat on mortality rates, it is important to note that the impacts are not equal, even on a localized scale. Urbanization and social variables play a significant role in the spatial distribution of heat impacts and mortality (Hattis et al. 2012). A study of heat impacts in Massachusetts found that the demographics of neighborhoods explain more of the heat-related mortality than the proportion of a city that is urbanized (Hattis et al. 2012). As a matter of fact, although urban areas tend to see an increase in temperature, rural areas are likely to experience increases in minimum temperatures, as well as heat-related mortality. A study in Ohio found that heat mortality in rural and suburban areas increases at a superior rate than urban deaths (Sheridan & Dolney 2003). Local differences in mortality are due to neighborhood nuances and adaptability. These factors can be quantified and analyzed in order to develop vulnerability indices that policy-makers can use to prevent heat-related deaths.

Socioeconomic factors can affect not only an individuals' susceptibility to heat events, but also dictates an individual's ability to reduce the impacts. Socioeconomic status (SES) is defined as the 'social standing or class of an individual or group and is often measured as a combination of education, income and occupation' (APA). Frequently, these factors are reflected in neighborhoods, or census tracts. A low SES neighborhood consists of an area with majority low education, low income, as well as racially ethnic populations (non-white). Many studies have found a strong association between racial and ethnic community composition and heat mortality (Ye et al. 2012). Racial and ethnic minority populations in the United States are associated with lower income, poorer physical health, living in urbanized areas away from green space, and lower air conditioning ownership (Grunlund 2014). Many studies have shown that ambient temperatures can be drastically different in an urbanized area. The urban heat island effect (UHI) is due to a combination of impervious surfaces that don't evaporate well, and practices such as transportation that add sensible heat to an urban setting (Yuan 2006). Air conditioning prevalence is often a proxy for heat vulnerability because it represents an opportunity of relief from high outdoor temperatures. During heat events, city governments will often ask public facilities such as libraries to extend their hours for people who don't have central AC (Corcos 2018). There is even a difference in whether a house has central AC or a single AC unit in a separate room.

Pre-existing conditions play a significant role in the level of vulnerability a person experiences during an extreme heat event (Cutter et al. 2003). Research suggests greater vulnerability for the elderly, children, and those with pre-existing medical conditions, as these groups experience weakened thermoregulatory capacity (Mora at el. 2017). Comorbidity describes two or more disorders or illnesses occurring in the same person and are often used as an immediate indicator of vulnerability (Gronlund 2014). The effects from heat are often exacerbated by these comorbidities, and vice-a-versa. For example, exposure to increased temperatures can lead to dehydration, which consequently affects kidney function. Individuals with existing kidney disease may experience a worsening of their condition (Hansen et al. 2008).

As mentioned in previous literature, elderly populations represent a vulnerable population to heat-related events for a variety of reasons (Astrom et al. 2011). The association between heat and mortality in the elderly has been well researched and documented (Gronlund et al. 2014). This is due to preexisting conditions, decreased physical health, and/or due to living alone or not having adequate access to care. The elderly require health services, and the population density of senior citizens is a proxy of the ease of access of those services which benefit other vulnerable populations as well. An individual who is socially isolated doesn't have access to services that are meant to ease effects of heat.

Environmental risk factors indicate a level of exposure that is immediately experienced by at-risk populations. Environmental pollution can manifest in many different forms, and can negatively affect the health of individuals being exposed to a given factor. The most obvious environmental risk factor when discussing vulnerability to heat events is maximum and minimum daily temperatures. As stated earlier, heat wave events raise the minimum night temperatures. Other environmental conditions such as pollution are an immediate source of exposure. An important pollutant that adversely affects vulnerable populations is tropospheric ozone (O_3). In the stratosphere, O_3 acts as a shield from harmful ultraviolet radiation from the sun. However, at the ground-level, O_3 is a well-known pulmonary irritant that affects respiratory functions and is associated with increased hospitalizations from respiratory diseases (Ebi 2008). O_3 is an environmental pollutant because the atmospheric concentration is dependent on concentrations of nitrogen oxides (NOx) and volatile organic compounds (VOCs) (Government of Canada 2016). These pollutants chemically react with sunlight to create O_3. Stagnant air associated with heat wave conditions is important for the formation of harmful O_3 (Luber & McGeehin 2008). Particulate matter is another well-known atmospheric pollutant that is found in many sizes and from many sources, though primarily from combustion and gas-to-particle conversion processes in the atmosphere. PM2.5 represents particles in the air with a diameter of 2.5 micrometers. PM2.5 is particularly harmful because it is easily deposited into the lungs, causing respiratory issues and can lead to heart failure and premature death (Pui et al. 2014). The development of these health issues has a direct association with the development or exacerbation of comorbidities in vulnerable populations susceptible to immediate and prolonged exposure. Traffic density represents a variable that increases vulnerability, especially for those already suffering from respiratory illnesses such as asthma.

Several cities in the United States have county-wide heat-related warning systems currently in action (Ebi et al 2004). The most commonly used method of spatially specific heat-related warning systems is the Heat-Health Watch Warning System (HWWS), which is used by the National Weather Service (NWS) to inform the general public of extreme events (Kalkstein et al. 2007. In the summer of 2002, Phoenix, Arizona adopted the HWWS after an improvement to the system. Instead of using arbitrary thresholds like many of the older systems did, the Phoenix system used human-health responses (Kalkstein et al. 2007). The Phoenix system was used by the local NWS office to issue heat warnings, watches, or advisories, depending on the forecasted severity. By combining this process with intervention by the city and health department to help prevent any deterioration in human health, Phoenix tried to decrease instances of heat mortality in a systematic fashion. Philadelphia, Pennsylvania implemented a similar system with more elaborate steps for intervention. This system actively focuses on atmospheric conditions which have previously contributed to heat-related mortality. The most pronounced limitation mentioned in literature pertaining to this existing framework is the lack of spatial delineation in determining localized levels of risk, as it focuses on larger spatial resolutions at the city or county boundaries (Johnson et al. 2009). Many epidemiological studies have tried to address the shortcomings of spatial specificity in heat warning systems at the local level (Uejio et al. 2011). These approaches incorporate geospatial technologies such as remote sensing and geographic information systems (ArcGIS in this study). This combination of data systems provides a useful framework that emphasizes the specified spatial nature of heat-related events and consequential hazards. Without a methodical understanding of where vulnerable populations are, and what areas are expected to have higher vulnerability, adaptation solutions are likely to fall short of protecting large proportions of the population. These analysis tools provide a method to incorporate both social and environmental data, a sort of hybridization through indexing. The indexing process combines both the social and environmental aspects of the health risks associated with extreme heat exposure to ultimately develop a heat vulnerability index. Modeled after "SoVI" or the social vulnerability index pioneered by Cutter et al., this method utilizes a number of variables to determine the level of social vulnerability based on the spatial scale used (Schmidtlein et al. 2008). Vulnerability maps are a culmination of community properties and population composition variables. Variables for analysis are chosen that have been demonstrated to modify the relationship between heat and health outcomes in the literature and for which data sets are readily available (Reid et al. 2009). Since data is collected on the U.S. population every year, adequate data exists to produce and update vulnerability maps, even on a census-tract scale. Cities and counties are able to figure out the vulnerability levels within the boundaries, and use data-driven analyses to direct resources to the most vulnerable areas. Indexing provides an efficient way to outline localized risks.

SAN DIEGO, CALIFORNIA & THE HOMELESS

The state of California has been described as having a Mediterranean climate, with warm, dry summers and cool, wet winters, and San Diego captures this description quite well (Jennings et al. 2018). San Diego County is the southernmost county in California, sharing a border with Mexico. San Diego County represents a unique landscape that will likely change due to increased global warming. The county's boundary contains a variety of eco-regions, including mountains, deserts, and coastal beach environments, as well as numerous urban centers, all with varying maximum and minimum temperatures and projected changes due to climate change. Projections of climate change in the region include warming by 4-9˚F on average by the middle of the century, increasing the likelihood and length of dangerous heat waves (Cayan et al. 2008). Climate models have predicted that there will be fewer precipitation days, leading to more frequent and intense drought (Jennings et al. 2018). With increasing variability in precipitation, droughts may occur more frequently due to increased occurrence of dry days and could intensify because of warmer temperatures. Santa Ana winds occur in San Diego during the fall months, and with increased dry days, can create conditions suitable for more frequent fires. Heat waves are often described as periods of unusually high atmospheric heat-stress and are often given arbitrary thresholds depending on the region (Robinson 2001). Communication with the National Weather Service is necessary to predict and prepare for a heat wave event. Coastal low clouds and fog along San Diego's coast mitigate the effects of warming and drying through shading and cooling. However, there is uncertainty in future changes due to this phenomenon, so the spatial and temporal scales at which the climate is studied is important for building policy (Jennings et al. 2018).

