

BEYOND THE FIRE LINE: A COMMUNITY HEALTH VULNERABILITY INDEX AND
ANALYSIS OF POST FIRE RECOVERY IN SANTA CRUZ COUNTY

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Abstract

In August of 2020 the CZU (San Mateo-Santa Cruz Unit) Complex Fire's blaze was ignited by a lightning strike, which resulted in the burning of 86,509 acres, the destruction of 1,490 structures, the damage of an additional 140 structures and 1 death across Santa Cruz and San Mateo County (CZU Lightning Complex, 2020). A wildfire's dangers and destruction extend far beyond the fire line, as the deadly nature of wildfire smoke can travel upwards of 40 miles away from the blaze. Pre-existing vulnerabilities dictate the road to recovery communities in Santa Cruz County will have to follow, as disasters exacerbate social inequalities and worsen existing vulnerabilities. Through the lens of health geographies the implications of this on human health can be understood better through the construction of a *community health vulnerability index*. Individual vulnerability factors (i.e. age, social isolation, educational attainment) percentages were established at the block group level utilizing the 2016-2020 5-year estimates from the American Community Survey. The statistical tools of principal component analysis and factor analysis were employed to incorporate all ten of the vulnerability factors into a singular sensitivity score. When overlaid with smoke exposure data from the CZU Complex Fire it highlights priority areas of high sensitivity and high exposure. A community health vulnerability index provides valuable insights into the spatial distribution of vulnerability and inequality at a granular scale. The results of this index indicate the areas and communities within Santa Cruz County that require targeted interventions in order to 1) fully recover from the CZU Complex Fire and 2) address the underlying vulnerabilities in order to prevent this scale of disaster from occurring again. In the rapidly changing climate swift action is needed to ensure that a disaster at the intensity of CZU Complex Fire does not burn again.

Introduction

In the early morning hours of August 16, 2020 over 11,000 lightning strikes in a lightning siege lit up the California coastline sky. I remember waking up suddenly as I heard and saw the bright cracks of light. At approximately 6:41am the CZU Complex Fire was lit as eleven strikes of lightning ignited fires (Morris & Dennis, 2021). Over the course of 37 days the fire raged on, burning a total of 86,509 acres across two counties (Santa Cruz County and San Mateo County). This fire accounted for the complete demolition of 1,490 structures and damaged an additional 140 structures (CZU Lightning Complex, 2020). In Santa Cruz County, 911 single family homes were completely destroyed (Hagemann, 2022). A majority of these 911 homes that were destroyed were located in block groups that have high levels of pre-existing vulnerabilities, such as pre-existing high levels of renters or those who lack an internet subscription. In addition to infrastructure damage, the fire claimed one life and injured one (CZU Lightning Complex, 2020). 81 personnel were directed by the California Department of Forestry and Fire Protection or CalFire, to combat the flames of the CZU Complex Fire, with the assistance of 10 engines and 4 water tenders. It plummeted the county of Santa Cruz into days with an apocalyptic sky seen as far as 40 miles away. Thousands of people had to be evacuated or put on high alert as a result of the fast burning pace of the fire. The devastation caused by the fire destroyed California's oldest state park, Big Basin Redwoods, which I had just backpacked through the summer before. An ecological marvel, natural beauty and a pride of Santa Cruz County was gone as a result of this fire.

This large scale of the fire was a result of decades of fire suppression as the forest management policy of California. Fire suppression policy was not unique to California but a common practice across the United States. In 1935 the US Forest Service enacted a policy called the 10am policy (US Forest Service Fire Suppression, n.d.). This policy stated that every fire that erupts must be contained and suppressed by 10am the following day, resulting in the quick extinguishment of a typical ecological function for a forest (US Forest Service Fire Suppression, n.d). Fire suppression practices have led to more intense wildfires today due to the increase in fuel sources. This is evident in the case of the CZU Complex Fire as the high winds, increased summertime temperatures and the accumulation of undergrowth fueled the hungry flames on their quick journey to 86,000 acres. Containing the fire was a slow and arduous process with only 5% of the fire declared contained a week after the fire began (Sierra, 2020). 37 days after the initial blaze began the CZU Complex Fire was officially declared contained at 7:53pm on September 22, 2020 (CZU Lightning Complex, 2020). While the fire was declared contained by CalFire on September 22 the fire was not officially extinguished until December 23, 2020 (KTVU, 2020). This was four months and eight days after the initial lightning strike occurred, subsequently releasing smoke and actively destroying land for that entire time period. Recovery was the next step for the people of Santa Cruz County whose lives had been turned upside down by the destruction this fire caused (KTVU, 2020).

Anthropogenic climate change has led to increases in the number and intensity of wildfires that are occurring in a given year. The Intergovernmental Panel on Climate Change has agreed with medium confidence that with every increment of global warming there is a projected increase in the amount of wildfires a region will experience with devastating impacts (IPCC, 2022). This increased volume in wildfires put additional pressure and strain on the resources

available to combat the fire. Two days after the CZU Complex Fire erupted the SCU Lightning Complex fire began (SCU Lightning Complex Incident, 2020). These fires burned simultaneously in different areas of Northern California and while these fires never met, they impacted each other from afar. The coupling of these two fires led to increased smoke particulates entering the atmosphere and forced CalFire to split focus between two large scale fires. In light of anthropogenic climate change it can be expected to see more wildfires with these longer durations and heightened intensities across the state of California and the American West (Simon, 2018). Wildfires are expanding from being a natural disaster to now vectors of large scale human health impacts that illuminate social inequalities. Wildfire smoke poses health risks for those far away from the burn line and does not impact every member of society equally. Increases in the frequency of large scale smoke dispersion means that it exacerbates vulnerabilities each time. One cannot discuss the impacts of climate change and increased wildfires without acknowledging the hand in hand relationship the health impacts have with environmental justice. Furthermore, the impacts on human health extend past the short term smoke exposure but can develop into long term and chronic issues, including housing instability, displacement, mental health and economic stability.

Today, nearly two years following the blaze, residents who lost their homes are still in the process of recovery as the fire left the environment in an unstable condition and access to permits to rebuild has been slow (Hattis, 2022). Social factors coupled with the environmental exposure of the wildfire created many pockets of vulnerable people throughout Santa Cruz County who felt the harsh consequences of the fire. This fire is particularly important to me because I am from Santa Cruz County and call this beautiful area my home. It is a very special place and state parks such as Big Basin Redwood State Parks, which burned as a result of the CZU Complex

Fire, introduced me to the extent of the natural beauty in Santa Cruz County. However, this natural ecological beauty can not be used to hide the high levels of social inequality and overall vectors of vulnerability which impact a community's ability to respond to disasters.

This thesis will analyze the framework of health geographies and will apply it to the measure of social vulnerability, mitigation efforts and recovery as it relates to the CZU Complex Fire. This will be supported through the creation and analysis of a community health vulnerability index that has been created specifically to highlight Santa Cruz County's vulnerability to wildfire smoke. Community health vulnerability indices possess the ability to highlight underlying vulnerabilities that feed into the damage caused by wildfires, both during the blaze and in the aftermath of recovery. It is an important tool in the development and implementation of vulnerability reduction strategies for wildfires in Santa Cruz County.

Literature Review

What are health geographies?

The region one calls home is more than a place of personal significance, but a place that determines many aspects of their place in society. An individual's place of origin formulates more than their identity as a person but determines their vulnerability to the ways in which climate change will affect their world (Armah et al. 2015). The field of health geographies centers around the idea that people, materials and the environment interact to form the conditions of human health (Brown et. al. 2015). As climate change intensifies, areas with predisposed vulnerabilities are where the most prominent repercussions will be manifested (Brown et. al. 2015). It can create good health or ill health based on the experiences with the social structure, exposure to environmental factors and other site-specific characteristics. These predisposed

vulnerabilities are a result of a community's specific access to medical care, climate resilience, political stability, and socio-economic structures (Brown et. al. 2015). These predisposed vulnerability vectors tie into the concept of the social determinants of health.

The social determinants of health are the societal structures and environmental conditions in which people live and work that determine one's overall quality of life and human health (US Department of Health and Human Services, n.d.). Individual contributors to the social determinants of health can be grouped in five overarching themes of the social determinants of health include economic stability, education access, health care access, neighborhood and built environments, and social and community context (US Department of Health and Human Services, n.d.). The framework of health geographies are one lens through which we can understand how the social determinants of health are shaped. There are five central themes that are a part of the critical analysis of health geographies: neoliberalism, inequality, globalization/urbanization, biopolitics and resistance/resilience/care (Brown et. al. 2015).

The political philosophy of neoliberalism centers around the ideology of returning the “freedom” to the people and reducing the role and influence of the state (Brown et. al. 2015). Neoliberalism's connection to health is with the return of the “freedom” can be seen in the privatization of health care services which prevents those from obtaining medical treatment, the reduction of safety nets for people experiencing homelessness, and a lack of a centralized emergency management plan. However, this “freedom” comes at the cost of allowing for the deepening of social inequalities and vulnerabilities because of the goal of reducing state involvement. Neoliberal ideologies are not a foreign concept to the people of Santa Cruz County. As a result of inadequate resources CalFire was stretched thin as they dealt with multiple large scale fires at once and were denying support to Santa Cruz mountain towns (Rust, 2020). In

response a group of volunteer firefighters who were a part of the California Task Force 3 came to their aid (Rust, 2020). The California Task Force 3 is a part of the highly specialized FEMA Urban Search and Rescue team and is typically deployed in response to the worst of natural disasters (Rust, 2020). The CZU Complex Fire was a special situation where the members of the task force's own homes were threatened and they jumped at the ready to respond when CalFire was not providing aid (Rust, 2020). This is a form of neoliberalism because it was volunteers and members of the community who happened to be a part of a task force responding when the state agency was failing them (Rust, 2020).

Health geographies are not able to be discussed without the mention of social justice and inequality. Inequality and specifically economic inequality is one of the largest contributors to social vulnerabilities. Areas of the world where economic inequality is high are likely to have higher disparities in their health outcomes and risks when it comes to environmental disasters (Brown et.al 2015). The social world is a rapidly growing place, with the human population growing exponentially each day. This leads to the global phenomenon of globalization/urbanization, where previously rural and isolated communities become more urban and engaged in the global economy (Brown et. al. 2015). Urbanization and California are highly connected as California is home to some of the largest cities in the United States. This creates a unique environment where massive cities grow exponentially over a short period of time creating gaps in infrastructure that will require billions of dollars to remedy (Villaraigosa, 2000). Santa Cruz County is home to over 260,000 citizens within a 441 square mile area, but most of those people are located within towns that are between 1.6 to 12 square miles (Santa Cruz, 2022). This creates a housing density of 237.7 houses per square mile (Santa Cruz County, CA Housing Data, 2022). This is significantly higher than the average United States 90 house per square mile

housing density and demonstrates how urbanization contributes to the social inequities Santa Cruz possesses (Cohen, 2015). Urbanized areas often have higher levels of ambient air pollution, higher rates of diseases such as asthma and put people at increased risks for diseases such as COVID-19 (Urban Health, 2021). Specifically, rapid urbanization creates areas within the city that are in a more vulnerable position to these negative health outcomes and are a large determinant of a community's overall health outcomes (Urban Health, 2021). The pattern of urbanization in Santa Cruz County specifically incentivized building in fire prone hills, hills a combination of retirees, wealthier homeowners, and undocumented outdoor workers all now call home.

Biopolitics refers to the establishment of "biological citizens". Biopolitical-centric thinking can be used by liberal countries in attempts to eradicate diseases or manage health and wellbeing. A limitation of this concept is that the issue regarding not all citizens will be awarded the same biopolitical "value" due to it is nearly impossible to govern welfare in its entirety, meaning there are constantly going to be populations of individuals who are going with lesser care. Biopolitical thinking can shift the conversation for social structure failings to individual weaknesses being the cause of disparities between social classes (Brown et. al. 2015).

The fifth theme of health geographies is the idea of resistance, resilience and care, which are guiding principles when it comes to the establishment of human health promoting measures (Brown et. al. 2015). This three-fold concept breaks into three distinct tracts. Resistance is in referral to the resistance to increasing inequalities, resilience looks at how communities build their health in their everyday lives and care focuses on the ethical stance to provide care for those who lack access due to societal infrastructure. This specific health geography theme is central to

this thesis because I am analyzing the gaps of resilience to climate change specific to Santa Cruz County.

The geographic approach to analyzing human health takes into account these vulnerabilities when established when place-specific characteristics come into account as environmental disasters increase in prevalence. Environmental disasters will have varying impacts on members of the population where it occurred. However, in the case of environmental disasters such as wildfires the range of the impacts is increased substantially due to smoke and other air-based pollutants, such as particulate matter 2.5, entering the atmosphere (Fann et. al. 2016). Geography and community-specific vulnerabilities become very important in these cases as the scope of repercussions expands greatly. By using health geographies to analyze scopes of impact, targeted policy and management strategies can be implemented on a site-specific basis opposed to overarching policies which may not target the community-specific vulnerabilities.

The health geographies framework is usefully applied when analyzing the health impacts disasters have on communities' health and their ability to adapt and respond to it. I am applying this framework to the CZU Complex Fire because it allows for the connection between where people are experiencing wildfires and are exposed to smoke to be connected to their pre-existing vulnerabilities due to their physical location and space they inhabit. There is more than simply an emotional connection one has with the place they call home. It can determine their political views, what type of food they eat and their overall physical and mental health.

What is the social construction of vulnerability?

The vulnerabilities of a community are not created in a vacuum, it is the intersection of environmental exposures and the social structures that have been put in place throughout history.

Many factors contribute to the social construction of vulnerability, including socioeconomic status, access to healthcare, access to clean water and healthy food, and occupational hazards (i.e. outdoor workers) (Gamble et. al. 2016). When populations of people experience multiple of these vulnerabilities coupled with environmental exposures they are considered *populations of concern* (Gamble et. al. 2016). These populations often have high vulnerability, high exposure and low adaptive capacity heightening their risks of collapse in the face of climate change (Gamble et. al. 2016). High vulnerability stems from the culmination of sociodemographic factors, environmental exposure comes from the amount of exposure to the elements such as air pollution or extreme heat, and adaptive capacity refers to a community's ability to bounce back following a disaster or event. Indigeneous peoples, children, immigrants, outdoor workers and older adults are often considered populations of concern for various reasons in different scenarios, tied to the social structures in place in their communities. There is high confidence shared amongst the international community that human vulnerability and ecosystem vulnerability are interdependent and influence each other (IPCC, 2022). Meaning that as climate change drives increases in the exposure pathways by increasing the frequency of natural disasters, it increases overall vulnerability, and therefore increases negative health impacts for populations of concern (Gamble et. al. 2016). This means that the wildfires and the smoke it creates poses a large risk for populations of concern because some groups such as outdoor workers will have prolonged exposures due to their field of work (Alonso-Blanco et. al. 2018).

