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Comparing Heatwave Related Mortality Data from Distressed Counties to Affluent Counties in Central and Southern Central Appalachia

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Comparing Heatwave Related Mortality Data from Distressed Counties to Affluent Counties in Central and Southern Central Appalachia

By

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An Undergraduate Thesis Submitted in Partial Fulfillment
of the Requirements for the
Honors-in Environmental Health Program
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Miranda T. Pardue Date

Dr. Ying Li, Thesis Mentor Date

Dr. Kurt J. Maier, Reader Date

Abstract

The Appalachian Mountains are home to some of the most culturally rich places in the United States, but also some of the most impoverished communities as well. Several recent events support climate change across the globe. It is expected that Appalachian communities may suffer more dire consequences, as many communities lack strategies to help relieve some of the worst effects of climate change. Heatwaves are predicted to increase in duration and frequency over time, and communities that are not well prepared for the damaging effects of heatwaves can suffer unduly. This study aims to quantify the likelihood that people living in economically distressed counties in the Central and Southern Central regions of Appalachia will face heatwave related mortality more intensely than those who live in more affluent counties in the same regions. Twelve counties from each socioeconomic group have been selected based on the county economic status to analyze climate and mortality data over thirty-eight years starting in 1981 and ending in 2018. Data was collected during the warm season for each county, May 1st to September 30th, and compared to the mortality data from the same county during the same warm season. This study used all-cause mortality numbers from each of the twenty-four counties for the mortality data. The relative risk for each county in both the distressed and affluent categories was calculated. The average relative risk for each socioeconomic status were then compared. The results of this study did not show statistical significance in the likelihood that being in a socioeconomically distressed county increases one's chances of succumbing to heatwave related mortality in the Central and Southern Central regions of Appalachia. More research with larger sample sizes and more attention paid to the factors driving socioeconomic status is needed to better assess the relationship of heatwave mortality to socioeconomic status.

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Dedication

This thesis is, in part, dedicated to my peers and mentors of the Environmental Health Department of East Tennessee State University. The friendship, advice, and mentorship of the ENVH community have been so influential and essential to the completion of my life goals and personal growth. The relationships that have been cultivated over my four years are ones that I will remember and cherish, always. May the culture of the department continue to raise the bar and create the very best professionals in the field of Environmental Health.

Finally, this thesis is dedicated to my family, whose love and encouragement has inspired me to never give up. Thank you for the continual support and confidence in my capabilities. Thank you for all the phone calls, care packages, and letters, and thank you for all the badgering over the years, as I am sure I would not be the woman I am today without it.

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First and foremost, I would like to thank Dr. Ying Li, my research mentor. I cannot thank you enough for the support and guidance you have provided during the entire process, and I am so incredibly grateful for you allowing me to be your first undergraduate thesis advisee.

I would also like to thank Dr. Andrew Joyner from the Geosciences Department of East Tennessee State University as his help with the climate data downloading and analyses, as well as his help in the creation of a map, were essential to this research.

Finally, I would like to thank my academic advisor, Dr. Kurt Maier, for all of his words of wisdom and “prodding” over the years. I know I am a better student and overall person as a result of his guidance.

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Chapter 1

INTRODUCTION

The unique Appalachian culture is characteristic of hundreds of years of the strife and struggle on the backs of the hard-working people who call the Appalachian Mountains their home. The distinctive way of life is under threat from many different factors, but none are as duplicitous as the rising temperatures the region faces due to climate change. The systemically impoverished people who have inhabited the various regions of Appalachia have lived in poverty for generations. However, those people are now beginning to see the effects of climate change on the home front. Increased duration, frequency, and intensity of heatwaves are one of the many side effects of a rapidly changing climate, and the implications and changes the heatwaves can bring about could result in unchecked disaster for Appalachian residents.

Climate change is regarded as the defining moral issue of the 21st century with the consequences of which will affect future generations for ages to come (Levy & Patz, 2015). The consensus amongst the scientific community is that the world is, in fact, warming, and this is due to a rapid increase of anthropogenic sources polluting the atmosphere. The mass industrialization of multiple countries throughout the world has led to an unprecedented spike in carbon dioxide production (amid other greenhouse gases) that coincides with recent warming trends in data. In the United States alone, average temperatures have increased by 1.3°F to 1.9°F since record-keeping began in 1895 (Sarofim, et al., 2016). The Earth's climate has warmed by 0.6 C over the past 100 years, and it is continuing to rise (Walther, et al., 2002). Although the numbers seem insignificant, the reality of the situation is that such minute changes can have a drastic effect on Earth's biota. Evidence shows how recent climate change affects a broad range of organisms residing in diverse geological locations (Walther, et al., 2002).

The effects of global warming are all-encompassing. Extreme droughts and extreme floods will be occurring simultaneously across the globe, affecting millions of people. One of the biggest concerns of the rapidly changing climate is heatwaves. Heatwaves are prolonged periods of hot weather, and their intensity and frequency are increasing as the climate continues to change. In the United States, heatwaves are responsible for more annual fatalities than any other extreme weather event (Habeeb, Vargo, & Stone Jr, 2015). The findings of one study have confirmed that the frequency, duration, timing, and intensity of heatwaves are increasing across the country over fifty years (Habeeb, Vargo, & Stone Jr, 2015). Heatwave related illness and injury were also seen to increase (Habeeb, Vargo, & Stone Jr, 2015). The intensity of heatwaves can have severe consequences that affect all components of an ecosystem and even the Earth. Recently, prolonged and severe heatwaves and droughts are causing large-scale losses in carbon uptake and productivity (Ph. Ciais, 2005), which will inevitably result in ecosystem stress, reduced biological activity, and a positive feedback loop involving carbon (Williams, 2014). Heatwaves even affect oceans, as heatwaves are causing drastically warmer temperatures under the waves affecting marine biodiversity (Gibbens, 2019).

Humans are also threatened by rising temperatures, especially in the summer months. Whether it is direct or indirect, heatwaves can have severe effects on human health. Heatwaves can directly impact human health by aggravating pre-existing conditions, the immunocompromised, and young children and the elderly. In July of 1995, the event of a heatwave killed 522 people in Chicago alone (Adams, n.d.), and the Center for Disease Control has found that 384 people were killed each year due to excessive heat annually during the years of 1979 – 1992 (NOAA, 1995). Those at the most considerable risk were urban-dwelling elderly without access to air-conditioned environments (Adams, n.d.).

Humans can suffer direct consequences of extreme heat events due to the body's response to high temperatures as the human body is a complicated arrangement of intermingling cells that have evolved from intermingling chemicals. Arguably, the most important structure found in the human body (and many other places) is the protein, which accounts for about 50% of the organic material in the body (Widmaier, Raff, & Strang, 2016). Proteins have a crucial function in almost every physiological and homeostatic process from the regulation of gene expression to providing structural support for tissues and organs (Widmaier, Raff, & Strang, 2016). Despite the importance to the body, proteins are relatively fragile structures that can be denatured by high temperatures or variations in pH. High temperatures, especially like those found during the summer months, can be devastating to outside workers such as those who work on farms.

As average temperatures rise in the United States, the chances increase for a heat overload to occur on the feedback system responsible for maintaining a stable temperature in the body. Should a worker be exposed to the heat for prolonged periods, the body could experience a heatstroke, the consequences of which could be devastating. During a heat stroke, thermal stress can cause apoptosis or programmed cell death, with protein denaturation being the leading cause of such an event. As temperatures increase, the rate of damage increases; while this process may be reversible, denatured proteins ultimately form aggregates which disrupt normal cellular function and prevent replication, and ultimately cell death (Walter & Carraretto, 2016). Without treatment, a heatstroke will lead to organ failures and, eventually, death. Those most at risk of heat-related illness and injury are those over the age of 75, infants and young children, the overweight and obese, those with chronic illness, the pregnant or breastfeeding, the homeless, the socially isolated, those working in hot environments, and those exercising vigorously in the heat.

Indirect human health effects of heatwaves include transportation, agriculture, energy, and water resource impacts (Adams, n.d.). Extreme heat events cause aircraft to lose lift, which can result in airport closings or potentially downed aircraft (Adams, n.d.). The infrastructure of roads and highways are affected by extreme heat events; the events cause the asphalt to soften and concrete roads to "explode." This can cause roads to physically lift from the ground three to four feet in the air, which can cause car accidents and severe traffic jams (Adams, n.d.). During a 1980 heat event, hundreds of miles of roads across the country buckled due to an extreme heat event (NOAA, 1980). Motorized vehicles also face stress due to high temperatures as their cooling systems struggle to keep up, and train rails can develop kinks and distortions during extreme temperature events resulting in train backups and potentially de-railings.

Many agricultural practices are sensitive to high temperatures. Much like humans, livestock can be severely impacted by extreme heat events, especially birds and poultry. Millions of birds are lost during heatwaves resulting in a decrease in quantity and quality of food products. The effect of heatwaves on crops and crop yields is harder to enumerate due to the fluctuations in temperature day to day and week to week, so it is unclear to know if the reduction in crop yields is a result of a few days of high temperatures or just above average summer temperatures (Adams, n.d.). Although, certain key cash and nutrient crops are more susceptible to heat stress than others. The protein content of wheat grain has been shown to vary in response to changes in temperatures, especially with higher temperatures (Schubert, 2014). High temperatures during key stages of plant development in plants like rice, maize, potato, and soybean can result in crop yield reductions as well (Adams, n.d.).

It is prevalent for an increase in power outages to be seen during the summer months due to an increase in air conditioning use. However, high temperatures can affect electricity transmission, storage, and distribution systems (U.S. Department of Energy, 2013). As climate change continues to worsen, the extreme events that weaken the electricity systems are increasing. Electricity grids cannot handle prolonged periods of hot weather, and it results in transformer burnouts and power line failures (U.S. Department of Energy, 2013).