San Diego County was chosen as the focus for this analysis, and contains a myriad of microclimates that will affect the way heat waves are perceived and mitigated. San Diego has been very progressive with action plans involving green technology and climate adaptation. However, there is a substantial public health gap concerning the protection of vulnerable populations. The risk of heat illness exists for the entire population, yet important social factors exist that put populations at an adverse risk. Currently, there is no scenario that shows a decrease in the number of heat days per year in San Diego. The County of San Diego Health and Human Services Agency (HHSA) Public Health Services (PHS) prepared an Excessive Heat Response Plan (EHRP) in

2013. The EHRP details the procedures for coordinating the preparedness and response efforts of HHSA to protect vulnerable populations from extreme heat events. The EHRP outlines the roles and responsibilities for addressing certain heat-related stresses (HHSA 2013). The most recently adopted county climate action plan lists vulnerable populations as 'the elderly, children, agricultural and outdoor workers, and those suffering from preexisting cardiovascular or respiratory conditions'. The criteria for most studies concerning risk factors to heat and disadvantaged communities limit categorizing income levels to "low". In the assessment of sensitivity, populations are defined as "the general human population and segments of the population that are most likely to be sensitive or vulnerable to climate change impacts. This applies, particularly to non-English speaking or elderly populations who may require special response assistance or special medical care after a climate-influenced disaster, and disadvantaged communities." While there is recognition of increased risk for individuals experiencing homelessness within the climate action plan, much remains to be researched for adequate mediation that relieve heat stresses for these individuals. Data collection and organization as well as clear language among all policy is necessary to keep track of a plan's effectiveness after implementation.

The motivation of this study is to emphasize and support the inclusion of homelessness into plans concerning adaptation and mitigation to climate change, as they are not often included in estimates of vulnerability (Ramin et al. 2009). The definition of homelessness from an epidemiological lens includes individuals who sleep in shelters as well as 'absolute homelessness', which describes individuals who sleep outdoors or in other places not intended for human habitation (Ramin et al. 2009). The county of San Diego has the fourth highest population of people experiencing homelessness in the United States (KPBS 2018). As of 2018, there were a documented 8,600 unsheltered people counted in a census conducted by the Regional Task Force on the Homeless (RTFHSD). Heat exposure is usually readily perceived by the exposed individuals. Individuals experiencing homelessness in the United States share a 1.6 times greater death rate compared to the non-homeless populations' (Morrison 2009). All of the studied risk factors of heat related events on vulnerable populations are found among the homeless. Homeless populations represent the most vulnerable population to heat events, suffering from high rates of poorly controlled chronic disease, smoking, respiratory conditions, and mental illness, all of which render them vulnerable to changes in heat wave occurrence associated with climate change (Ramin et al. 2009).

The homeless are vulnerable because the risk factors for mortality and morbidity from heat correlate closely with the characteristics of homeless individuals (Ramin et al. 2009). Well-known risk factors for mortality during a heat wave event include medical conditions such as cardiovascular disease and pulmonary disease, being elderly, living alone, being socially isolated, lack of access to air conditioning, alcoholism, drug abuse, and mental health issues, all of which are more common amongst homeless individuals. Veterans of war returning from overseas are more likely to experience homelessness due to increased rates of extreme poverty, psychiatric disorders from combat, and general isolation (Nicolay et al. 2016). Those experiencing homelessness often have other chronic medical issues, such as kidney disease and hypertensive diseases, making it even harder to attribute heat events to cause of mortality. Chronic diseases in homeless populations are often greater than in the general public due to a lack of access, and these illnesses are likely to exacerbate the effects associated with a changing climate (Ramin et al. 2009). Additionally, those with mental health issues may be less able to take actions to reduce their exposure to extreme heat. According to Michael McConnell, a homeless advocate stationed in San Diego, the policies that are put into place end up ‘pushing the homeless out of urban areas with resources and into rural areas that are often away from the social service system completely’. The spatial distribution of the homeless population in San Diego is important because of this representation of the most vulnerable populations. Since vulnerability is representative of the social and environmental factors of an area, in this case census tracts, then homelessness can be considered a proxy. Populations with a higher concentration of individuals experiencing homelessness are more exposed to the effects of heat. Lack of general access to services that ease climate pressures can have serious health impacts and even lead to an increase in mortality rates among the homeless and other vulnerable populations (Hwang 2011). According to Kevin Corinth, Senior Economist at the Council of Economic Advisors to the White House, “the homeless over-represent the vulnerable segments of society” (Corinth 2013). Spatial analysis allows for the delegation of resources where they will be most effective in preventing heat mortality. All populations within San Diego County will benefit from inclusive climate or public health policies that act on the risk variables associated with increased vulnerability.

METHODOLOGY

DATA

San Diego County spans 4,530 square miles and is comprised of 627 census tracts. The heat vulnerability index (HVI) incorporates well-recognized variables, both physical and social, which are known to contribute to extreme heat vulnerability (Johnson et al. 2012). Data was collected on 28 of these recognized variables.

Social variables encompass those variables that are socioeconomic and demographic in nature. Social data was compiled as five year averages (2012-2016) from the United States Census Bureau's American Community Survey. Another socioeconomic indicator is access to air conditioning, or specifically whether the AC unit in a household is central, or in a separate room. Air conditioning offers relief to extreme heat, but only to those who can afford to have it or be in an area that has a central cooling system. Household data of AC that is centralized or in a separate room was gathered from the ESRI Market Potential database from 2017.

Comorbidity describes two or more disorders or illnesses occurring in the same person and can occur either at the same time or one after the other. Pre-existing conditions play a significant role in the level of vulnerability a person experiences during an extreme heat event (Cutter et al. 2003). There are 16 medical conditions included in the analysis which were gathered from the California Office of Statewide Health Planning and Development and Vital Records Business Intelligence System. Conditions were coded using ICD9-CM for 2011 through September 2015, and ICD10-CM for October 2015 to 2016. Primary and secondary diagnosis/injury variables were searched for any mention of the listed condition. All emergency discharge data (EDD) and patient discharge data (PDD) encounter data were summarized across all years by zip code. For any mention of heat injury/illness, multiple cause of death (MCOD) was included for 2016 (the only year for which these data were available). Total medical encounters were derived by aggregating cases by condition and zip code, and then allocating by census tract by the percent of spatial overlap of zip code and tract. Final total medical encounter estimates were calculated as the percent of total medical encounters by condition for each census tract (Benmarhnia 2019). These medical conditions represent comorbidities and are often hard to distinguish from heat as the cause of hospitalization or death. The number of hospitalizations due to heat illness is likely to be underestimated (Ostro et al. 2009). Potential for more accurate data collection and access will be discussed.

Environmental pollution data was collected from CalEnvironScreen, and represents conditions which the most vulnerable populations, such as the homeless, experience most frequently. These variables include daily maximum tropospheric Ozone concentration, traffic density, PM2.5 concentrations, and general housing burden. These indicators are used by the state of California to assess overall vulnerability among populations. Data was downloaded and organized in a spreadsheet by census tract. Census tract number 99.02 was removed completely because it represents San Diego Bay.

Table 1. Heat-health vulnerability data, 627 San Diego County census tracts.