The analytical framework created by health geographies allows for the analysis of populations of concern and their communities in order to identify specific vulnerabilities. The social vulnerabilities that impact populations of concern today were not created in a vacuum and are a result of historical injustices. Once the detection of a vulnerability is made at the block

group level, targeted policies can help address the root of social inequality as well as treat the symptoms of it. Increases in adaptive capacity allow for overall vulnerability to be reduced if the underlying factor (i.e. age) cannot be changed. Increases in adaptive capacity include social structures designed to provide support for impoverished community members, easy and safe access to evacuation centers in the event of fire, increased discussions regarding what to do when there's a fire, and early notification in multiple languages of when fire and smoke are imminent. The underlying social and political structures that are the root cause of the social vulnerabilities must also be addressed but require long term mitigation plans and a restructuring of the society that made it possible for them to take root. For example, these long term mitigation goals can include the deconstruction of neoliberal policies that block centralized public health care.

Vulnerabilities and populations of concern throughout a community can be mapped with geographic information systems (Gamble et. al. 2016). The geospatial data represent the range in which social vulnerability can contribute to increased environmental exposures (Yu, 2021). No community or region will share identical social vulnerabilities and environmental exposures (Yu, 2021). Geospatial data that depicts social vulnerability and environmental exposure is a fundamental deliverable that is being created as a result of this thesis. The analysis of the spatial relationship between high vulnerability locations and exposure allows for targeted policy and assistance to be implemented in areas of highest risk to wildfire and wildfire health impacts.

How do spatial, economic and racial inequalities get magnified through disasters/climate change?

Anthropogenic climate change refers to the human-led changes in the global climate and environment. These are a result of industrialization and globalization which have led to increases

in the global concentrations of carbon dioxide and other greenhouse gasses, including methane, nitrous oxide, and water vapor. The mostly widely discussed implication of climate change is the global rise of temperature. At the current rate of global warming it is highly likely that there will be 1.5°C-2°C warming across the planet. The warming does not happen across the planet at the same rate, as the Arctic circle is one of the forefronts of seeing the impacts from climate change. This is due to the climate phenomenon of arctic amplification which is the positive feedback loop which involves that as sea ice melts the albedo goes down lowering the reflexivity of the Arctic. This then allows for more solar radiation to be absorbed and melt more sea ice leading to a repetition of the cycle.

The state of California is at risk for two of the most widely discussed climate change implications: rising temperatures and sea level rise. For the purpose of this thesis the focus on the impacts climate change will have on California and its environment will be centered around rising temperatures. California is a drought-prone region, which means it is in a constant state of having an insufficient amount of water in the hydrological cycle (Parakul, 2022). In the past two years California has been experiencing a meteorological drought, meaning the state is experiencing below average rainfall (Parakul, 2022). Droughts are very dangerous when discussing the potential likelihood and intensity of wildfires, as well as the length of the wildfire season. As water resources dwindle, forests and surrounding vegetation begin to dry out, essentially becoming an expectant tinder box which is waiting for the match to be lit. The higher temperatures and drier conditions lead to an increase in the amount and intensity of yearly fires (EPA, 2016). As the intensity of wildfires shifts, it leads to more smoke and pollutants being released into the atmosphere resulting in increases in negative health outcomes such as increased asthma rates (Fann et. al. 2016). Rising near surface air temperatures and absence of clean,

unpolluted air can cause dehydration, heat stroke, and cardiovascular issues (What Climate Change means for California, 2016). Populations of concern, such as the elderly and those who live below the poverty line, are at an increased risk for these negative health effects of climate change in California because they lack the capacity to build resilience to climate change (What Climate Change means for California, 2016).

When disaster strikes the physical, emotional, and economic damage it causes extends beyond when the final first responder leaves and the community is cleared to re-enter the area. Pre-existing vulnerabilities determine whether or not a community or family will have the ability to bounce back after a disaster. Even if they are able to recover from the disaster the vulnerabilities they had prior still exist and are only now amplified due to the stressors from the disaster. In the case of the CZU Complex Fire this mainly applies to housing stability (i.e. rent or own property) and economic stability, as those are main factors in establishing whether or not you have the means to repair your home or stay in the one you are renting as displaced homeowners put pressure on the local housing market. Historic racial and economic injustices and exclusions influence the ability for today's generations to recover from disaster because the impacts felt from the injustices are multigenerational. It is impossible to obtain environmental justice without taking into account racial justice and economic justice (CA Climate Action Team, 2020).

When disasters occur these vectors for vulnerability become exacerbated as the negative aspects become magnified. This is because any of the stability households and community members possessed is now thrown into disarray as a result of the wildfires. If they do not have the adaptive capacity to bounce back, these vulnerabilities which may have been low before are now greatly increased. This process will continue every time disaster strikes, meaning that as

climate change fuels more wildfires vulnerabilities will only be further magnified (Yu et. al. 2021). An example of this is, if someone's income is below the poverty level and then they lose their house in a wildfire it is highly likely they will struggle to rebuild due to a lack of financial resources. This example also connects to the negative impacts that are also transferred onto the community as a whole. When families lose their homes they are forced to move to another area of urbanized Santa Cruz County that increases the average rent, because demand has increased. The cost of renting a home in Santa Cruz County is extremely high as the average monthly rent for an apartment is \$3,080 per month (Santa Cruz, CA Rental Markets, 2022). Market trends have shown that when housing becomes more desired rent prices increase, and after a disaster there is an influx in housing needed as community members rebuild thus increasing rent. Marginalized groups are then faced with the impossible situation of rebuilding their lives without access to affordable housing. The state of California faces a housing shortage even before wildfires and climate disasters wipe through communities (Anguiano, 2022). The Camp Fire, which burned in 2018, demonstrates how individuals who lose their homes in fires become refugees in their own communities (Anguiano, 2022). They are refugees in the sense that they are permanently displaced, unable to find permanent housing as a result of impacted markets and high rents (Anguiano, 2022). The housing crisis that existed prior to the Camp Fire was worsened significantly as a result of the thousands of homes destroyed in this devastating fire. The local police and government in Chico, the city most of the refugees from Paradise (which burned nearly in its entirety) fled to, have cracked down on people experiencing homelessness, making it difficult for them to be anywhere (Anguiano, 2022). Discriminatory practices of evicting people experiencing homelessness from their encampments furthers the negative impacts they are experiencing as a result of being homeless. As they are constantly kept on the

move it limits their ability to develop resilience or the stability needed to take the steps, such as working a consistent job, that would allow for them to establish more permanent housing. This specifically can also be applied to migrant farm working communities.

California's agricultural sector of their economy is dependent on the work done by migrant farmworkers. Nearly three quarters of farmworkers in the state of California are undocumented farmworkers who are experiencing the most severe scenarios as climate change rips through California (Guerrero, 2021). This creates a very specific, and dangerous vulnerability for them as undocumented farm workers do not have access to the federal disaster assistance, health insurance, or unemployment benefits following a fire that their documented counterparts and land owners have (Guerrero, 2021). The cycle of poverty, chronic illness and instability is exacerbated by wildfires, as often undocumented workers have to make the split-second decision whether to keep working or evacuate, both coming with devastating consequences of illness or loss of pay (Guerrero, 2021). During the CZU Complex Fire, when thousands were being evacuated and air quality levels designated the need for masks, farmworkers were still harvesting crops (Ho, 2020). Regardless of the air quality, many workers were faced with the impossible choice of putting their health first or earning a paycheck (Ho, 2020). By being out in the field during the unhealthy air quality and completing manual labor without protective equipment have led to exacerbation in negative health outcomes for farmworkers (Hassanein, 2022). Sore throats, asthma, respiratory infections, and black saliva are a few of the symptoms migrant farmworkers experience as a result of their prolonged exposure to smoke during wildfire season (Hassanein, 2022). These worsen pre-existing health inequalities amongst the community as often farmworkers, specifically those who are undocumented, are not receiving health care in general or have access to a primary care doctor (Hassanein, 2022). When

one does not have access to medical care and are unable to address any underlying illnesses or ailments when disaster strikes and they are working in unhealthy air, these underlying illnesses will worsen (Hassanein, 2022). This creates a cycle which cycles through underlying health conditions, creating comorbidities, lack of medical care, inability to work, increase in financial strain and the need to then work even when it will make the comorbidities worse. Farmworkers', both documented and undocumented, social vulnerabilities are worsened significantly as a result of wildfires in California and as climate change continues to intensify, if left unaddressed and unsupported, their vulnerabilities will only continue to increase.

What are the health related risks of wildfires?

Wildfire smoke knows no bounds and travels far beyond the borders of the burn area. Studies have shown that smoke from wildfires can travel up to 70 km from its initial source (Alonso-Blanco, 2018). This means that even if the home area of the population of concern is not physically on fire it is still facing environmental health repercussions from the fire. Communities who are on the receiving end of the smoke often have air heavily polluted with PM_{2.5} and PM₁₀ as a result from burning forests and homes (Alonso-Blanco, 2018). There are many other carcinogens present in wildfire smoke which can result in long term negative health outcomes if the exposure is prolonged and repeated (Rappold et. al. 2017). Wildfire smoke also decreases the albedo of a region meaning there will be increased absorption and a decrease in reflection of solar radiation, increasing temperatures. This means that residents in California will see an increase in these negative impacts as the wildfire season expands and the intensity of fires and smoke increases. This increase in wildfire range would also mean an increase in smoke range, putting more communities at risk and increasing the environmental pressures they face.

Additionally, an important factor to consider when looking at the long term impacts of wildfire smoke inhalation that results in negative health outcomes means that households will have to spend more money on treatments rather than on building their adaptive capacity. This further increases their vulnerability and puts them in a precarious position for the next wave of wildfires or other related disasters (i.e. landslides).

Populations of concern are more likely to face severe consequences as a result of wildfire smoke exposure. Children who are repeatedly exposed to wildfire smoke in utero and as newborns have been linked to having higher rates of allergies and asthma down the line (CA Climate Action Team, 2020). Outdoor workers who are unable to reduce their exposure over the years to the smoke can develop serious medical conditions including cancer and respiratory infections. Individuals who are white, upper middle class, and are able to stay inside while smoke concentration levels are high are at a significant advantage against many populations of people who do not have that level of security and adaptive capacity (CA Climate Action Team, 2020). The climate is changing and wildfires are increasing in range and intensity. As more people move into the forests and mountains, the line between urban and wildlands becomes blurry. However, that will not stop a wildfire and actually increases its severity due to the pollutants that are released when building materials in houses and buildings are burned.

Smoke also does not immediately dissipate once introduced to an environment. It will sit and fester until the conditions become favorable for it to be dispersed (Alonso-Blanco et. al. 2018). This leads to the situation where the conditions of the disaster continue long past the initial start. The CZU Complex fire took over a month to reach 100% containment and much longer to stop burning (CZU Lightning Complex, 2020). During that entire time period smoke is constantly being released and traveling far distances. Wildfires in California are one of the most

large-scale risks of climate change as increasing them can doom the health of the state (What Climate Change means for California, 2016). Due to the nature of the smoke matter the small particulates are able to remain in the lungs and human body for substantial amounts of time, furthering the damage it causes on human health (CA Climate Action Team, 2020). This is not something to be taken lightly as thousands of people are at risk for losing their health and developing chronic health issues. California in response to major wildfire smoke exposures have canceled school, closed roads, and promoted wearing masks as ways to limit the amount of smoke one is exposed to and inhaling.

The health impacts of wildfire stem beyond smoke exposure and inhalation. As disasters exacerbate the underlying equity issues as it interrupts daily life to a point where it can not immediately re-adjust. There are many social determinants of health that extend beyond the typical environmental exposure focused scope. In periods following disasters it is common to see a decrease in mental health for those affected as they now face a period in their life filled with instability and disorder. Hurricane Katrina has well documented cases where following the disaster there were increased levels in depression and anxiety throughout New Orleans (Austin, 2017). There is also a loss of community ties when a disaster strikes, completely removing one of the social determinants of health (US Department of Health and Human Services, n.d). Additionally, even those who were not initially falling below the poverty line in the months leading up to the disaster when forced to rebuild may cause the loss of any “cushion” they may have. This limits their ability to respond to any disasters that may happen after, as this was seen with those recovering from Hurricane Katrina who were then forced to recover from the ecological degradation from the Deepwater Horizon disaster in addition to Hurricane Katrina (Austin, 2017). As it relates to this thesis and the CZU Complex Fire the sector of society that

feels this most significantly is the housing market. The housing market in California is extremely impacted and the cost of relocating to a temporary place of residence can be very costly. This can compound with already instabilities is socioeconomic status to tip the scales in the downwards direction. Large wildfires cause the gaps between the vulnerable and the un-vulnerable to grow, highlighting issues such as racial inequities and socioeconomic inequalities. If vulnerabilities that are exposed in a previous wildfire or other natural disaster are not addressed they compound when another fire or disaster strikes. The underlying social causes of vulnerability need to be addressed in order to see any differences in the outcomes from one wildfire to another.

Populations of concern are at a heightened risk of these additional health impacts from the fire as they are typically the ones whose social inequalities are being exacerbated (Gamble et. al. 2016).

What is the background of Santa Cruz County?

Santa Cruz County is located along the coast in Northern California. Its name directly translated in Spanish means *Holy Cross* and was established originally by Spanish explorer Don Gaspar de Portola. The city of Santa Cruz was incorporated into the state in 1866 with them receiving their town charter in 1867. With miles of beautiful coastline, redwood tree forests and mild climate Santa Cruz quickly became a bustling tourist destination. Santa Cruz County is home to over 260,000 people and has a diverse ethnic and racial makeup. The median household income is \$96,093 and 10.7% of people live below the federal poverty line (QuickFacts Santa Cruz County, 2021). However, the Monterey Bay Economic Partnership identified that in order to afford the typical rent in Santa Cruz County, households need to make \$48.08 per hour (Principi, 2022). This means that even if the household does not fall below the federal poverty line, they are unable to afford the basic necessities at the price level they are in Santa Cruz

County (Principi, 2022). The socio demographic make-up of Santa Cruz County is a large determinant of their vulnerabilities to environmental disasters and other major events as it establishes the adaptive capacities of the people affected. Past disasters and the impacts they have on the community contribute to their ability or inability to respond to future disasters, based on if the underlying causes for the devastation were altered. While it is impossible to stop a disaster from occurring, better protocols for when they strike including rebuilding funds and housing for those displaced would help alleviate the recovery burden and set the county up for more resilience in the future against other disasters. Due to its location close to the ocean, flooding and storm damage are common disasters alongside wildfires to befall Santa Cruz County (Santa Cruz Historical Disasters, n.d). These disasters destroy many homes and businesses at each occurrence. If one is not able to rebuild due to socioeconomic status or if the land they previously inhabited is deemed unlivable they lose not only housing but potentially job security. Additionally, due to California's location close to the Mexican border many individuals who live and work in Santa Cruz County face the issue of citizenship, where those undocumented are less likely to feel comfortable accessing government run centers or accessing federal emergency relief money to help aid in recovery efforts. This further exacerbates the inequalities that lead to a compounding effect when a disaster such as the CZU Complex Fire in the middle of the COVID-19 pandemic happens.

Community Health Vulnerability Index

What is a community health vulnerability index?