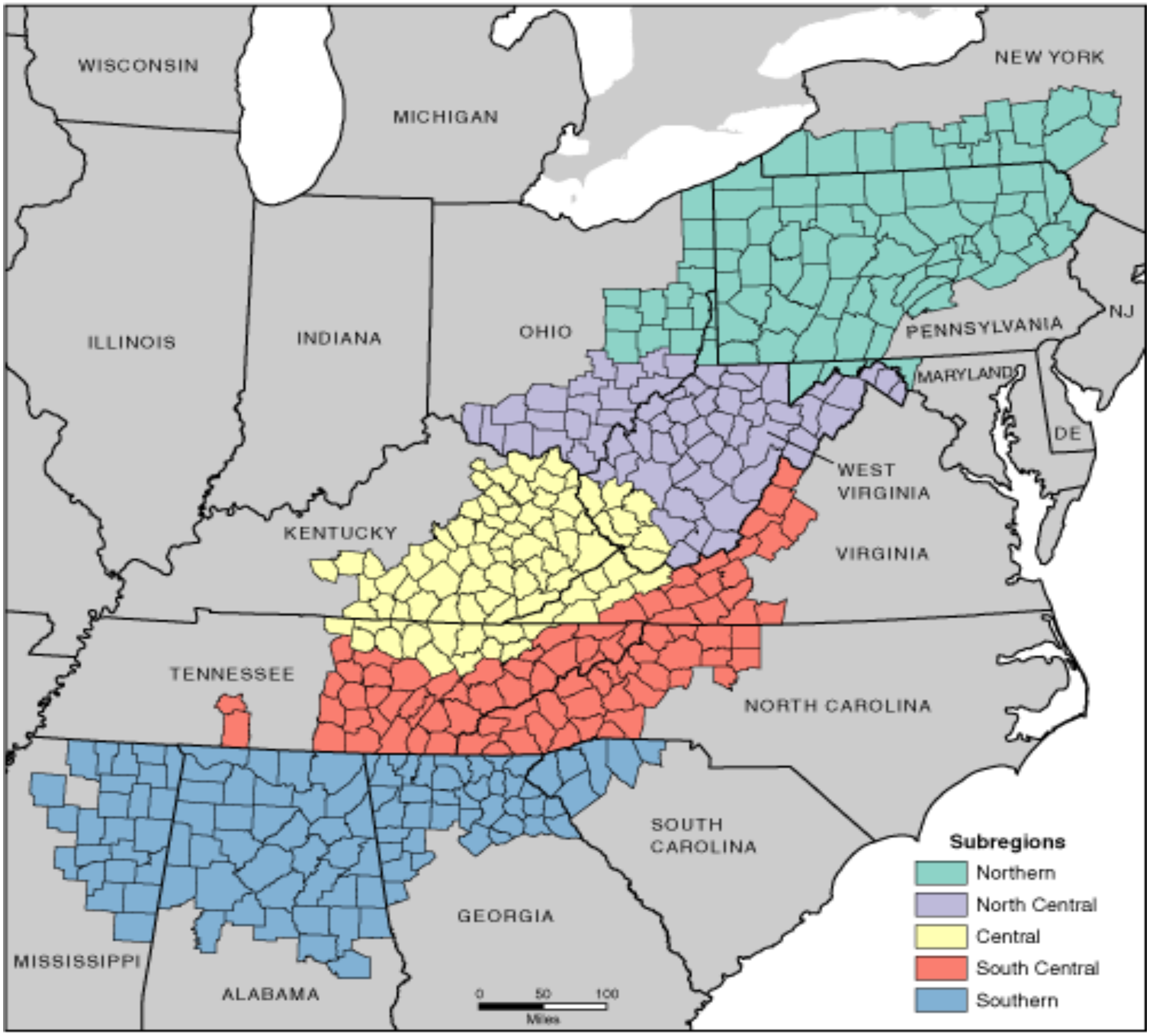
The most important indirect consequence of extreme heat events is water scarcity as a result of increased evaporation. Water is a crucial necessity for all human life, and climate change is accelerating the loss of drinkable surface and groundwater reserves. Climate change is worsening droughts' frequency, intensity, and duration, and heatwaves play a significant role in the evaporation of water (U.S. Department of Energy, 2013). The increasing temperatures will increase the rate of water evaporation, which will result in faster water loss. This will result in a reduction of water available for hydropower (U.S. Department of Energy, 2013). The reduction in hydropower will indirectly affect those populations who rely on hydropower for electricity. This can lead to higher rates of heat-based mortality in the future as many individuals need that electricity to fuel mitigating heatwave strategies.

There are more factors involved with the dangers of heat-related illness than just temperature. Humidity, wind speed, and fluctuations in solar activity all have the potential to influence trends in heat-related mortality. However, it is difficult to assess the severity of heatwaves nationwide due to the climate variations region to region. This means that the climate in the northwestern part of the country is different from the climate in the southeastern part of the country. These deviations will skew data on a national level, so it is best to perform this kind of study on a regional level in order to obtain more accurate data and draw conclusions from it.

Many risk factors influence the likelihood of heatwave vulnerability. Age, gender, socioeconomic status, remoteness, and geographical locations are all factors considered in assessing the heatwave vulnerability of populations. This study aims to focus on determining the influence socioeconomic status has on heatwave mortality in the central and southern central regions of Appalachia. There is evidence from recent U.S. studies that conclude that the rise in temperatures can result in a higher incidence of premature deaths, and there is evidence that being of low socioeconomic status has a role in heatwave mortality. However, the connection is multifaceted and difficult to ascertain (Sarofim, et al., 2016).

GOALS & OBJECTIVES

This study examines climate data and mortality data to ascertain the extent to which two regions of Appalachia are affected by the changing climate temperatures. The two regions of concern are central and southern central Appalachia which are shown in yellow and orange in **Figure 1** below (Appalachian Regional Commission, 2009).



Map by: Appalachian Regional Commission, November 2009.

Figure 1 Map and Regions of Appalachia. Reprinted from "County Economic Status in Appalachia", Appalachian Regional Commission, (2018, August). https://www.arc.gov/research/MapsofAppalachia.asp?MAP_ID=148

The main goal of this study is to investigate the trends of heatwaves over the last several decades and determine if socioeconomic status can be correlated to total mortality numbers during a heatwave in the specific regions of central and southern central Appalachia. It is hypothesized that the economically distressed counties will have a higher heatwave mortality relative risk than more affluent counties. This study aims to provide the foundations of research for Appalachian heatwave mortality rates, and it is meant to provide the basic structure and research design for future analyses.

BACKGROUND & LITERATURE REVIEW

The Appalachians

The regions encompass Tennessee, Kentucky, North Carolina, Virginia, and West Virginia. These regions are rich with high-value resources like coal, natural gas, and timber that have provided jobs to the residents of the regions for two centuries. Regardless of the resources available, the regions have been experiencing economic distress and poverty for decades (Housing Assistance Council, 2009). The region is also experiencing a phenomenon termed the "brain drain," as educated individuals are leaving the area in order to find more prosperous areas that have more opportunities (Housing Assistance Council, 2009). The "brain drain" effect leaves the regions without the new professional and leadership skills that have developed with the younger, educated people of the area. This leaves behind the older generations, and this also creates a unique set of problems as the older generations often need specialized healthcare and other related services.

The most critical setback for central and southern central Appalachia is the startling poverty and economic distress rates in the region (Appalachian Regional Commission, 2018).

Each county within the regions is classified into one of five economic categories, as noted in Figure 2: distressed, at-risk, transitional, competitive, and attainment (Appalachian Regional Commission, 2018). Distressed is defined as the most economically depressed counties, and they are ranked in the worst ten percent of the nation's counties (Appalachian Regional Commission, 2018). At-risk is defined as the counties that are at risk of becoming distressed, and they rank in the worst ten to twenty-five percent of the nation's counties (Appalachian Regional Commission, 2018). Transitional is defined as the counties that are transitioning between strong and weak economies, and they rank between the worst twenty-five percent and the best twenty-five percent of the nation's counties (Appalachian Regional Commission, 2018). Competitive is defined as the counties that are able to compete in the national economy, and they are ranked in the best ten to twenty-five percent of the nation's counties (Appalachian Regional Commission, 2018). The final category is attainment, which is defined as the economically most robust counties, and they rank in the best ten percent of the nation's counties (Appalachian Regional Commission, 2018).

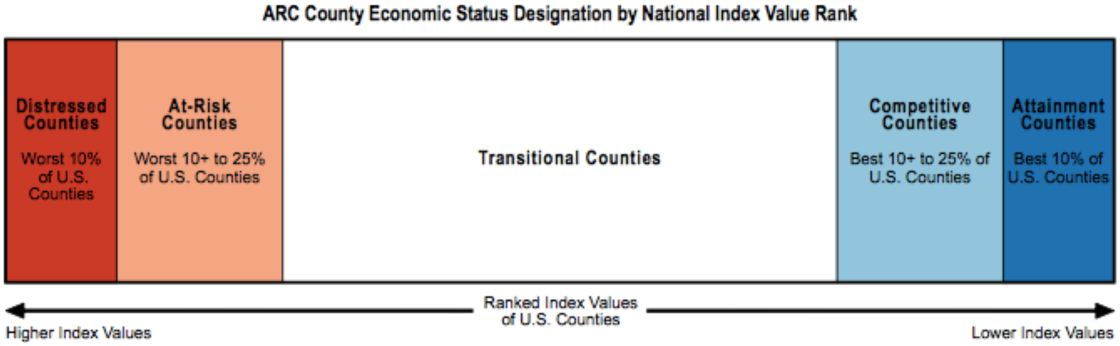
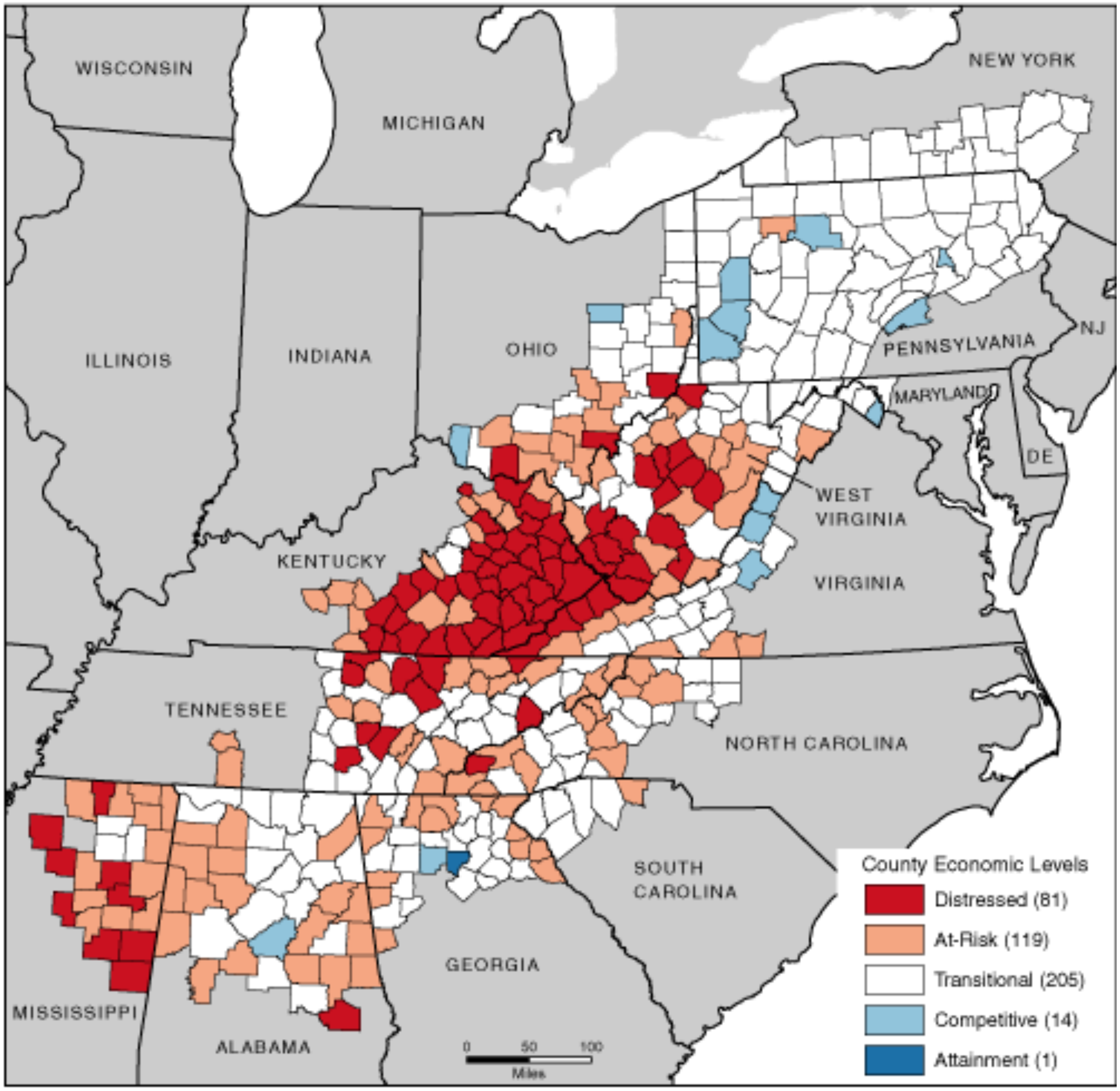


Figure 2 Index Value Rank Distribution Reprinted from "County Economic Status in Appalachia", Appalachian Regional Commission, (2018, August). https://www.arc.gov/research/MapsofAppalachia.asp?MAP_ID=148

The counties colored in red are the counties that are defined as distressed. The counties colored in a peach color represent the at-risk counties. The counties colored white are transitional. The counties colored light blue are competitive, and the counties colored dark blue are counties that are in the attainment category.