Category	Data Source (year)	Variable Definition
Medical Conditions	Vital Records Business Intelligence System	Any mention heat illness injury
	The California Office of Statewide Health Planning and Development (2011-2016 five year average)	Any mention of alcohol abuse
		Any mention heart disease
		Any mention childhood disorders
		Any mention chronic kidney disease
		Any mention diabetes
		Any mention impulse disorders
		Any mention mood disorders
		Any mention multiple sclerosis
		Any mention Alzheimer's/dementia
		Any mention all cancer
		Any mention hypertensive disease
		Any mention pulmonary disease
		Any mention schizophrenia
		Any mention stroke
		Any mention substance abuse
Demographic Variables	United States Census Bureau's American Community Survey (2012-2016)	Population age 65 and older
		Population age 65 and older and alone
		Population living alone
		Population below poverty line
		Population with less than a high school degree
		Population non-white
	ESRI Market Potential Data base (2017)	AC centralized
		AC separate room
Pollution Burden	CalEnviroScreen 3.0	Daily 8 hour ozone maximum
		Traffic density
		PM2.5
		Housing Burden

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		Any mention hypertensive disease
		Any mention pulmonary disease

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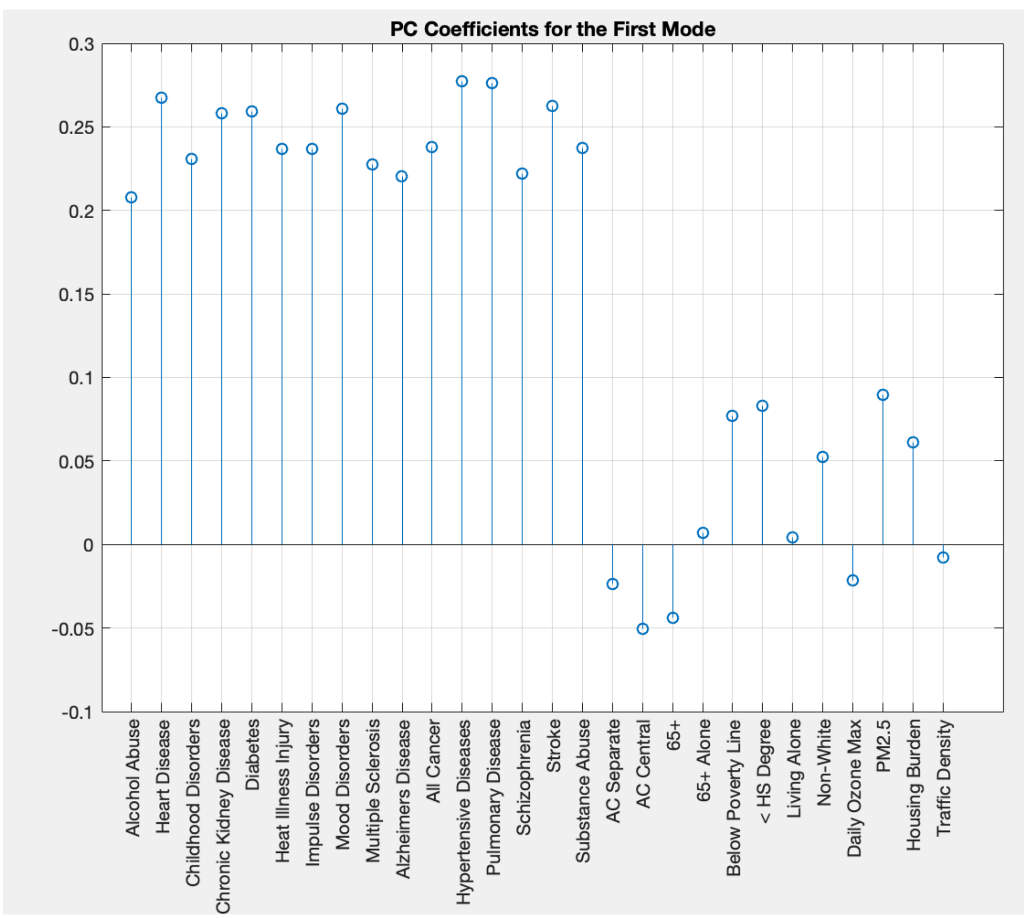
		PM2.5
		Housing Burden

Analysis of the data was completed using MATLAB software. Instances of no data were treated as 'not a number' (NaN) for analysis, meaning the values were ignored and not treated as zeroes. All demographic and medical, data for heat vulnerability was in the form of percentage of population within each census tract. Pollution burden had percentage values for all variables except traffic density. The data matrix was standardized using the z-score function, which takes the normal distribution of values and converts it to standard deviations away from a mean of zero. This allows for comparison among different units.

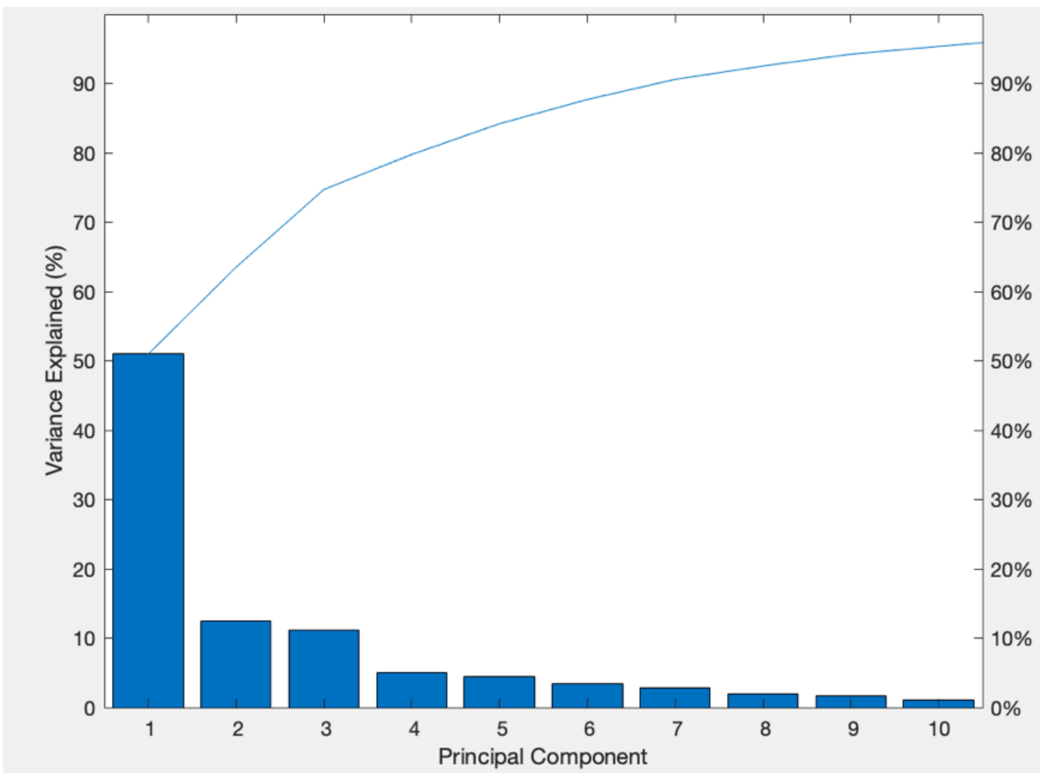
Principal component analysis (PCA) is a data exploration tool that converts a set of potentially correlated variables with a shared spatial scale into a set of uncorrelated variables that capture the variability in the underlying data (Abson et al. 2012). The PCA approach provides several potential advantages in the aggregation of spatially explicit, potentially incomparable variables. The PCA reduces the dimensionality or number of variables without sacrificing any data. PCA finds the best combinations of the original 28 variables so that the variance is maximized. Four 'umbrella' factors emerged, which represented all 28 variables. These four factors were: medical conditions, elderly and isolation, socioeconomic status, and environmental conditions (Fig 1.).

Figure 1. First PC coefficients shows grouping of variables by category.



Higher order PCs (1^{st}, 2^{nd}, 3^{rd}) will capture more of the total variability in the data than any individual original variable. The first PC explains 51% of the variance between variables (Fig. 2). The first column of the coefficient output corresponds to the strength of the relationship between the variables. The matrix of z-scores was multiplied by the corresponding coefficients from the first PC, for each of the 28 variables (PCZ matrix). The summation of all values for each census tracts represents the index score for heat vulnerability.

Figure 2. First principal component and variance explained



MISSING DATA

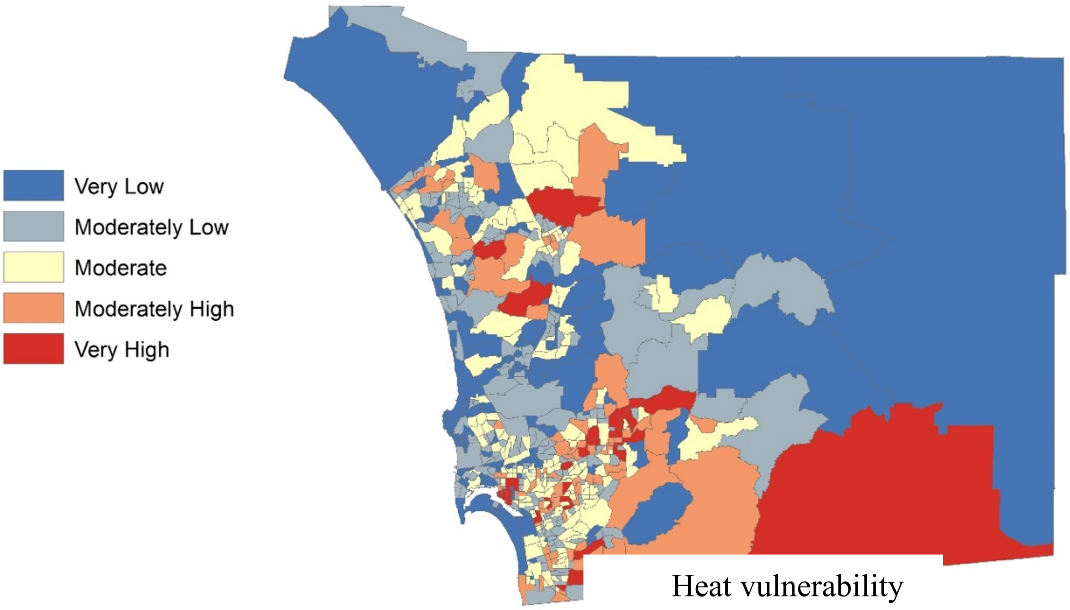
There were a total of 63 NaN (not a number) values out of a total of 18,840 cells. When an indicator has a missing value, it typically means no monitoring or reporting was conducted or no population was reported within that census tract. For example, census tract number 99.02