Vulnerability indices can help identify the areas and people who are most vulnerable to environmental disasters and climate change impacts indices. A vulnerability index combines

environmental exposures, sociodemographic factors and adaptive capacity relative to the climatic event or natural disaster being looked at. A popular example of a vulnerability index is a Heat Vulnerability Index or HVI. HVIs have been done in cities and towns across the country to analyze the people in each community who are most impacted and put at risk by the urban heat island effect. Philadelphia, Pennsylvania conducted an extensive HVI for their community in order to establish priority areas for targeted policy implementation (Hammer et. al. 2020). This study cites the importance in recognizing the site-specific nature of vulnerability indices and how it must be tailored to each community (Hammer et. al. 2020). The typical sociodemographic factors that create sensitivity to extreme heat are old age, social isolation, economic status, race/ethnicity and income level (Hammer et. al. 2020). This is not an all inclusive list of factors that contribute to sensitivity as each community may have different factors identified as their contributors to sensitivity. The sensitivity scores derived from the selected sociodemographic factors are overlaid with environmental exposure data (i.e. temperature data) to highlight the areas that have the highest temperature exposure coupled with the highest sensitivity scores. As the Philadelphia HVI was done at the Census tract layer of block group the areas identified as priority were able to be highly specified (Hammer et. al. 2020). The more granular the scale is in creating a vulnerability index the more useful it can be in policy implementation.

In understanding the significance the knowledge developed by heat vulnerability indices can have on communities a deliverable of this thesis is the creation of a community health vulnerability index or CHVI that is tailored to impact wildland fire smoke will have on the health of Santa Cruz County residents based on pre-existing vulnerabilities. Due to the projection for wildfires to increase as the climate continues to warm, wildfires are going to become a more prevalent issue for the United States and their negative impacts will not be felt equally (Rappold

et. al. 2017). This unequal impact distribution is a compelling argument for the creation of a CHVI for wildland fire smoke. The spatial connection created between sensitivity and exposure as it relates to wildland fire smoke allows for identification of regions across the United States who will be more vulnerable to increased wildfire frequency (Rappold et. al. 2017).

The state of California recognizes the importance of analyzing the specific sociodemographic factors, environmental exposures, and adaptive capacities when it comes to determining their next steps due to climate change. The California Department of Public Health's Office of Health Equity in partnership with CalBRACE have compiled sociodemographic variables, environmental exposures and adaptive capacity variables to create the *Climate Change & Health Vulnerability Indicators for California* (CalBRACE, n.d.). They have done an analysis using 2011-2015 reported data on all of the individual factors that make each county at risk for certain climate change impacts. These individual factors can be examined at the block group level but the areas of vulnerability are being compared at the county level. According to their indicators Santa Cruz County is at a heightened risk for wildfires and wildfire smoke (CalBRACE, n.d). The CHVI that I am creating as a deliverable for this thesis will be taking the analysis a step further by doing the complete index at the block group level and identifying the block groups within the county which are especially vulnerable to wildland fire smoke. It is a well known fact that wildfire smoke exposure is dangerous and extended exposure can lead to both acute and chronic health implications, the CHVI will allow for policy makers to see where the exposure and implications will be felt the strongest.

Variable Identification for the Index

The CHVI being made for Santa Cruz County as it relates to wildland fire smoke is being done at the block group level. This is because of the availability of block group data from the 2016-2020 American Community Survey 5-year estimates across all of the desired sensitivity factors. Due to the site-specific nature of vulnerability indices, sensitivity factors have been chosen that represent Santa Cruz’s specific populations of concern and those with known heightened vulnerabilities to wildland fire smoke exposure. The variable identification for this CHVI was supported by the CHVI created by Rappold et. al. 2016, and the state of California’s CCHVIZ. The sociodemographic factors chosen for the CHVI are listed below.

Table 1: Socioeconomic Factors for the CHVI

Factor	Measure	Source	Supporting Literature
Age	% of the population over the age of 65	American Community Survey	Rappold et. al. 2016, California’s CCHVIZ
Social Isolation	% of the population over the age of 65 and lives alone	American Community Survey	Rappold et. al. 2016
Race/Ethnicity	% of the population that is nonwhite	American Community Survey	California’s CCHVIZ
Language Barrier	% of the population without someone in the home over the age of 14 who can speak English well or very well	American Community Survey	Rappold et. al. 2016 California’s CCHVIZ
Poverty Status	% of the households with income below the poverty line in the past 12 months	American Community Survey	Rappold et. al. 2016 California’s CCHVIZ
Educational Attainment	% of population who are over the age of 25 without a high school diploma	American Community Survey	Rappold et. al. 2016 California’s CCHVIZ

Transportation Access	% of occupied households without vehicle ownership	American Community Survey	California's CCHVIZ
Internet Access	% of households without access to internet	American Community Survey	New with this CHVI
Outdoor Workers	% of population employed and over the age of 16 working outdoors	American Community Survey	California's CCHVIZ

The sensitivity factors that are specific to the CZU Complex Fire vulnerability in Santa Cruz County are age, ethnicity, language barrier, educational attainment, income, access to vehicles, and access to the internet. When individuals are over the age of 65 they are considered at a higher risk for negative health outcomes from wildfire and smoke exposure. Ethnicity and the language barrier are closely tied together in the creation of populations of concern. This is due to systemic issues in society that have been the results of generations of injustice that create barriers to access to care and resources. This CHVI is only going to look at individuals over the age of 65 as an age-based vulnerability indicator, but looking at children under the age of 5 is an additional commonly chosen age-based vulnerability indicator. It is not included in this index because based on previous indices that were used in the variable selection individuals under the age of 5 were not included. This is a limitation of indices and in future iterations of CHVIs it warrants additional resources as there is a strong link between poor air quality exposure and asthma development. Educational attainment is defined as individuals who are over the age of 25 and have a high school diploma. Lacking a high school diploma has been linked to having less job mobility and therefore a decreased adaptive capacity when it comes to responding to disasters. Income is in reference to if the household is above the poverty line. When a household falls below the poverty line they are then unable to provide for their basic needs and often have

increased negative health outcomes due to lack of access to affordable resources. For wildfires, specifically smoke exposure, those in poverty who can not afford to evacuate may be in positions where they are forced to have increased smoke exposure and inhalation worsening the impacts that smoke will have on their body. The amount of access a household or community member has to vehicles or the internet determines whether or not they will be able to evacuate in a timely manner and reduce their amount of exposure to the fire and smoke. Additionally, due to the mountainous terrain of Santa Cruz County there are some areas where people reside where there is unreliable cellular service and households are fully dependent on wifi/internet. This increases their vulnerability to wildfires because if that wifi goes out they may not be able to receive evacuation information or contact emergency services. The percentage of the population who is working outdoors also contributes to the sensitivity of a block group to wildland fire smoke because outdoor workers are at a heightened risk of respiratory related impacts due to their often prolonged exposure to the wildland fire smoke.

The exposure data that will be included in the Santa Cruz County CHVI in regards to wildland fire smoke is an important piece in identifying the areas of high vulnerability and high exposure. The environmental exposure values will be operationalized by the smoke coverage data that is sourced from the NOAA Office of Satellite and Product Operations Hazard Mapping System Fire and Smoke Product. The data from this source provides the spatial location and density of the smoke cover for Santa Cruz County on September 9, 2020. This date was chosen specifically due to the time passage from the initial blaze to show the longevity and extent of the CZU Complex Fire smoke.

Table 2: Environmental Exposure Factors for CHVI

Factor	Measure	Source	Supporting Literature
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Smoke Exposure	Smoke Density and Coverage on September 9, 2022 as a result of the CZU Complex Fire	NOAA Office of Satellite and Product Operations Hazard Mapping System Fire and Smoke Product	Environmental Exposure unique to making this community health vulnerability index for Santa Cruz County
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As recovery and the ability to respond to wildfires is also being analyzed for the CZU Complex fire there are certain adaptive capacity variables that can either increase or decrease one’s vulnerability to wildfires and their smoke. The adaptive capacity factors that will be included in the CHVI for Santa Cruz County are as follows.

Table 3: Adaptive Capacity Factors for CHVI

Factor	Measure	Source	Supporting Literature
Housing Instability	% of households who rent their home	American Community Survey	New with this CHVI

Housing instability is a new factor being examined in this community health vulnerability index (CHVI) that has not historically been included when creating CHVIs. However, it is a critical factor to include as there are distinct ties between health outcomes and housing stability, or rather, instability. There are three factors that can be utilized to describe housing instability, homelessness, housing insecurity, and affordability (Parekh et. al., 2022). In this thesis and index, housing instability is being operationalized by the percentage of renters (as opposed to homeowners) in each block group of households. This way of analyzing housing instability is a good metric to then look at recovery from disaster, as renters follow a different path towards recovery than homeowners. In addition to the road to recovery post disaster renters versus homeowners will face, the quality of home may differ based on if it is being rented or owned by the resident. This can lead to differences in the amount of smoke pollutants that are able to

permeate into the home, even if the house is miles from the fire. The lack of stability in one's place of residence can be an assault on a multitude of facets in their life, including physical health, mental health, and their interpersonal relationships. There is significant literature supporting housing stability as a social determinant of health, and substandard living conditions can be tied to decreases in both health and overall wellbeing (Rolfe et. al., 2020). When one is experiencing unstable living situations and is in constant flux, their health suffers as a result (Rolfe et. al., 2020). It is apparent through analyzing vulnerabilities through a health geographies lens that housing instability is a direct consequence of the structural violence already vulnerable individuals experience in this country (Padgett, 2020).

In previous literature, differences in mortality and morbidity rates were identified based on if households were renting or owning their homes (Mehdipanah et. al. 2021). When compared to those who own their homes, renters were found to have higher mortality and morbidity rates (Mehdipanah et. al. 2021). These increased rates develop as housing instability may contribute to conditions that increase the transmission of infectious diseases, such as overcrowding (OASH, 2022). Overcrowding can result in the “doubling up” of families within one shared household, which can inadvertently worsen the burdens of housing instability on already vulnerable families (Pedroza, 2019). Furthermore, housing instability has the power to intensify other vulnerabilities, such as food insecurity, when shelter must take financial precedence for a household (Yousefi-Rizi et. al., 2021). In a situation where a decision has to be made on whether to pay for rent or to pay for a meal, either choice places the household's health on the line. Future research has been called for in order to better understand all of the various nuances that come with the correlations between housing instability and other vulnerabilities, but the consensus is clear—inadequate and insecure housing impacts one's physical health. Those who are housing

insecure have an increased likelihood of requiring hospitalizations and having health problems, including respiratory illness and skin conditions (Padgett, 2020).

Epidemiological studies have been conducted that analyze mental health as it coincides with housing instability, and has long been established that the rates of depression and suicidal thoughts were more prevalent those in unstable housing situations versus those in secure housing (Padgett, 2020). Children are especially vulnerable to the psychological aftermath of living in unstable housing, as they can become disconnected from the societal structures that they require to integrate fully into society and thrive (Parry et. al. 2022, & Padgett, 2020). Even though housing instability's impact on mental health has been identified since the 1980s, there is a significant gap in resources available for those who are housing insecure (Padgett, 2020). As those who are housing insecure face rising disasters as a result of climate change, these insecurities are only going to deepen further, and thus, accelerate the mental health concerns for communities fraught with housing instability.

Wellbeing metrics outside of the standard definitions of physical and mental health are often also impacted by housing instability. Intimate partner violence or domestic violence is “a pattern of behavior in any relationship that is used to gain or maintain power and control over an intimate partner” (UN, n.d.). There is significant evidence of the connection between domestic violence and housing instability, as victims who are financially dependent on their partner have a more difficult time leaving the relationship due to the housing instability that the leaving may cause (Pavao et. al., 2007). One study concluded that in their sample of women, they found that 30% of the women who were classified as having unstable housing also reported domestic violence in the past year (Pavao et. al., 2007). The relationship between housing instability and domestic violence is nuanced, but research indicates that reductions in housing instability may

contribute to declines in domestic violence. This is a clear indication of how housing stability can determine the standard of health in one's home environment, from the perspective of interpersonal relationships.

Housing stability, or lack thereof, has not been included in other variations of a community health vulnerability index for wildfire smoke. This is significant oversight for the state of California, where housing is a critical issue for many residents. To understand the level of vulnerability a community possesses, all of the factors that impact health must be included in the analysis. The research is clear—housing instability negatively impacts human health and wellbeing. The CZU Complex Fire highlighted how housing instability after a disaster is not limited to just the households whose homes were destroyed, but can disseminate to the entirety of the county. Equitable recovery and fire resilience will not be developed successfully for Santa Cruz County if housing stability is not being brought to the forefront of the conversation. The CHVI created by the state of California does not include housing stability as a vulnerability factor and this is the gap in the literature my thesis will address.

Housing instability affects both the susceptibility and adaptive capacity relative to the long term health impacts of those in fire prone areas, such as Santa Cruz County. Housing security is a fundamental human right and without it the risk of immediate health impacts from wildfires and wildfire smoke exposure is raised (Office of the High Commissioner for Human Rights, n.d). This is in addition to the long term impacts on recovery and rebuilding, as the difficulties associated with recovery will be unequally distributed amongst those who are housing secured and those who are not. This illustrates the power that housing has on the health of a community, especially when it comes to environmental disasters.

Methodology

A series of various health and environmental indices were analyzed prior to the creation of this community health vulnerability index. After careful review, the methodology selected for this index utilized methods from both Reid et. al. 2009, Rappold et. al. 2016, Hammer et. al. 2020, and Habeeb (2021-2023). The information about the socio-demographic makeup of Santa Cruz County is gathered from the American Community Survey 2016-2020 5 year estimates as raw numbers that are in various categories. The first step of creating the community health vulnerability index was to establish percentages for each of the factors for each individual block group (ACS, 2020). Appendix A provides the code lists and formulas utilized to establish the percentages for each of the block groups for the ten sensitivity factors. A visual inspection was done of the data after the computation to ensure that all values were clear and valid. In order to establish one sensitivity score for each block group the variables for socioeconomic factors and adaptive capacity were joined. This is because housing instability is a limiter to adaptive capacity and increases vulnerability rather than decreases. Due to this they are able to be combined into one sensitivity score. If a metric for housing stability was utilized this would not have been done because housing stability decreases vulnerability and would have required its own score. The percentages were rounded to the nearest 100th of a percent. This was done in excel and exported once completed. Once the percentages were established the Spearman's Correlation Coefficient was calculated for each factor using R-Studio. These values are shown in Table 4 and Appendix C.

