WILDFIRE SMOKE: TRENDS, CHALLENGES, UNKNOWNS, AND HUMAN RESPONSE

by

Mariah Dawn Fowler

A thesis

submitted in partial fulfillment

of the requirements for the degree of

Master of Science in Civil Engineering

Boise State University

May 2019

BOISE STATE UNIVERSITY GRADUATE COLLEGE

DEFENSE COMMITTEE AND FINAL READING APPROVALS

of the thesis submitted by

Mariah Dawn Fowler

Thesis Title: Wildfire Smoke: Trends, Challenges, Unknowns, and Human Response

Date of Final Oral Examination: 09 April 2019

The following individuals read and discussed the thesis submitted by student Mariah Dawn Fowler, and they evaluated her presentation and response to questions during the final oral examination. They found that the student passed the final oral examination.

Mojtaba Sadegh, Ph.D.	Chair, Supervisory Committee
Bhaskar Chittoori, Ph.D.	Member, Supervisory Committee
Stephen M. Utych, Ph.D.	Member, Supervisory Committee
Thad B. Welch, Ph.D.	Member, Supervisory Committee

The final reading approval of the thesis was granted by Mojtaba Sadegh, Ph.D., Chair of the Supervisory Committee. The thesis was approved by the Graduate College.

DEDICATION

To my beloved mother, father, sister, and daughters who have supported my thirst for more knowledge and showered me with unconditional love.

ACKNOWLEDGEMENTS

I would like to express my deepest gratitude to my advisor, Dr. Mojtaba (Moji) Sadegh, who has been my guiding light and made this thesis possible. I will forever be thankful for the encouragement, guidance, and support you provided me.

I would like to thank Dr. Thad Welch for his gentle soul, most caring heart that provided me strength, and many smiles of encouragement. I would like to thank Dr. Bhaskar Chittoori for your support and pushing me for more. I sincerely thank Dr. Steve Utych for his energetic and fun way of looking at people. I could not have completed such a successful survey without you.

I would like to thank all of the professors that I have had the privilege of knowing and have supported my educational experience. My special thanks goes to Chasitity Ellis, Junelle Goins, Aaron Gaipl, Katina Dutton, Andy Adams, Jenn McAtee, Austin Berry, Md. Fazle Rabbi, Hanna Irving, and Donna Welch for their continued support and companionship.

ABSTRACT

Wildfire smoke is a growing threat to human livelihood in the Western United States. The economic and the health burden of smoke is accelerating in response to a growing fire season and escalating fire activity. This study first evaluates the trends in air quality over Boise, Idaho and the entire Northwest (and Montana) to assess the impacts of wildfire smoke in the region. The Mann-Kendall trend analysis shows that there is a statistically significant trend in the average and maximum air quality index (AQI) during the fire season (July-August-September) in the Boise area. The AQI shows a decreasing trend, although not statistically significant, for the rest of the year. The analysis of the aerosol optical depth (AOD) provided by MERRA-2 reanalysis from NASA also shows the number of days with average and maximum AOD values above the 90^{th} percentile (higher tail of the AOD distribution) also shows a statistically significant trend over the entire Pacific Northwest and Montana. The second section of this study evaluates the human response to this growing hazard.

While significant strides have been made in modelling wildfire activity, little work has been dedicated to understanding how people perceive and respond to this growing hazard. This is critical because decision-makers need such information to mitigate the negative impacts of smoke. The purpose of this study is to gather and analyze information about the publics' level of outside activity during smoke event(s), their source of air quality information and their effective messaging preferences, their perception of wildfire smoke as a hazard, and their smoke-related health experiences.

This work provides crucial policy-relevant smoke-related social behavioral information to decision-makers, and believe such information should be integrated into risk mitigation decision-making processes. Our results show that roughly 90% of the survey participants observed at least one symptom (most frequently irritated eyes and runny nose) associated with wildfire smoke. A majority of the survey population (80%) perceive smoke as a hazard, but a majority of them are not willing to evacuate their homes to mitigate the adverse impacts of wildfire smoke.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AOD	Aerosol Optical Depth
AQI	Air Quality Index
BLM	Bureau of Land Management
BSU	Boise State University
CITI	Collaborative Institutional Training Initiative
EPA	Environmental Protection Agency
ha	Hectares
IDEQ	Idaho Department of Environmental Quality
IRB	Institutional Review Board
M-K	Mann-Kendall
MERRA-2	Modern-Era Retrospective analysis for Research and Applications, Version 2
NAAQS	National Ambient Air Quality Standards
NASA	National Aeronautics and Space Administration
NIFC	National Interagency Fire Center
PM	Particulate Matter
WUI	Wildland Urban Interface

CHAPTER ONE: INTRODUCTION

1.1 Introduction

Fires have been around since the emergence of terrestrial plants. The National Interagency Fire Center (NIFC) defines wildfires as “unplanned, unwanted wildland fire including unauthorized human-caused fires, escaped wildland fire use events, escaped prescribed fire projects, and all other wildland fires where the objective is to put the fire out” (National Interagency Fire Center n.d.). The area burned in many regions of the world including the Western United States is increasing and is projected to continue increasing (Flannigan et al. 2009). Wildfire smoke is a byproduct of wildfires and exposure to it affects millions of people every year. In 2011, an estimated 212 million people were affected by smoke conditions (Knowlton 2013).

Wildfire smoke is a growing threat to human livelihood in the Western United States. The economic and health burdens of wildfire smoke are accelerating in response to a growing fire season and escalating fire activity. While significant strides have been made in modelling wildfire activity, little work has been dedicated to understanding how people perceive and respond to this growing hazard. The purpose of this study is to establish that the wildfire smoke is a growing hazard in the Boise area of Idaho and the entire Northwest United States, and bridge the knowledge gap in regard to how people in the Northwest United States respond to wildfire smoke.

1.2 Background Regarding Fires

Wildfires happen everywhere, which impacts millions of people each year. In the Western United States, the frequency of large wildfires has increased, as well as the area burned. Climate change has affected fire intensities regardless of whether fires are human started or lightning ignited.

1.2.1 Global Problems

Globally, there are changes in the magnitude of fires and enormity of impacts. In 2018 alone, major fires occurred in the United Kingdom, scorching more than seven square miles in three weeks. In Athens, Greece, 99 people were killed and hundreds injured as a fire swept through the city. And by the end of July 2018 more than 80 wildfires had taken over Sweden, with some even occurring in the Arctic Circle (AghaKouchak et al. 2018).

The annual global area burned ranges from 273 to 608 Mha (Mega hectares) per year. Eighty to eighty-six percent of the global area burned happens primarily in savannas and grasslands and the rest in forested areas. Globally, fires are typically not prevalent poleward of 70 ° N and 70 ° S, and are increasingly becoming more frequent in the tropics and savannas (Flannigan et al. 2009).

An average of 339,000 people die worldwide each year because of exposure to wildfire smoke. Sub-Saharan Africa was the most affected area, with approximately 157,000 deaths and Southeast Asia was second with 110,000 annual deaths (Johnston et al. 2012).

Global warming and climate change also wreaks havoc on the natural ecosystems. Warmer winter temperatures push for earlier spring snowmelt, lowering the humidity in late spring, intensifying dry conditions. The warmer temperatures boost plants to pull more moisture from the ground and when the available water is gone, the plants die (Flannigan et al. 2009). With a shorter spring growing season and late spring drought conditions, dry plants become fire fuel, which supports an increase in wildfire frequency and fire intensity in fire prone areas (Balch et al. 2017; Barbero et al. n.d.; Brown, Hall, and Westerling 2004; A. L. Westerling et al. 2003; Wilson, McCaffrey, and Toman 2017). Fires emit CO_2 and black carbon, both of which support global warming that in turn creates increasing dry seasons. Fire ignitions due to lightning also happen more frequently in dry, warm air. This becomes a never-ending loop as the warmer climate creates a longer fire season, so that more fires are present, which emit more CO_2 and black carbon. Black carbon can be removed from the air by rain and snow, which changes the albedo properties of snow and ice, thus increasing early snow melting (Flannigan et al. 2009).

High temperature, low relative humidity, low precipitation (and/or longer dry season), and high wind speed are the largest drivers of wildfires. Fires happen when there is an ignition source paired with dry weather and a good source of fuel. The intensity and spread rate of fires depend predominantly on the location of the ignition and the alignment of fuel availability and weather. Hot and dry winds dry out forest and add energy to a fire, pushing it to the next level (Dennison et al. 2014).

A recent study determined that the global fire season has lengthened by 18%, which doubles the burnable area because of the longer fire season (Jolly et al. 2015). Longer fire seasons, larger areas primed to burn, and warmer temperatures ensure more fires to come.

1.2.2 Western US Problems

In December, 2017, a wildfire near Montecito, California destroyed vegetation and left the steep slope's soil unstable. A month later, moderate rains generated a massive mud slide with boulders and branches that crashed into homes, killing 21 people. The fire was just the start of changes in this community, but left long-term effects (AghaKouchak et al. 2018).

In 2018 by the end of August, there were over 80 large fires that burned over 770,000 hectares (ha) in the Western United States. August 21, 2018, Seattle recorded the worst air quality of any major city in the world. The smoke caused an Air Quality Index (AQI) rating of 190 (ranked 'very unhealthy') where an AQI of 150 is roughly equal to smoking seven cigarettes in a day.

Wildfires are prompted by four factors: climate or weather, fuel source, ignition agent, and people. Climate change and the changing of weather patterns creates a warmer, dryer area which affects fuel sources. When the forests are dry, they create an abundant fuel source. Ignition sources are either by natural forces, such as lightning, or caused by people (Flannigan et al. 2009).

Multiple studies have focused on the Western United States, determining fire season length, fire intensities, and area burned (Dennison et al. 2014; Jolly et al. 2015; Littell et al. n.d.; A. L. Westerling et al. 2006; A. L. R. Westerling 2016). The length of the fire season was an average of 138 days in the years between 1973-1982, and increased to an average of 222 days from 2003-2012, for an increase of 84 days in 30 years. There were also about 20 additional large fires per decade during the same time period (A. L. Westerling et al. 2006).

Fuel load, or the amount of available fuel (trees, brush, etc.), increased because of fire suppression practices and reduction of logging. The forest structure and growth changed because fires and logging were not allowed to maintain the healthy forest balance (A. L. Westerling et al. 2006). Second, some years spring temperatures were low, allowing a later snow melt followed by a warm summer which created a longer growing season. In these years, because forests were still wet and growing there were typically less fires. Third, spring temperatures were warm causing an early snow melt. These years had short growing seasons with a hot, dry spring and summer, and hence a large supply of dry fuel for the fire season. A combination of a long growing season one year, followed by an extremely dry spring the next year, generated the perfect fire season with an increase in frequency of large fires and burned area (Dennison et al. 2014; A. L. Westerling et al. 2006).

Fire intensity and the area burned can be considered codependent. Hot intense fires are harder to control and thus will increase the total amount of area burned. The main factors that influence the intensity and burned area include: temperature, relative humidity, precipitation, fuel moisture, fuel abundancy, and wind speed (J. T. Abatzoglou and Williams 2016). “Fuel aridity is a combination of multiple factors, however in general, with little to no precipitation and warm temperatures plants, trees, and soil release moisture into the air, which makes them drier” (J. T. Abatzoglou and Williams 2016). Anthropogenic climate change (human-caused climate change) supported the increasing trends in fire-season fuel aridity by approximately 55% from the years 1979-2015, which also supports favorable fire conditions (J. T. Abatzoglou and Williams 2016).

The alignment of abundant and dry fuel, low humidity, many days without precipitation, high temperatures, and a weather pattern bringing high winds create the perfect scenario to support an extremely intense fire that will be hard to put out (J. T. Abatzoglou and Williams 2016).

1.2.3 Causes – Human and Natural

Wildfires are ignited either by natural processes, like lightning, or they are human caused, including arson, fireworks, campfires, smoking, power lines, railroads, or vehicle traffic with dragging chains or hot tailpipes that ignite grass.

As the human population continues to grow, urban development and homes push against private and public wildlands, the interface of which is also known as the wildland-urban interface (WUI) (Radeloff et al. 2005). More people are building homes in the WUI, which increases the imposed risk to structures during a wildfire. Within the United States, from the years 1970-2000, there was a 52% increase in WUI area, which is projected to continue to increase by at least 10% by the year 2030, with the most growth occurring in the fire prone areas of Arizona, Nevada, Utah, Colorado, and Idaho (Theobald and Romme 2007; Wilson, McCaffrey, and Toman 2017). According to the National Interagency Coordination Center, in 2015, wildland fires within the United States destroyed 4,600 structures, of which 2,600 were homes located within the WUI (National Interagency Fire Center n.d.). People living within the WUI need to obtain more fire safety training to ensure they prevent fires and protect their homes (Firewise.org n.d.).