Created by the Appalachian Regional Commission, August 2018
Data Sources:
Unemployment data: U.S. Bureau of Labor Statistics, LAUS, 2014–2016
Income data: U.S. Bureau of Economic Analysis, REIS, 2016
Poverty data: U.S. Census Bureau, American Community Survey, 2012–2016

Effective October 1, 2018
through September 30, 2019

Figure 3. County Economic Status Reprinted from "County Economic Status in Appalachia", Appalachian Regional Commission, (2018, August). https://www.arc.gov/research/MapsofAppalachia.asp?MAP_ID=148

Based on Figure 3 (Appalachian Regional Commission, 2018), central Appalachia suffers one of the worst economically distressed county concentrations out of all of Appalachia with a total of fifty-four categorically distressed counties. Southern central Appalachia has five categorically distressed counties. As a result of the high concentration of categorically distressed counties, the poverty rate in south-central and central Appalachia is also high compared to the rest of the nation. The nation's poverty rate average is 15.1 % as of 2016 data, and the poverty rate for all of Appalachia is 16.7 %, with the highest concentration of poverty being in central Appalachia. The high poverty rates in the Appalachian area can be attributed to the lack-luster mineral extraction industry that used to be the life-blood of the Appalachian region. Many of the central Appalachian residents used to be directly or indirectly involved with the booming coal industry. However, with advancing technology, the amount of labor needed to extract coal efficiently has decreased exponentially. Now, the industry employs around three percent of residents in the region, and the heavy reliance on the shrinking industry has left Appalachia without alternative employment options (Housing Assistance Council, 2009). Without the necessary funding, those who are impoverished face more severe consequences of exposure to heatwaves.

Temperatures were recorded in the central Appalachian region from the year 1901 to the year 2011, and it was found that the minimum temperatures of the region had increased by 1.1F (Butler, 2015). It was also found that both minimum and maximum temperatures were rising in the months of April and November, and across the region, the rainfall had increased by 2.3 inches (Butler, 2015). Appalachia is dealing with the repercussions of climate change now, and many of the inhabitants are not prepared for the threats of the changing climate. Those who are impoverished and isolated are the ones who suffer most in prolonged heat. A combination of climate change and a lack of funding for intense heat mitigating essentials has resulted in a new inequality issue, and those who cannot afford the essentials are more likely to suffer from heatwaves than those who are more economically advantaged. The energy industry that has rooted itself in the Appalachian Mountains has depleted many of the natural resources that would have helped mitigate the oncoming onslaught of heatwave effects (Karfakis, Lipper, & Smulders, 2012). The adverse reaction of unchecked industry and poverty with climate change has left Appalachian natives in a dangerous situation concerning heatwaves and heat mortality. This study aims to quantify how much more the counties that are categorically distressed are compared to those that are not by comparing climate data and mortality data.

Socioeconomic Status and Heatwaves

Heatwaves, which are among the most impactful naturally occurring events to society, are increasing in their frequency, duration, and magnitude across the globe (World Health Organization, 2018). The most significant burden of heatwave morbidity and mortality are felt most poignantly with those who are physiologically impaired, those who are socially isolated, those who are of low socioeconomic status, and those who are older, typically 75+ years of age (Schifano, et al., 2009). Despite being commonly described as a contributing factor to one's increased morbidity and mortality risk in a heatwave, there is not an abundance of studies showing significant evidence contributing to the theory. This could be due to poor study design, various biases, and confounding factors impeding the effectiveness of the research. There is also no set definition of socioeconomic status because it is a broad concept that can include many factors like education, attainment, occupation, income, wealth, and deprivation (Andrew, 2010). For the scope of this study, socioeconomic status is a result of where the county falls on the federal poverty line.

A study performed in Europe showed that socioeconomic status was a vulnerability to morbidity and mortality during heatwaves (Michelozzi P, 2005). A study measuring the differences of heatwave mortality by sociodemographic and urban landscape characteristics found both of those characteristics to be associated with mortality risk during heatwaves (Xu Y, 2013). A study performed in Seoul suggested that residents with no education were particularly vulnerable to heatwave mortality, and education might be an indicator of low socioeconomic status (Son, Lee, Anderson, & Bell, 2012). However, a follow-up study conducted in Rome found that there was not enough evidence to support the rejection of the null hypothesis that socioeconomic status was a factor in heatwave morbidity and mortality (Schifano, et al., 2009), and a study performed in São Paulo, Brazil found little evidence that heatwave stress on mortality was different according to the socioeconomic status (Gouveia, Hajat, & Armstrong, 2003).

Chapter 2

MATERIALS & METHODS

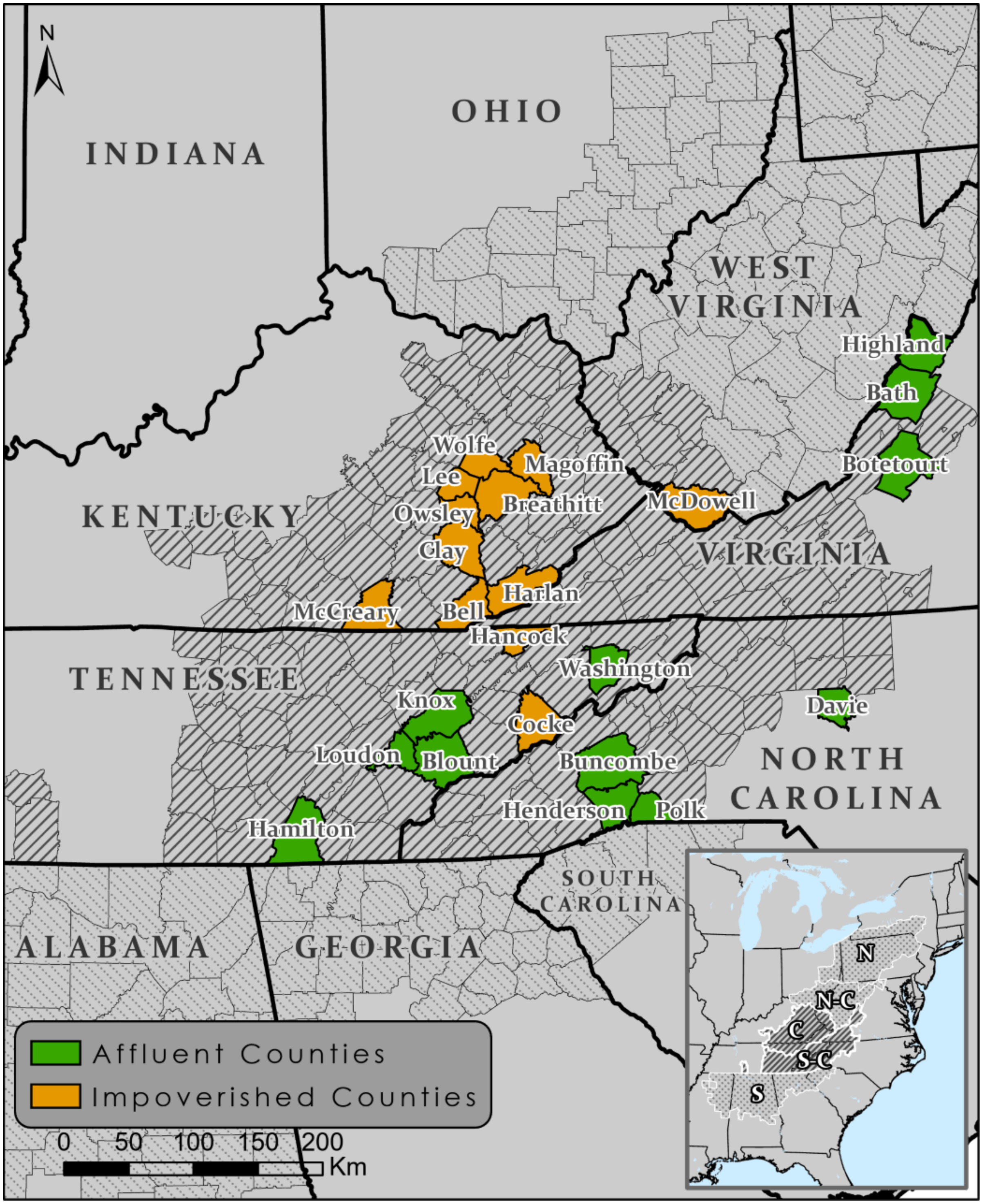


Figure 4. Map of Affluent and Impoverished Counties. Note: Impoverished is interchangeable with Distressed

Purpose

The purpose of this study was to determine if socioeconomic status has any effect on the likelihood of an individual dying during a heatwave due to complications as a direct or indirect result of the heatwave in the central and southern central Appalachian Regions. The first task was to determine the twelve most distressed and twelve most Affluent counties in the selected Appalachian region. The second task was to ascertain the quantity and frequency of heatwaves within those twenty-four counties and then to select a definition that is the most suitable for the study area. The third task was then to compare the months with confirmed heatwaves to the matching month's total mortality numbers for all twenty-four counties. The final task was to compare the twelve distressed counties' data to the twelve affluent counties' data and test for statistical significance.

1. Collection

Region Selection

There are five sub-regions in Appalachia as determined by the Appalachian Regional Commission: Northern, North Central, Central, Southern Central, and Southern (Figure 1). The two regions chosen for this study were Central and Southern Central. Central Appalachia has the highest density of distressed counties in the Appalachia region (Figure 3). Southern Central region was also included because it has climate similar to the Central region, but has more of the counties at higher levels of economic status, and thus allows the investigation of county economic status as a possible modifying effect..

County Selection

The twenty-four counties were systematically chosen based on economic criteria and the counties' index value rank. The index value rank is the county's ranking amongst all the counties in the country. The counties were chosen if they frequently ranked in the top twelve highest-ranked counties and the top twelve lowest-ranked counties within the central and southern central region. The ranking was determined by counting the regularity of the counties being within the top twelve lowest and highest indexed counties over ten years from 2012 through 2020. The distressed and affluent counties are displayed in **Table 1** and **Table 2** below, and **Figure 1** displays the map with the location of the counties.