Table 4: Spearman Correlation Coefficients

	Age (>65)	Social Isolation	Race/Ethnicity	Language Barrier	Educational Attainment	Below Poverty	No Access to Vehicle	No Access to Internet	Outdoor Workers	Housing Instability
Age (>65)	1.00									
Social Isolation	0.30	1.00								
Race/Ethnicity	-0.53	-0.15	1.00							
Language Barrier	-0.24	-0.17	0.55	1.00						
Educational Attainment	-0.33	-0.24	0.64	0.60	1.00					
Below Poverty	-0.37	-0.08	0.36	0.26	0.27	1.00				
No Access to Vehicles	-0.07	-0.01	0.26	0.22	0.19	0.30	1.00			
No Access to Internet	-0.05	0.07	0.35	0.38	0.41	0.17	0.28	1.00		
Outdoor Workers	-0.20	-0.23	0.42	0.43	0.55	0.07	0.18	0.32	1.00	
Housing Instability	-0.53	-0.09	0.40	0.24	0.20	0.54	0.35	0.09	-0.04	1.00

Principal component analysis with a varimax rotation was performed in order to establish the factors where the eigenvalues were greater than one. Using the Kaiser criterion principal components with eigenvalues less than 1 were excluded. This leaves 3 principal components

with eigenvalues of 3.67, 1.57 and 1.26 respectfully. After an initial principal component analysis was conducted to derive an estimate for the amount of factors, a factor analysis was then performed. The factor analysis with a varimax rotation was conducted to confirm the three principal components and their individual loadings. The results indicated that the three principal factors which can be categorized as Factor 1: Social Vulnerabilities, Factor 2: Housing and Age Demographics, and Factor 3: Social Isolation. Reference Table 5 and Appendix G for the loadings of the variables for each factor. Figure 1 depicts the loading diagrams for each factor. A Kaiser-Meyer-Olkin Factor Adequacy test was performed in order to ensure that all of the variables used in the factor analysis are suitable. All of the factors passed the test as all MSA values were greater than 0.5. Appendix H can be referenced for more information surrounding the results of the Kaiser-Meyer-Olkin Factor Adequacy test. All of the statistical tests were done utilizing R-Studio.

Table 5: Variable Loadings for each of the three factors

	Factor 1: Social Vulnerabilities	Factor 2: Housing and Age Demographics	Factor 3: Social Isolation
Race/Ethnicity	0.68	0.48	
Language Barrier	0.80	0.33	
Educational Attainment	0.93		
No Access to Internet	0.60		
Outdoor Workers	0.73		
Age (>65)		-0.69	0.33
Poverty		0.55	
Housing Instability		0.86	0.33

Social Isolation			0.34
No Access to Vehicle		0.31	0.47

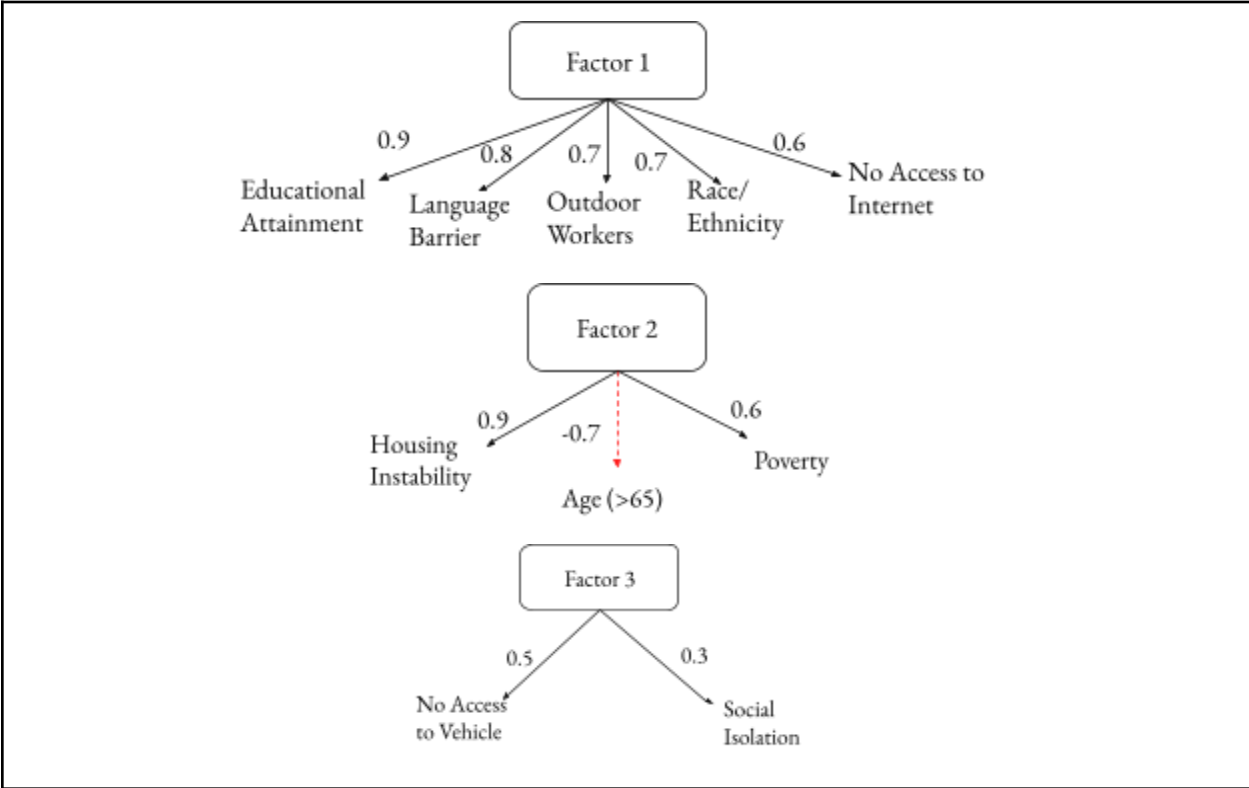


Figure 1: Individual loadings diagrams that illuminate the loading of each variable for their respectful factor.

The estimated factor scores were derived from the factor analysis and then divided into quartiles. Each quartile was assigned a value between 1 and 4, with 1 being the lowest vulnerability and 4 being the highest vulnerability. The quartile scores from factor 1, factor 2 and factor 3 were totalled to form the final sensitivity score for each block group. This means that the highest possible vulnerability score is 12 and the lowest possible vulnerability score is 3. The sensitivity scores for the Santa Cruz County block groups in this community health vulnerability

index ranged from 4 to 12. 12 is the score that indicates highest sensitivity and 4 is the score that indicates the lowest sensitivity.

After the sensitivity scores for each block group were identified, the next step was to overlay the environmental exposures to establish the priority areas as it related to the CZU Complex Fire. The factor of environmental exposure is operationalized by the smoke coverage and density from September 5th, 2020. The date of September 5th was chosen because it was 27 days after the blaze initiated and it illustrates how smoke is a far reaching and long lasting community health issue.

Finally, in order to represent this information spatially the software of ArcGIS Pro was utilized to create thematic maps. These maps demonstrate how the areas of highest vulnerability are dispersed throughout Santa Cruz County.

A map of the smoke coverage in Santa Cruz County from September 5, 2020 with the CZU Complex Fire perimeter has also been included in the thematic map creation but not in the final community health vulnerability index. This map illustrates how the range of wildfire smoke is extensive and is a health issue for all of Santa Cruz County significantly passed the burn line.

What will a Community Vulnerability Index tell us about Recovery?

The thematic maps and results created through the community health vulnerability index for Santa Cruz County illuminate the areas of the community which have heightened vulnerabilities to the health impacts associated with wildfires. Pre-existing social vulnerability indicators compound with environmental exposures to create situations where populations of concern are created. CHVIs also can indicate the areas of Santa Cruz County which may have a more difficult time recovering from the CZU Complex Fire and subsequent disasters. A typical

primary goal when creating a CHVI is to highlight areas of populations with highest vulnerability and exposure and then create targeted policies to help reduce their vulnerabilities (Hammer et. al. 2020). As this index is being created post-disaster, it will give an insight on what social vulnerabilities need to be addressed in order for equitable recovery to be achievable in the case of another fire like the CZU Complex Fire.

Thematic Maps

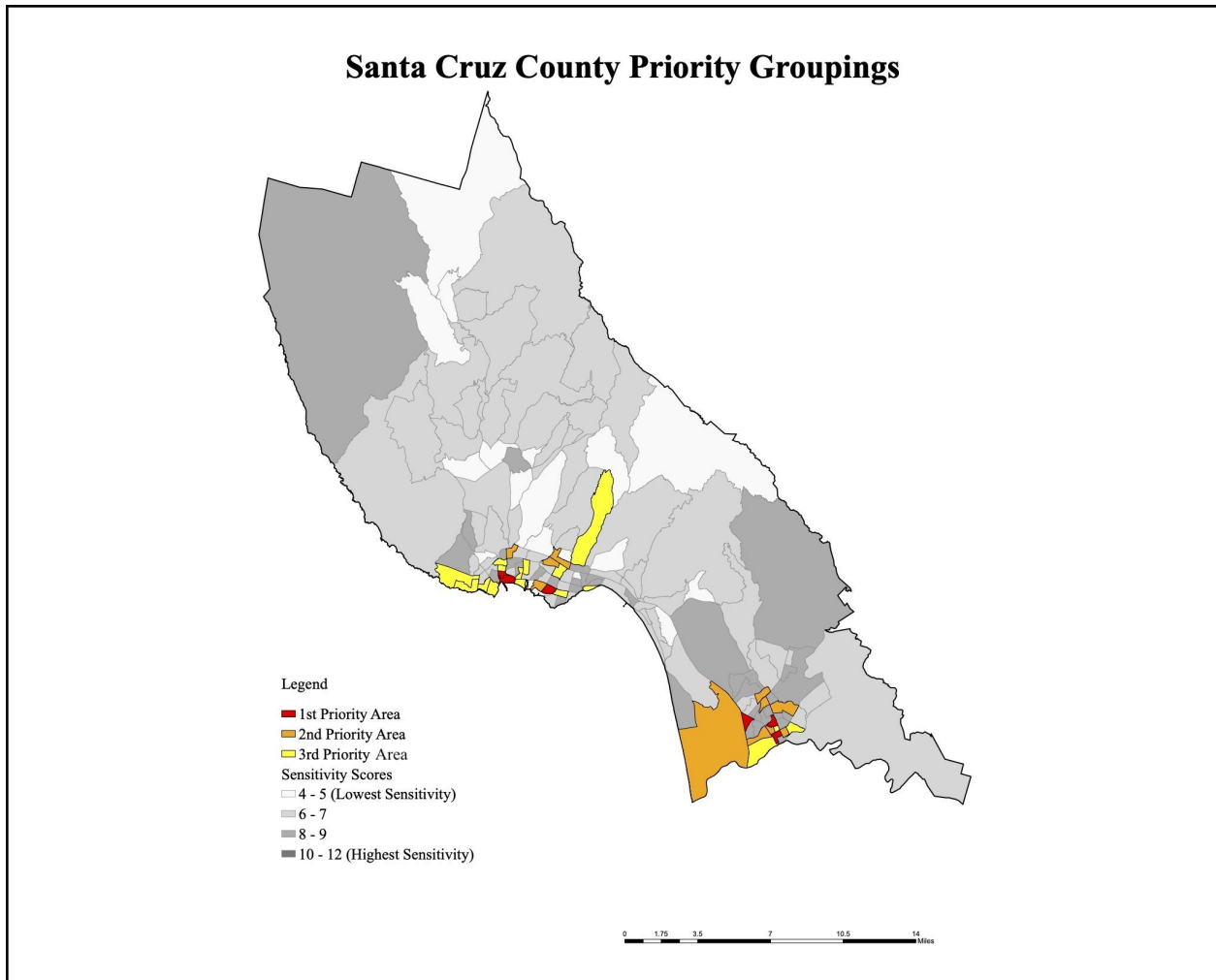


Figure 2: Final Priority Mapping of Santa Cruz County. This thematic map takes into account the sensitivity scores and environmental exposures to highlight the block groups with the highest vulnerability to wildfire smoke.

Santa Cruz County Sensitivity Scores

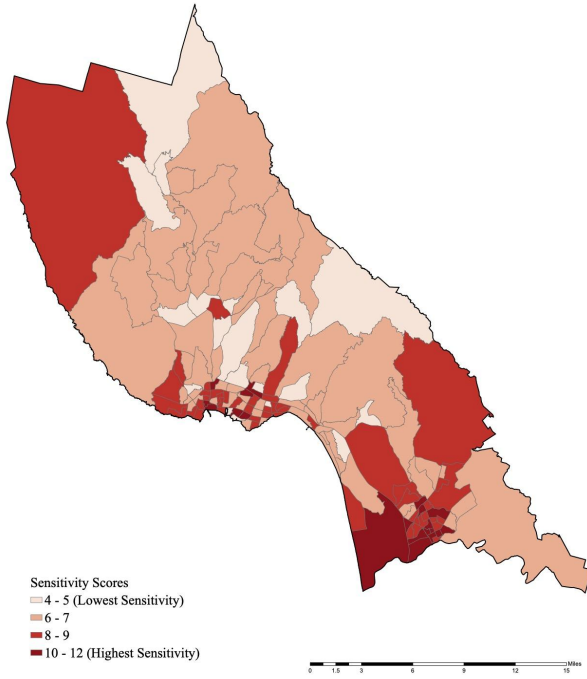


Figure 3: The Sensitivity Scores created for the CHVI for Santa Cruz County. The darker the shade of red the higher level of sensitivity the block group holds.

September 5th Smoke from the CZU Complex Fire

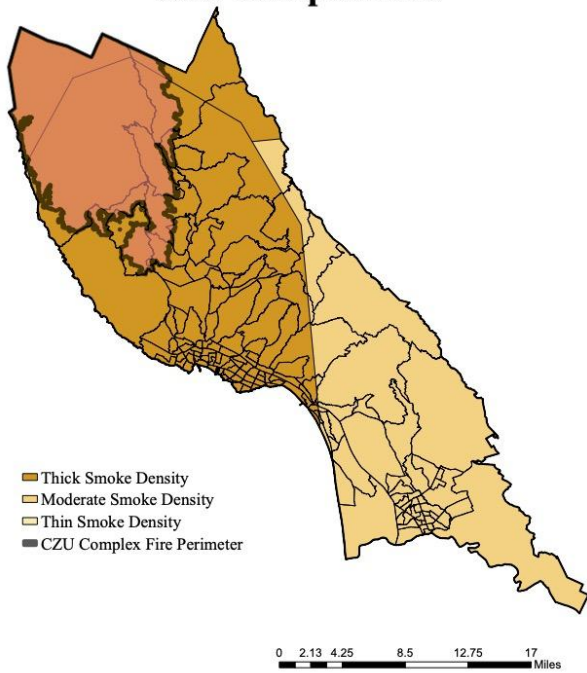


Figure 4: Smoke coverage and density in Santa Cruz County as a result of the CZU Complex Fire