In the study completed by Balch, it is demonstrated that humans started 84% of the 1.5 million wildfires in the United States in the years between 1992 and 2012 (Balch et al. 2017). Sixty percent of the total coterminous United States burned area or 5.1 million km^2 was human caused while 0.7 million km^2 or 8% was lightning caused (Balch et al. 2017).

In the western United States lightning is the predominant cause of fires, especially in mountainous regions (Balch et al. 2017). Abatzoglou and Williams (2016) states that 40% of the reported wildfires were lightning ignited across the western US and that lightning accounts for 69% of the total area burned from the years 1992 to 2013. However, in the mountainous regions, approximately 98% of the area burned was ignited by lightning. The study also shows that there is seasonal variability of lightning caused fires: with 19% lightning caused fires in April, 35% in May, 54% in July, 61% in August, and 40% in September (J. Abatzoglou et al. n.d.). The 2017 study by Balch et al. states that 78% of lightning caused fires occurred June-August (Balch et al. 2017). Westerling's 2016 study concludes that from the year 1970 through the year 2012, there was an increase in annual large forest fires, over 400 ha, with most of the increases due to lightning ignitions (A. L. R. Westerling 2016). Lightning strikes are more effective during dry (no moisture) weather patterns and strikes are unpredictable as to where they will land.

Overall, the studies show that both human-caused and naturally occurring wildfires are increasing in the United States. Projections suggest that both causes will continue to increase.

1.2.4 Trends in Wildfire Activity

Using historical data of climate and fire information, future projections can be made. Globally, fire season length has increased by 18.7% and there is a 108.1% increase of global burnable area due to the longer fire season. The United States has also seen an increase in large fire frequency and season length, specifically within the Northern Rocky Mountains, which is attributed to snowmelt timing (Jolly et al. 2015). As stated earlier, Westerling's 2006 study reported an increase of an additional 84 days of fire season, 20 additional large fires per decade, and an increase in area of 123,000 ha burned per decade (A. L. Westerling et al. 2006).

Dennison et al. used satellite data over the United States from 1984-2011, excluded prescribed burns, and completed a trend analysis with four fire variables and twelve climate variables. The results concluded that there was an increase of seven large fires per year and that climates with high drought have increased the number of fires. Also, one wet year equates to greater fuel growth which is followed by an increase of fire activity the next year in forested areas and increase of fire activity in brush/grassland areas during the same year (Dennison et al. 2014).

The area burned has also increased over the decades. In the Western United States approximately 5.9 million ha were burned between the years 1986-1995. The burned area increased to over 16 million hectares between the years 2006-2015 (AghaKouchak et al. 2018). The elevations at which fires occur has also increased, meaning that large fires are occurring at higher elevations where there are between two and four months without snow, where previously, fires rarely existed (AghaKouchak et al. 2018; A. L. R. Westerling 2016).

1.2.5 Climate Drivers

Climate change has affected fire intensity and the areas burned. Timing of snowmelt, temperature, relative humidity, precipitation, fuel moisture, and weather patterns are all driven by climate (J. T. Abatzoglou and Williams 2016). Early spring snowmelt is driven by higher temperatures. Summer relative humidity and fuel moisture are governed by both higher temperatures and precipitation amount and pattern. As the winter weather seasons shorten and the summers are longer and dryer, fire seasons will lengthen. “High temperatures are associated with clear skies, persistent stagnation, and dry fuel: conditions that favor wildfire occurrence” (Spracklen et al. 2009).

Spracklen et al. 2009 study concluded that the increase in temperature will cause the annual burned area to increase by 54% in the western United States by 2050. They projected that the burned area in Pacific Northwest ecosystem will increase by 78% and in the Rocky Mountain ecosystem by 175% (Spracklen et al. 2009).

El Nino conditions in the Pacific Northwest cause earlier snowmelt and warmer, drier summer patterns, thus increasing fire probability in the region. The strongest contributors to global warming are CO_2 and black carbon emissions and both are produced by fires. A cycle is created where fires produce CO_2 and black carbon emissions which prompts global warming, consequently creating a warmer and dryer climate. The dry weather and warm temperatures increase evapotranspiration, subsequently drying out soil moisture and plants. Lightning ignitions are more prone to occur and are more effective in dry, warm air (Flannigan et al. 2009). Smoke plumes that contain black carbon lift from the ground level into the troposphere, and reduce vertical convection thus, limiting cloud formation and precipitation (Bowman et al. 2009). Black carbon that settles on snow and ice will change the albedo, thus increasing melting (Flannigan et al. 2009).

Fuel aridity is the measure of moisture within multiple factors. With warm temperatures and very little precipitation, plants, trees, and the soil will release stored water into the surrounding air, thus making them drier. The higher the fuel aridity; the drier the plants, trees and soil will be. Anthropogenic climate change accounts for a 55% increase in fuel aridity between the years 1979 and 2015 in the western US forests (J. T. Abatzoglou and Williams 2016). The Abatzoglou (2016) study estimated that anthropogenic climate change caused an additional 4.2 million ha of forest fire area burned between the years 1984 – 2015, which is double the expected area burned without the human-caused climate conditions. Thus, anthropogenic climate change has materialized as the leading driver of the increased forest fire activity (J. T. Abatzoglou and Williams 2016).

1.2.6 Future Wildfire Projections

Multiple studies have focused on predicting what the future fire seasons length, intensities, and burned areas will be (J. T. Abatzoglou and Williams 2016; Balch et al. 2017; Balshi et al. 2009; Bowman et al. 2009; Dennison et al. 2014; Flannigan et al. 2009; Jolly et al. 2015; Price and Rind 2004; Spracklen et al. 2009).

Price and Rind predict a 44% increase of lightning caused fires in the United States by the end of the 21st century (Flannigan et al. 2009; Price and Rind 2004). Balshi et al. 2008 predict the decadal area burned in western boreal North American forest to double by the year 2041–2050 and increase 3.5 to 5.5 times by the year 2190, when compared to burned areas between 1991–2000 (Balshi et al. 2009; Flannigan et al. 2009).

Spracklen et al.'s study concluded that the increase in temperature will cause the annual area burned to increase by 54% in the western United States by 2050. This study projected that the area burned in Pacific Northwest ecosystem will increase by 78% and the Rocky Mountain ecosystem by 175% (Spracklen et al. 2009). Spracklen et al. also predicts an increase of 40% of organic carbon and 20% of elemental carbon concentrations across the western United States in summer time air compared to 2009 values. Increases of this nature will have an impact on atmospheric visibility (Spracklen et al. 2009).

The Pacific Northwest will continue to be impacted by anthropogenic climate variables, early snowmelt, warm, dry summers with higher probabilities of lightning-caused fires, and larger areas burned (J. T. Abatzoglou and Williams 2016; Balch et al. 2017; Bowman et al. 2009; Dennison et al. 2014; Flannigan et al. 2009; Jolly et al. 2015; Spracklen et al. 2009).

1.3 Background - Smoke

An inevitable byproduct of wildfires is smoke. It has no boundaries and is able to disperse wherever the wind blows it. Smoke is comprised of particulate matter (PM) and is measured according to the size of the particles. PM_{10} refers to particles that are 10 micrometer (µm) in size or smaller. $PM_{2.5}$ are smaller, finer particles than PM_{10} and are 2.5µm or smaller in size. The smaller $PM_{2.5}$ smoke particles can remain suspended in air for longer periods of time. Across the United States from 1988-2016 the extreme levels of $PM_{2.5}$ have decreased except for the Northwest United States, where the trend is increasing and is attributed to wildfire smoke. This area includes parts of Idaho, Montana, Wyoming, Utah, Nevada, Washington, and Oregon. During a high wildfire year, $PM_{2.5}$ concentrations can be double the regular summer concentrations (McClure and Jaffe 2018).

The study completed by Spracklen et al. determined that the large areas burned in the Northwest United States (Oregon, Washington, Idaho, western Montana, and northern California) caused the increase in carbonaceous aerosol concentrations, also known as smoke (Spracklen et al. 2009).

A study completed by van der Werf et al. concluded that globally, approximately 2 pentagrams (2×10^{12} kg) of carbon is released into the atmosphere by fires annually (Johnston et al. 2012; Van Der Werf et al. 2008).

The Environmental Protection Agency (EPA) monitors air quality throughout the United States, and establishes regulations and policies to ensure healthier air for everyone. Fifty-two percent of all summer exceedance events within the United States are due to smoke. However, in the Western United States alone it is closer to 80% exceedance for individual monitors (Kaulfus et al. 2017).

1.3.1 Impacts

Wildfire impacts are multiple scale events across time and space. Within a few days fires will impact the loss of life and property. The emotional trauma could last for years and economic impact for decades. After fires, there is potential for floods and debris flows that can impact from a few miles to hundreds of miles. Smoke, however, can impact people thousands of miles away and affect atmospheric conditions on a local and a global scale. With the jet stream that crosses the United States, smoke from a fire in California can sweep Northeast into Nevada, Oregon, Washington and move eastward into Idaho, Montana and Wyoming before continuing across the Great Plains to Pennsylvania and the state of New York. Smoke impacts people’s health in both the short and long term, which creates an associated risk and concern for policy makers.

1.3.2 Risks

Risk in terms of wildfire smoke as a hazard is hard to define. Peoples' response to any hazard is dependent on their interpretation of the risk, which is "shaped by their own experience, personal feelings and values, cultural beliefs and interpersonal and societal dynamics" (Eiser et al. 2012).

In a hazardous situation, the public must decide their own perception of risk and determine what actions to take. These decisions and thought processes are a blending of natural/physical factors and human/behavioral factors. Physical factors include facts and projections but also the uncertainty of the unknown. Human behavioral factors would include a decision about the known and unknown facts, weighing the risk and the required actions to mitigate the personal risk. Individuals with background experience with the hazardous situations have a different perception of the risk than those who do not have a background. Typically, those who do not have a background rely on experts to provide the risk severity and to provide decisions or actions to protect them (Eiser et al. 2012).

Public safety officials, along with fire and resource managers, are viewed as experts in regard to wildfires. They are expected to make critical decisions using a risk management process; then communicate with involved agencies and the public. Communication with the public is to encourage household level risk mitigation and support for fire management as a tool to reduce future wildfire risk. The key to increasing community support is more transparency about the situation, fire suppression activities, as well as engaging the public in bidirectional conversations, and building long-term relationships and trust between the agencies and the public (Calkin et al. 2011; Olsen et al. 2014; Wilson, McCaffrey, and Toman 2017). Those who assume the role as experts need to understand how different communities perceive both the immediate danger and how they perceive the experts' messages. Without understanding the specific community, well-intended rules and policies could be ineffective (Slovic 1987).

1.3.3 Long-Tterm and Short Term

The overall health impact in terms of long-term and short-term exposure to wildfire smoke is relatively unknown.

Holstius' study considered human birth weight changes due to the mother's smoke exposure during her pregnancy during the 2003 southern California wildfires. This study found overall lower birth weights and especially with mother's exposed during their second and third trimesters. Birth weights were compared to babies who were born before the wildfires or more than nine months after the fires within the same region of California (Holstius et al. 2012; Reid et al. 2016).

According to Shaposhnikov's study of the wildfires and heat wave in Moscow, Russia in 2010, there is a correlation between high temperatures and high PM_{10} on deaths. During the 44-day heat wave it was determined that 29% of the 10,489 excess deaths were due to the elevated temperatures and to smoke exposure (Reid et al. 2016; Shaposhnikov et al. 2014).

Of the 339,000 annual global deaths due to wildfire smoke, 81% are caused by chronic exposure and 19% are caused by sporadic exposure to wildfire smoke (Johnston et al. 2012). Studies show that approximately one-third of households have at least one person that may be impacted by wildfire smoke (McCaffrey 2015; Wilson, McCaffrey, and Toman 2017). Economic costs due to health issues associated with wildfire smoke exposure is estimated to be $63 billion per year in the US due to short- term health impacts and $450 billion per year due to long-term health impacts in the US. Firefighting and suppression exceed $2.9 billion per year in the US (Fann et al. 2018).

Air pollution is associated with reduced life expectancy and a range of health problems, including cardiovascular diseases, cancer, respiratory diseases, and cognitive diseases such as Alzheimer's and dementia (Gordon 2014; Pope, Ezzati, and Dockery 2009; Shaposhnikov et al. 2014). EPA regulations have reduced air pollution from industrial and vehicular sources, however wildfire smoke is a major source of poor air quality, especially in the Northwestern United States (McClure and Jaffe 2018).