represents an area of San Diego County that is predominantly covered by water, due to the fact that this census tract is located on San Diego Bay. Most data reported for this tract is NaN, for analysis in MATLAB and left blank for GIS analysis and mapping. Census tract 38 had 8 out of 28 variables recorded as NaN. This tract is located along the Bay as well, so areas including water bodies with no census data were treated with NaNs. Some values for environmental pollution were still able to be included. Census tracts 63 and 65 are near the San Diego International Airport, so some data was missing and filled in with NaN. Census tract 55 is the Navy's medical center and was lacking complete data. Census tract 113 is San Diego's Naval Base, and has multiple NaN data. NaN's were not zeroed out in data analysis but were ignored.

RESULTS

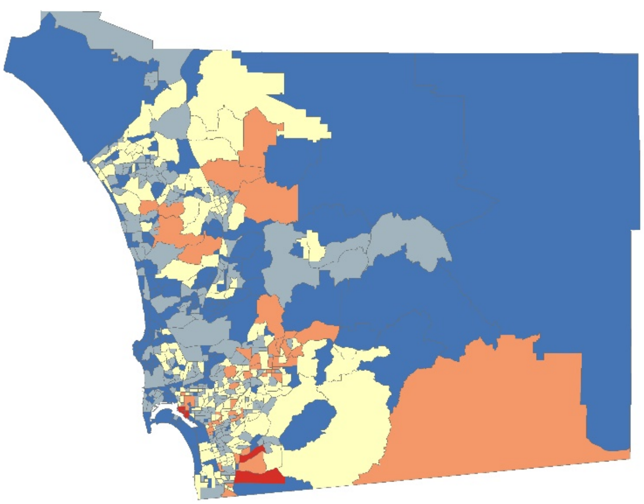
The newly constructed matrix of heat vulnerability index (HVI) scores was exported to ArcGIS for mapping. The index values were sorted into quantiles. The 'Very Low' quantile represents the lowest 20% of values, or those census tracts that are least vulnerable to extreme heat events. Census tracts in *moderately high* to *very high* quantiles represent those tracts that are at an adverse risk to social and environmental factors that affect overall vulnerability.

The top 40% of the index (Moderately High + Very High) accounts for 31% of the geographic area of San Diego County and 40% of the 627 census tracts. The top five most vulnerable census tracts in order are 133.1, 100.14, 54, 53, and 51, and are selected in red in the figure below (Fig. 3).

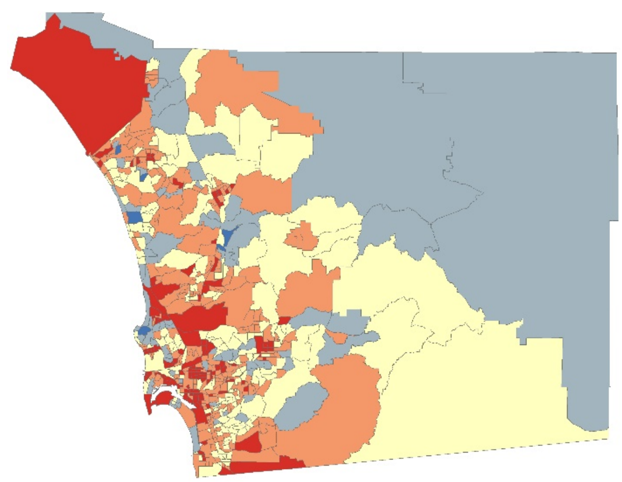


Heat vulnerability

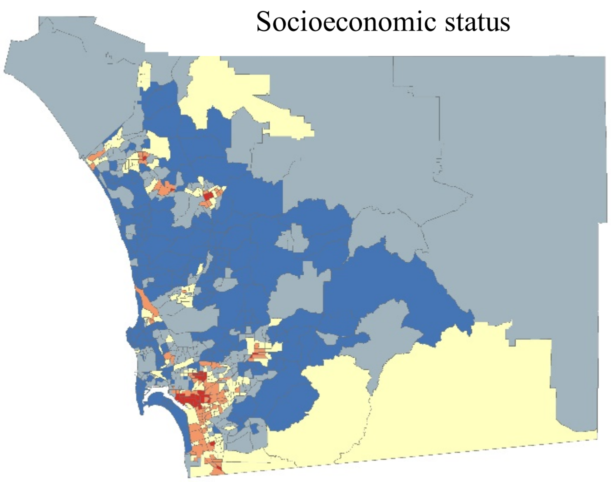
Comorbidity



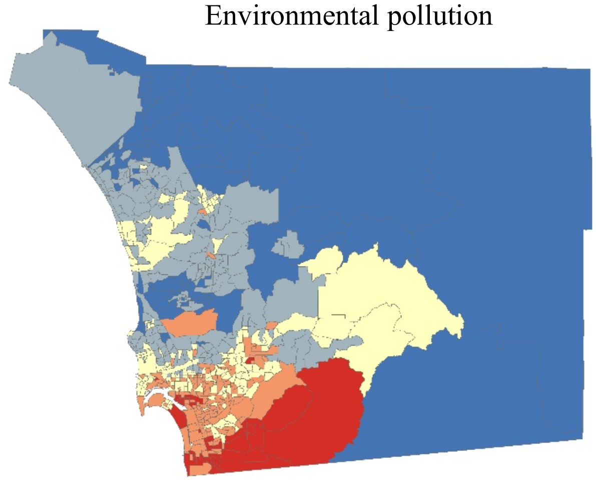
Elderly and isolated



Socioeconomic status

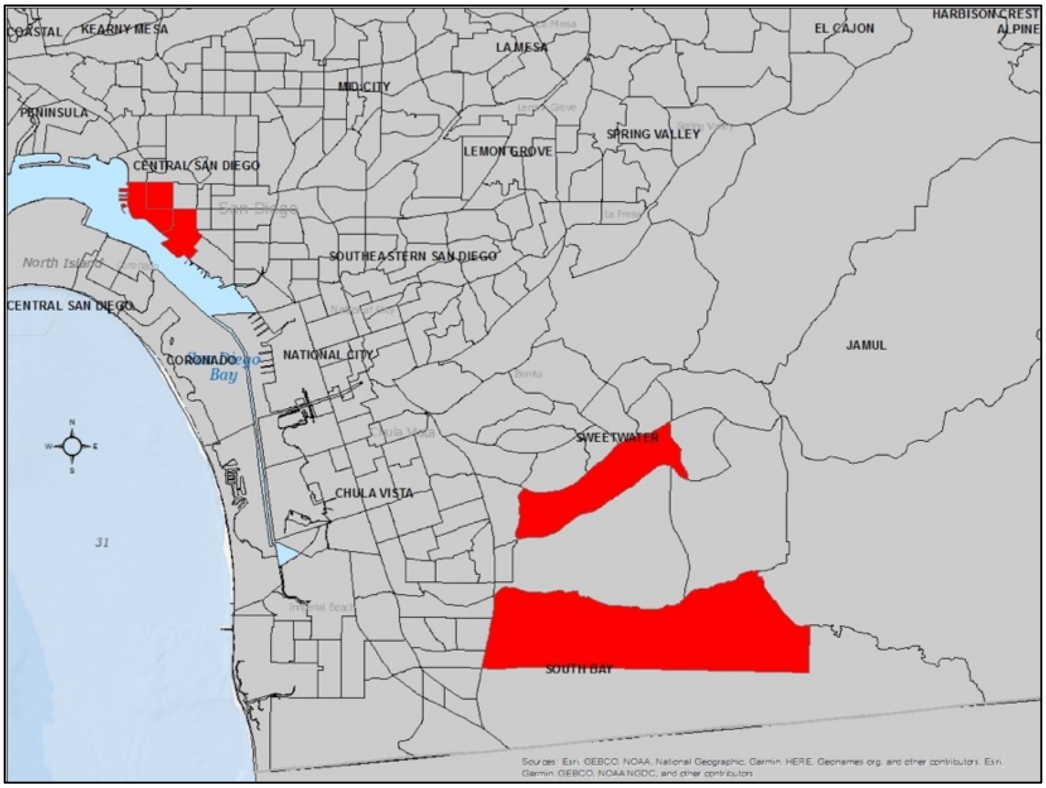


Environmental pollution



The top 40% of the index (Moderately High + Very High) accounts for 31% of the geographic area of San Diego County and 40% of the 627 census tracts. The top five most vulnerable census tracts in order are 133.1, 100.14, 54, 53, and 51, and are selected in red in the figure below (Fig. 3).