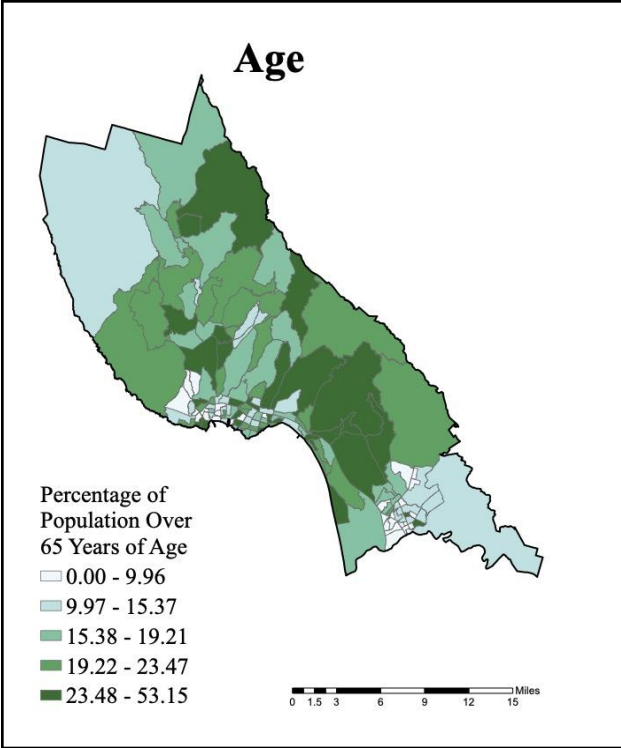


Figure 5: Thematic Map of the Percentage of the Population over the age of 65

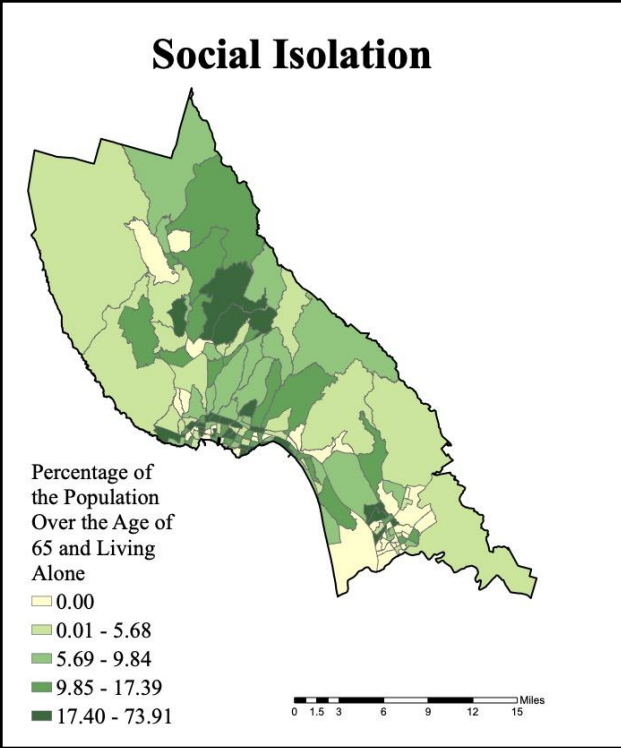


Figure 6: Thematic Map of the Percentage of the population who is over the age of 65 and living alone

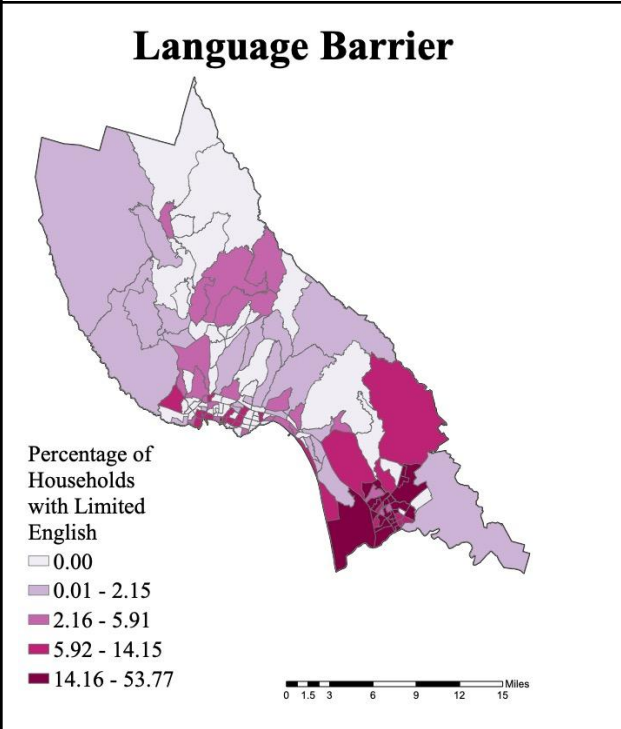
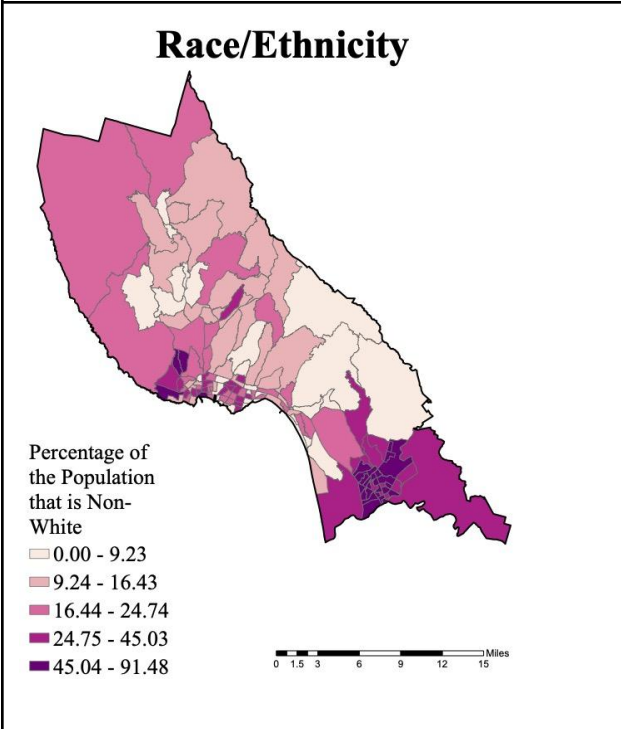


Figure 7: Thematic Map of the Percentage of the Population who is non-white

Figure 8: Thematic Map of the Percentage of Households who have Limited English

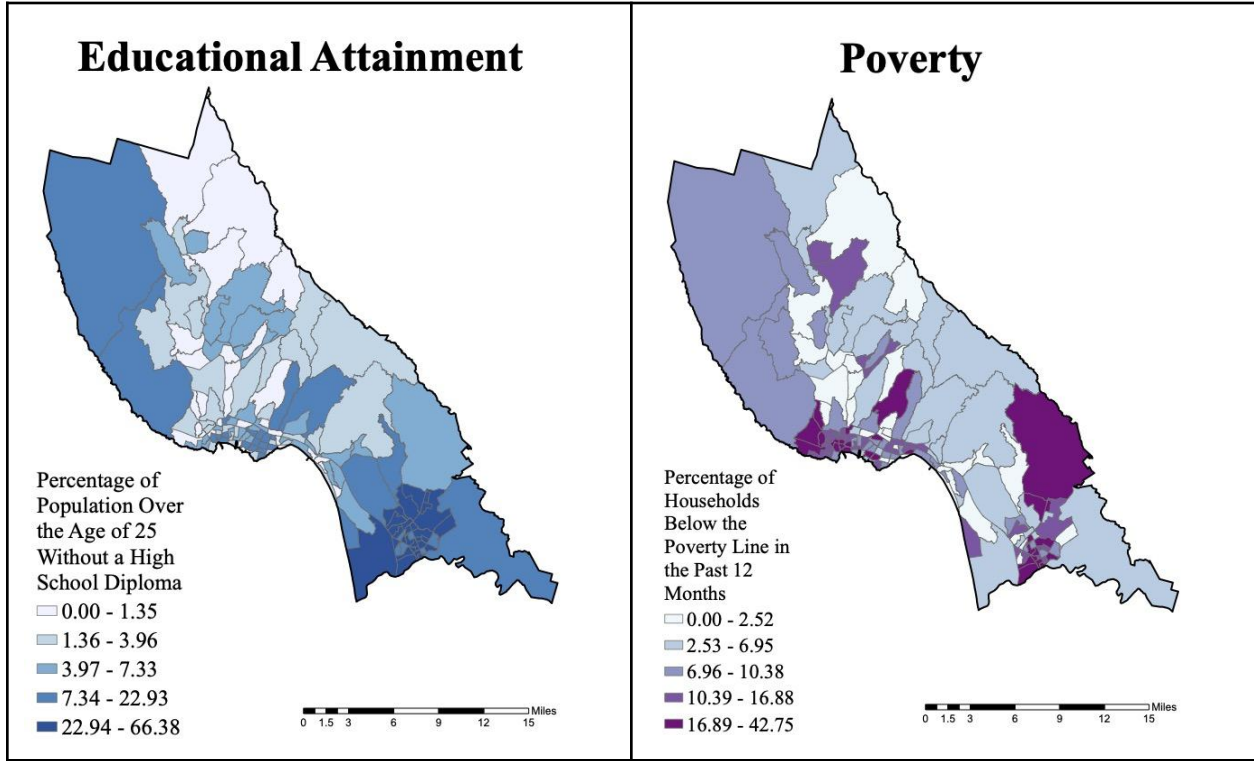


Figure 9: Thematic Map of the Percentage of the Population over the age of 25 without a HS diploma

Figure 10: Thematic Map of the Percentage of Households below the poverty line in the past 12 months

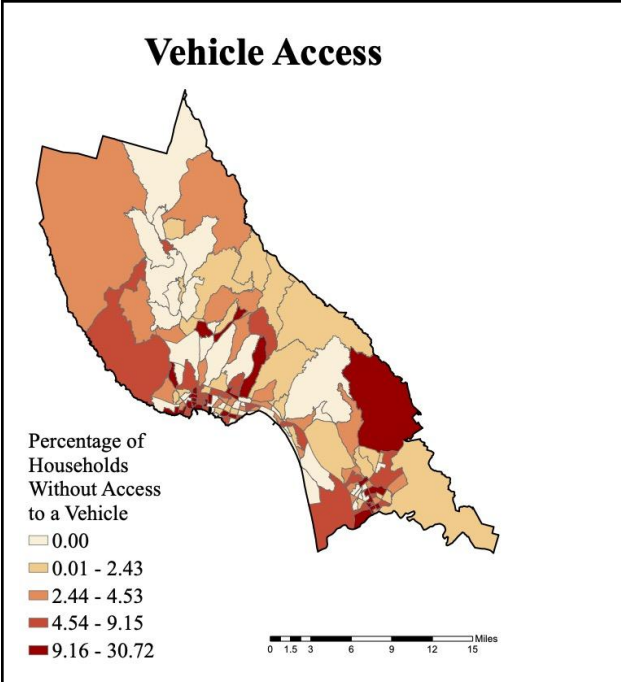


Figure 11: Thematic Map of the Percentage of Households without a Vehicle

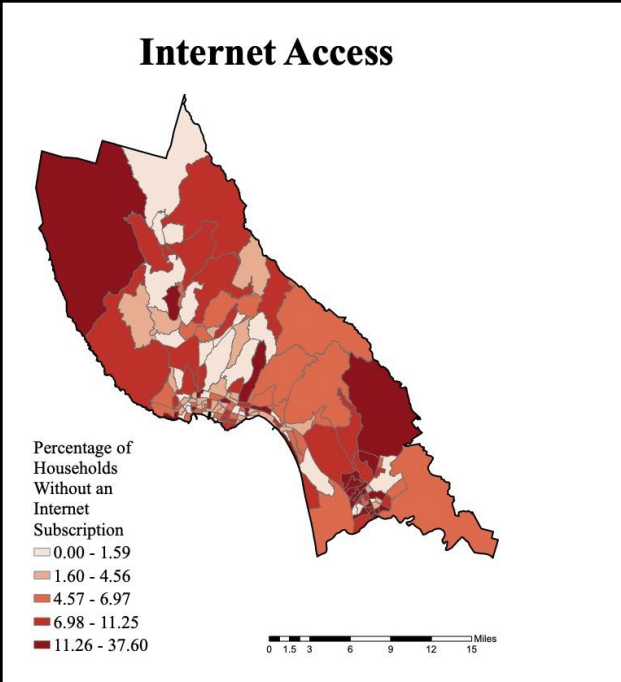


Figure 12: Thematic Map of the Percentage of Households without an Internet Subscription

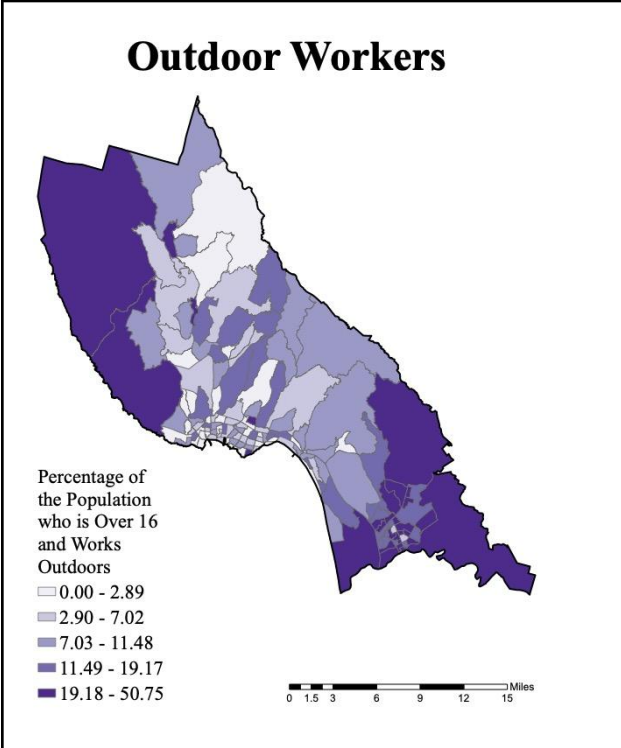


Figure 12: Thematic Map of the Percentage of the Population who is over 16 and works outdoors

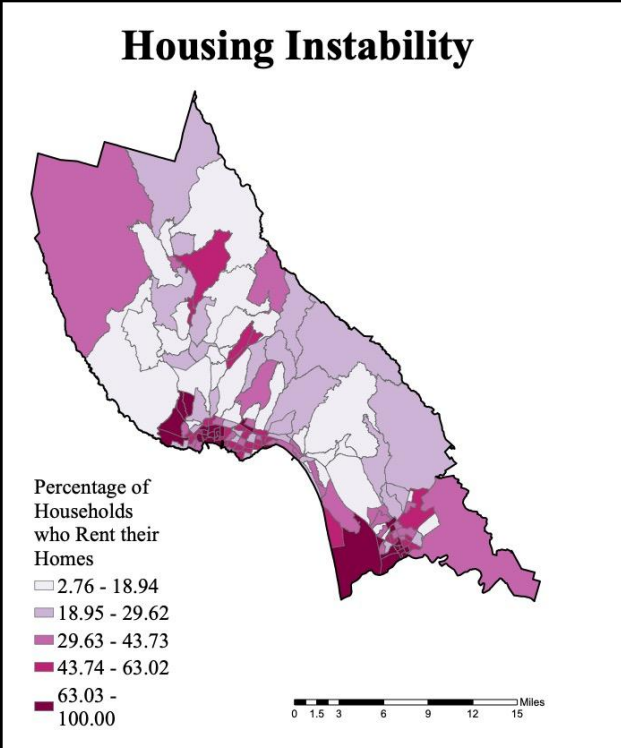


Figure 13: Thematic Map of the Percentage of Households who rent their homes.