According to the National Emissions Inventory of 2011 from the EPA, it is estimated that 41% of $PM_{2.5}$ emissions originate from wildfires (Fann et al. 2018). The types and sizes of PM produced by a wildfire depends on the type of fuel, intensity of the fire, and if the fire is flaming or smoldering (Black et al. 2017). Wildfires are capable of producing more fine (smaller than $PM_{2.5}$) and ultrafine (under $PM_{1.0}$) particles (Black et al. 2017). Coarse particulates (PM_{10}) are larger and heavier and will settle out of the atmosphere easier than fine and ultrafine particles (Black et al. 2017). Thus, the very small particles are transported great distances. The biggest problem is that fine and ultrafine particles penetrate deeper into the lungs, creating graver concerns for human health. The EPA has focused on monitoring and created guidelines pertaining to $PM_{2.5}$ with human health considerations in mind (Black et al. 2017).

The study completed by Fann et. al estimated that in the United States between the years 2008 to 2013: 5,200 – 8,500 people were admitted to the hospital for respiratory problems, 1,500 – 2,500 people were admitted for cardiovascular problems, and 1,500 –

2,500 reported deaths are attributed to short term exposure to wildfire smoke and $PM_{2.5}$ (Fann et al. 2018). Nunes' study determined that there was a "significant association between the percentage of hours of $PM_{2.5}$ over 25 $\mu g/m^3$ and cardiovascular mortality" (Nunes, Ignotti, and Hacon 2013; Reid et al. 2016).

The exposure to smoke whether it's a few minutes or days has an impact on people. Perceptions of risks and health effects could govern actions that people take to mitigate smoke exposure.

1.4 Human Response

Previous studies have concluded that wildfire frequencies will increase, as well as the size of the areas burned, and that smoke will continue to disperse away from those fires impacting more people. Minimal research has focused on the social behavioral aspects of wildfire smoke (Calkin et al. 2011; Kulemeka 2015; McCaffrey 2015). The areas of focus within the social behavioral aspects of wildfire smoke include public health messaging and content, and acceptance of smoke from various sources and its perception as a hazard. The only way to determine the public's perception of the risk and to determine behavioral characteristics is to ask them about it.

1.4.1 Messaging and Content

Studies indicate that effective public health messaging must be short and direct with clear actionable directions, should address at-risk populations, and should be released from a trusted institution (Fish et al. 2017; Glik 2007; Kolbe and Gilchrist 2009; Lundgren and McMakin 2009; Olsen et al. 2014; Rappold et al. 2012). Messages that are bidirectional engage the public and can be on different communication channels (Fish et al. 2017; Lundgren and McMakin 2009). Clear communication between inter- and intra-agencies is also important (Olsen et al. 2014).

Kulemeka's study on the use of smartphone applications (apps) determined that demand for real-time contextual information is on the rise. People use smartphone apps to map current fire locations, to have emergency plans, and for informational apps that advise on preparedness, response, and recovery (Kulemeka 2015). As technology increases, the door for public communication is open.

1.4.2 Surveys Public Perceptions

To determine the public's perception about air quality and potential health impacts of smoke, researchers have used focus groups and public questionnaires.

Kunzli's study surveyed high school and elementary age children in sixteen Southern California communities by submission of a questionnaire between one and seven months after a wildfire in the area. The results revealed that individuals that had asthma were more likely to wear masks or stay indoors as a preventative action (Künzli et al. 2006).

In a 2007 San Diego study about smoke, respondents preferred a phone call warning instead of a public service announcement via mass media or no warning (Fish et al. 2017; Sugerman et al. 2012). A 2009 Australia brushfire study examining the means of receiving public health messages found that people over 40 years of age preferred government-funded local radio, local papers, and state/council spokesperson and emergency services. In the same study those under 40 years of age preferred television, local papers, and emergency services (Burns, Robinson, and Smith 2010; Fish et al.

2017). Both the San Diego and Australian studies demonstrate that the mode of communication is dependent on the community to which it is given.

A few studies have focused on acceptance of smoke from various sources and its perception as a hazard (Blades, Shook, and Hall 2014; Burns, Robinson, and Smith 2010; Olsen, Toman, and Frederick 2017). Weisshaupt and colleagues created purposively-chosen participant focus groups located around the Spokane, WA and Missoula, MT areas and concentrated on prescribed fires (Weisshaupt et al. n.d.). The 2014 study completed by Blades from the University of Idaho, used public surveys to determine the publics' smoke tolerance in regard to four situational factors: smoke origin, smoke duration, health impact, and advanced warning. Participants reported that advanced warnings of smoke were important and that they preferred personal communication (i.e. phone call) over public service announcements (Blades, Shook, and Hall 2014). Olsen's 2017 study of four states (California, Montana, Oregon and South Carolina) concluded that most communities accept smoke when it is coming from an uncontrollable wildfire or from prescribed burns which benefit the broader area or community (Olsen et al. 2017).

The 2014 study completed by Blades determined that the most important factors with regard to the publics' forbearance of smoke depends on the origin of the smoke and advanced public warnings (Blades, Shook, and Hall 2014).

Whether using focus groups or public surveys, communication around public perception about wildfires and smoke has begun. The public perception and attitudes regarding smoke is key for the development of effective wildfire policies.

1.5 Study Motivation

Currently, the US federal wildland fire policy and operations leaders have focused on creating a risk management system that only focuses on wildfire warnings. This system also needs to include warnings for wildfire smoke (Calkin et al. 2011). McCaffrey's study highlights the knowledge that some variables, such as risk perception, can affect the publics' response to wildfires. Also relationships between community members and fire personnel build a sense of community and supports preparedness at both the individual and community level (McCaffrey 2015). Research specifically focusing on the social behavioral aspect of smoke and the public perceptions is scarce (Blades, Shook, and Hall 2014; Olsen et al. 2014).

This thesis focuses on understanding the trends in air quality in the Boise, Idaho area as well as the Northwest of the United States. This thesis also bridges the gap in knowledge in regard to how people in the Western United States respond to wildfire smoke. Emphasis is on understanding the media in which people receive air quality notifications, public health messaging content and timing for effective responses to smoke events, the perception of smoke as a hazard, and health problems and mitigation of symptoms during smoke events. Chapter 2 evaluates the trend in air quality in the Treasure Valley, Idaho.

CHAPTER TWO: TRENDS OF AIR QUALITY IN BOISE, IDAHO AND THE NORTHWEST

2.1 Introduction

Air quality can be observed in two different ways, at ground level and from satellites. This chapter focuses on both ground level monitoring, which is reported as the Air Quality Index (AQI) by the EPA and observations from satellites, reported as the Aerosol Optical Depth (AOD). The trends of both measurements and a discussion are also included in this chapter.

2.2 Air Quality Index (AQI)

The Clean Air Act of 1970 and the EPA established the National Ambient Air Quality Standards (NAAQS) focusing on six criteria pollutants: ground-level ozone (O_3), particulate matter (PM), carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and lead (Pb). Each of the pollutants have their own concentration levels which are considered harmful to the public. Ground-level ozone and PM are the pollutants that present the most danger to human health (United States Environmental Protection Agency - 1 2019). PM is measured depending on the aerodynamic diameter of the aerosol particle, where $PM_{2.5}$ are particles that are 2.5 µm or smaller in size. $PM_{2.5}$ is a dry mass concentration usually measured in microgram per cubic meter ($\mu g/m^3$) and is usually collected over 24-hour intervals (National Aeronautics and Space Administration 2016). PM monitoring is divided into PM_{10} and $PM_{2.5}$, with collection stations across the United

States, and is reported to the Air Quality System database by state, local, and tribal agencies (United States Environmental Protection Agency - 2 2019).

The AQI is a ranking system used to establish daily how clean or polluted the ambient air is. The six criteria pollutants are monitored and reported with an AQI value that corresponds with their concentration level based on the national air quality standard for that pollutant. The pollutant with the highest value governs the AQI for that day (United States Environmental Protection Agency - 2 2019). Table 2.1 denotes the six AQI color categories with the numeric values and the level of health concern for the public.

Table 2.1: AQI Rating (United States Government 2016)

Air Quality Index Levels of Health Concern	Numerical Value	Meaning
Good	0 to 50	Air quality is considered satisfactory, and air pollution poses little or no risk.
Moderate	51 to 100	Air quality is acceptable; however, for some pollutants there may be a moderate health concern for a very small number of people who are unusually sensitive to air pollution.
Unhealthy for Sensitive Groups	101 to 150	Members of sensitive groups may experience health effects. The general public is not likely to be affected.
Unhealthy	151 to 200	Everyone may begin to experience health effects; members of sensitive groups may experience more serious health effects.
Very Unhealthy	201 to 300	Health alert: everyone may experience more serious health effects.
Hazardous	301 to 500	Health warnings of emergency conditions. The entire population is more likely to be affected.

AQI data from March 1999 through December 2018 in the Boise, Idaho area was downloaded from the EPA's Air Quality System database for this analysis. Linear interpolation was used for any missing daily values and they were graphed using the AQI rating system. Figure 2.1 presents the daily AQI values in Boise for the last 20 years. For a majority of days Boise's air quality was in the Good (green) and Moderate (yellow) categories; however, there was an increase in Unhealthy (red) and Very Unhealthy (purple) groups. To understand possible reasons for the increase, seasonal variations were analyzed.

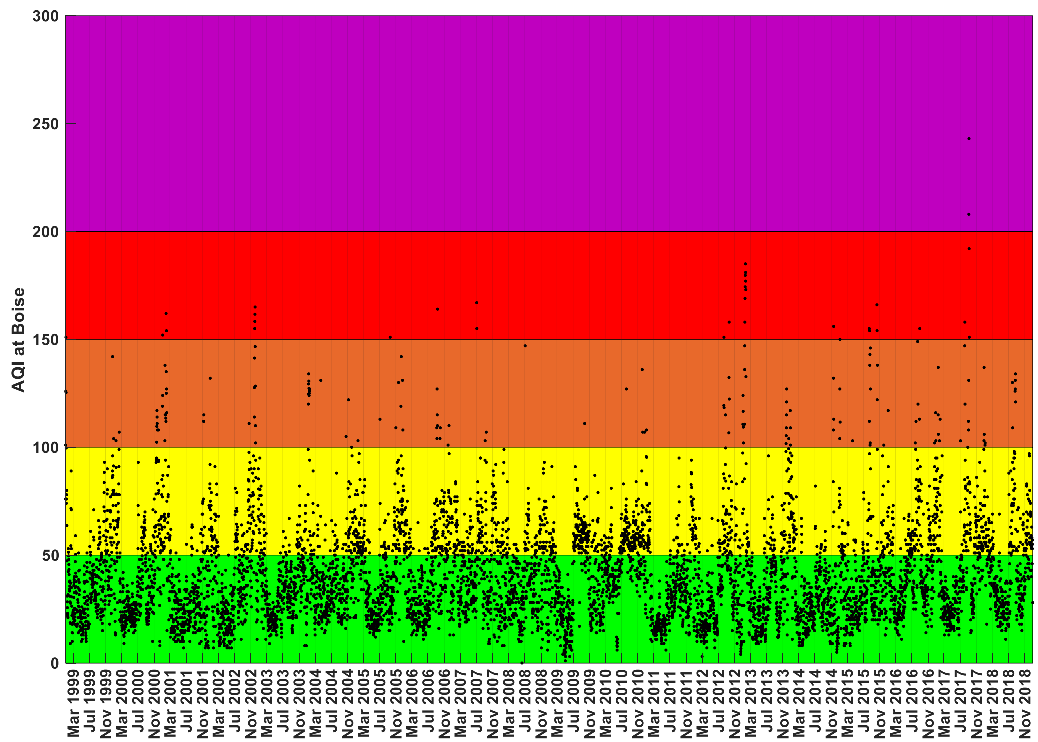

Figure 2.1: 20 Years of Boise AQI

AQI data for the fire season, July through September, can be seen in Figure 2.2. The solid line shows the linear trend of mean fire season AQI values. The dashed line portrays the linear fit to the maximum AQI values of each fire season. Both lines show increasing trends, but the line fitted to maximum AQI shows a higher slope. It is also apparent by looking at this figure that the amount of Unhealthy for Sensitive Groups (orange), Unhealthy (red), and Very Unhealthy (purple) days have also increased. The first orange and red days were in 2005. They have increased in frequency since then, and the first purple days were observed in 2017. The increases are all are attributed to wildfire smoke.