Table 1. Relevant Information about the Selected Distressed Counties in Central and Southern Central Appalachia

County	**State**	**Population (as of 2010)**	**Per Capita Income (2017)**	**Poverty Rate (2013-2017)**	**Ranking in United States (2017)**	**Geo-coordinate of the highest temperature point**
Bell	Kentucky	28,691	$28,395	38.0%	3,076	(Y) Lat. 36.65 (X) Lon. -83.72
Breathitt	Kentucky	13,878	$32,512	36.0%	3,085	(Y) Lat. 37.60 (X) Lon. -83.43
Cocke	Tennessee	35,662	$31,362	25.0%	2,847	(Y) Lat. 35.996 (X) Lon. -83.246
Clay	Kentucky	21,730	$29,924	39.5%	3,105	(Y) Lat. 37.330 (X) Lon. -83.671
Hancock	Tennessee	6,819	$26,422	25.7%	3,038	(Y) Lat. 36.432 (X) Lon. 83.368
Harlan	Kentucky	29,278	$29,428	35.6%	3,096	(Y) Lat. 36.751 (X) Lon. -83.253
Lee	Kentucky	7,887	$31,422	32.7%	3,098	(Y) Lat. 37.628 (X) Lon. -83.555
Magoffin	Kentucky	13,333	$29,243	28.6%	3,104	(Y) Lat. 37.77 (X) Lon. -83.17
McCreary	Kentucky	18,306	$24,937	41.0%	3,112	(Y) Lat. 36.945 (X) Lon. -84.383
McDowell	West Virginia	22,113	$29,939	34.9%	3,089	(Y) Lat. 37.47 (X) Lon. -81.89
Owsley	Kentucky	4,755	$30,453	33.0%	3,108	(Y) Lat. 37.457 (X) Lon. -83.663
Wolfe	Kentucky	7,355	$30,392	36.9%	3,113	(Y) Lat. 37.669

						(X) Lon. -83.543

Table 2. . Relevant Information about the Selected Affluent Counties in Central and Southern Central Appalachia

County	**State**	**Population (as of 2010)**	**Per Capita Income (2017)**	**Poverty Rate (2013-2017)**	**Ranking in United States (2017)**	**Geo-coordinate** of **the highest temperature point**
Bath	Virginia	4,731	$58,876	9.3%	280	(Y) Lat. 37.957 (X) Lon. -79.709
Botetourt	Virginia	33,148	$48,152	7.7%	386	(Y) Lon. 37.585 (X) Lat. -79.749
Buncombe	North Carolina	238,318	$46,102	13.2%	852	(Y) Lat. 35.71 (X) Lon. -82.63
Blount	Tennessee	123,010	$41,224	13.0%	1,136	(Y) Lat. 35.785 (X) Lon. -84.162
Davie	North Carolina	41,240	$45,625	14.0%	1101	(Y) Lat. 35.866 (X) Lon. -80.415
Hamilton	Tennessee	336,463	$50,196	14.5%	964	(Y) Lat. 35.041 (X) Lon. -85.207
Henderson	North Carolina	106,740	$41,179	11.8%	1115	(Y) Lat. 35.249 (X) Lon. -82.377
Highland	Virginia	2,321	$42,873	10.6%	756	(Y) Lat. 38.212 (X) Lon. -79.534
Knox	Tennessee	432,226	$48,160	15.8%	953	(Y) Lat. 35.885 (X) Lon. -83.958
Loudon	Tennessee	48,556	$46,183	13.7%	1123	(Y) Lat. 35.748 (X) Lon. -84.337
Polk	North Carolina	20,510	$43,278	10.9%	1072	(Y) Lat. 35.286 (X) Lon. -82.044
Washington	Tennessee	122,979	$42,002	16.8%	1,464	(Y) Lat. 36.213 (X) Lon. -82.629

Climate Data Retrieval

Daily weather data over thirty-eight years (1981-2018) for each of the twenty-four counties, including daily mean, maximum, and minimum temperature, were downloaded from gridded data on a 4-km resolution across the U.S. from PRISM (http://www.prism.oregonstate.edu/), which is the USDA's official climatological data source.

The current PRISM normals, covering the period 1981-2010, were used to determine the point of the highest temperature within each county (**Tables 1 & 2**). The coordinates retrieved from the hottest point of each county were plugged into the PRISM Climate Group's time series data analysis tool (http://www.prism.oregonstate.edu/explorer/). This online and publicly available tool provides analysis for time-series data of a single location, and it has the capability of managing multiple measurements for various periods. The daily temperature data from the geo-coordinates was downloaded into an excel sheet for further investigation.

A thirty-eight-year range was chosen because it allowed for sufficient time to show long-term change or a trend in the daily temperature data. Consistent with earlier studies of the impacts of heatwaves on human health, only data in the warm season, May through September, were analyzed to examine the frequency and intensity of heatwaves over the 38-year study period.

Heatwave Definition

This study applied four distinct heatwaves (HW) definitions adopted from Li et al. (2019), as listed in Table 1. These definitions use different temperature metrics, including mean, maximum, and minimum air temperature, and they are all based on a 95% percentile threshold. A fourth heatwave definition from Li et al. (2019), which uses 35◦C (95◦F) as the threshold to define a heatwave, was also tested but not used, due to the fact daily maximum temperature in the study region rarely exceed 35◦C.

Calculating the 95th percentile temperature for each the minimum, mean, and maximum daily temperature sets from every county formed the basis for the individual definitions of a heatwave listed in Table 3. The 95th percentile temperatures from the three temperature definition data sets were calculated using the excel formula (=percentile(array, k)) below. The intent of having three temperature sets for analysis was to determine which matching heatwave definition most showed an increasing trend of heatwave frequency and quantity over the thirty-eight-year testing period.

Table 3. Heatwave definitions tested and used in this study

Heatwaves Definition One	Minimum daily temperature > 95th percentile for ≥ 2 days	Used
Heatwaves Definition Two	Mean daily temperature > 95th percentile for ≥ 2 days	Used
Heatwaves Definition Three	Maximum daily temperature > 95th percentile for ≥ 2 days	Used
Heatwaves Definition Four	Maximum daily temperature>35◦C (95◦F) for≥1 day	Not used

An excel logic code (=if(cell value > 0.95 value,1,0) was used to determine if the daily temperatures met the criteria of each the definitions the particular data set applied to, i.e., minimum daily temperatures apply to heatwave definition one, etc., etc. The data was then arranged and manually sorted through to determine if the temperatures were over the set 95th percentile temperature for at least two days to ensure it met the definition criteria. Those that did were marked and enumerated into a master list. This was repeated for each of the three heatwave definitions and accompanying daily temperature data sets for all twenty-four counties.

The numbers of heatwave events and heatwave days per year were added up for the distressed and affluent counties into an aggregate data chart, which included the three heatwave definitions from **Table 3**. Heatwave definition one (based on minimum daily temperature threshold) showed the best-growing trend for the climate data for both the quantity and frequency of heatwaves, so that definition was selected for the comparison of the all counties' mortality data to the counties' climate data.

Mortality Data Retrieval

Monthly all-cause mortality for the 24 counties were obtained from the Center for Disease Control and Prevention's Wonder database (https://wonder.cdc.gov/ucd-icd10.html). Monthly mortality data were only available for the years between 1999 and 2018.

2. Analysis

Comparison of Climate Data to Mortality Data

Once the mortality data was compiled into an excel sheet, the months with heatwaves were compared with the corresponding month of the mortality data over the twenty years for the impoverished and affluent counties. The months that had heatwaves were gathered into the experimental group, and the months without heatwaves were gathered into the control group. The data was appropriately separated into the experiment or control groups, and the average total death count for each county was calculated. The experimental county average was divided by the same control county average to get the relative risk for the county. Relative risk was used to allow for different population sizes across the counties, where using just the mortality averages would not account for variations population. Owsley County, KY, was eliminated from the impoverished county group because the county had zero deaths during the months with heatwaves resulting in relative risk of zero. Highland County, VA, was eliminated as the population size was so small, the WONDER database did not record any monthly mortality data. The average of the relative risks for the remaining distressed and affluent counties was calculated. They are shown in Tables 4 & 5 in the Results section. An independent t-test (two-sample t-test assuming unequal variances in EXCEL) was performed to measure the statistical significance of the averages of the relative risks.

Chapter 3

RESULTS

Heatwave Definition One

Minimum Daily Temperature > 95th Percentile for ≥ 2 days

The heatwave definition that best fits the increasing heatwave events and frequency trend the study calls for is Heatwave Definition One (HWD1). As seen in **Figure 5**, the orange trend line has a positive slope indicating the increasing amount of heatwave days over the years for the cumulative number of heatwave days in the distressed counties. The coefficient of determination, R^2, is 0.2352, which is indicative of data that is not best fitted to the trend line but compared to the two other heatwave definitions, the R^2 is stronger.

Figure 8 shows the increasing occurrence of heatwave events with the positive slope of the trend line for HWD1 for all twelve distressed counties. The R2 is 0.3063, which is indicative of data that is not the best fit for the trend line. **Figure 11** shows a comparatively strong increasing frequency of heatwave days in the twelve affluent counties with a comparatively high positive slope. The R^2 is 0.2582, which is indicative of a poor fit of the data to the trend line. **Figure 14** shows an increasing occurrence of heatwave events for the twelve affluent counties with a positive slope for the trend line. The R^2 is 0.3656, which is not indicative of the best fit of the data to the trend line.

Heatwave Definition Two

Mean Daily Temperature > 95th Percentile for ≥ 2 days

Heatwave Definition Two (HWD2) **Figures 6, 9, 12, & 15** display almost no increasing trend for both the cumulative heatwave days and the cumulative heatwave events in the affluent and distressed counties. The R^2 values for all four charts are under 4 %, with the R^2 value for **Figure 6** being 0.000064, an incredibly low percentage showing incredibly low fit to the trend line.

Heatwave Definition Three

Maximum Daily Temperature > 95th Percentile for ≥ 2 days

Interestingly, Heatwave Definition Three (HWD3) **Figures 7, 10, 13, & 16** display a slight decreasing trend of both cumulative heatwave days and cumulative heatwave events in affluent and distressed counties. The R^2 values for all four figures are all under 3 %, which indicative that the data is not a good fit for the trend lines of each figure.

Distressed and Affluent Counties Heatwave Mortality Relative Risk

Relative risk was the selected parameter of comparison between the two sets of data as it accounts for the varying population sizes across each county. **Table 4** shows the relative risks for each distressed county. **Table 5** shows the relative risk for each affluent county. The average relative risk for the distressed counties is 1.0029. The average relative risk for the affluent counties is 1.0275. At face value, the analyzed data shows that the average relative risk for the affluent counties is higher than that of the distressed counties. This finding suggests that the residents of the affluent counties are more likely to have more mortalities during heatwaves than the distressed counties. A two-sample t-test assuming unequal variances, **Table 6,** was used to determine the statistical significance of the findings. The results from the averaging of the relative risks for each data set are similar enough that for the statistical comparison, the study wants to know if there is a difference between the two findings, meaning a two-tailed analysis.

As a result of the statistical comparison, this study fails to reject the null hypothesis, and in doing so, rejects the alternate hypothesis that there was enough statistical evidence to support difference between the two relative risk averages. This finding is a result of the two-tailed p = 0. 503 found in **Table 6.**

Table 4. Distressed Counties Relative Risks and Average Relative Risk. Relative risk for each county was found by dividing the experiment group mortality average by that of the control group.

County name	Average Monthly Mortality in Experiment Group	Average Monthly Mortality in Control Group	Relative Risk
Bell County	30.0625	30.0147	1.0016
Breathitt County	14.8571	14.5797	1.0190
Clay County	20.3030	19.6418	1.0337
Harlan County	32.7879	34.3134	0.9555
Lee County	2.7931	3.2639	0.8558
McCreary County	15.3548	14.4478	1.0628
Magoffin County	9.2778	8.3125	1.1161
Wolfe County	3.4643	3.0870	1.1222
Cocke County	36.8148	36.3014	1.0141
Hancock County	2.3571	2.7083	0.8703
McDowell County	28.0690	28.6338	0.9803
			Average Relative Risk **1.0029**

Table 5. Affluent Counties Relative Risks and Average Relative Risk. Relative risk for each county was found by dividing the experiment group mortality average by that of the control group.