Discussion

Thematic Map and Index Discussion

The resulting thematic maps from this thesis describe the spatial patterns of sensitivity and vulnerability in Santa Cruz County. The sensitivity scores highlight the block groups where multiple vectors of vulnerability create a highly sensitive population (Figure 3). The most sensitive communities in Santa Cruz are located primarily in Southern Santa Cruz County and Central Santa Cruz County. There was no block group that scored the minimum sensitivity score of 3, meaning that each block group has some varying degree of vulnerability albeit in different ways. The distributions of the sensitivity scores across the county are distinctly unequal, demonstrating visually the inequities in the distribution of the social determinants of health as it relates to wildfires. The comorbidities of social vulnerabilities become evident when spatially displayed. The CHVI created in this index analyzes at a block group level the specific vulnerabilities different areas experience. It illustrates that while areas across the county may have comparable levels of sensitivity and vulnerability, the combination of factors that make them vulnerable is specific and unique to their local community. There is no community which is going to experience vulnerability exactly the same way as another, and the community health vulnerability index supports this claim. The identification of the specific contributors to vulnerability for each block group, allow for targeted policies and interventions to be established at this block group level, that is typically overlooked when planning for disasters. In Figure 3, it is clear that there are multiple areas all around the county that have been classified as highest sensitivity. When diving deeper and looking at the individual factors in conjunction with the sensitivity maps, the differences in what causes the high levels of sensitivity become clear. In

Southern Santa Cruz County (near Watsonville) the sensitivity is driven by high percentages of those who are non-white, have limited English and are outdoor workers. On the opposite side of the county in Northern Santa Cruz County (near Ben Lomond and Big Basin) there are block groups that scored the same sensitivity scores, but their sensitivity is being driven by a lack of internet access, and housing instability. Both of these regions are highly sensitive to wildfire smoke exposure, but for different reasons and the CHVI allows for those differences to be known without erasing the fact that both regions are equally vulnerable to the health impacts of smoke exposure. In addition to illustrating the areas that are highly sensitive to wildfire smoke exposure it also highlights areas of the community which have decreased adaptive capacity during fire recovery based on the pre-existing vulnerabilities. These individual vulnerabilities compound one another resulting in high overall sensitivity scores for those block groups. These co-existing and pre-existing vulnerabilities increase these communities' risks as it relates to wildfire recovery and health implications from wildfire smoke exposure. Furthermore, in Northern Santa Cruz County where the CZU Complex Fire charred the earth had pre-existing high levels of sensitivity to the health impacts of wildfire smoke exposure and had a reduced capacity to recover for the fire because of their pre-existing vulnerabilities.

The use of spatial data, specifically as it relates to vulnerability, sensitivity and exposure, is a necessary component of the process for establishing targeted interventions in regards to wildfire health vulnerabilities in Santa Cruz County. The sensitivity metrics created and analyzed in this thesis can provide statistical evidence for the need for targeted interventions for specific block groups to help with wildfire prevention and recovery efforts. Viewing these vulnerability factors spatially, both individually and together, allows for the data to garner more context than it would remaining on a spreadsheet. Targeted interventions and mitigation strategies need to be

created with local context in mind and the mapping of these vulnerability factors highlight the specific vulnerabilities that need to be addressed in each community, rather than a blanket approach.

Smoke Exposure

Wildfires are a particularly unique disaster in the sense that it impacts the health of individuals who are miles away from the initial disaster. This is due to the significant amounts of smoke that these large scale wildfires create. Wildfire smoke can travel up to 70 km or roughly 43 miles from the initial source, increasing the range of the disaster the fire causes (Alonso-Blanco, 2018). This was true with the smoke coverage that occurred during the CZU Complex Fire. Figure 4 illustrates the smoke coverage on September 5th that is from the CZU Complex Fire. The NOAA Satellite Analysis Branch of the Hazard Mapping System Fire and Smoke Product classifies smoke coverage into three categories: thick smoke density, moderate smoke density and thin smoke density (NOAA Office of Satellite and Product Operations, n.d). On September 5th 2020, all of Santa Cruz County was at least covered by moderate smoke density with roughly 50% of the county having thick smoke density. Smoke is extremely harmful to human health and it has significant impacts on those with pre-existing vulnerabilities. Its pervasive nature creates the conditions where those in Watsonville, who have high pre-existing vulnerabilities, are put at risk for those negative health implications even though they are miles from the perimeter of the CZU Complex Fire. The CZU Complex Fire disrupted all of the lives of individuals in Santa Cruz County, whether it be through evacuations, homes burning down or the subjection to the inhalation of harmful toxins in the air.

Insights for Resilience and Recovery in Santa Cruz County

The CHVI created in this thesis, while created with the primary purpose of analyzing vulnerability as it relates to wildfires, can be utilized to increase the overall resilience and adaptive capacity of Santa Cruz County. Many of the vulnerability variables selected for this CHVI also increase the sensitivity of a community to other environmental disasters or hazards, such as extreme heat. The utilization of spatial data to view community vulnerability can highlight the broader health hazard prevention measures needed for Santa Cruz County. Different communities in Santa Cruz County face different dimensions of vulnerability and these different vulnerabilities impact them outside of simply their susceptibility and recovery from wildfires and wildfire smoke. If steps are taken to address these underlying vulnerabilities it will increase the communities resilience to more than just wildfires and smoke, but increase their overall health resilience.

Early Evacuations: Early Notification and Access to Evacuation

Evacuations are a critical component in saving lives during wildfires and early notification of evacuations are a critical factor when determining how one will be able to escape the fire. Every minute counts when someone is executing an emergency evacuation, as every minute spent waiting is another minute of smoke exposure and another minute closer to the flames. Evacuations during a wildfire are a primary tool utilized to protect human health and life. Early notification and early evacuation allow for communities to remain safe from the fast traveling flames as well as reduce their exposure to the highly toxic smoke. Early notification and evacuation orders are only effective if individuals and communities are in a language that they can understand, and they have access to the notifications. The language that evacuation

orders are given in is a deciding factor on whether or not that individual will know to evacuate. In Figure 8 the language demographics are mapped for Santa Cruz County, and in some areas of Southern Santa Cruz there are block groups with up to 53% of the households with limited English capacity. These same block groups also have up to 91% of the population identifying as non-white. The community health vulnerability index clearly highlights these block groups of scoring highly in terms of sensitivity. Understanding the evacuation notifications and warnings are only part of the necessary components to a safe evacuation during a wildfire. Communities must also have access to these notifications, operationalized in this index by having an internet subscription. Having access to the internet can mean the difference between an early evacuation or being trapped and unable to evacuate. Figure 12, the individual thematic map for internet access, shows that up to 37% of some block groups are without an internet subscription. These individual vulnerability factors are not existing in a vacuum, and compound each other in these highly vulnerable block groups. Historical and present social inequalities have allowed for the increases in vulnerabilities to occur intensely in some block groups and no increases in vulnerabilities in others. Easy access to wildfire and evacuation notifications are a necessity in order to save lives and allow for people to take the steps necessary to protect their lives and their health (Funes, 2020). Words typically utilized in emergency notifications, such as vulnerability or brush fire, have difficulty translating into other languages, as often the meanings are lost in translation (Yoder, 2021). Comprehensive emergency notifications, in both messaging and language, should be a mandated element in California's disaster management and response plans. When evacuations are delayed, whether due to the language barrier or obstacles in obtaining the information, human health is put at significant risk due to the prolonged exposure to the toxins in wildfire smokes. It is those who are already most vulnerable who are in a situation where they do

not have equal access to emergency notifications, meaning this disaster will then only further exacerbate these vulnerabilities and inequities. Equitable recovery is not in the realm of possibility if everyone is not aware of the situation around them.

The CZU Complex Fire highlighted the dire need for early and comprehensive evacuation notifications and plans. Some of the mountain communities of Santa Cruz, such as the community called Last Chance, were not notified of the fire until it was too late for them to escape the flames (Larson, 2020). As roads in the mountain communities are slim, traffic as a result of everyone trying to evacuate at once led to leaving people stranded in the middle of a burning forest (Larson, 2020). This resulted in one death, and scars to last a lifetime for those who made it out of the burning forest (Larson, 2020). CalFire has acknowledged the gaps they have when it comes to emergency notifications for fires, which the CZU Complex Fire brought clearly to light. In 2021, CalFire announced the creation of ZoneHaven, an online mapping software that displays hundreds of evacuation routes and zones (Larson, 2021). The goal of this software is to display real time evacuation notices and procedures, something that CalFire struggled to do with CZU as they had to use helicopters and megaphones to get messaging across (Larson, 2021). As helpful as this may be, there are two critical components that if a household is without the software is moot: the ability to read English and internet access.

Online platforms such as ZoneHaven and other internet based emergency notifications are standard notification systems in California for when disaster strikes. It is easy to believe that today everyone is always connected to the internet or has cellular service, but that is not the case for those in Santa Cruz County. For a variety of reasons households and individuals may be without access to the internet or cellular data. For example, in a mountain community where cell service is weak or non-existent and they rely solely on wireless internet or the radio, if the power

is cut to their region due to the fire they are essentially in an information blackout. These groups of individuals, who do not have consistent or reliable access to the internet, are an urgently important group that disaster management plans must account for. Internet access or lack thereof, is an underlying vulnerability that needs to be addressed in the interlude between disasters, as if it is not it will become a compounding factor of increasing vulnerabilities and losses.

Information access is only one element of establishing early and safe evacuations from wildfires, the other important aspect is a physical way to evacuate from a wildfire. In the context of this CHVI it has been operationalized as access to a vehicle. The thematic maps created by the CHVI illustrate that there are multiple block groups which are more physically isolated in Santa Cruz County. The CHVI also illuminated how these isolated areas without access to vehicles have other vulnerabilities such as high percentages of non-English speakers or high percentages of people over the age of 65, which increase their overall susceptibility to health impacts from wildfire smoke. This means that those who are already at a heightened risk for the health impacts are being limited in the steps they can take to limit their exposure and protect their health. This means that traditional fire evacuation protocols will not be applicable to these communities, as it's very difficult to follow an evacuation mandate when there is no vehicle to use. This is a critical insight that this CHVI and thesis have illuminated because one's ability to survive the fire should not be dependent on if they have a working vehicle. Additionally, as it is clear that there are compounding vulnerabilities that are inhibiting one's access to a safe and early evacuation, the need is shown for a community-based approach on mitigating these vulnerabilities. This CHVI provides information that can be used to tailor evacuation plans and procedures for each block group, that takes into account its unique makeup.

Evacuations are a clear example of how tracking and identifying vulnerabilities at the block group level is important. Without analyzing the data on this level there would be no knowledge on how to best develop and implement disaster management plans for each community. Based on where an individual resides in Santa Cruz County and their personal vulnerabilities is going to dictate the best evacuation protocols. In order for these evacuation protocols to be implementable and successful these underlying vulnerabilities such as language barriers, internet access, and vehicle access need to be highlighted and included.

Immediate Displacement: Where to go when You Have No Where

For those evacuated because of a wildfire there is an immediate displacement that occurs. Even if their house stands after the fire is extinguished while the flames still rage, households are forced to seek other living arrangements while anxiously awaiting for more news. Financial stability prior to disaster is a critical component of how well one will be able to survive the disaster, prior to even considering recovery. Financial stability is being analyzed throughout this index by analyzing the road to recovery a household will have based on whether they are above or below the poverty line. Santa Cruz County block groups range from having 0% of households below the poverty line in the past 12 months to 42.75% of households below the federal poverty line, but as discussed above there are many more who are not considered “in poverty” as they fall above the the federal poverty line but are not making an income high enough for a sustainable life in Santa Cruz County (Figure 10). Households that are falling below the poverty line often have pre-existing financial stressors prior to having to quickly secure new housing when their homes are threatened. Shelter is a basic element required for the protection of human health, especially during a wildfire, and securing shelter after being evacuated should not be something

that further throws a household deeper below the poverty line. Hotels, evacuation centers and staying with families or friends are traditional temporary housing options for those during a wildfire. However, each option puts a community's health at risk for a variety of reasons. Overcrowding, substandard qualities of living and exorbitant expenses are all examples of how immediate displacement can exacerbate pre-existing vulnerability conditions and put those in the situation's health at risk.

The CZU Complex Fire's thirty seven days of burning impacted the lives and livelihoods of thousands of individuals in Santa Cruz County. As nearly 1,000 homes were destroyed in the fire, individuals have been displaced and are forced to find housing in an already housing-strapped community (Hattis, 2022). The CZU Complex Fire raged during one of the peaks of the COVID-19 pandemic where a positive test may mean ending up on a ventilator and it sent waves of fear through displaced individuals making the decisions about where to stay (Bion, 2020). As a result hotels became an important source of housing for displaced people. Hotels in San Jose, a city "just over the hill" thirty miles from Santa Cruz, reduced their rates to as low as \$99 a night for people displaced from the fire (Castillo, 2020). The hotels in San Jose chose to support their neighbors and reduced room rates to well below typical, even with increased demand (Castillo, 2020). Even with hotels taking steps to reduce the financial barriers of individuals accessing hotel rooms, some are still unable to afford hotels for more than a few nights before the price becomes too much (Castillo, 2020). For a household under the poverty line even the lowered rate of \$99 a night is too much. If unable to pay for hotel rooms, households then have to make a choice between staying with friends and family, utilizing the evacuation centers, or sleeping in their cars in a parking lot. Evacuating from a wildfire should not be a household's reason for sinking deeper into poverty.

The COVID-19 pandemic limited individuals' access to safe evacuation zones and temporary shelters (Bion, 2020). People were then faced with an impossible choice of subjecting themselves to smoke exposure, risking a COVID-19 infection by entering an evacuation shelter (Bion, 2020). Those who were forced to evacuate due to the dangers the fire posed to their life and property struggled to find vacancies where they felt safe from both the fire and COVID-19 (Castillo, 2020). In a “typical” fire, while crowded, evacuation centers provide for housing needs for those who cannot afford to stay in hotels or do not have family in the area they can stay with, however this was not a “typical” fire. While evacuation centers are open to the public, individuals who are undocumented may not feel safe accessing government resources, at the worry that it will mean they will be deported. This highlights an underlying issue of lack of resources available to those who are undocumented, even in times of great distress and disaster. Decisions about how to recover, especially in California, must take into account the populations of undocumented people, without putting them at risk for deportation.

Long term Recovery: Rebuilding Homes and Livelihoods

Housing stability is an important aspect in protecting community health as living in a constant transient state is dangerous for both physical and mental health. When housing is not consistent and is constantly changing for any reason has been linked to increases in negative health consequences for children (OASH, n.d.). When recovering from a disaster in a housing impacted county such as Santa Cruz, many households may be forced into substandard living conditions, as that is what they can gain access to. This increases the risk of overcrowding, potential for infectious diseases and levels of stress (OASH, n.d.). If they are unable to access housing it may force people into homelessness, and further increase the risk of developing

various illnesses and decrease their personal safety. Housing stability, or lack thereof, following a disaster needs to be on the forefront of California and Santa Cruz's mind when developing and implementing disaster management and mitigation plans so that it does not continue to harm the health of the community. Housing instability is prevalent throughout Santa Cruz County and the state of California as a whole. In Santa Cruz County there are block groups where up to 100% of households rent their homes. These block groups where there are high percentages for those who rent their homes overlap with other vulnerability factors such as race/ethnicity and the language barrier. This index also indicates that there are a significant number of renters across the county, meaning that the stability of housing for renters must always be a consideration when disaster planning.