Figure 3. Top five most vulnerable census tracts in San Diego.

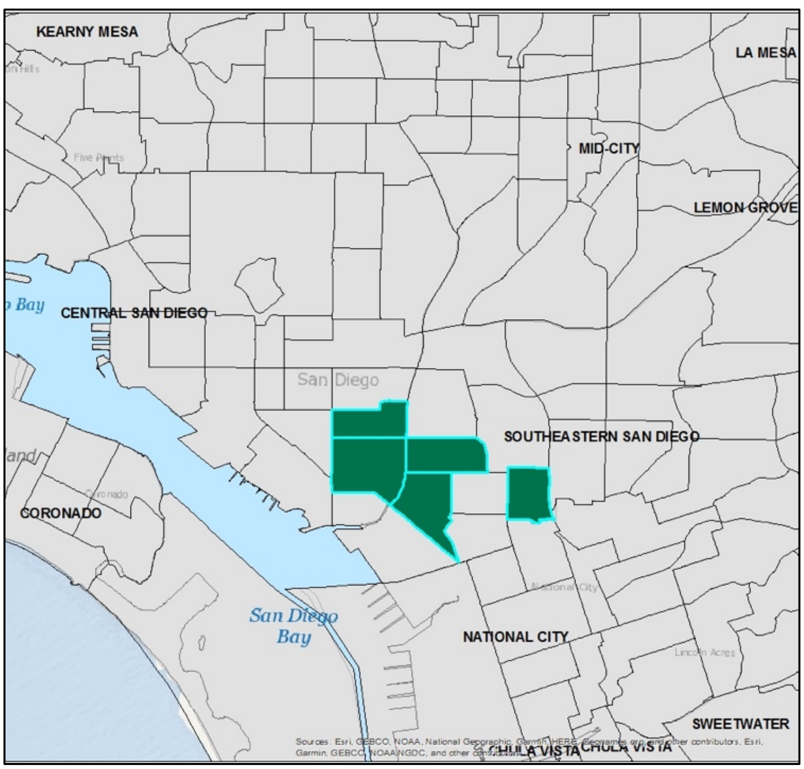


The index values of these five census tracts are disproportionately larger than the other tracts, with a range of scores from 14 to 22.5. In order to visualize the effects of the variables on the HVI, separate indices were created from the four umbrella factors mentioned previously.

The comorbidity index was created by summing the values of the PCZ matrix that were medical conditions (16 variables). Once again, census tracts 133.1, 100.14, 54, 53, and 51 were the top five among the index values. This group of tracts experience a higher percentage of reported or mentioned medical conditions. This particular index shows a connection between pre-existing medical conditions and the level of vulnerability to an extreme heat event.

The SES index was constructed to show where the least-privileged populations based on census tract. This index was found by summing the values of the PCZ matrix corresponding to the first five demographic variables in Table 1. The five least privileged census tracts within San Diego County are 39.01, 35.02, 39.02, 33.03, and 36.01, all of which are in close proximity to one another (Figure 4). Note that these are different than the comorbidity index's top census tracts. SES appears to be clustered around San Diego's downtown region

Figure 4. Top five census tracts with highest (SES) index scores for San Diego County.

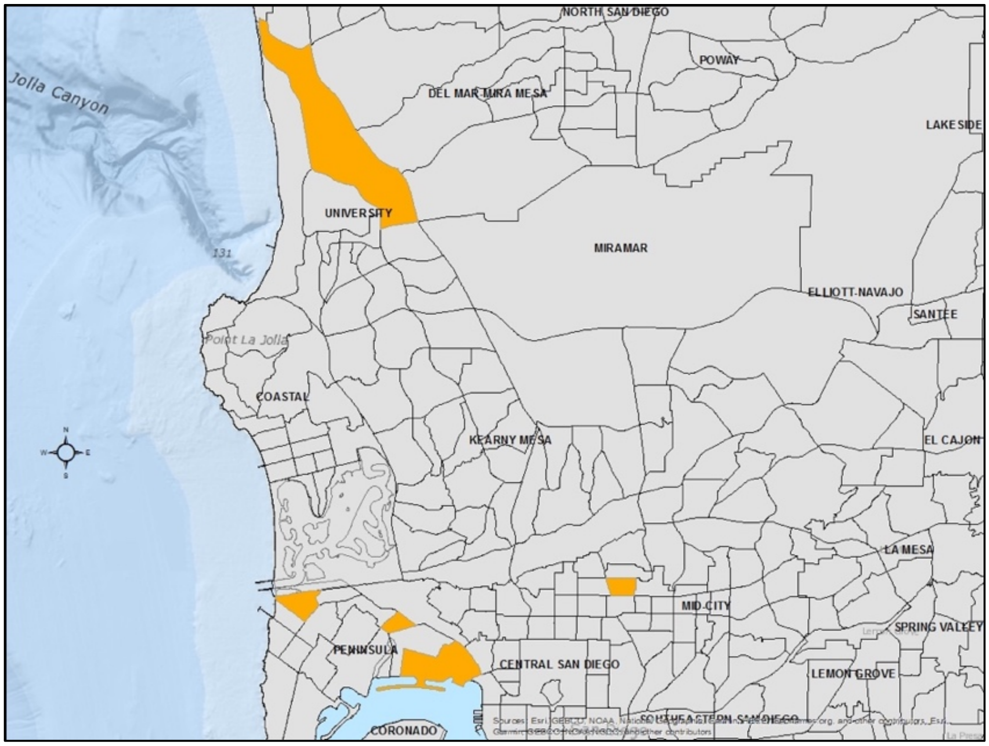


Located just north of the San Diego naval base, this set of census tracts outlines the least-advantaged communities of San Diego based on education level, ethnicity, and income level. However, this particular index does not include information on ‘no-income’ communities, or homeless population counts. A similar analysis will be done that includes mapping homeless population densities by tract.

Improvements towards more scientific and methodical data collection can assist with more accurate modeling of SES in a county which experiences the 4th highest homeless population in the country. Solutions for the least-advantaged communities will have co-benefits for all other vulnerable populations as well.

The elderly and isolation index can be used to represent populations that would require better access to services that mediate the risks from extreme heat. The majority of San Diego’s population is located along the western coast. The census tracts experiencing a higher percentage of elderly and isolated populations (65yr+, 65yr+ and alone, population living alone) represent a population group that has a higher vulnerability to heat events. The top five census tracts for elderly and isolation values are very different than those of the other indices. Census tracts 66, 17, 75.01, 83.39, and 62 are shown in orange and are more spatially spread out (Figure 5).

Figure 5. Top five census tracts with highest elderly index score for San Diego County.