County name	Average Monthly Mortality in Experiment Group	Average Monthly Mortality in the Control Group	Relative Risk
Buncombe County	188.6286	183.1846	1.0297
Davie County	29.7931	30.9296	0.9633
Henderson County	98.4074	97.7945	1.0063
Polk County	22.1875	22.2500	0.9972
Blount County	97.9615	98.2027	0.9975
Hamilton County	267.6071	261.8611	1.0219
Knox County	318.1429	308.3611	1.0317
Washington County	99.2593	99.4521	0.9981
Botetourt County	23.4286	22.9167	1.0223
Bath County	0.6061	0.4776	1.2689
Loudon County	40.5000	41.9583	0.9652
			Average Relative Risk **1.0275**

Table 6. Comparison of Distressed Counties' Relative Risk to Affluent Counties' Relative Risk

t-Test: Two-Sample Assuming Equal Variances

	Distressed Counties	*Affluent Counties*
Mean	1.002861238	1.027474851
Variance	0.007396091	0.006950988
Observations	11	11
Pooled Variance	0.007173539	
Hypothesized Mean Difference	0	
df	20	
t Stat	-0.681537834	
P(T<=t) one-tail	0.251673768	
t Critical one-tail	1.724718243	
P(T<=t) two-tail	**0.503347537**	
t Critical two-tail	2.085963447	