Of the 1,490 structures that were destroyed in the flames of the CZU Complex Fire, of that 1,490 there were 911 homes destroyed. As of November 7, 2022 198 single-family dwelling units, and 547 non-dwelling permits have been approved and issued (Santa Cruz Fire Recovery, 2022). There are an additional 170 units that are eligible to submit for a single-family dwelling permit (Santa Cruz Fire Recovery, 2022). Two years after the fire, there have been just over half of the destroyed structures approved to be rebuilt. This slow moving process to rebuild the homes destroyed delays the ability for the community to recover as a whole. This should be a call to action to the local government of Santa Cruz County, to take initiative and provide the recovery their community needs. While homeowners can choose whether or not to rebuild, those who rent their homes are at the mercy of their landlords on when or even if they will be able to move back into their pre-fire homes Renters are in a specifically vulnerable position during wildfire recovery as if their house is fully destroyed their lease is terminated and the original landlord is not required to provide housing ("9. Landlord and Tenant," n.d.). This places renters

in a precarious situation as they now are forced to find new housing, after losing everything they may have. Homeowners are eligible to apply for assistance through the Federal Emergency Management Agency which can provide assistance on recovery elements that are not covered by insurance (FEMA, 2022). While this assistance can help renters find temporary housing immediately following a disaster, it does not provide assistance for them to find permanent housing. For homeowners, they can assist in rebuilding or replacement of their homes (FEMA, 2022). Long term shifts need to be established in the ways that housing losses are recouped after wildfires. Renters need to be offered the same if not more protections than homeowners following disasters at both the federal and local level.

Those who own their homes are not immune to housing instability in the recovery process from a fire, but experience its impacts in a different way. As homeowners were becoming accustomed to their new surroundings after the CZU Complex Fire altered their worlds, they are faced with the shocking news that their home insurance companies are refusing to continue coverage (Varian, 2022). Those who live in the Santa Cruz Mountains are being told that they are now too “risky” to cover, as the threat of consistent and destructive wildfires increases (Varian, 2022). In the specific case of wildfire, insurers are required to cover impacts from the initial blaze and any mudslides or debris flows that can be linked to the fire (Artemis, 2018). This has caused many insurance companies to end their coverage of homes in “high risk” areas, rather than assume the coverage. In 2020 alone, 212,000 properties had their insurance coverage ended, and of that 77,000 homeowners could not find private insurance and were forced onto public insurance through the state (Varian, 2022). This is the California FAIR insurance plan which has basic fire protections (California Fair Plan Association, n.d.). This plan has higher premiums than previous insurance policies, and Santa Cruz County homeowners are

forced to pay it or they risk having no coverage when a fire happens again (Varian, 2022). This public insurance can cost upwards of 3xs there original insurance quotes for some homeowners. This issue further delays the recovery of a community and allows for the continuation of vulnerability exacerbating situations.

The lack of established support for its residents is an embarrassment for Santa Cruz County and needs to be addressed swiftly. Renters are being left without housing and homeowners are losing their insurance necessary to rebuild. In the short term, the residents who are still struggling to rebuild must be given the funds they need in order to make their homes habitable once more or relocate to an area where there is safe housing. In the long term, California lawmakers need to re-evaluate statues surrounding insurance regulations and work with both the insurance agencies and the homeowners to insure that no California is without fire insurance or being bankrupted as a result.

Limitations of Indices

While CHVIs are extremely useful in highlighting areas of highest sensitivity in a community for targeted interventions there are some limitations. CHVIs bring together a multitude of factors to create one sensitivity score, which can cause confusion for governments or researchers who are trying to see what is driving the vulnerabilities in their communities. With this confusion, it then has the potential to be misinterpreted and utilized in ways that are not appropriate for the community context. In order to combat this limitation in this thesis, the individual vulnerability factor maps have been included and analyzed alongside the sensitivity scores and priority areas. CHVIs take into account many vulnerability indicators and the indicators selected play a large role in determining the results it will produce, therefore the

results of a CHVI are not stagnant and will potentially vary with each iteration (Conlon et. al. 2021). Another limitation of CHVIs is that they are only as place-specific as the data that is available for analysis. While the analysis for this index was done at the block group level, that is still not hyper-localized. If a hyper-localized approach is desired then there must be a push for a shift in the data availability for the vulnerability indicators. The most limiting variable in this CHVI creation was the environmental exposure data, as it was very coarse. The smoke exposure data for CZU Complex Fire was only readily available at the large-scale county level and that greatly impacted the precision that can be assigned for the smoke exposure in each block group. There is a current move in the research to increase the amount of local air-quality monitoring stations, and in future iterations of CHVIs, that data will be important in establishing more granular smoke exposure data.

Looking forward: What needs to be done so that this does not happen again

The CZU Complex Fire was more than a natural disaster for the people of Santa Cruz County, but a health disaster that illuminates the social vulnerability of its people. It is important that the government officials and local citizens prepare both themselves and their communities to be prepared for the increase in wildfires that will be seen because of anthropogenic climate change in California. Vulnerability cannot be analyzed or addressed through just one facet, it is the combinations of various vectors of vulnerability that create the sensitivity makeup for a region. Santa Cruz County illustrates that specific parts of the county are highly vulnerable in very specific ways. In order to support equitable recovery following a wildfire and increase resilience against future fires, mitigation and adaptation measures must meet communities where they are at. This means that the mitigation and adaptation measures must conform to fit into the

vulnerability context for that specific community, not force the entire community to adapt in the same way, as that may not be the vector of vulnerability that was driving their sensitivity.

The five central themes of health geographies that impact the social determinants of health must be sustainably addressed in the near future to fortify Santa Cruz's resilience to wildfires. Neoliberal policies, which create structures such as privatized health and home insurance, deepen social inequalities for those who are unable to spend extensive amounts of money. In the case of Santa Cruz County this has been manifested in homeowners who are then unable to hold home insurance (and thus maintain a mortgage) because private insurers do not want to cover high fire risk areas. It is impossible to have social justice without having climate justice as well, and that requires the identification of the populations of concern in Santa Cruz who are facing the impacts of anthropogenic induced wildfires more severely than others. Underlying social vulnerabilities, such as poverty and discrimination based on race, on no fault of their own, determine a community's ability to recover and rebuild after a disaster such as a wildfire. These must be deconstructed and society must take responsibility for the historical maltreatments of people that have caused the current social injustices. Urbanization is a compounding factor for the social injustices that are plaguing Santa Cruz County and has expanded the gaps of society where people in vulnerable communities fall into. Santa Cruz County needs to shift the thinking from one of analyzing why the individual weaknesses exist and instead focus on adapting the structure that failed the communities in the first place. The final theme of critical health geographies is resistance, resilience and care, which is the theme of health geographies that Santa Cruz County needs to lean on to as they face more climate change impacts. Building resilience to climate change impacts and caring for those who have already been impacted by them in a negative way is the way that Santa Cruz County can incorporate this

theme into their disaster management strategies. Health geographies is a way of framing and analyzing human health by taking into account their site specific characteristics. This same methodology can be applied to analyzing the best course of action for protecting vulnerable populations based on their site specific characteristics.

The social construction of vulnerability is a large determinant of why the CZU Complex Fire was the disaster that it was, and addressing that is one of the key ways to ensure it does not happen again. In order to deconstruct and mitigate the social construction of vulnerability the societal infrastructure that created the vulnerabilities in the first place must be dismantled and rebuilt in an equitable manner. It is in these times that it is important to listen to indigenous perspectives and to those who are a part of the vulnerable communities to develop solutions, rather than attempt to provide a one-size-fits all approach to the unique problems each community faces. These solutions must include both immediate and long-term relief, as addressing the current situation is just as important as establishing protocols to prevent this from occurring again. In the immediate future, it is critical that support through funds, labor or social services must be provided to those who are still actively trying to recover from the CZU Complex Fire. Long term relief can occur in various forms, whether it through the growth of social services, climate action or policies specifically targeted towards wildfires. In the 2022 California midterm elections a proposition focused on providing funding for programs targeting air pollution and wildfires was put on the ballot. Proposition 30 proposes a personal income tax on those who make over \$2 million with the funds being directed into wildfire response and prevention, and zero emission vehicles (LAO, 2022). This proposition demonstrates a longer term solution, in addressing wildfires in California. While this proposition did not pass, it was able to bring wildfire initiatives to the front of voters' minds. Another fire, one that will likely

burn hotter and longer, is on the horizon and Santa Cruz County must fortify their people to be ready to adapt to their new climate altered world.

Conclusion

Anthropogenic climate change is rapidly altering the landscape of the California coast, and another wildfire is on the horizon for Santa Cruz County. This thesis outlines the areas of primary vulnerabilities as it relates to smoke exposure and wildfires, laying the groundwork for formative action to be taken to mitigate these vulnerabilities. The CZU Complex Fire has permanently altered the socioeconomic and physical landscape of Santa Cruz County. The scars left by the fire extend beyond the physical burns left behind by the flames as communities are still actively recovering two years later. Disasters at any scale can worsen vulnerabilities, and the large-scale nature of CZU Complex Fire was a mechanism for that to occur in Santa Cruz. The CZU Complex Fire was more than an environmental disaster, it was a catalyst for the social crisis of health inequity to be illuminated. The community health vulnerability index creates the spatial awareness necessary for understanding the true extent of vulnerability in Santa Cruz. There was no block group in Santa Cruz that did not have some vulnerability in some capacity. Additionally, for many block groups the coexisting nature of vulnerability was made clear as no vulnerability factor exists in a vacuum. Analyzing vulnerability through a health geography lens allows for the connection between human health and place to be more clearly identified. Where one calls home is a considerable determinant when analyzing their health and resilience, and thousands, including myself, call Santa Cruz home. Immediate relief and the long term dismantling of unequal societal structures are necessary to protect the future of those in Santa Cruz County. Wildfire response and recovery plans must be comprehensive and take into account

the unique makeup of Santa Cruz in order to create a more fire resilient community. The community health vulnerability index has made clear that a one size fits all approach to recovery and resilience to wildfires cannot be applied to Santa Cruz County. Community vulnerability is highly personal, and while there may be areas of similar vulnerability they are going to require different mitigation and adaptation measures that are specifically tailored to the vulnerabilities that impact them the most. California and Santa Cruz County have a responsibility to take steps to reduce vulnerability on the local level and improve the quality of health for all of its residents. The CZU Complex Fire provided a window into the future of our planet if social vulnerability and climate change are not taken into account when preparing for disasters.

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Appendix A

Codebook for CHVI Creation

Age

The community health vulnerability index variable for age is operationalized as the percentage of the population over the age of 65. This sociodemographic factor increases individual's vulnerability to wildfire smoke as those who are over the age of 65 are more likely to experience negative health outcomes as a result of wildfire smoke exposure than those who are younger. This variable's data is provided from the American Community Survey using the 2016-2020 5 year estimates.

There are thirteen ACS variables that are required in order to establish the percentage of the population over the age of 65. AMPKE001, AMPKE020, AMPKE021, AMPKE022, AMPKE023, AMPKE024, AMPKE025, AMPKE044, AMPKE045, AMPKE046, AMPKE047, AMPKE048, AMPKE049.

Over the Age of 65 Formula:

$$\frac{((AMPKE020 + AMPKE021 + AMPKE022 + AMPKE023 + AMPKE024 + AMPKE025, + AMPKE044 + AMPKE045 + AMPKE046 + AMPKE047 + AMPKE048 + AMPKE049) / AMPKE001) \times 100}{100} = \% \text{ of population over the age of 65.}$$

Codes:

AMPKE001: Total
AMPKE020: Male: 65 and 66 years
AMPKE021: Male: 67 to 69 years
AMPKE022: Male: 70 to 74 years
AMPKE023: Male: 75 to 79 years
AMPKE024: Male: 80 to 84 years
AMPKE025: Male: 85 years and over
AMPKE044: Female: 65 and 66 years
AMPKE045: Female: 67 to 69 years
AMPKE046: Female: 70 to 74 years
AMPKE047: Female: 75 to 79 years
AMPKE048: Female: 80 to 84 years
AMPKE049: Female: 85 years and over

Social Isolation:

The community health vulnerability index variable for social isolation is operationalized as the percentage of the population over the age of 65 and living alone. This variable's data is provided from the American Community Survey using the 2016-2020 5 year estimates. Individuals who are over the age of 65 and living alone possess a heightened vulnerability to wildfire smoke due to their isolation from others as it may inhibit their ability to respond when exposure to wildfire smoke occurs.

Three ACS variables are required in order to establish the percentage of the population that are over the age of 65 and living alone. These ACS variables are specific to only the population over the age of 65. They are AMQQE001, AMQQE015, and AMQQE019.

Individuals Over the Age of 65 and Living Alone Formula:

$((AMQQE015 + AMQQE019) / AMQQE001) \times 100 =$ % of the population over the age of 65 and living alone.

Codes:

AMQQE001: Total
 AMQQE015: In Households: In Nonfamily Households: Male: Living Alone
 AMQQE019: In Households: In Nonfamily Households: Female: Living Alone

Race/Ethnicity

The community health vulnerability index variable for age is operationalized as the percentage of the population that is non-white. This variable’s data is provided from the American Community Survey using the 2016-2020 5 year estimates. Race/ethnicity is a large contributor to social vulnerability to wildfire smoke due to historical marginalization of non-white communities.

Two ACS variables are required in order to establish the percentage of the population that is non-white, AMPWE001 and AMPWE002. The work plan for this variable is $(Total\ Population - White\ Alone) / Total\ Population \times 100$.

Population that is Non-White Formula:

$(AMPWE001 - AMPWE002) / AMPWE001 \times 100\% =$ % of the population that is non-white

Codes:

AMPWE001: Total Population
 AMPWE002: White Alone

Language Barrier

The community health vulnerability index variable for language is operationalized as the percentage of limited English households. This is defined as the households who are without someone over the age of 14 who speaks English well or very well. If all people over the age of 14 speak a language other than English and do not speak English well or very well it is a limited English household (ACS). This sociodemographic factor increases an individual's vulnerability to wildfire smoke because emergency notifications go out primarily in English and being able to understand the language of notification is essential to responding to the message. This variable’s data is provided from the American Community Survey using the 2016-2020 5 year estimates.

There are five ACS variables that are needed in order to establish the percentage of limited English households. These variables are AMZLE001, AMZLE004, AMZLE007, AMZLE010, and AMZLE014.

Language Barrier Formula:

$((AMZLE004 + AMZLE007 + AMZLE010 + AMZLE014) / AMZLE001) \times 100 = \% \text{ of Limited English Hosuseholds '}$

Codes:

AMZLE001: Total
AMZLE004: Spanish: Limited English Speaking Household
AMZLE007: Other Indo-European Languages: Limited English Speaking Household
AMZLE010: Asian and Pacific Island Languages: Limited English Speaking Household
AMZLE014: Other Languages: Limited English Speaking Household

Poverty Status

The community health vulnerability index variable for poverty status is operationalized as the percentage of households with income below the poverty line in the past 12 months. This sociodemographic factor increases individual’s vulnerability to wildfire smoke as those who are below the poverty line have a decreased capacity to respond to wildfires, whether that be through evacuating or rebuilding following the fire. This variable’s data is provided from the American Community Survey using the 2016-2020 5 year estimates.