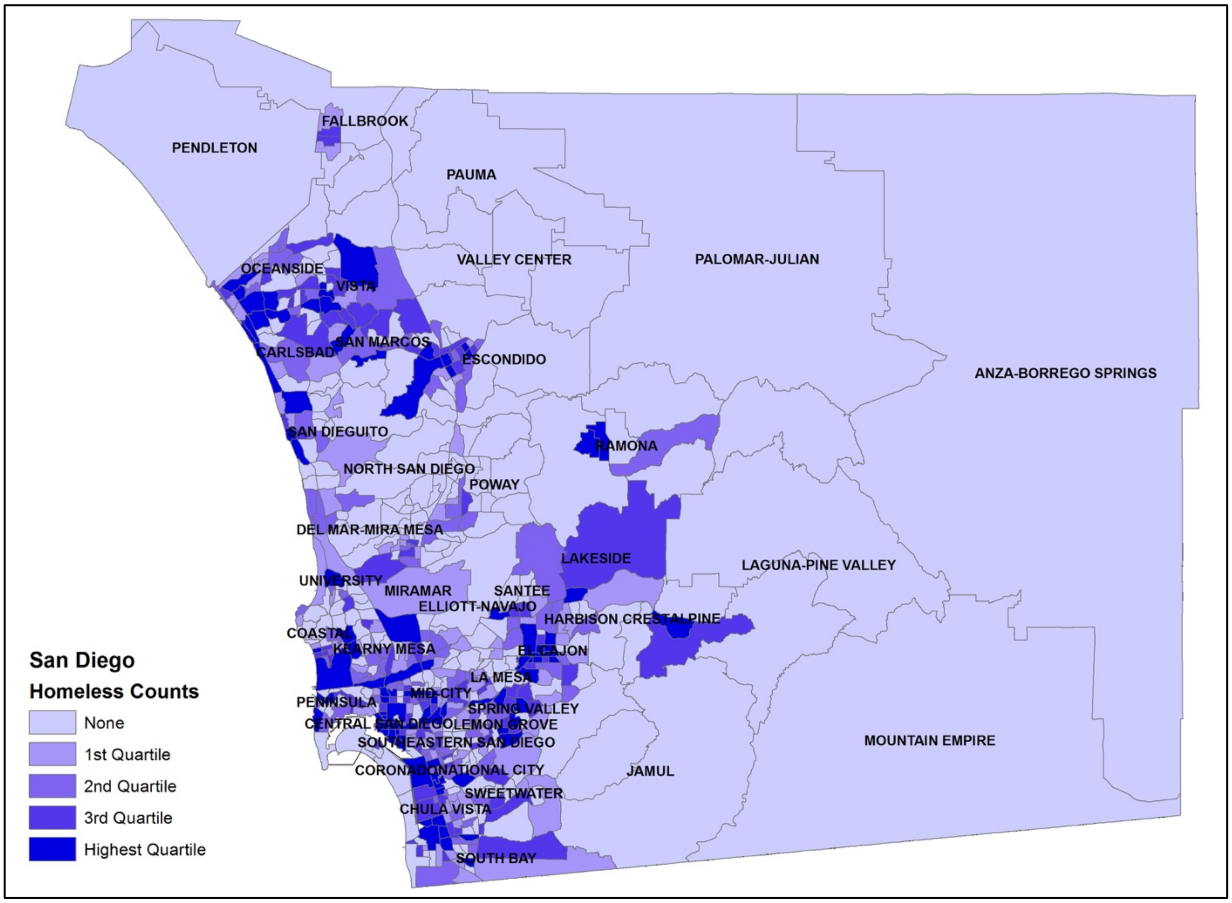
The coefficient scores for the dataset indicate that elderly and isolation variables do not affect the total vulnerability of a particular tract as much as medical conditions, SES components, or environmental conditions. However, the elderly and isolation index is an indicator of access to services that can mitigate challenges exacerbated by heat.

The index scores for the top five census tracts considering environmental pollution are the same as comorbidity and overall heat vulnerability. Environmental pollution variables include traffic density, tropospheric ozone daily maximum concentrations, PM2.5 concentrations, and housing burden, which CalEnviroScreen 3.0 includes in their estimates of overall vulnerability due to lack of adequate housing to avoid harmful environmental conditions. Traffic density is measured in vehicle-kilometers per hour per road length, within 150 meters of the census tract boundary. Air pollution is a hazard to the most vulnerable populations, including outdoor workers, low income communities, the elderly, and the homeless (Makri 2008). It appears from this analysis that environmental factors and medical conditions control much of the attribution to overall heat vulnerability.

By using the HVI for San Diego County, locally inclusive climate adaptation and mitigation plans can be revised to properly include all vulnerable populations in the most efficient way. In order for San Diego County to protect all populations including the most vulnerable, the regional nuances in climate and predicted changes should be assessed, as well as a culmination of intuitive and qualitative input from those populations themselves. San Diego's complex climate regions will be analyzed and paired with the index to direct resources and services where they are needed the most.

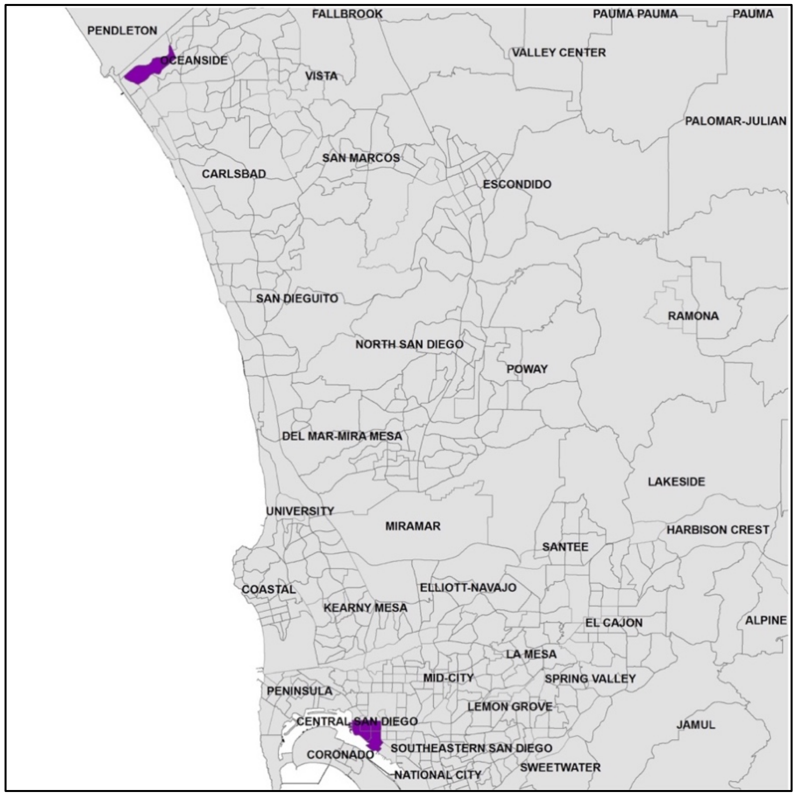
Data on homeless population density was downloaded from the Regional Task Force on the Homeless in San Diego (RTFHSD). Each year, point-in-time counts (PITC) are conducted by RTFHSD volunteers. Data from 2016 was mapped by quantiles (Figure 6). Individual year was chosen instead of an average because of the transient nature of the population. Estimates are updated annually, but the methodology lacks scientific structure and efficiency.

Figure 6. Homeless distribution for San Diego County.



The census tracts with the highest count of homeless people in order are 51, 53, 52, 54, and 186.03. All of these tracts have over 100 homeless people residing within them, with the maximum value of 435 people in census tract 51. Figure 7 below shows the locations of these disproportionately populated census tracts. Three out of the top five census tracts with the highest density of homeless population are including in the top values for the HVI (51, 53, 54).