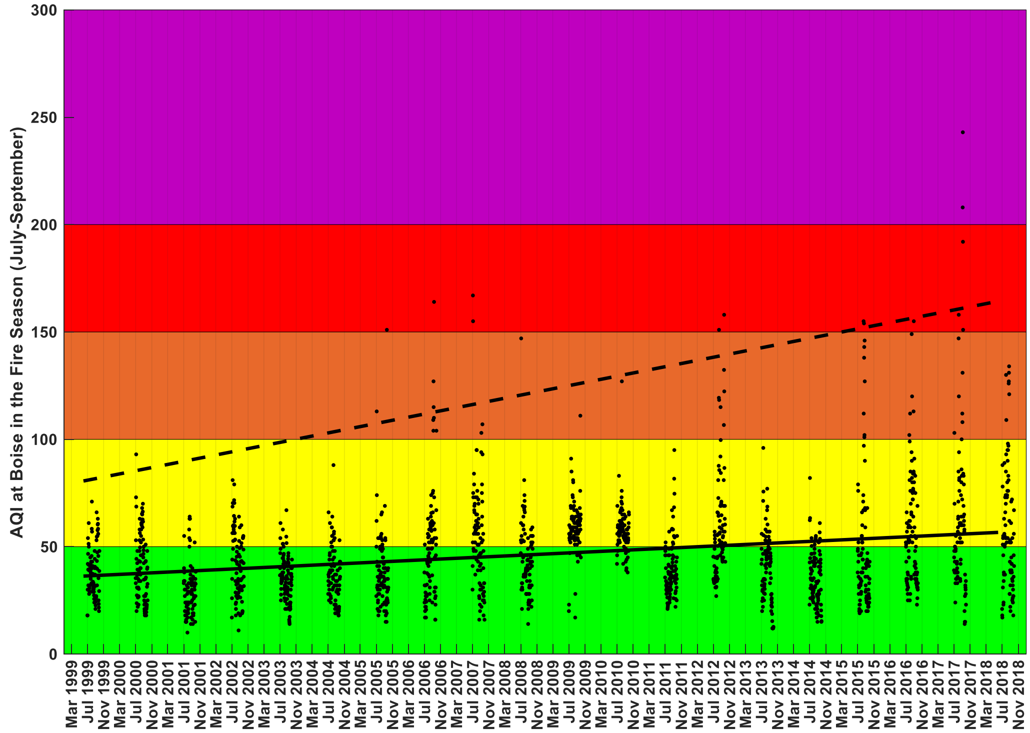

Figure 2.2: Boise AQI Fire Season - July through September

Figure 2.3 illustrates the Boise, ID AQI values for inversion prone months of November through February. The solid and dashed lines depict linear fit to the average and the maximum AQI values, respectively, during the inversion season. Both lines show a marginally decreasing trend, meaning that the air quality in these months has improved from year to year since 1999. The improvements could be from reduced vehicle emissions because of testing in Ada and Canyon County, and a reduction of people using wood burning fireplaces.

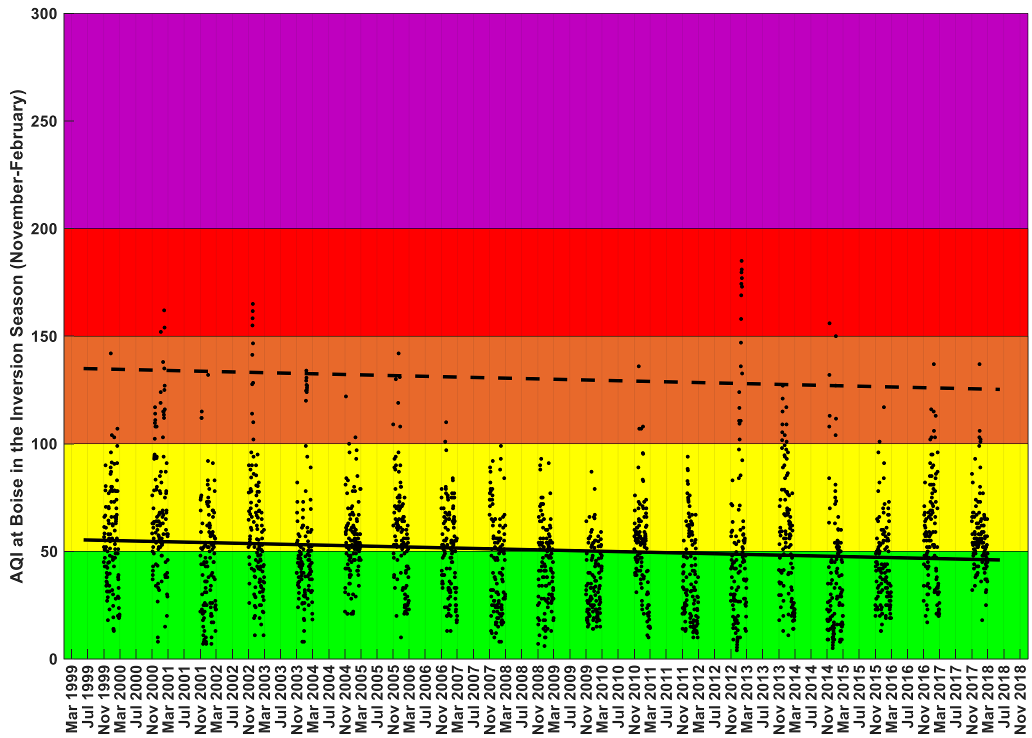

Figure 2.3: Boise AQI Inversion Months - November through February

The other five months, March through June, and October were categorized as non-fire or non-inversion months and Figure 2.4 shows the AQI data for them. Both the solid line and dashed line show a slight decrease since 1999.

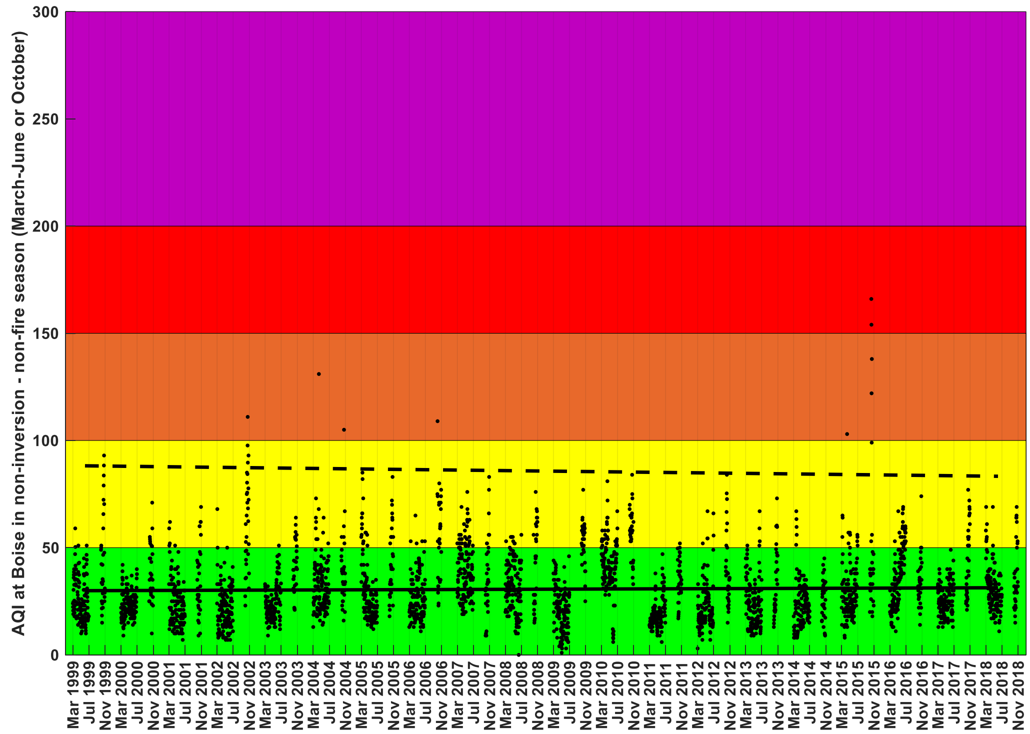

Figure 2.4: Boise AQI Non-fire and Non-inversion Months - March through June, and October

In order to check whether these trends are statistically significant, the Mann-Kendall (M-K) trend analysis method was used. Trend analysis results for each period of the year (fire season, inversion prone period, and the rest of the year) are summarized in Table 2.2. Based on these results, the increasing trend during fire season, months of July through September, with p-values of 0.0195 and 0.0048 for the average and maximum AQI, respectively, are statistically significant at a 95% confidence level. The increase in AQI values during the fire season are statistically significant and not random.

Table 2.2: Mann-Kendall Trend Season Variation Analysis

		Statistically significant at 95% confidence level?	P-value
November – February (Inversion)	maximum	No	0.5288
	average	No	0.2629
July – September (Fire)	maximum	Yes	0.0195
	average	Yes	0.0048
March – June & October	maximum	No	0.3304
	average	No	0.6731

Overall, it is apparent that wildfire smoke has increased the AQI values in the Boise area since 1999. The first orange and red days during fire season were in 2005 and have now increased to having purple days in 2017. More discussion regarding the AQI trends is in Section 2.4.

2.3 Aerosol Optical Depth (AOD)

The first American satellite was launched on January 31, 1958 and the National Aeronautics and Space Administration (NASA) was created on October 1, 1958, which began the research of flights that were within and outside of the Earth's atmosphere. Since then many human space flights, space explorations, and satellites have moved our understanding of Earth and space forward. Satellites orbit the Earth with sensors or instruments attached to them that are used to create land images, track forest fires and tropical deforestation, and much more (National Aeronautics and Space Administration 2019).

The Modern-Era Retrospective analysis for Research and Applications, Version 2 (MERRA-2) was developed by NASA's Global Modeling and Assimilation Office for several applications including: meteorological assimilation, ozone profile observations, and to observe aerosols and represent aerosol interaction within Earth's climate system

(National Aeronautics and Space Administration: Goddard Space Flight Center 2019). MERRA-2 obtains aerosol optical depth (AOD) data from NOAA Polar Operational Environmental Satellites (POES), NASA Earth Observing System (EOS) platforms, and NASA ground-based observations, and then analyzes the data for specific outcomes (Koster et al. 2016).

AOD is a measure of how light passes through a medium. When aerosol particles are in the path of a light beam, they will either scatter or absorb the light, causing the light intensity to change. Satellite AOD is a vertical column that goes from the satellite in the atmosphere to the Earth's surface. It is a measure of aerosol loading and does not have units associated with it. AOD is a function dependent on the shape, size, type, and concentration of aerosols within the column (National Aeronautics and Space Administration 2016).

MERRA-2 AOD data was downloaded focusing on the Northwestern United States and the M-K trend analysis method was applied to determine AOD trends. The M-K test is used to statistically assess a trend in data over time. It is used to identify geographical locations where AOD changes were significant. The M-K test determines whether to accept the null hypothesis (there is no trend) or to accept an alternative hypothesis (there is a trend and it is positive or negative).

Using the M-K test with the MERRA-2 data from 1981 to 2018, the frequency of the AOD at the 90^{th} percentile was determined. Figure 2.5 displays the slope of a line that is fitted to the annual frequency of the 90^{th} percentile daily average AOD values. Eastern Montana had the highest increase in the frequency of daily AOD values above the local 90^{th} percentile, with a slope of 23%, while southwestern Idaho had about a 16% increase the in frequency of high daily AOD values (above the 90th percentile). Note that M-K test shows a statistically significant trend for this entire region. When the trend is not significant, the color is changed to white.