There are two variables that are needed in order to establish the percentage of households below the poverty level in the past 12 months. These variables are AMR5E001 and AMR5E002.

Households Who Fall Under The Poverty Line In The Last 12 Months Formula:

$(AMR5E002/AMR5E001) \times 100 = \% \text{ of households with income below the poverty line in the past 12 months}$

Codes:

AMR5E001: Total Households
AMR5E002: Income in the past 12 months below the poverty line

Educational Attainment

The community health vulnerability index variable for educational attainment is operationalized as the percentage of the population who are above the age of 25 without a high school diploma. This sociodemographic factor increases individual’s vulnerability to wildfire smoke as those who have a lower educational attainment are typically less likely to have the resources or the means to respond to disasters. This is due to many societal structures that make it difficult for those without a high school diploma. This variable’s data is provided from the American Community Survey using the 2016-2020 5 year estimates.

There are fifteen variables needed in order to establish the percentage of the population over the age of 25 without a high school diploma. The codes are reference to the highest level of

schooling completed. AMRZE001, AMRZE002, AMRZE003, AMRZE004, AMRZE005, AMRZE006, AMRZE007, AMRZE008, AMRZE009, AMRZE010, AMRZE011, AMRZE012, AMRZE013, AMRZE014, AMRZE015, and AMRZE016.

Educational Attainment Formula:

$((AMRZE002 + AMRZE003 + AMRZE004 + AMRZE005 + AMRZE006 + AMRZE007, AMRZE008 + AMRZE009 + AMRZE010 + AMRZE011 + AMRZE012 + AMRZE013 + AMRZE014 + AMRZE015 + AMRZE016) / AMRZE001) \times 100 = \% \text{ of the population who are above the age of 65 without a high school diploma.}$

Codes:

AMRZE001: Total	AMRZE009: 5th Grade
AMRZE002: No schooling completed	AMRZE010: 6th Grade
AMRZE003: Nursery School	AMRZE011: 7th Grade
AMRZE004: Kindergarten	AMRZE012: 8th Grade
AMRZE005: 1st Grade	AMRZE013: 9th Grade
AMRZE006: 2nd Grade	AMRZE014: 10th Grade
AMRZE007: 3rd Grade	AMRZE015: 11th Grade
AMRZE008: 4th Grade	AMRZE016: 12th Grade, no diploma

Vehicle Access

The community health vulnerability index variable for vehicle access is operationalized as the percentage of occupied housing units with no vehicle available. This sociodemographic factor increases individual’s vulnerability to wildfire smoke as those who do not have access to vehicles will have more difficulty evacuating zones where there is an active wildfire or areas of high smoke concentration. The inability to evacuate quickly can lead to prolonged exposure to the harmful pollutants in the smoke and can lead to potentially increases in negative health consequences. This variable’s data is provided from the American Community Survey using the 2016-2020 5 year estimates.

There are three variables that are needed in order to establish the percentage of households that are without vehicles. These variables take into account owner and renter occupied housing units. The variables are AMVHE001, AMVHE003 and AMVHE010.

Access to Vehicles Formula:

$((AMVHE003 + AMVHE010) / AMVHE001) \times 100 = \% \text{ of households without access to vehicles}$

Code:

AMVHE001: Total
AMVHE003: Owner Occupied: No Vehicle Available
AMVHE010: Renter Occupied: No Vehicle Available

Internet Access

The community health vulnerability index variable for internet access is operationalized as households with no internet access. This sociodemographic factor contributes to one's vulnerability to wildfire smoke because in households in remote areas without reliable cell service the internet becomes one of the only ways for information to be conferred. Households who do not have access to the internet are then at a higher risk of not learning about developing wildfires or unsafe air conditions. This can lead to an increased risk in smoke related illness as without learning about unsafe conditions it can lead to prolonged exposure. This variable's data is provided from the American Community Survey using the 2016-2020 5 year estimates.

There are two ACS variables that are required for the percentage of households without internet access to be established. These variables are AMW9E001 and AMW9E008.

Access to the Internet Formula:

$(AMW9E008 / AMW9E001) \times 100 = \% \text{ of}$
households without access to internet

Codes:

AMW9E001: Total
AMW9E008: No Internet Access

Outdoor Workers

The community health vulnerability index variable for outdoor workers is as the percentage of population who work in fields where a majority of the work is likely to have been done outside. In the case of this community health vulnerability index and the literature review specific to California this will include workers in agriculture, forestry, fishing, hunting, mining, and construction. This is an important socio-demographic variable for Santa Cruz County where there are many individuals who work primarily outdoors. Working outdoors during a fire increases the risks of smoke related illness and they are considered a vulnerable population due to the common comorbidities of poverty and language barriers. It is important to note for outdoor workers specifically that the number may be underreported due to worries about citizenship by those who are undocumented.

There are five ACS variables needed to determine the percentage of the population who are outdoor workers. These variables are AMZZE001, AMZZE003, AMZZE006, AMZZE030, and AMZZE033.

Outdoor Workers Formula:

$((AMZZE003 + AMZZE006 + AMZZE030 + AMZZE033) / AMZZE001) \times 100 = \% \text{ of}$
population who work primarily outdoors

Codes:

AMZZE001: Total
AMZZE003: Male: Agriculture, Forestry,
Fishing, Hunting and Mining
AMZZE006: Male: Construction
AMZZE030: Female: Agriculture, Forestry,
Fishing, Hunting and Mining
AMZZE033: Female: Construction

Housing Stability and Instability

Housing stability, lack of, is an important adaptive capacity fire when it comes to recovery from wildfires. This is an understudied aspect when it comes to wildfire recovery and vulnerability to future climate change impacts. Housing stability as a vector of adaptive capacity will be defined as the percentage of households that own their homes, while housing instability is defined as the percentage of householders who rent their homes. This distinction is important because it determines a householders ability to apply and receive homeowners insurance or emergency relief. The values for these variables are provided by the 2016-2020 5-year estimates from the American Community Survey.

There are three variables that are needed in order to determine the percentage of the householders that either rent or own their homes. These variables are AMUFE001, AMUFE002, and AMUFE003.

Housing Instability Formula:

$(AMUFE003 / AMUFE001) \times 100 = \% \text{ of}$
householders who rent their homes

Codes:

AMUFE001: Total

AMUFE002: Owner Occupied

AMUFE003: Renter Occupied

Appendix B

R-Script Code for Initial Principal Component Analysis

```
#load data
data("CZU")

#scale data
CZU.scaled <- scale(CZU, center= TRUE, scale = TRUE)

#perform a spearman correlation test
CZU.spear <- cor(CZU,method= "spearman")

#table of spearman correlation results
print(CZU.spear)

#calculate eigenvectors/eigenvalues of the correlation matrix
res.eig <- eigen(CZU.spear)
res.eig

#transpose eigenvectors
eigenvectors.t <- t(res.eig$vector)

#calculate principal components
PCA_Results <- prcomp(CZU.spear, center= TRUE, scale= TRUE)

#varimax rotation
varimax10 <- varimax(PCA_Results$rotation[,1:10])

#reverse the signs
PCA_Results$rotation <- -1*PCA_Results$rotation

#display principal components
PCA_Results$rotation
#show summary of PCA
summary(PCA_Results)
```

Appendix C

Table 1: Spearman Correlation Coefficients

	Age (>65)	Social Isolation	Race/Ethnicity	Language Barrier	Educational Attainment	Below Poverty	No Access to Vehicle	No Access to Internet	Outdoor Workers	Housing Instability
Age (>65)	1.00									
Social Isolation	0.30	1.00								
Race/Ethnicity	-0.53	-0.15	1.00							
Language Barrier	-0.24	-0.17	0.55	1.00						
Educational Attainment	-0.33	-0.24	0.64	0.60	1.00					
Below Poverty	-0.37	-0.08	0.36	0.26	0.27	1.00				
No Access to Vehicles	-0.07	-0.01	0.26	0.22	0.19	0.30	1.00			
No Access to Internet	-0.05	0.07	0.35	0.38	0.41	0.17	0.28	1.00		
Outdoor Workers	-0.20	-0.23	0.42	0.43	0.55	0.07	0.18	0.32	1.00	
Housing Instability	-0.53	-0.09	0.40	0.24	0.20	0.54	0.35	0.09	-0.04	1.00

Appendix D

Eigenvalues for the Principal Components

Principal Component	Eigenvalue
Principal Component 1	3.67
Principal Component 2	1.57
Principal Component 3	1.26
Principal Component 4	0.82
Principal Component 5	0.60
Principal Component 6	0.56
Principal Component 7	0.53
Principal Component 8	0.38
Principal Component 9	0.33
Principal Component 10	0.27

For this principal component analysis and factor analysis the Kaiser Criterion was utilized to drop any principal component with an eigenvalue < 1 . This leaves three principal components for the analysis.

Appendix E

R-Script Code for Factor Analysis and Creation of Estimated Factor Scores

```
#Read Data
CZU <- data(CZU_fa)

#Conduct Factor Analysis on CZU Sensitivity Factors
Nfacs <- 3
fit <- factanal(CZU_fa, Nfacs, rotation= "varimax")
print(fit, digits=2, cutoff=0.3, sort=TRUE)

#Establish Estimated Factor Scores
factor_s <- factor.scores(CZU_fa, fit, Phi = NULL, method = c("Thurstone"), rho=NULL,
impute="none")
print(factor_s)

#Display Loadings Diagram for Principal Components
library(psych)
loads <- fit$loadings
fa.diagram(loads)
```

Appendix F

Results from the Factor Analysis

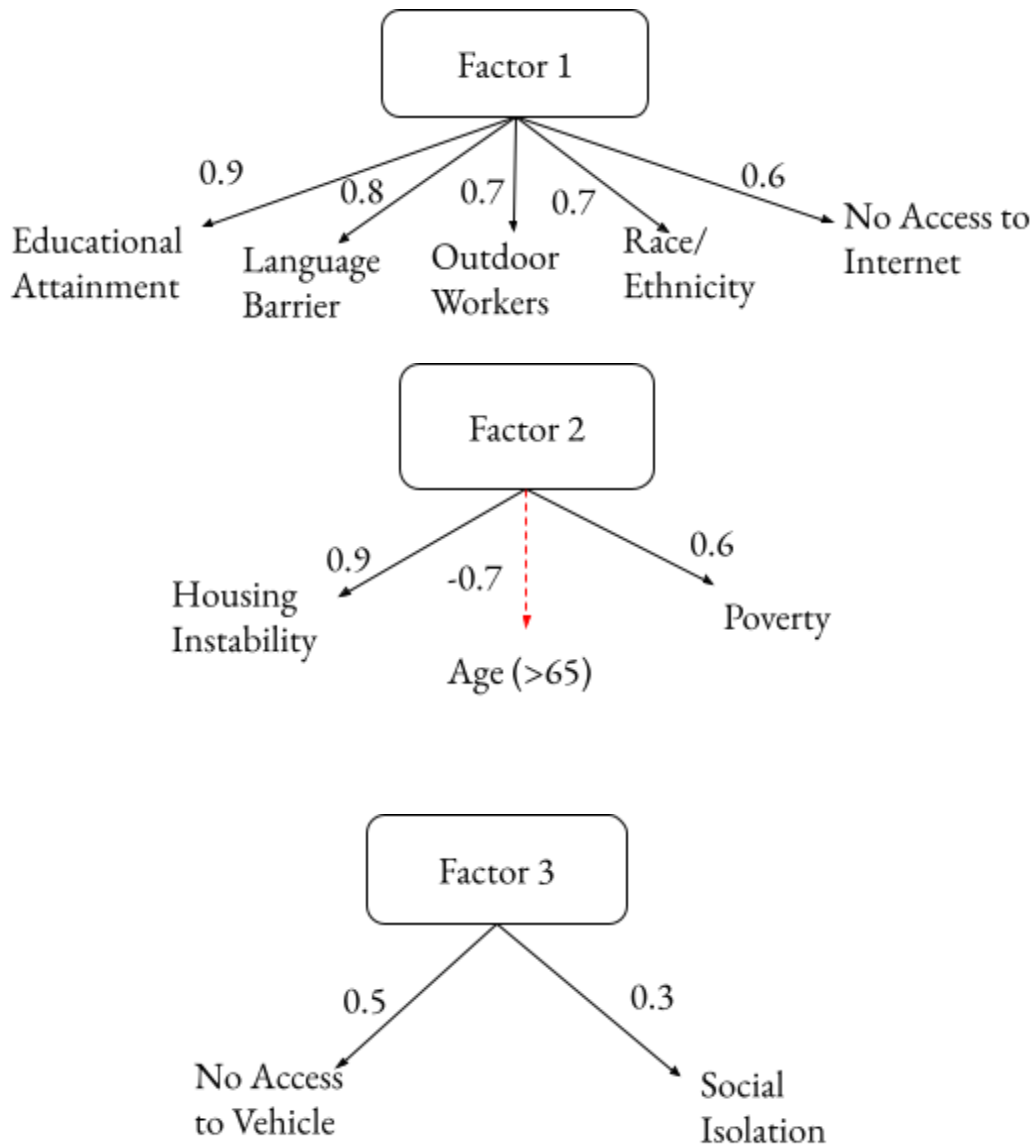
Uniquenesses:

Age (>65)	Social Isolation	Race/Ethnicity	Language Barrier
0.38	0.88	0.29	0.24
Educational Attainment	Poverty	No Vehicle Access	No Internet Access
0.05	0.61	0.66	0.58
Outdoor Workers	Housing Instability		
0.41	0.13		

Factor Loadings for the 3 Retained Varimax-Rotated Factor:

	Factor 1	Factor 2	Factor 3
Race/Ethnicity	0.68	0.48	
Language Barrier	0.80	0.33	
Educational Attainment	0.93		
No Access to Internet	0.60		
Outdoor Workers	0.73		
Age (>65)		-0.69	0.33
Poverty		0.55	
Housing Instability		0.86	0.33
Social Isolation			0.34
No Access to Vehicle		0.31	0.47

Factor Loadings Diagrams:



Appendix G

Kaiser-Meyer-Olkin Factor Adequacy Test

R-Script for KMO Test:

```
#Run Kaiser-Meyer-Olkin Factor Adequacy  
library(psych)  
KMO(CZU_fa)
```

Results:

Call: KMO(r = CZU_fa)

Overall MSA = 0.8

MSA for each item:

Age (>65)	0.77
Social Isolation	0.56
Race/Ethnicity	0.87
Language Barrier	0.85
Educational Attainment	0.78
Poverty	0.85
No Access to Vehicle	0.66
No Access to Internet	0.83
Outdoor Workers	0.85
Housing Instability	0.70

This test is to confirm if the variables are suitable for factor analysis. An unacceptable MSA would be any value less than 0.5. All factors pass the KMO test and the factor analysis results stand.