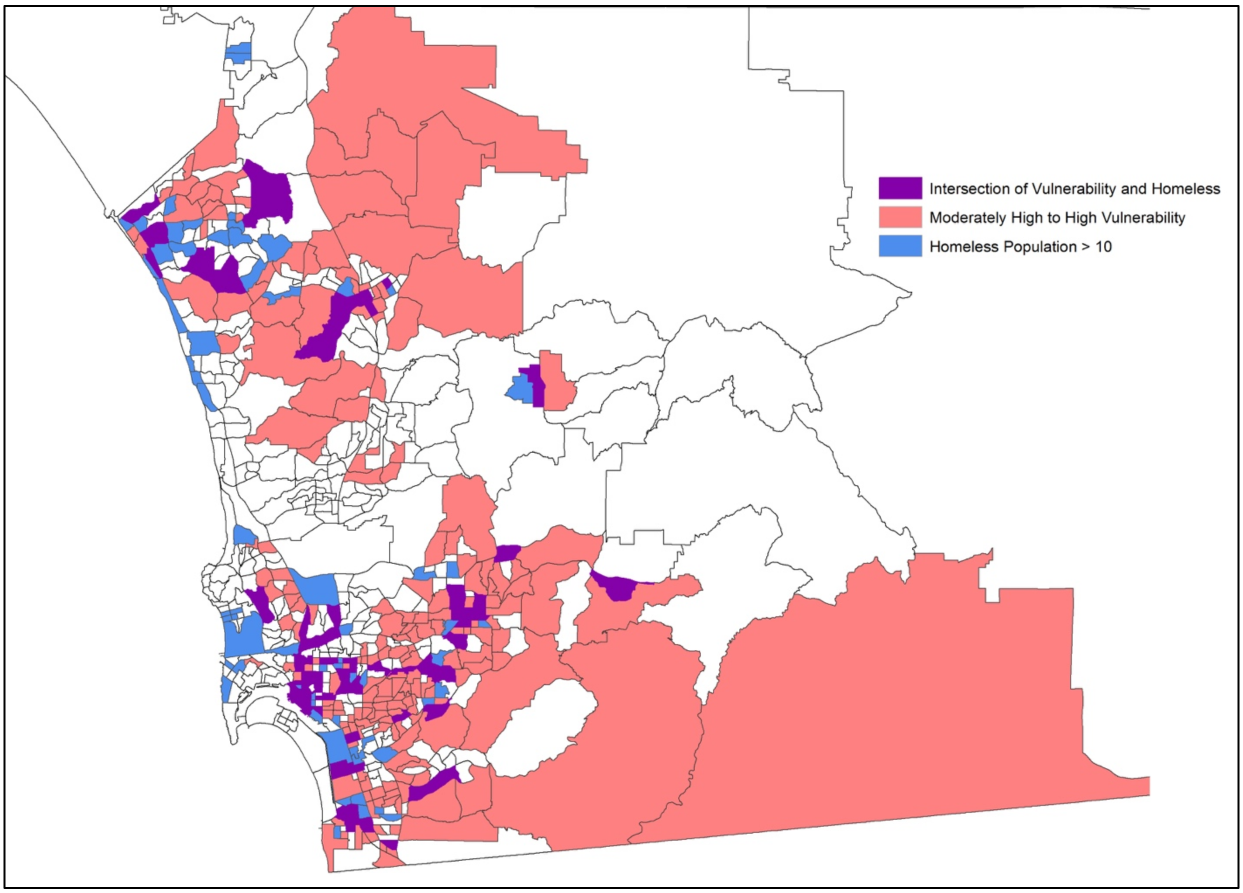
Figure 7. Top five census tracts with highest homeless density for San Diego County.



In order to analyze the spatial distribution of homeless within areas of heat vulnerability, homeless density was mapped among the top 40% of heat vulnerability index values (Figure 8). Areas in red represent moderately high to high vulnerability. Areas in blue represent census tracts with a homeless population greater than 10 individuals, and the purple areas are the census tracts where those two areas intersect.

In order to analyze the spatial distribution of homeless within areas of heat vulnerability, homeless density was mapped among the top 40% of heat vulnerability index values (Figure 8). Areas in red represent moderately high to high vulnerability. Areas in blue represent census tracts with a homeless population greater than 10 individuals, and the purple areas are the census tracts where those two areas intersect.

Figure 8. Census tracts with high heat vulnerability and high homeless density.



Out of San Diego's 627 census tracts, 60 of them fall into the purple regions. Out of regions experiencing homelessness greater than 10 individuals, 54% of them fall within a high heat vulnerability region. The spatial distribution of homeless appear to be clustered in various regions of the county.

Spatial analysis was performed using a geographically weighted regression (GWR). GWR models the relationship between dependent and independent covariates as a series of localized models (Mayfield et al. 2018). Census tracts were modelled to include weights based on neighboring census tracts, all of which affect the β score for each point. A GWR model produces multiple coefficients of variation and β coefficients, on for each observation in the sample and is more fluid than an ordinary least squares (OLS) regression. The GWR model within ArcGIS calls for a dependent and independent variable input. The analysis was performed to see if there is a spatial correlation between homeless population density and heat vulnerability (Figure 9). Heat vulnerability was found to be highly clustered using the Global Moran's I spatial autocorrelation tool

Figure 9. Geographically weighted regression of homeless population and vulnerability.

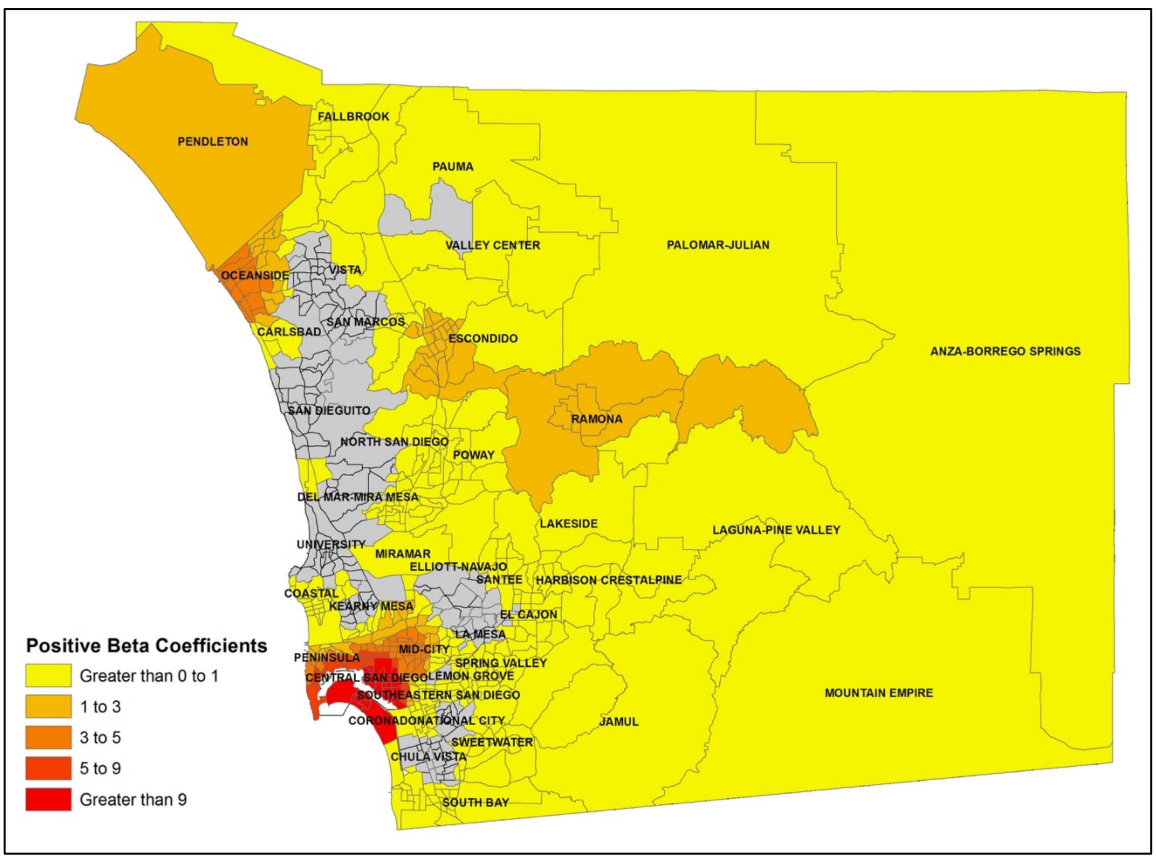


Figure 9 represents census tracts with β values greater than zero. A positive value indicates that for a unit increase in heat vulnerability, there is some increase of homeless population. Higher values of β (orange to deep red) indicate a stronger, positive relationship. The strongest relationship based on location appears to be centered around San Diego Bay and the downtown area, as well as the cluster northward towards Pendleton. The areas of high homeless and heat vulnerability are not random, meaning that all of the variables that went into the index have contextual importance, and that this relationship is systematically structured.

DISCUSSION

It has become clear that climate change will likely cause increases in extreme weather events and consequentially, increased rates of mortality. Recent epidemiologic studies try to assess the vulnerability of specific populations and geographic areas to extreme heat events. This particular study focuses on the vulnerable populations that are often neglected in society, specifically in climate action plans. Previous epidemiologic research was studied and used to develop an index and map that can be used to focus interventions to prevent heat-related illness and mortality in the most vulnerable populations, and to suggest solutions to gaps in data collection. In this analysis of San Diego County, heat vulnerability varies with census tract but is concentrated in clusters, especially in urban areas.

Epidemiologic studies investigating different geographic regions have found regional differences in heat impacts (Basu et al. 2009). These spatial differences might be due population adaptability, either socially or through technological advances in heat mitigation. By understanding the spatial variability of vulnerability on a small scale, individual counties within the United States such as San Diego can apply measures that are fine-tuned to fit the needs of specific areas.

When it comes to overall heat vulnerability, San Diego's urban regions, especially around the Bay, are most vulnerable. Neighboring census tracts can affect the spatial distribution of risk factors, and those close to each other are more likely to share similar characteristics. All of the individual indices have higher values around downtown San Diego. Urban effects such as higher temperatures and increased air pollution can contribute to changes in health.