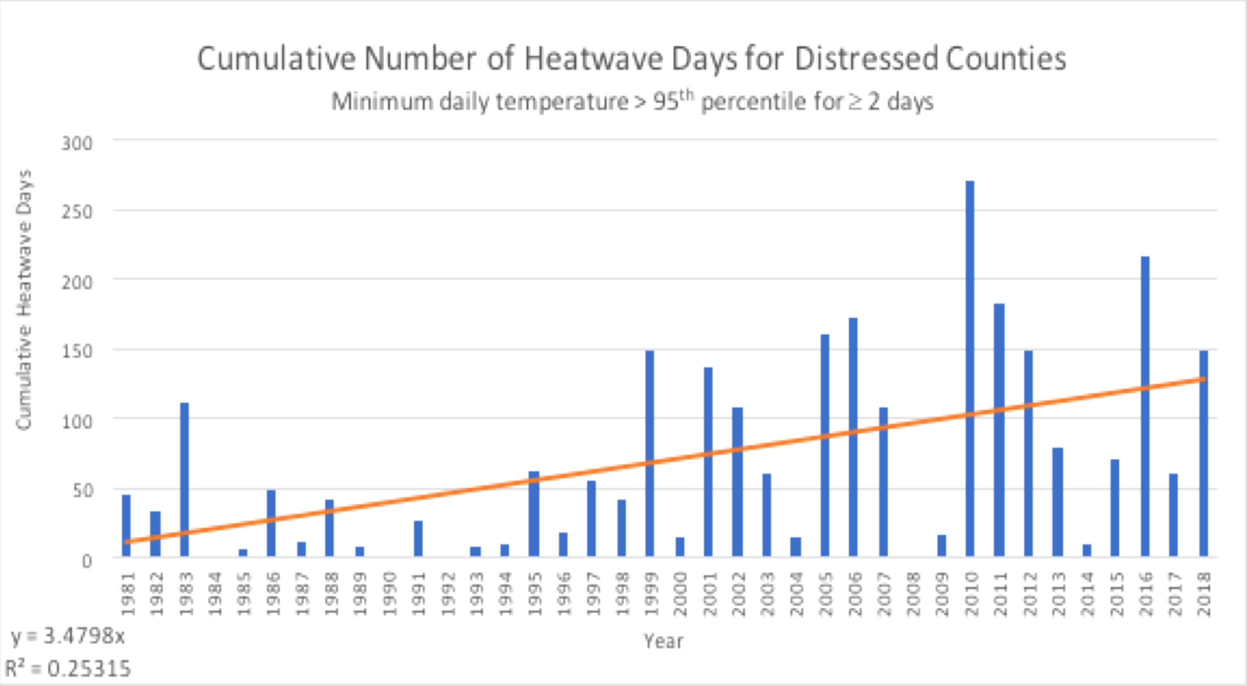


Figure 5. Minimum Daily Temperature Cumulative Number of Heatwave Days

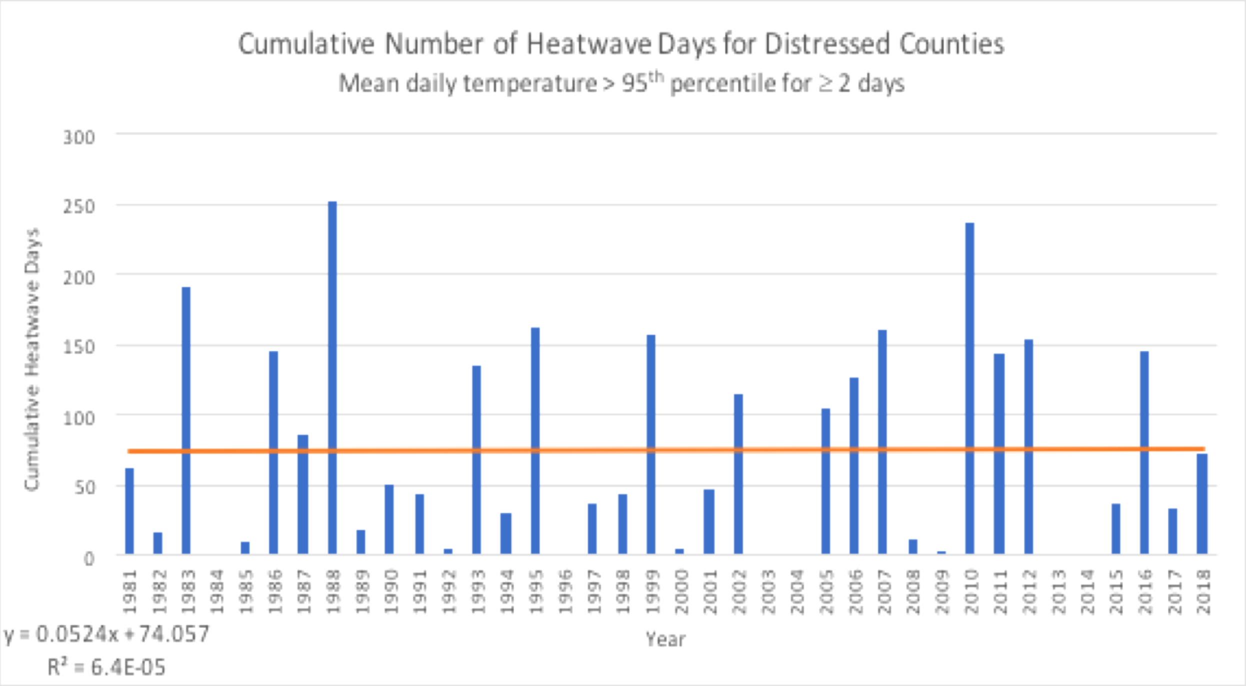


Figure 6. Mean Daily Temperature Cumulative Number of Heatwave Days

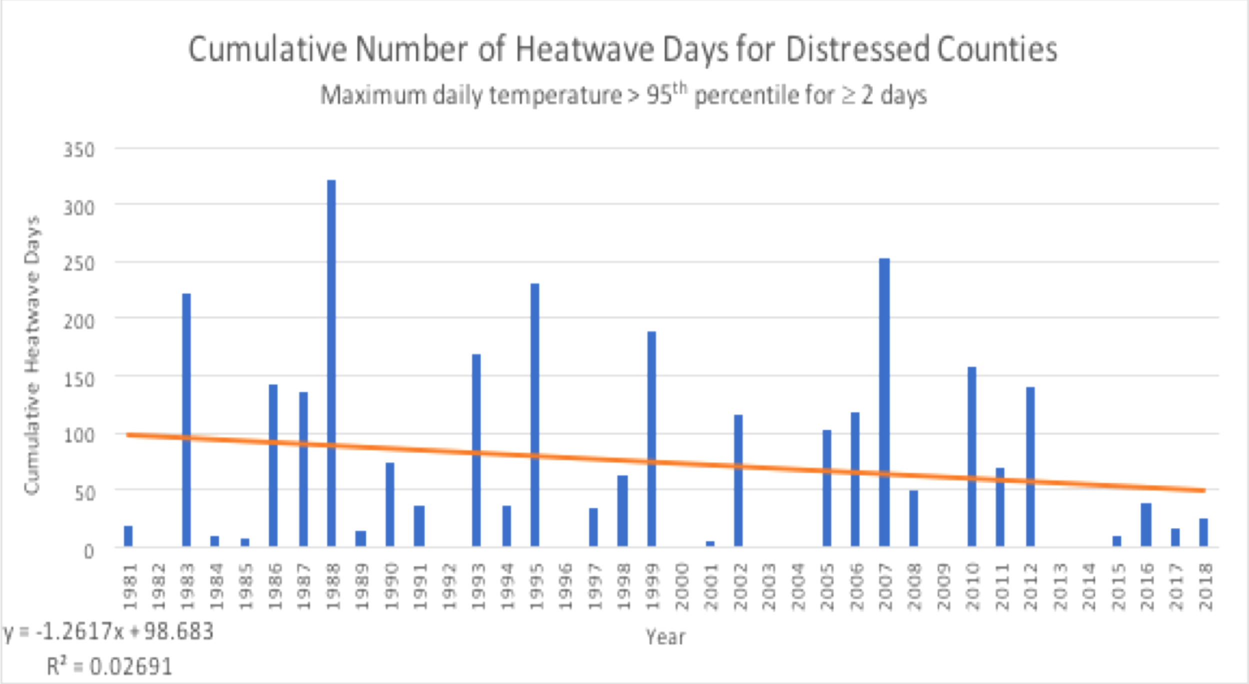


Figure 7. Maximum Daily Temperature Cumulative Number of Heatwave Days

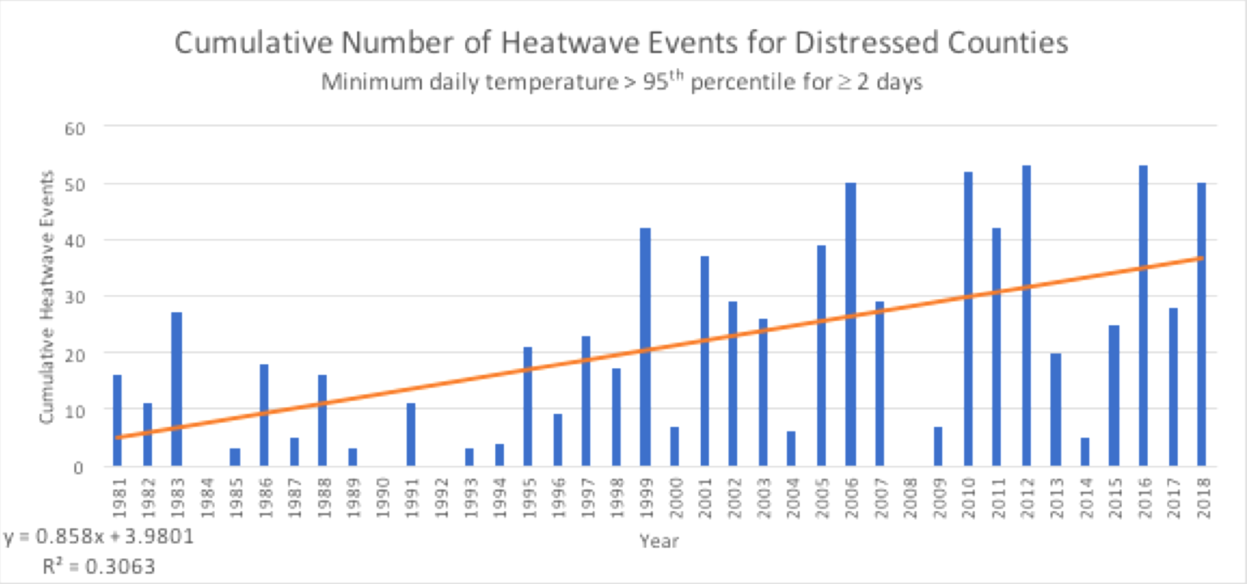


Figure 8. Minimum Daily Temperature Cumulative Number of Heatwave Events

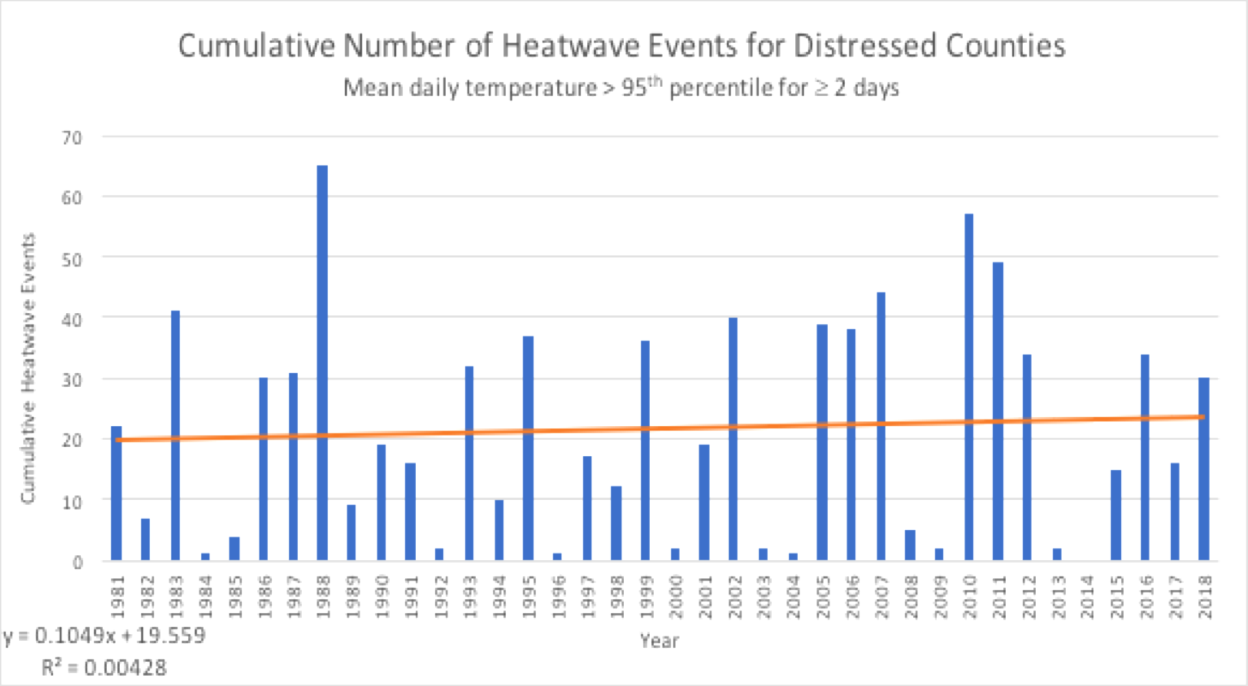


Figure 9. Mean Daily Temperature Cumulative Number of Heatwave Events

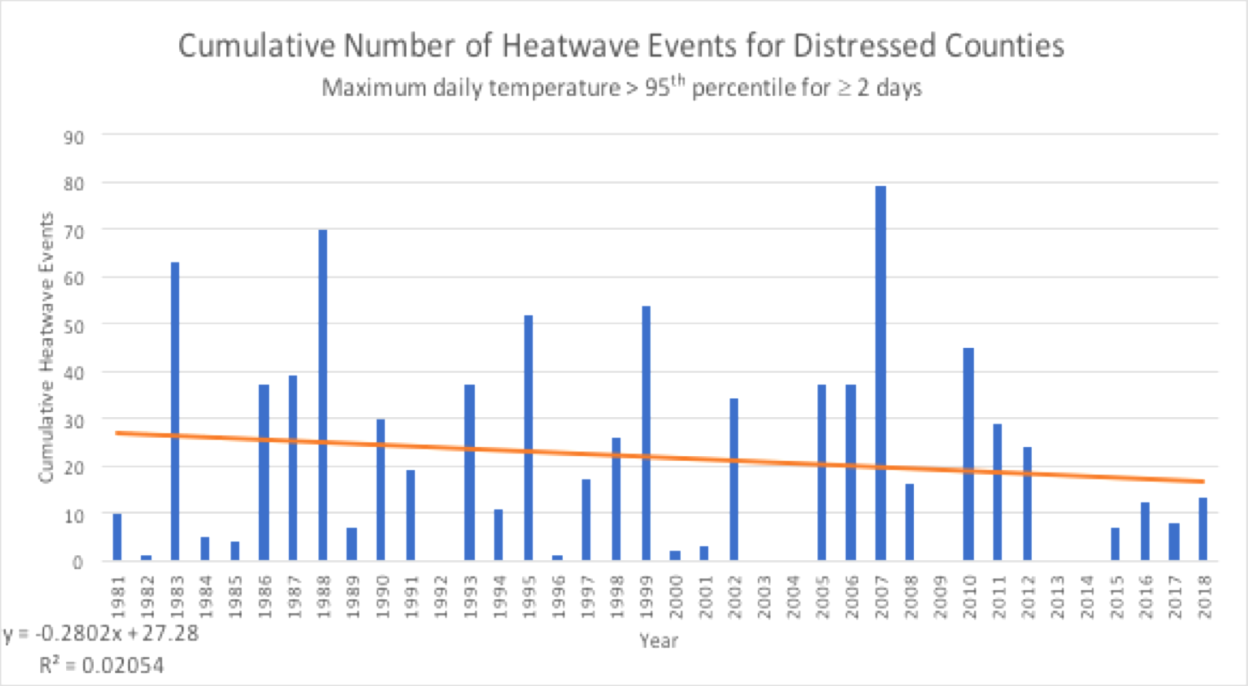


Figure 10. Maximum Daily Temperature Cumulative Number of Heatwave Events

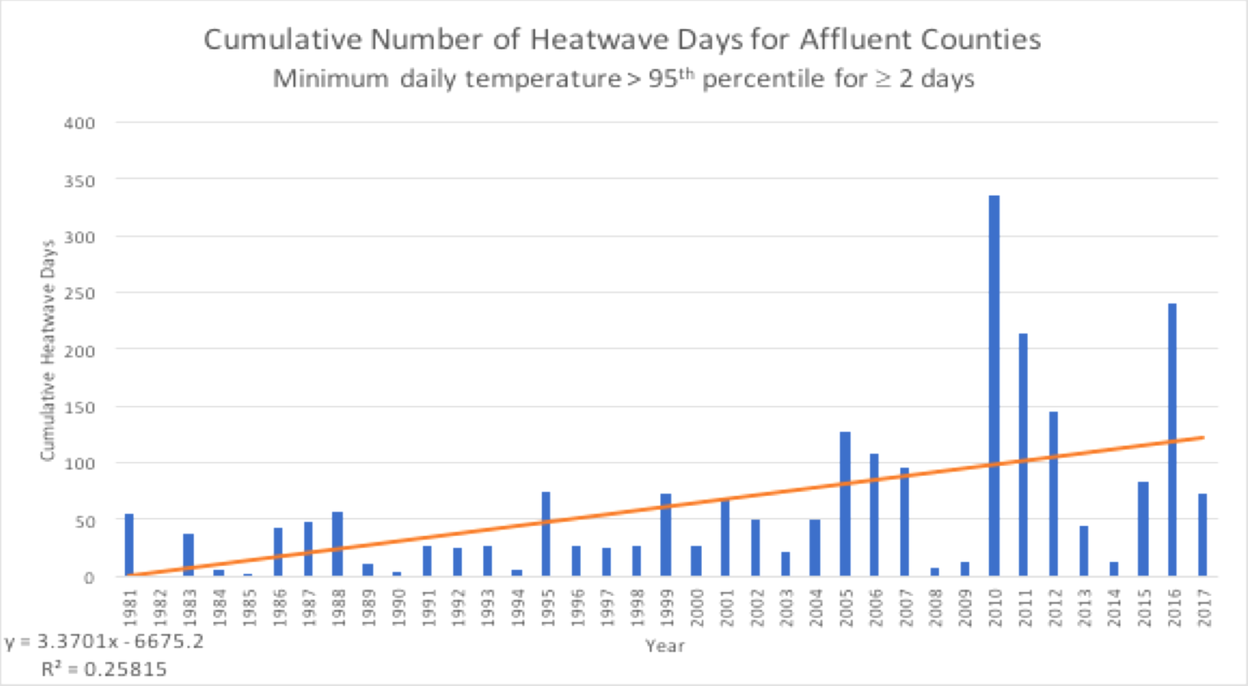


Figure 11. Minimum Daily Temperature Cumulative Number of Heatwave Days

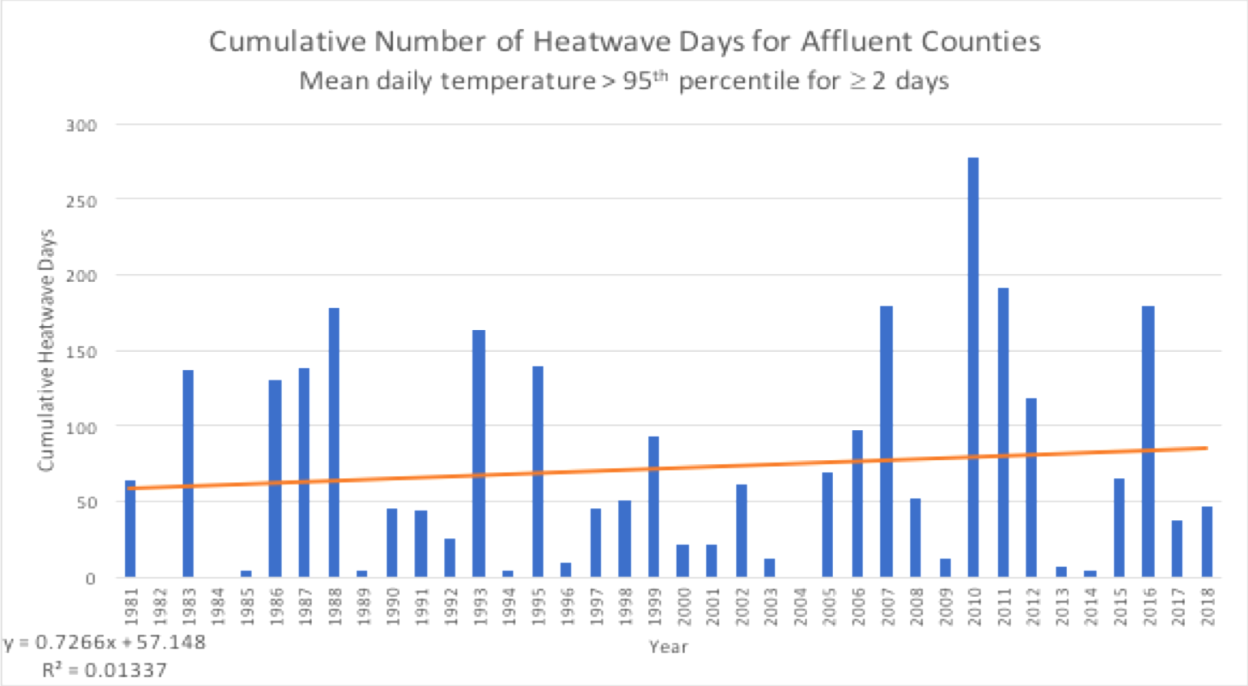


Figure 12. Mean Daily Temperature Cumulative Number of Heatwave Days

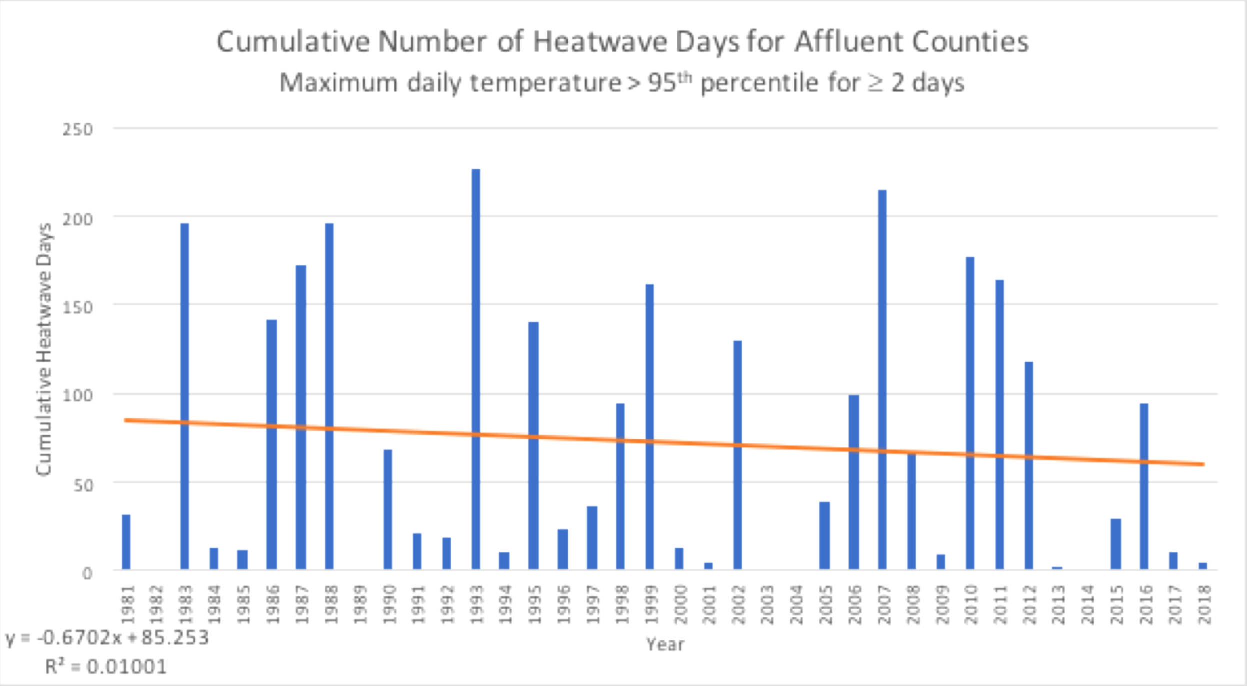


Figure 13. Maximum Daily Temperature Cumulative Number of Heatwave Days

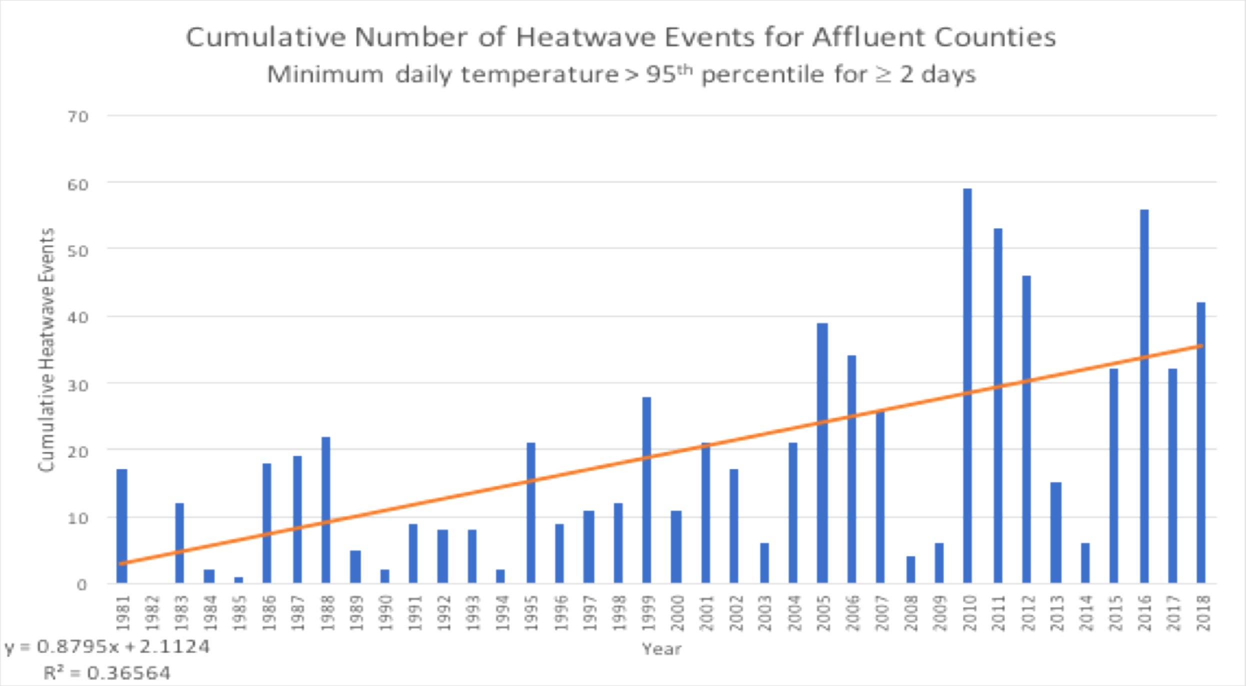


Figure 14. Minimum Daily Temperature Cumulative Number of Heatwave Events

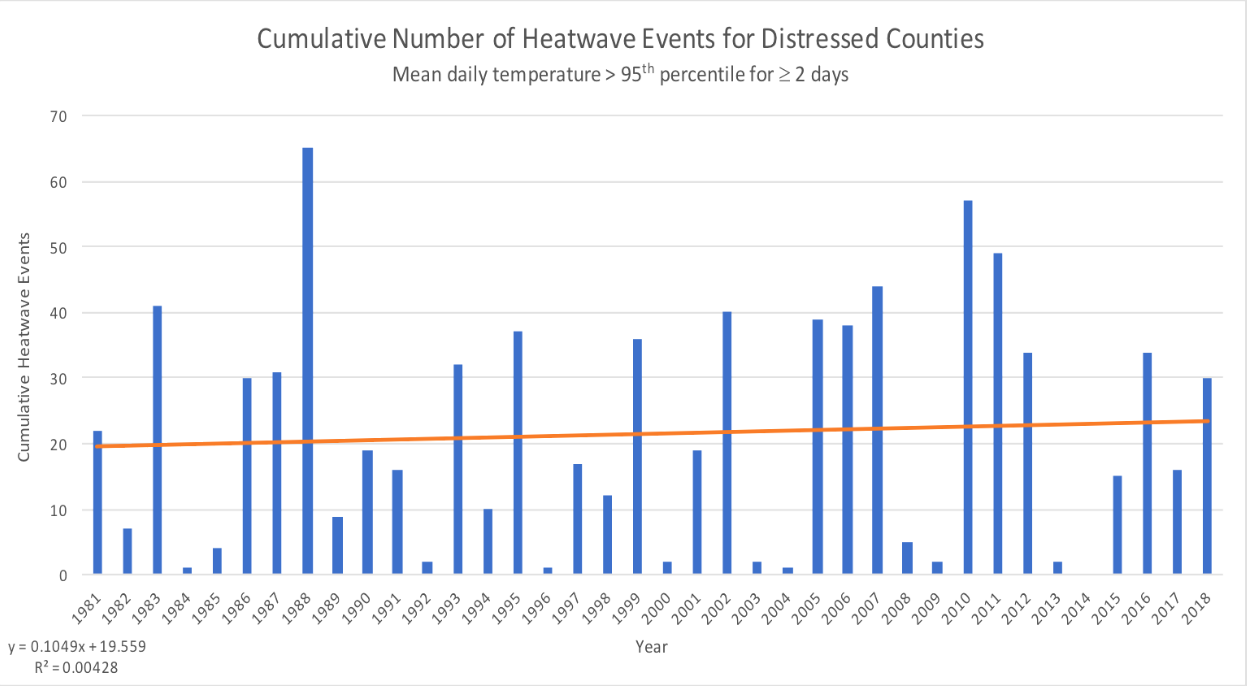


Figure 15. Mean Daily Temperature Cumulative Number of Heatwave Events

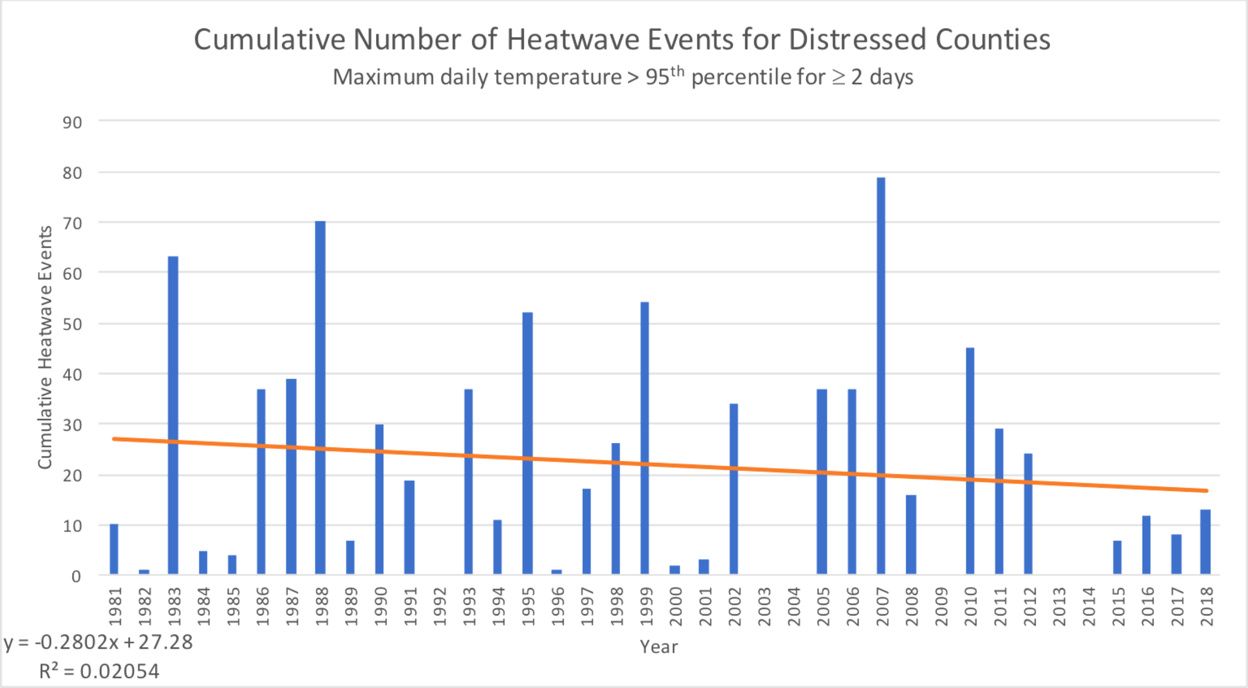


Figure 16. Maximum Daily Temperature Cumulative Number of Heatwave Events

Chapter 5

DISCUSSION

This study aimed to examine the trends of heatwaves in the central and southern central regions of Appalachia over the last several decades, and investigate the hypothesis that economically distressed counties are more likely to a have higher mortality risk during heatwaves than economically affluent counties in the same regions. It was found that both the total number of heatwave events and heatwave days per year have been considerably increased in the years after 2000, when heatwaves are defined as those with minimum daily temperature>95th percentile for more than two consecutive days. The results suggest that minimum temperature may be the most effective measure for predicting heatwaves in the study region. In order to achieve the purpose of this study, the first analysis that had to be completed was the evaluation of the cumulative quantity and the frequency of heatwaves days and events occurring in central and southern central Appalachia over thirty-eight years. This was ascertained by aggregating the daily temperature data across the chosen twenty-four counties that corresponded to their correct heatwave definition. As shown by **Figures 5, 8, 11, and 14** in the Results, heatwave definition one, which is defined as the minimum daily temperature > 95th percentile for at least two days, had the best trend line showing a growing quantity and frequency of heatwaves over the years. This finding is consistent with literature, which suggested that the minimum daily temperatures for 70-75% of the world's land area has seen statistically significant increases (Alexander, 2006).