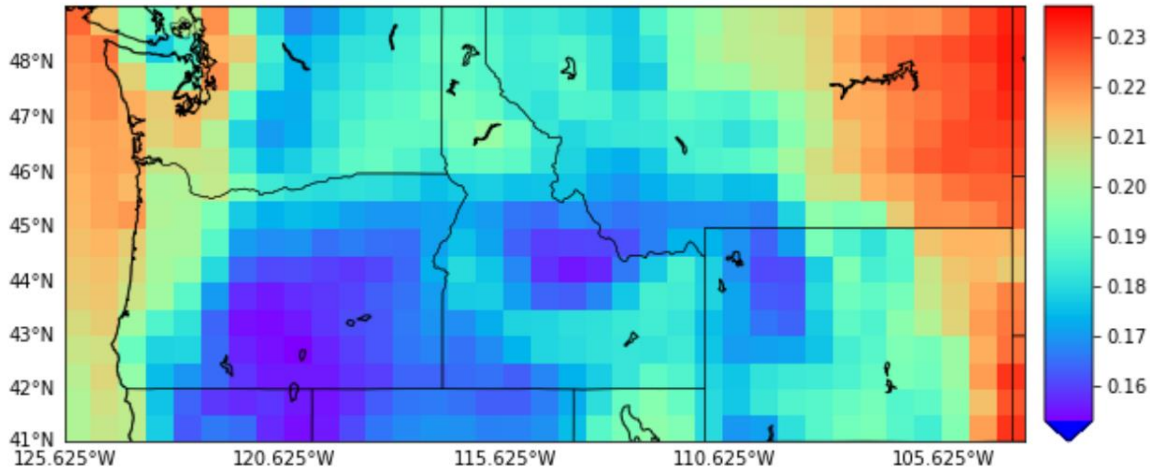

Figure 2.5: AOD Frequency at the 90th Percentile

Again using the M-K test for MERRA-2 data from 1981 to 2018, the trend in the annual frequency of the AOD at the 99th percentile was determined. Figure 2.6 displays this positive trend, where Eastern Montana's relative increase in annual frequency of the 99th percentile is 46%. Northeastern Idaho has locations that have increased about 43% in the frequency of worst AOD days, and the Treasure Valley had an approximate increase of 36% in the 99th percentile AOD range.

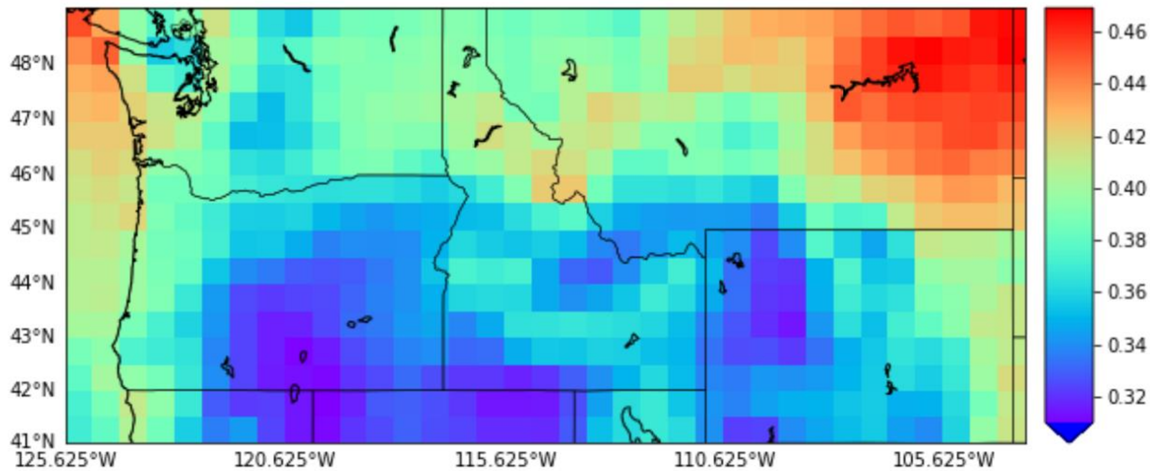

Figure 2.6: AOD Frequency at 99th Percentile

M-K tests were also completed to determine any seasonal variations. Figure 2.7 depicts the average AOD during the fire season months (July, August, and September) from 1981 to 2018. The resulting green color demonstrates that there is no trend, meaning that there is not a positive or negative trend. However, when using the maximum AOD values, there is a positive trend as seen in Figure 2.8. The northeastern Idaho Bitterroot Mountain area, had the largest increase in Idaho with about a 4.5% increase in maximum AOD in summer months, while the Treasure Valley had an increase of about 3%. The purple areas might be trends but they were not statistically significant at 95% confidence.

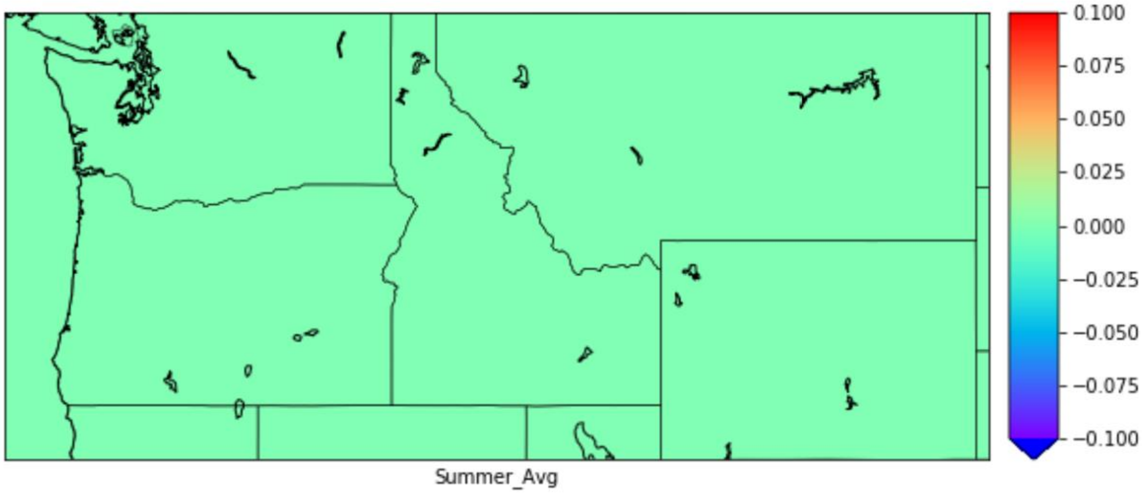

Figure 2.7: AOD Average during July, August, and September in Years 1981 to 2018

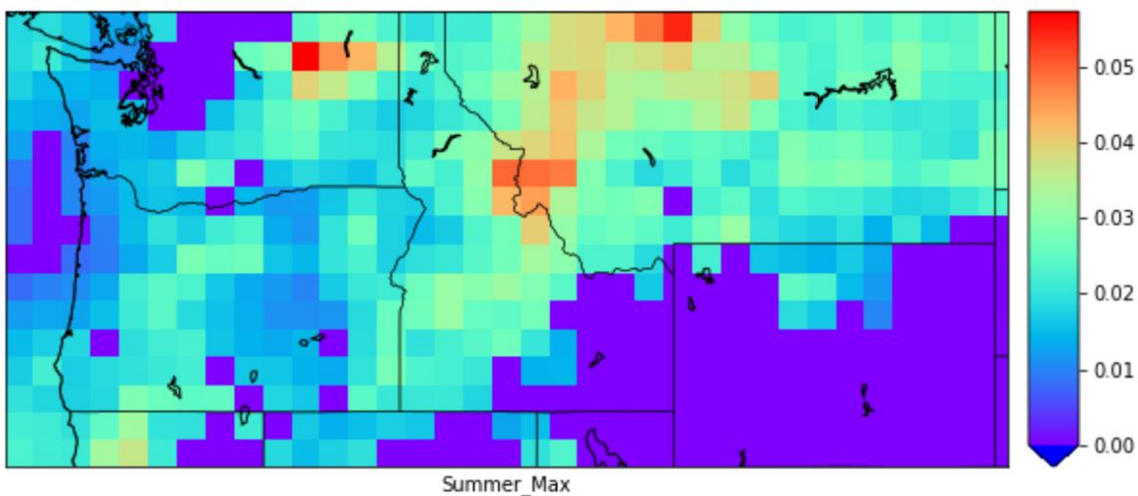

Figure 2.8: Maximum AOD during July, August, and September in Years 1981 to 2018

Figure 2.9 depicts trends in average AOD during the month of July from 1981 to 2018. The resulting green color demonstrates that there is no significant trend. However, when using the maximum July AOD values, Figure 2.10, there are a few locations which demonstrate a significant trend with a linear slope of 1.75%. Again the purple areas could have trends, but they were not statically significant.

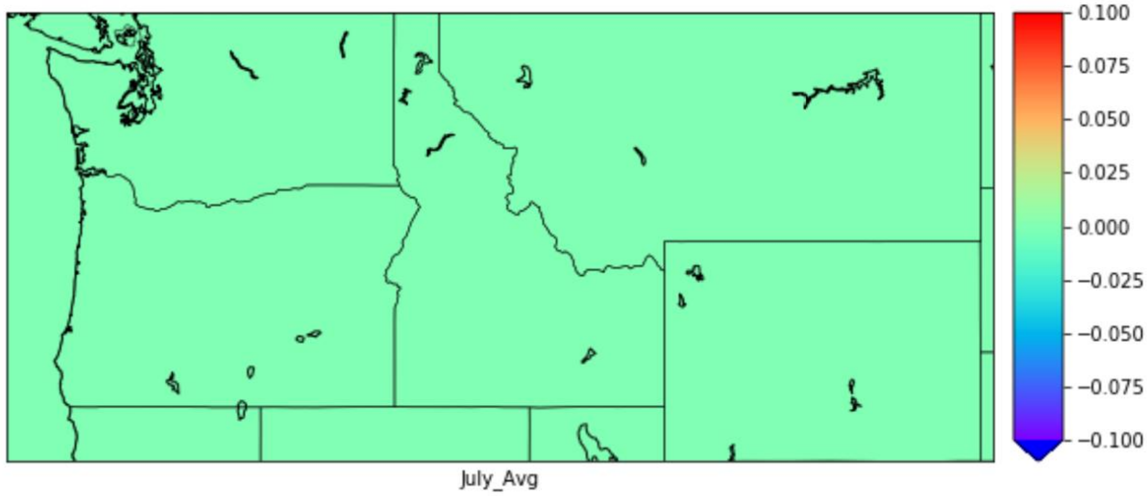

Figure 2.9: Average AOD during July from Years 1981 to 2018

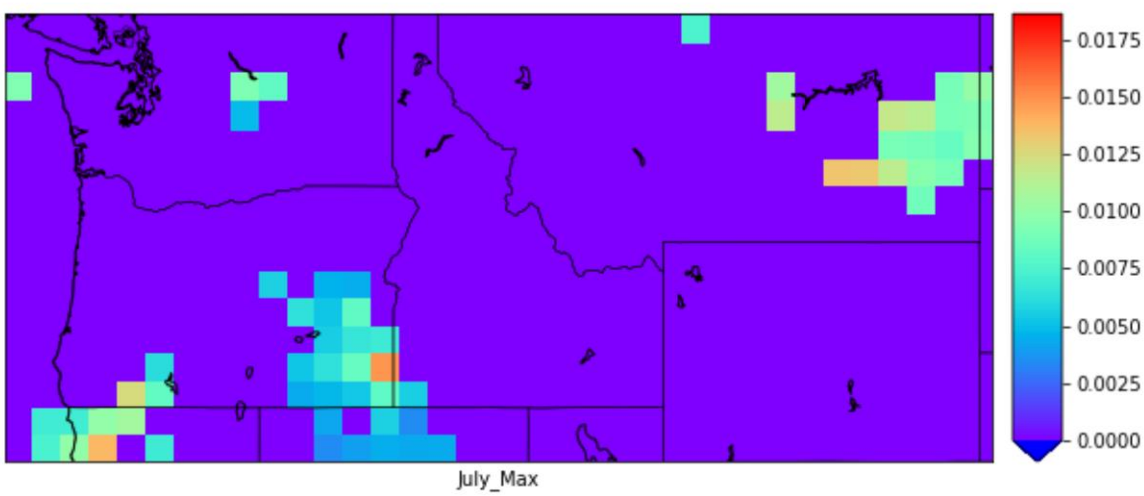

Figure 2.10: Maximum AOD during July from Years 1981 to 2018

Figure 2.11 depicts the average AOD during the month of August from 1981 to 2018. Again, the resulting green color demonstrates that there is not a significant trend. However, in the maximum August AOD values, Figure 2.12, about half of the locations register a trend that is statically significant. The Bitterroot Mountain area in northeastern Idaho had the largest AOD increase in Idaho (about 4.5 – 5.0% per year). The Treasure Valley had an AOD increase of about 2.5 - 3% per year.