When discussing the homeless population, many other factors contribute to vulnerability. In order to understand the needs of this vulnerable populations, more communication is needed, as well as increased availability to social services. Just because the downtown area is more susceptible to heat events doesn't mean that resources will be more beneficial if other factors determine where camps are set up. These maps shows areas of San Diego County that are more vulnerable and can be used to target the source of the risk factors associated with vulnerability. For example, environmental pollution is highest close to the San Diego/Mexican border. Socioeconomic status is lowest around San Diego bay. Although the vulnerability index aggregates these two indices, viewing them separately can aid in tackling the problems of pollution and poverty more efficiently, and for the benefit of the total population.

The homeless crisis places costs on society that the public is then responsible for. Local jurisdictions in San Diego have spent more than $630 million from 2016-2017 to combat homelessness, with RTFHSD receiving $18 million in allocated funds (Walsh et al. 2017). Housing initiatives account for 85 percent of the total expenditure. The remaining 15 percent is split between mental health services and drug and alcohol programs. In 2017, San Diego opened a storage facility downtown where the homeless could stow their personal possessions.

The mayor of San Diego, Kevin Faulconer, had the San Diego Police Department conduct extra patrols around the warehouse and by the next October just a year later, the police department had paid out almost $850,000 in overtime wages for "homeless related activities" (Krueger & Jones 2018). Along with the financial cost of patrolling activities just out of suspicion, there is a social cost of having police officers spending extra time on non-violent, non-apparent crimes, when they could be reporting to calls in which citizens are in dire need of assistance. San Diego is expected to suffer longer and more extreme heat waves, and the more people that are living on the street, the more medical attention will be required for instances of heat stroke and severe dehydration. San Diego is adding an additional cost for themselves by not preventing injuries to the homeless through service initiatives. Perhaps instead of housing receiving a majority of the budget, more funding can be allotted for climate-related preventative measures, such as cooling/heating centers, water stations, and practical policies for local businesses to remain open in the event of severe weather, such as a strong Santa Ana wind event, or a wildfire, or a predicted heat wave. There is strong evidence that both environmental factors, such as the absence of air conditioning, and population risk factors, such as having cardiovascular or psychiatric illnesses, increase the probability of heat-related deaths (Bouchama et al. 2007). Moreover, increased air conditioning or general use of electricity for the easement of suffering endured by the homeless may increase costs to the environment.

There are other ecological costs with the mismanagement of the homeless. In San Diego, loitering and other minor offenses that are nuisances to deal with for both the police force and the homeless cause a movement inland towards canyons or the San Diego River, away from social pressures (Warth 2018). The transient population brings with them their habits and belongings, which often end up as litter left behind when they decide to move to another location. During rain events that cause flooding, the water carries the trash, human excrement, and drug paraphernalia (needles) into the water supply, which has tremendous public health impacts and costs as well. With little access to proper hygiene, the homeless are thought to create an optimal environment for transmission of Hepatitis A. Hepatitis A is a highly contagious virus that is transmitted by the fecal-oral-route. According to San Diego's Health and Human Services Agency, a public outbreak of Hepatitis A began in November 2016 and lasted 100 days, which resulted in almost 600 cases and 20 deaths. From March 2017 through October of 2018, 203,850 Hepatitis A vaccines were administered by health care providers (San Diego County Government). According to the CDC, a 10-pack of single dose vaccines, ranging from pediatric to adult dosages, can cost healthcare providers anywhere from $20-60. This means that San Diego County spent anywhere from $408,000 – 1,223,100 on this single outbreak. As climate in San Diego transitions to a trend in increased extreme weather such as atmospheric river events, more precipitation will fall during singular events, and as a result, the washing of the pollution from land particularly around established homeless encampments, and flooding will lead to a decrease in water quality, as well as increased risk to public health (Dettinger 2011).

CONCLUSION & RECOMMENDATION

Individuals experiencing homeless are already under significant stress from difficult living conditions as well as extreme societal pressures. Coping strategies and physical mechanisms are threatened when temperature increases for substantial amounts of time. Outreach during extremely hot days, particularly with the homeless, should be approached differently due to these factors. There is often a stigma surrounding homelessness, and social services do not always reach those who need it most.

The inclusion of homeless people within a climate policy may increase the overall cost of mitigation of vulnerable populations for San Diego. However, by providing sufficient and updated services to the most vulnerable population, census-tract-level equity increases and overall leads to a better way of life for the entire population. Providing and promoting services that ease pressure for climate-exacerbated issues such as cooling centers or water stations, healthcare services like hospitals would become more efficient due to a decrease in the amount of time and money that would be spent seeing a homeless patient for an issue that could've been avoided in an inclusive action policy. Better access to services may mean an increased likelihood of seeking medical help. A population suffering from widespread mental illness could benefit tremendously from this access, and could start to reincorporate back into society and provide economic growth through earning wages, and could foster ecological improvements due to a change in public outlook, and not having to be forced to move into canyons to escape urban heat.

A detailed plan that can be implanted during heat events specifically targeting the homeless would lead to measures that benefit other vulnerable populations as well. For example, in the Philadelphia case mentioned earlier, when a heat warning is issued, a series of steps is taken. First, the media announces of warning, a "buddy system" goes into effect where volunteers check on the elderly, a telephone hotline is activated, the Department of Public Health makes visits to the homes of susceptible portions of the population, medical service staff are increased, outreach for the homeless increases, and designated air-conditioned facilities are opened for the public (Kalkstein et al. 2007). San Diego County currently has an extreme heat work group, which explicitly responds to alerts. A team of players meets before the start of 'heat season', which is typically May through October (Corcos interview, 2019). The County gathers information from the NWS and prepares materials for heat intervention. Cool zones are activated, represented by libraries, rec centers, and faith-based organizations. When there is a heat event, there are two levels of alerts that can be issued. The less extreme case arises where it may be hot but not for an extended period of time, and usually involves public notice to be careful, and recommended opening of cool zones. The second case, a heat emergency, involves the distribution of aid such as water to those who are in danger zones, such as desert areas.

The general public has many options to know whether or not one of these alerts is in effect. The information is on social media and may be broadcasted through local news stations. People experiencing homelessness may not have this same opportunity. The heat team is able to be aware of approaching sprawls of hot weather, so measures can be prepared ahead of time. A suggestion for the County of San Diego might be to take this weather information and target homeless populations first. Since urban areas and deserts heat up efficiently, census tracks with less green space or lack of facilities may be prioritized on the list. It is difficult to predict what future heat will look like in San Diego, but being prepared and ahead of the statistics would prove to be more cost efficient and help decrease mortality within vulnerable populations. If the response is not issued until a massive event is occurring, it becomes more expensive to deal with it than if these factors were worked in a plan.

Along with a detailed plan that takes affect during a heat wave, vulnerable areas in San Diego like those that are urbanized would benefit tremendously from the addition of green space. Due to urbanization and spatial community planning, more of the population faces the prospect of living in communities with fewer green resources. People from low SES quantiles without necessary resources to move to greener areas outside urban areas will be affected. In this way, it becomes an environmental injustice issue with regard to the distribution of access to public green spaces (Maas et al. 2006). An assessment of green space, including tree cover, public parks, and other green resources can provide vital health benefits to all communities

Many of San Diego's disadvantaged communities are located in census tracts with a majority urban setting. Those with no housing either seek out shelters or are subject to elements when they set up camps outside. San Diego County can take the HVI as well as the individual SES index and assess the level of green space in areas that experience a high index value, or contain larger densities of people experiencing homelessness. Urban shade cover can reverse the UHI effect and help to conserve energy as well (Rosenfeld 1995). According to Michael McConnell, many people experiencing homelessness in the San Diego region seek shelter in the canyons and along the river, where there is more green space. This notion is potentially hazardous, as there are less services in rural areas than those that are urbanized.

A collaboration with a carbon-farming project could prove beneficial towards the implementation of more public green space in San Diego, especially in the census tracts with a higher proportion of homeless. Until every individual can be taken off the street and housed, access to green space remains a necessity to vulnerable communities, especially in the event of a heat wave.

The County of San Diego has long been committed to protecting the environment, and over the last decade has taken several steps to address sustainability and reductions in greenhouse gas (GHG) emissions (sandiegocounty.gov). Local officials and other personnel have been hard at work coming up with strategies to mediate the risks of climate change events. By integrating data from the most vulnerable communities, strategies become more effective and easier to implement. Climate change is a big task to take on. However, until San Diego can solve their homelessness crisis, either by providing adequate housing or just with more approachable social services, the task will remain incomplete. The green age of technology will only benefit those who are able to afford the benefits. Regardless of an individual's circumstances, there remains a commitment to provide protection for all citizens within the County's boundaries.

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