Interestingly, **Figure 7** in the Results section had a negative trend line indicating a decline in the total amount heatwaves matching the maximum daily temperature heatwave definition. This could be a result of a "warming hole," or a local minimum of warming usually found in the central U.S. during the summer months of June, July, and August (Pan, et al., 2004).

This phenomenon is thought to be a result of an altered hydrologic feedback system that results in a local minimum due to an unusual replenishment of seasonally depleted soil moisture (Pan, et al., 2004). The epicenter of this phenomenon is found in the Kansas-Nebraska region. However, central and southern central Appalachia could be experiencing a lesser but still noticeable degree of this effect due to the nearby proximity of the regions.

Furthermore, the results of the study shown in **Tables 4 and 5**, show that both the distressed and affluent county groups had increased mortality risk in the months with heatwaves (The economically distressed counties had a combined average relative risk of 1.0029, and the economically affluent counties had a combined average relative risk of 1.0275). The risk was higher among the affluent counties than the distressed counties, but the difference was not statistically significant (the two-tailed p-value .503 in Table 6). The difference is minimal, but at face value, the results suggest that residents of economically affluent counties of the central and southern central Appalachian regions are 2.39 % more likely to die during a heatwave than the residents of economically distressed counties in the same region, which is the opposite of the hypothesis.

Despite the high temporal and spatial resolution climate data used, this study used best publicly available vital statistics (month mortality data at the county level), which makes it different to control possible confounding effects. The monthly mortality data at the county level did not allow the matching of heatwave events with the accurate date of deaths and controlling some critical health-related factors, such as temporal trends and socioeconomic factors at the individual level.

Observational studies often suffer from several biases, and this study is not an exception. By the study's very nature of having to select the counties based on their rank out of the counties of the United States means the sampling method was not randomized, meaning the study is not representative of the true population. Even though a county can be categorized as distressed, that does not mean all of that county's residents are economically distressed. This study also has the potential of suffering from measurement errors as it heavily relies on the accuracy of measuring instruments for retrospective data. Should a temperature be misread or a death misreported means inherent problems that are hard to negate, and it is believed that measurement errors can bias outcomes towards a null result (Hammer, du Prel, & Blettner, 2009). The sample size of this study is small enough to decrease the power of the study, and that increases the likelihood of a Type II error occurring. A Type II error suggests that a failure to reject the null hypothesis is false, and the alternative hypothesis is actually true.

Despite these limitations, this study provides evidence that heatwave frequency and intensity to be rising noticeably in the Central and South Central Appalachia regions when measured over a four-decade period. Although daily maximum or daily mean temperature are commonly used for heatwave warning systems, daily minimum temperature may be the most effective measure for the study regions. This study also suggests heatwaves may have increased mortality in Central Appalachia communities. Further studies are needed to investigate the association and socioeconomic risk factors for heat-related health outcomes in the Central Appalachia region.

Chapter 6

CONCLUSION

The primary goal of this study was to determine if socioeconomically distressed counties in the central and southern central Appalachian regions will have a higher number of mortalities during a heatwave than that of socioeconomically affluent counties. It was found that the affluent counties had a higher relative risk of heatwave mortality than that of the distressed counties. However, the results were determined not to have enough significant statistical evidence to conclude with reasonable confidence that there is a difference between the two findings. Many factors could be pushing the findings towards supporting the null hypothesis, but there is a decent probability that the findings of this study are due to random noise.

In the analysis of the total number of heatwave events and the total number of heatwave days, the exploration of three separate heatwave definitions concluded that the minimum daily temperature heatwave frequency and quantity are gradually increasing over time, that the mean daily temperature heatwave frequency and quantity showed little to no increase over time, and interestingly, that the maximum daily temperature heatwave frequency and quantity have shown a slight decrease over time. It is hypothesized that the maximum daily temperatures are decreasing in localized areas of the United States due to a “warming hole” phenomenon.

RECOMMENDATIONS & FUTURE RESEARCH

This research has principally provided a baseline of results that inspire more research into the topic. There are many more factors that can be considered in the designing of follow-up studies, namely a more in-depth investigation into what determines socioeconomic status. A larger sample size of both the distressed and affluent counties would give more accurate results, as the small sample size is limiting in the statistical information it can provide. Further research could be put into an investigation into the “warming hole” phenomena, as a negative trend in the maximum daily temperatures for both cumulative heatwave events and heatwave days in all twenty-four counties was arguably the most surprising find from this study.

References

Adams , C. R. (n.d.). *Impacts of Temperature Extremes.* Cooperative Institute for Research in the Atmosphere. Fort Collins: Colorado State University. Retrieved from Science Policy Colorado : https://sciencepolicy.colorado.edu/socasp/weather1/adams.html

Alexander, L. V. (2006). Global observed changes in daily climate extremes of temperature and precipitation. *Journal of Geophysical Research: Atmospheres, 111*(D5).

Andrew, M. K. (2010). Chapter 33 - Social Vulnerability . In M. K. Andrew, *Brocklehurst's Textbook of Geriatric Medicine and Gerontology* (Seventh Edition ed., pp. 198-204). Elsevier.

Appalachian Regional Commission . (2009, November). *Subregions in Appalachia.* Retrieved May 2019, from Appalachian Regional Commission : https://www.arc.gov/research/MapsofAppalachia.asp?MAP_ID=31

Appalachian Regional Commission . (2018, August). *County Economic Status in Appalachia, FY 2019.* Retrieved May 2019, from Appalachian Regional Commission : https://www.arc.gov/research/MapsofAppalachia.asp?MAP_ID=148

Butler, P. (2015). *Central Appalachians Ecosystem Vulnerability Assessment and Synthesis* . Retrieved May 2019, from Forest Adaptation : https://forestadaptation.org/sites/default/files/evas_technicalsummary_centralapps_June%202016_0.pdf

Clark, S. (2009). *Birth of the Mountains.* Denver, Colorado: USGS.

Gibbens , S. (2019, March 4). *Ocean heat waves are killing underwater life, threatening biodiversity* . Retrieved April 2019, from National Geographic :

https://www.nationalgeographic.com/environment/2019/03/ocean-heat-waves-threaten-sea-life-biodiversity/

Gouveia, N., Hajat, S., & Armstrong, B. (2003). Socioeconomic differentials in the temperature–mortality relationship in São Paulo, Brazil. *International Journal of Epidemiology, 32*(3), 390-397.

Habeeb, D., Vargo, J., , B., & Stone Jr. (2015). Rising heat wave trends in large US cities . *Natural Hazards*, 1651-1665.

Hammer, G., du Prel, J.-B., & Blettner, M. (2009). Avoiding Bias in Observational Studies. *Deutsches Ärzteblatt International , 106*(41), 664-668.

Housing Assistance Council. (2009). *Central Appalachia.* Retrieved May 2019, from http://www.ruralhome.org/storage/documents/ts2010/ts-report/ts10_central_appalachia.pdf

Karfakis , P., Lipper, L., & Smulders, M. (2012). *The assessment of the socio-economic impacts of climate change at household level and policy implications* . Food and Agriculture Organization of the United Nations , Agricultural Development Economics Division , Rome.

Levy, B., & Patz, J. A. (2015). Climate Change, Human Rights, and Social Justice . *Annals of Global Health, 81*(3), 310 - 322.

Li, Y., Akkus, C., Yu, X., Joyner, A., Kmet, J., Sweat, D., & Jia, C. (2019). Heatwave Events and Mortality Outcomes in Memphis, Tennessee: Testing Effect Modification by Socioeconomic Status and Urbanicity. *International Journal of Environmental Research and Public Health, 16*(4568), 14.

Michelozzi P, d. D. (2005). *The impact of the summer 2003 heat waves on mortality in four Italian cities.* Euro Surveill.

NOAA. (1980). *Impact Assessment: U.S. Social and Economic Effects of the Great 1980 Heat Wave* . U.S. Department of Commerce, National Oceanic and Atmospheric Administration , Washington, DC.

NOAA. (1995). *The July 1995 Heat Wave Natural Disaster Survey Report.* U.S. Department of Commerce, National Oceanic and Atmosphere Administration , Silver Spring, MD.

Pan, Z., Arritt, R., Takle, E., Gutowski, W., Anderson, C., & Segal, M. (2004). Altered hydrologic feedback in a warming climate introduces a "warming hole". *Geophysical Research Letters, 31*(17).

Ph. Ciais, M. R. (2005, September 22). Europe-wide reduction in primary productivity caused by the heat and drought in 2003. *nature, 437*, 529-533.

Sarofim, M. C., Saha, M., Hawkins, D., Mills, D., Hess, J., Horton, R., . . . Schwartz, J. (2016). *Ch. 2: Temperature Related Deaths and Illness*. Retrieved March 18, 2018, from U.S. Global Change Research Program: https://health2016.globalchange.gov/temperature-related-death-and-illness

Schifano, P. C. (2009). Susceptibility to heat wave-related mortality: a follow-up study of a cohort of elderly in Rome. *Environmental Health , 8*(50).

Schifano, P., Cappai, G., De Sario, M., Michelozzi, P., Marino, C., Bargagli, A., & Perucci, C. (2009). Susceptibility to heat wave-related mortality: a follow-up study of a cohort of elderly in Rome. *Environmental Health*.

Schubert, C. (2014, June 18). *What are the long-term effects from flash floods and heat waves on agriculture?* Retrieved April 2019, from Climate Change, Agriculture and Food Security : https://ccafs.cgiar.org/fr/node/50517#.XMMNSy-ZOfU

Son, J.-Y., Lee, J.-T., Anderson, B., & Bell, M. (2012). The Impact of Heat Waves on Mortality in Seven Major Cities in Korea. *Environmental Health Perspectives, 120*(4).

Strickland, P. (2016, November 8). *Inside Owsley: America's poorest white county* . Retrieved May 2019, from AlJazeera: https://www.aljazeera.com/indepth/features/2016/11/owsley-feeling-forgotten-america-white-county-161107111708901.html

U.S. Department of Energy . (2013, August 21). *U.S. Energy Sector Vulnerabilities to Climate Change and Extreme Weather* . U.S. Department of Energy , National Renewable Energy Laboratory . Washington D.C.: U.S. Department of Energy . Retrieved April 2019, from Center for American Progress: https://www.americanprogress.org/issues/green/news/2015/08/21/119763/climate-change-threatens-electric-grid-reliability-in-the-southwest/

Walter, E. J., & Carraretto, M. (2016, July 14). The neurological and cognitive consequences of hyperthermia . *BioMed Central, 20*.

Walther, G.-R., Post, E., Convey, P., Menzel, A., Parmesan, C., Beebee, T., . . . Bairlein, F. (2002, March 28). Ecological Responses to recent climate change . *Nature, 416*, 389 - 395.

Widmaier, E. P., Raff, H., & Strang, K. T. (2016). *Vander's Human Physiology: The Mechanisms of Body Function* (Vol. 14). New York, New York: McGraw-Hill Education .

Williams, C. A. (2014). Heat and drought extremes likely to stress ecosystem productivity equally or more in a warmer, CO2 rich future. *Environmental Research Letter*, 4.

World Health Organization. (2018, June 1). *Heat and Health*. Retrieved April 2020, from World Health Organization : https://www.who.int/news-room/fact-sheets/detail/climate-change-heat-and-health

Xu Y, D. P.-G. (2013). Differences on the effect of heat waves on mortality by sociodemographic and urban landscape characteristics. *Journal of Epidemiology & Community Health , 67*(6), 519-525.