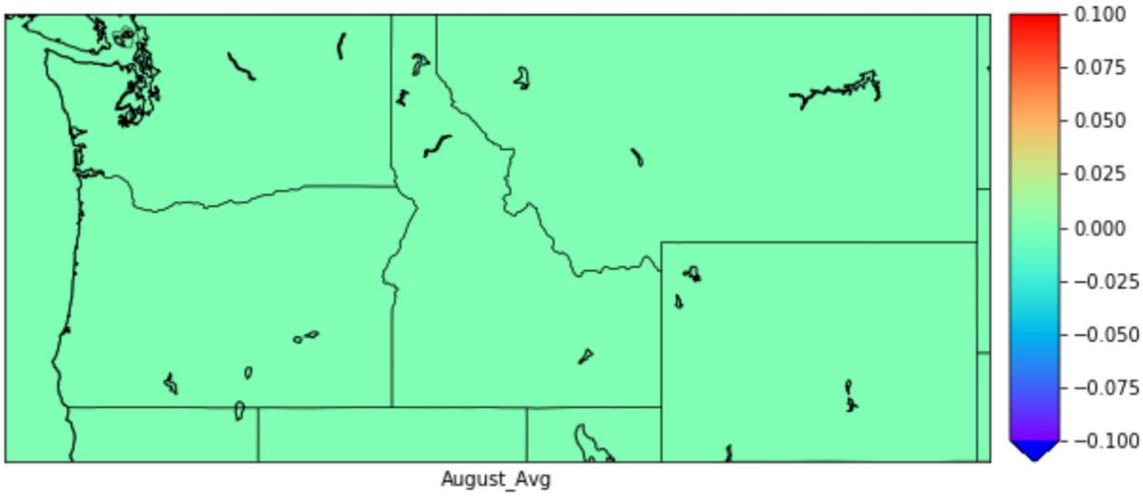

Figure 2.11: Average AOD during August from Years 1981 to 2018

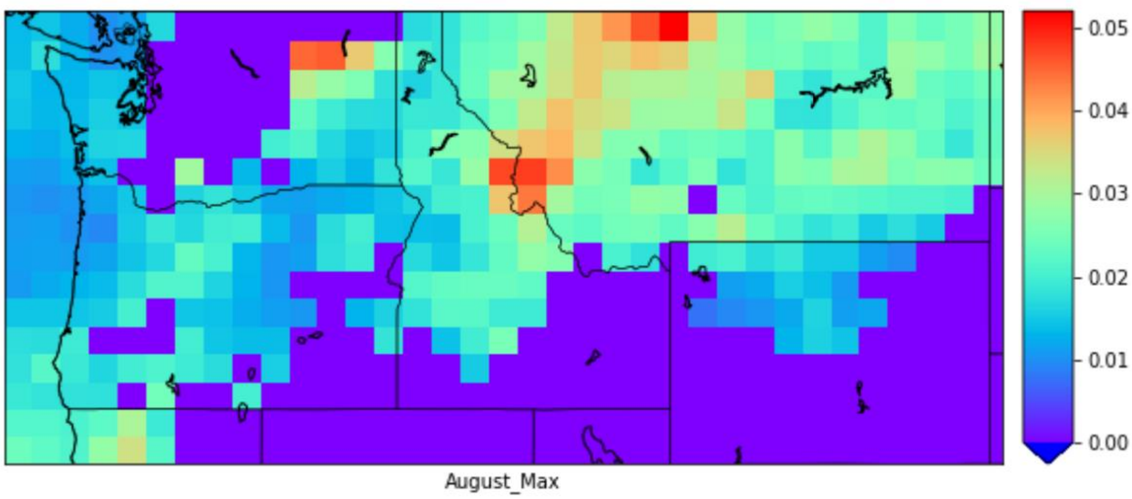

Figure 2.12: Maximum AOD during August from Years 1981 to 2018

Figure 2.13 depicts the average AOD during the month of September and there is no significant trend. In the maximum September AOD values, Figure 2.14, a few locations in Idaho register a significant trend with a slope of less than 2.0% per year. One location near the Treasure Valley had a maximum AOD increase of about 1.5% per year.

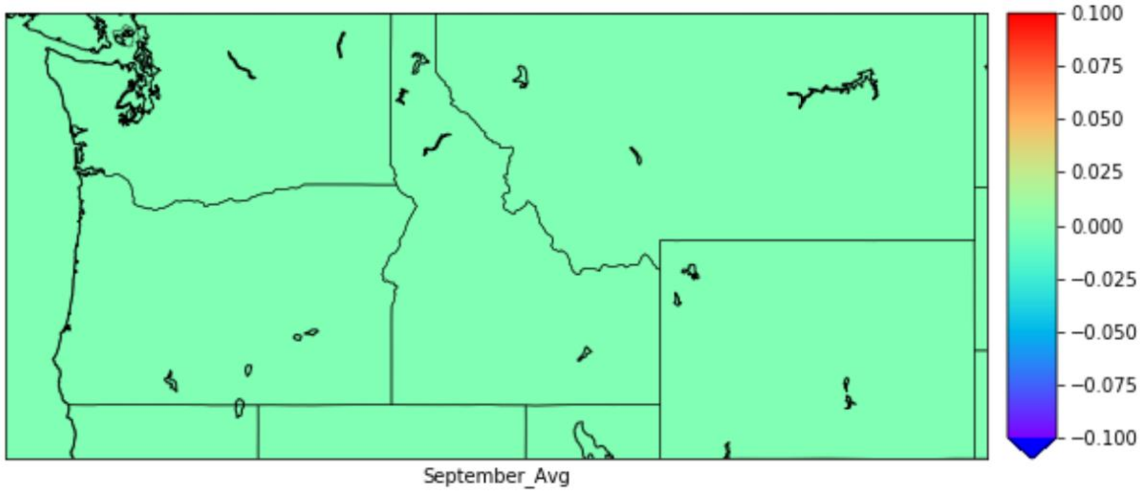

Figure 2.13: Average AOD during September from Years 1981 to 2018

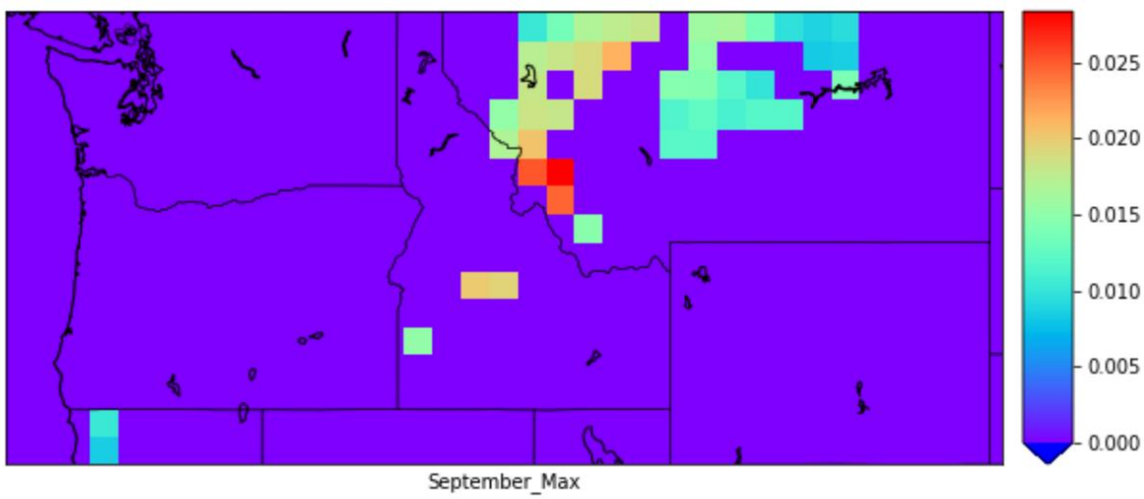

Figure 2.14: Maximum AOD during September from Years 1981 to 2018

Overall, average monthly AOD in the region has not changed significantly, whereas maximum monthly AOD shows some significant increasing trends within different summer months. More discussion on the AOD and AQI trends are in the next section.

2.4 Discussion

Ground observation of the AQI and a reanalysis simulation of the AOD were used in M-K trend analysis method to determine whether there is a statistically significant trend in air quality in Boise, Idaho and the entire Northwest.

Overall, ground level monitoring in the Boise area over the last 20 years has shown an increase in the number of poor air quality days, with a rise in yellow days (AQI = 50-100) and in orange days (AQI = 100-105) AQI levels. Dissecting the data into three seasons (fire, inversion, and non-fire and no-inversion) allowed for more understanding into the AQI trends. During the fire season, the average and maximum daily AQI values show significantly increasing trends, with the maximum daily AQI values showing a significantly higher increase. During the inversion months, both the average and maximum AQI levels have declined, although the decline is not statistically significant. During non-fire and non-inversion months there is also not a significant trend. Overwhelmingly, the months of July, August, and September have the greatest impact on Boise's air quality.

AOD observations of the Northwestern US also show an increase in the frequency of poor air quality days during the months of July, August, and September (fire season) over the last 37 years. In terms of the number of days above the 90th percentile, the Treasure Valley AOD shows an increasing slope of 17%, which is elevated to 36% if the number of days above the 99th percentile is considered. The summer average AOD values do not show a positive or negative trend; however, the summer maximum AOD values resulted in a positive trend over most of the Northwestern US study area. The Treasure Valley had an overall summer maximum AOD increase of 3% over the 37 years.

Both methods established trends in poor air quality during the fire season of July, August, and September. This analysis of 20 years of ground level monitoring and 37 years of satellite observations corroborates the publications provided in Chapter 1. Wildfire smoke disperses and travels to the Treasure Valley, and the impact of the poor air quality is increasing. Chapter 3 and Chapter 4 provide the methodology and analysis of the social behavioral aspects of the impact that wildfire smoke has caused in the Treasure Valley.

CHAPTER THREE: HUMAN RESPONSE TO WILDFIRE SMOKE: METHODOLOGY

3.1 Introduction

Human response to wildfire smoke is to date, an understudied topic. Does the presence of wildfire smoke change people's behavior? Will people avoid the smoke by staying inside, or will they carry on with their usual outdoor activities? The research within this thesis was designed to collect information regarding the human response to wildfire smoke from people around the Treasure Valley, analyze the collected data to determine the human response, and then share the data openly with other researchers. The process of data collection began with guidance from the Boise State University Office of Research and Compliance and the Institutional Review Board (IRB), while concurrently designing a survey questionnaire. The questionnaire was designed to gather pertinent information and was collected both in-person and online in August through October of 2018. Analysis and discussion is included within Chapter 4.

3.2 Institutional Review Board (IRB)

Boise State University's Office of Research and Compliance is the office that governs human subjects' research for those associated with Boise State University (BSU). Human subject research investigates human behaviors and human interactions. The collection of data for this research would include human interactions, thus it had to be in compliance with the Code of Federal Regulations (45 CFR 46) Protection of Human

Subjects. All researchers directly collecting data completed the Collaborative Institutional Training Initiative (CITI) training (CITI Program n.d.).

The first step to gaining BSU IRB approval was for all members of the research team to complete the Social and Behavioral Research modules within the CITI training. CITI training was an online workshop that allowed the research team to understand the importance of the history of human research, ethical principles, and interpersonal relationships. Other topics included informed consent, privacy and confidentiality, records based research, populations in research requiring additional considerations and/or protection, internet based research, conflicts of interest with human subjects, and unanticipated problems with research (CITI Program n.d.). Data collection methods, data storage, and interpersonal relationships were discussed within the research team as part of the planning process (Meadow 2018).

Once the CITI training was completed, the IRB application began. The Principal Investigator (PI) was Mariah Fowler, the Co-Investigator was Dr. Mojtaba Sadegh, and the Key Personnel was Andrew 'Andy' Adams to complete the research data collection team. The IRB application guided the research team in determining what data would need to be collected, how it would be collected, and how it would be stored.

Participants would be divided into two categories, in-person and online. The in-person participants were randomly selected in public areas within the Treasure Valley, and the online participants were selected by their affiliation to Boise State University. The intention was to gain information from persons of all genders, ages, ethnic backgrounds, and health status. In addition to this, the purpose was to determine the general public's level of understanding about health problems associated with smoke waves, and whether they applied that knowledge to decreasing their outdoor activities during smoke waves.

During the summer of 2018, data collection began after the smoke wave had both permeated and subsided within the Treasure Valley. Limitations of the research included that participants had to be able to read or speak English, and the research was not designed for vulnerable populations such as people under the age of 18, pregnant women, or cognitively, economically, or educationally impaired participants. The cover letter with the questionnaire stated that this study did not involve any foreseeable serious risk. The cover letter and investigators expressed that any questions that made the participant uncomfortable could be skipped and that the survey could be stopped at any time. The cover letter and complete questionnaire can be found in the Appendix.

In-person data collection locations included public places in Boise, Caldwell, Eagle, Kuna, Meridian, and Nampa. The research team randomly selected participants to complete a paper questionnaire and were available for any questions that the participants might have. Online data collection was completed using the Qualtrics program with participants having connections with Boise State University. Collection of data is discussed further in Section 4.4.

3.3 Design of data collection

The purpose of this research was to gain an understanding of the general public's knowledge of health hazards associated with wildfire smoke, specifically people within the Idaho and Boise Metropolitan area. Agencies that were collaborated with include the Bureau of Land Management (Boise office), the Idaho Department of Environmental Quality (IDEQ), and the Nez Perce Tribe. The questions were designed and refined by the collaboration team to ensure that the questionnaire would meet the needs of the decision makers.

Designing of the questions and the interagency collaboration of question content went on simultaneously with the IRB application process. Questions were divided into five categories comprised of demographic data, activity data, air quality notifications, natural hazards, and finally, health questions. These categories and questions were chosen to cover the different aspects of social behavioral studies on wildfire smoke hazards (Fish et al. 2017; Künzli et al. 2006; Olsen, Toman, and Frederick 2017). Table 3.1 summarizes the question content and the complete questionnaire can be found in the Appendix.

Table 3.1: Summary of Survey Questions

Category	Question content
Demographic Data (6 questions)	• Age • Gender • Race • Zip code • Education level • Income
Activity Data (3 questions)	• General health status • Engagement in outside activities • Frequency of outside activities
Air Quality Notification (13 questions)	• Receiving/Seeking air quality information and its source • Frequency of seeking air quality information • Reducing outside activities • Longest period of consecutive days to reduce outside activities • Minimum air quality index that convinced to reduce/eliminate outside activities • Effective warning content and delivery method • Timing of warning • Future mitigation planning
Natural Hazard Questions (3 questions)	• Perception of smoke as a hazard • Comparison with other hazards such as tornadoes and hurricanes • Evacuating home to prevent smoke impacts
Health Questions (3 questions)	• Smoke-related health experience • Type of observed symptoms • Mitigation strategies to reduce health issues

3.3.1 Design of Questions Within the Survey

The question wording was designed with the guidance of Dr. Steve Utych, an Assistant Professor in the Political Science Department at Boise State University, and based on surveys used in national social science studies such as the American National Election Study and the General Social Survey. The survey employed branching questions with Yes/No answers, followed with a question requesting more details. Multiple answer questions were also given an ‘other’ option which allowed participants the ability to answer the question in their own words. Questions that could be perceived as difficult also had a ‘not sure’ response option (Tourangeau, Rips, and Rasinski 2012). Participants were also allowed to skip any question that they did not feel comfortable answering. Seven questions focused directly on the smoke event of 2018, so that participants could focus their memories on that time period (Achen 1975).

Questions were ordered in a way that would encourage the most unbiased answers. The initial questions were demographic or background information that included age, gender, race / ethnic background, zip code, and finished with education and income questions. The intent of this category of questions was to provide background information for researchers and provide key social and economic characteristics of participants.

The next category of questions were designed for participants to reflect on their own general health status and list their own outdoor activities. Then the questions moved to air quality notifications and whether or not the participant reduced their outdoor activities based on those air quality notifications. Placing the questions in this order allowed participants to think about their outdoor activity levels prior to the wildfire smoke event and then during the event.

Two questions concerned the AQI ratings that are used by IDEQ to determine outdoor air quality and outdoor activity levels. This question also allowed for those who were not fully aware of this rating system to give a ‘not sure’ answer. This would allow

IDEQ to determine if the public is knowledgeable about the AQI rating system and if more public involvement or education is needed.

Participants were then asked about the air quality message system, the content of its messages, and the best timing for the warnings. This is key for IDEQ to determine where there is an area for growth as far as sending out notifications, types of messages that the public wants, and the best time of day to deliver the message.

The final question in the air quality notification section asked what the participant's future mitigation plans are. This also allowed for a smooth transition to the natural hazard section. Does the public perceive smoke as a hazard and how does it compare to other natural hazards such as tornadoes and hurricanes? The final question in this category asked if the participant would evacuate their home because of wildfire smoke.

The health questions were strategically placed at the end of the questionnaire so that participants would have already listed their outdoor activities, thought about if they reduced their outdoor activities, and then could focus on any symptoms that they or household members had during the smoke event. They were able to list their symptoms and then list actions that they did to mitigate the symptoms.

3.4 Collection of data

The timing of data collections was placed after the initial smoke wave in the Treasure Valley had subsided. Survey collection was completed with in-person questionnaire response at public locations within the Boise area and also online with participants associated with Boise State University. A combined total of 2,237 surveys were acquired during both the in-person and online forum. Figure 3.1 shows the AQI

PM_{10} (Particulate Matter less than 10 microns in size) values during the summer of 2018, collected from the downtown Boise Fire Station #5 location. The blue boxes illustrate the dates in which in-person and online surveys were collected, as compared to the AQI PM_{10} ratings.

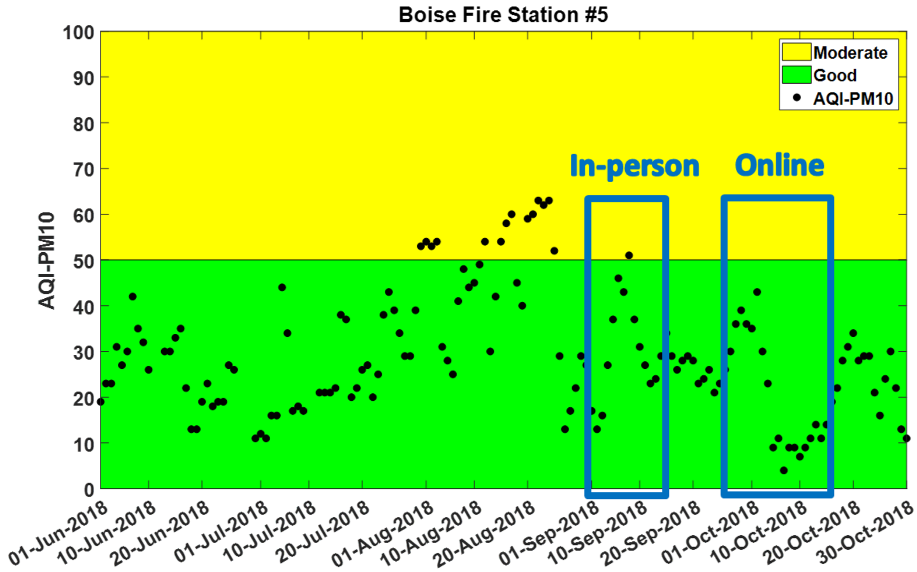

Figure 3.15: Summer 2018 Boise AQI values

3.4.1 In-Person Collection

The in-person surveys were conducted between August 28, 2018 and September 15, 2018 in several locations across the Treasure Valley including Boise, Caldwell, Eagle, Kuna, Meridian and Nampa. The research team used between 15-30 clipboards, depending on the location, to collect in-person surveys from the general public. The research team asked participants to complete the survey and offered bottled water. As surveys were completed they were placed in an envelope that was labeled with the date, time and location.

Boise surveys were completed at Alive After Five, Julia Davis Park, Kristin Armstrong Park, Ann Morrison Park, Spirit of Boise Balloon Night Glow, Esther Simplot

Park, a Boise State University home football game, and the Hyde Park Street Fair. Meridian interviews were completed at the Meridian Farmer's Market in downtown Meridian, and at the Movie in the Park in Settlers Park. Interviews in Kuna were completed in downtown Kuna, Bernie Fisher Park and Kuna Middle School. Locations for the Eagle area included Guerber Park, downtown Eagle, and Eagle Island State Park. Collections in Nampa were at Lakeview Park and downtown Nampa at the Nampa Farmer's Market. Collections in Caldwell were at the Caldwell Farmer's Market in Indian Creek Park. Table 3.2 provides location, dates, times, and number of surveys collected. A total of 614 in-person surveys were collected within the 13 days.

Table 3.2: Summary of In-Person Collection

Location	Date	Time	Surveys
Julia Davis Park - Boise	8/28/2018	5:30-8:00pm	40
Alive After 5 - Boise	8/29/2018	5:30-8:30pm	58
Kristin Armstrong & Ann Morrison - Boise	8/30/2018	5:30-8:00pm	44
Movie in the Park - Meridian	8/31/2018	6:30-9:00pm	29
Night Glow - Boise	8/31/2018	5:30-8:00pm	102
Farmers Market - Meridian	9/1/2018	10:00am-noon	25
Julia Davis - Boise	9/1/2018	noon-12:30pm	4
Downtown Eagle & Eagle Island State Park - Eagle	9/2/2018	1:00-3:30pm	21
Guerber Park - Eagle	9/4/2018	6:00-7:30pm	30
Bernie Fisher Park and Kuna Middle School - Kuna	9/5/2018	6:00-7:30pm	31
Esther Simplot Park - Boise	9/6/2018	6:00-7:00pm	15
Kristin Armstrong - Boise	9/7/2018	5:30-6:30pm	24
Farmers Market & Lakeview Park - Nampa	9/8/2018	9:30-1:00pm	34
BSU home football game - Boise	9/8/2018	4:30-8:00pm	90
Farmers Market - Caldwell	9/12/2018	3:00-7:00pm	37
Hyde Park Street Fair - Boise	9/15/2018	12:30-2:00pm	24
Boise	varied		6
		Total	614

The 614 completed surveys were then converted into a digital format by eight undergraduate students, five volunteer graduate students, and six other volunteers. Each data entry person was assigned 20-50 paper surveys to digitize. Each location was assigned a batch number and each survey was numbered within each batch. Each survey was tagged with an X-Y format, where the X was the batch number and the Y was the survey number within that batch. Each batch was double checked as a measure of quality assurance by randomly selecting 10% of the surveys within the batch and checking the digitized answers with the paper submitted answers. Any batch that had more than a 1% error resulted in the entire batch being reevaluated for accuracy.

3.4.2 Online Collection

The online collections were conducted between September 25, 2018 and October 16, 2018, using an online survey program called Qualtrics. With the support of the Associate Dean of Research at Boise State University, the questionnaire was emailed to a randomly selected subset (5,020) Boise State students, as well as faculty and staff (3,748) for a total of 8,768 selected individuals. The first email was sent to participants on September 25th, followed by two reminder emails on October 1st and October 3rd for those who had not attempted the online survey. A total of 1,745 online surveys were started within the Qualtrics program. However, 1,623 online surveys were completed during the 21 days of collection.

3.5 Discussion

The in-person surveys were completed with the survey questions printed on both sides of the paper and question 29 was the only question on the back of the last page. By printing on both sides of the paper, participants had to remove the paper from the clipboards, which was inconvenient. Also, the last two questions (numbers 28 and 29) did not have a possible response: “none of the above”. This meant surveys on which question

29 was left blank, created problems for the researchers in determining if the participant read the question and did not answer because it did not apply to them, or did not answer because they did not see the question. Approximately 9% of participants who selected a symptom in Question 28 did not answer Question 29.

Problems with the in-person surveys included approaching unknown individuals to ask for their time to complete a survey. In very crowded areas, more research data collectors would have been helpful (Night glow). If the survey was available to complete on an iPad or other digital format, it may have reduced the digitizing time, but more researchers on the data collection team would be needed to secure the iPads.

Problems with using the online program included a limited number of emails that were allowed to be sent at one time, the dialog sent in the first reminder, and the numerous bounce back emails sent to the survey sender.

Chapter 4 contains the analysis of the 2,237 completed surveys from both the in-person and online groups.

CHAPTER FOUR: HUMAN RESPONSE TO WILDFIRE SMOKE: ANALYSIS

4.1 Introduction

This section is designed to analyze the collected data from participants around the Treasure Valley to determine their response during smoke events. This chapter is divided into three sections, a Survey Results that provides results from the individual survey questions, a Research Question Analysis which analyzes the inquiries into smoke and human behaviors, and finally, the Results and Discussion.

4.2 Survey Results

This section looks at how participants answered the 29 survey questions. The comprehensive questionnaire provides critical information to map how one person's background and experience translates into a certain belief or behavior. The analysis was broken down into the same categories as the survey: demographics, activities, air quality, natural hazards, and health.

Demographics

Overall, most of the in-person participants were in their 20s, 30s and 40s, while a majority of the online participants were between 18-22 years old, which is indicative of an undergraduate student population. In-person participants were 59% female and 41% male and online participants were 65% female and 34% male. See Figures 4.1 and 4.2.

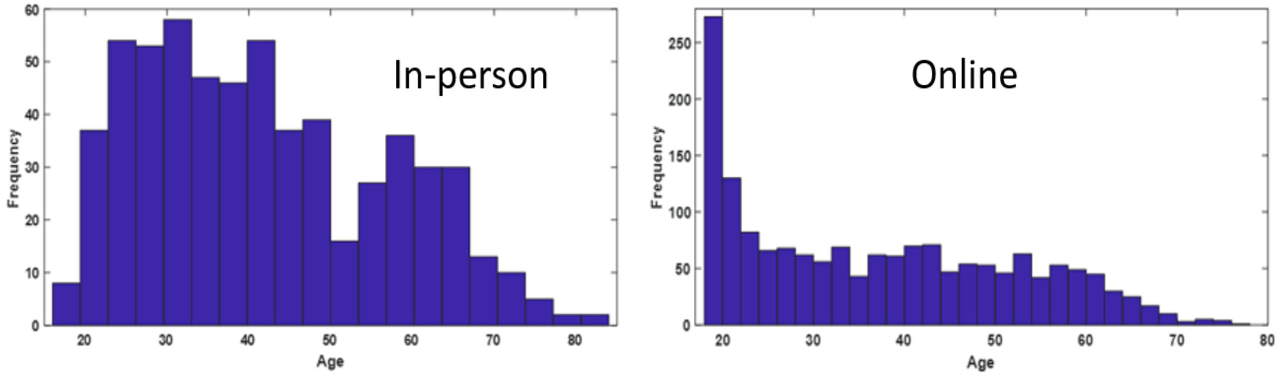

Figure 4.16: Age of Participants

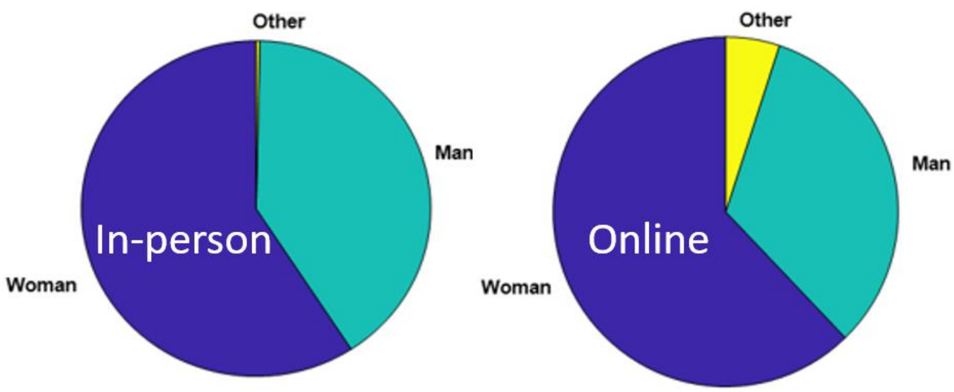

Figure 17: Gender of Participants

The racial or ethnic group that participants felt best described themselves is depicted in Figure 4.3. Most identified as White or Caucasian descent with a few Hispanic/Latino or Asian/Pacific Islander. Participants were able to select more than one answer for this question.

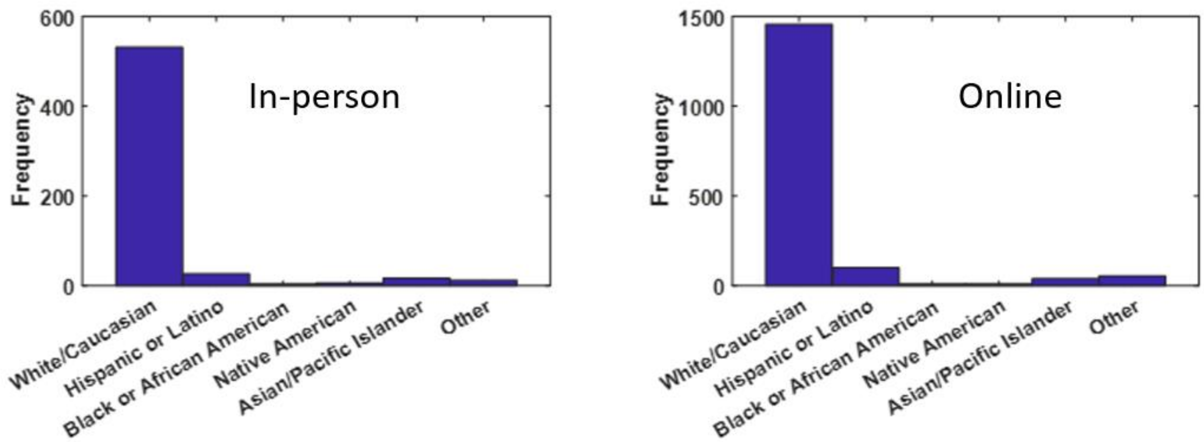

Figure 18: Racial or Ethnic Group of Participants

Almost all participants provided the ZIP Code where they currently reside. This allowed for a special distribution of where participants live. In Figure 4.4 the color coded dots represent the frequency of collected samples in each zip code location in a log based color scale. Most participants live within the Treasure Valley.

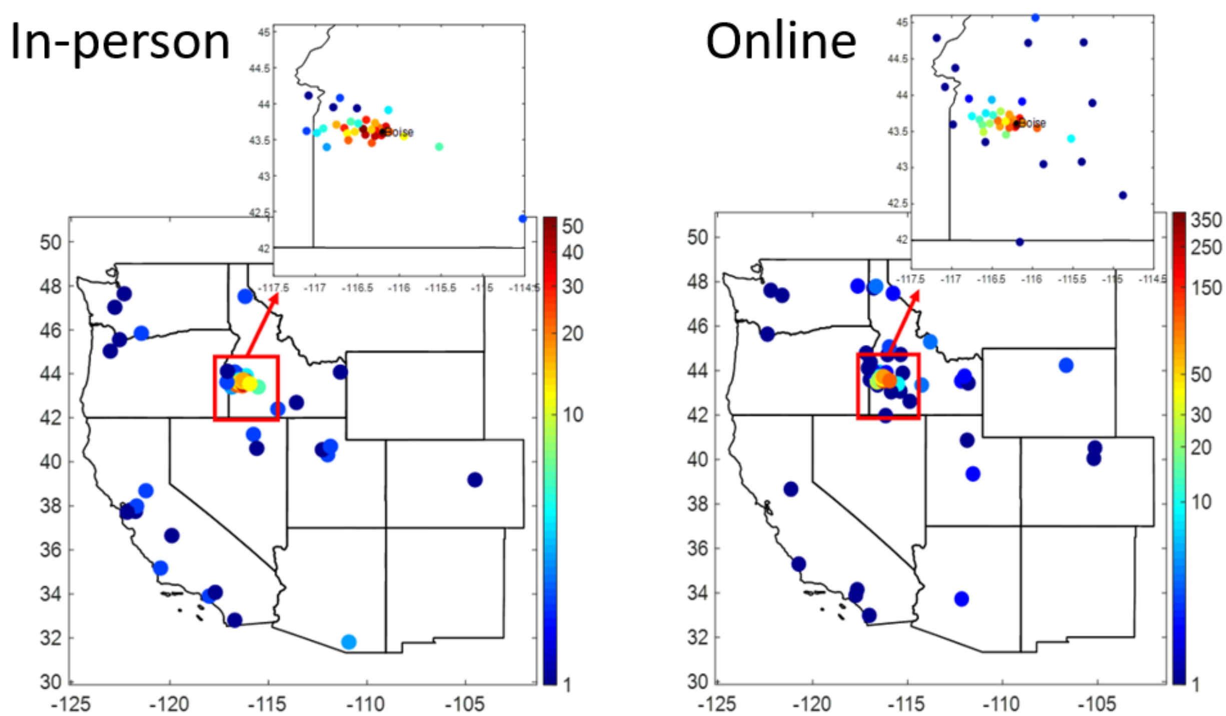

Figure 19: Frequency of Collected Samples by Zip Code

Most of the public participants have at least a high school diploma or GED with 1.5% reported completing some high school and 11.2% stating that they were a high school graduate or obtained a GED. Twenty-five percent have some college experience, 7.9% have an Associate's degree and 37.5% hold a Bachelor's degree, 12.9% have acquired a Master's degree, and 3.6% achieved a Ph.D., M.D., J.D, or similar education level.

The online participants were able to provide their level of education as either: undergraduate freshman or sophomore, undergraduate junior or senior, graduate student, Boise State staff, or Boise State faculty. Fourteen percent stated they were undergraduate freshman or sophomores, 19.7% selected undergraduate junior or senior, and 6.6% were graduate students. Thirty-seven percent of online participants were Boise State staff and 22.1% selected faculty. Figure 4.5 below graphically depicts the both the in-person and online results of this survey question.

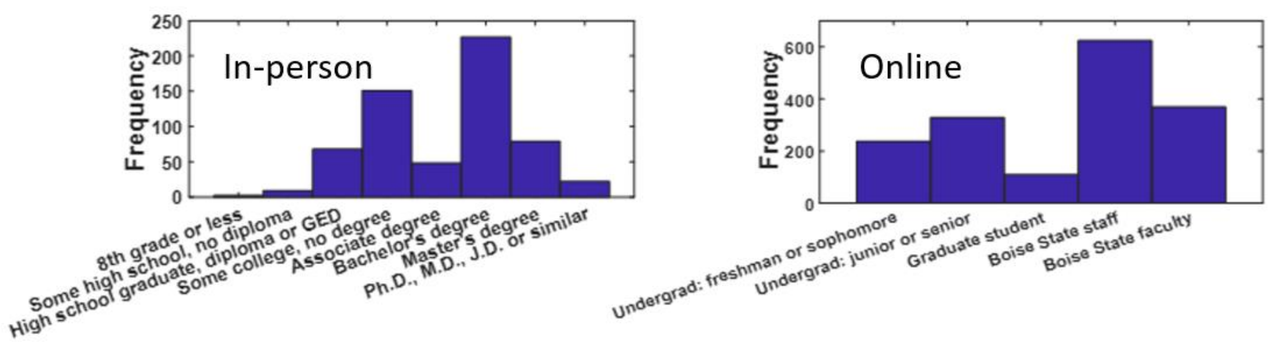

Figure 20: Participants Level of Education

Participants identified their total household income, including income from all members of their family, using their 2017 taxes. As can be seen in Figure 4.6, most participants identified the household income as above $100,000. Public participants disclosed that 12% have an income less than $25,000, 20% have an income between

$25,000 and $50,000. Twenty percent reported their income between $50,000 to $75,000, 13% between $75,000 - $100,000 and 34.6% divulged an income over $100,000 per year. The online participants revealed similar income levels with 14% less than $25,000, 21% between $25,000 - $50,000, 19.8% between $50,000 - $75,000, 16% between $75,000 - $100,000, and 28.6% made more than $100,000 last year.

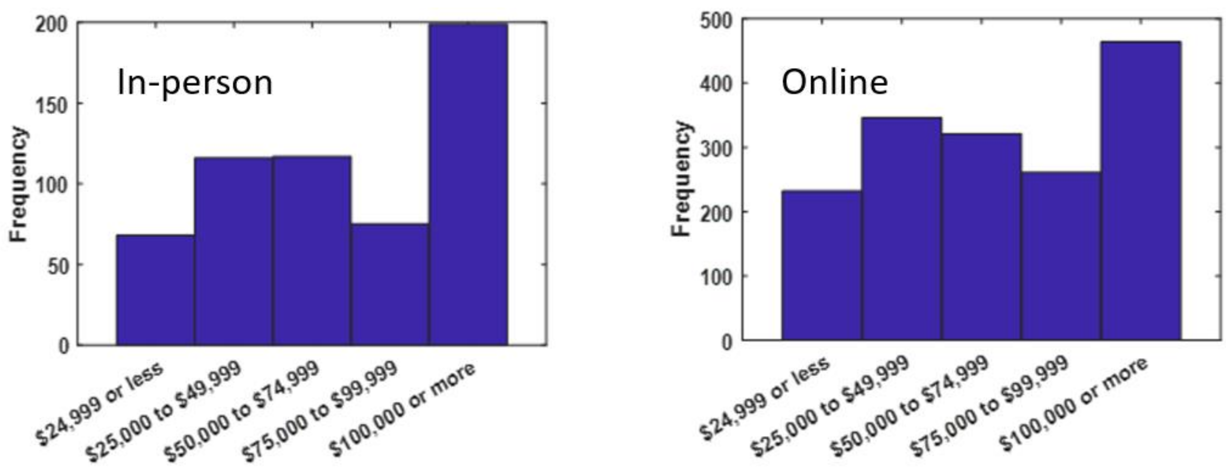

Figure 21: Participants Level of Income

Activities

During the summer of 2018, 95% of in-person and 92% of online participants reported that they had engaged in outdoor activities, such as hiking, biking, fishing, gardening, running, or any other outdoor activity as seen in Figure 4.7.

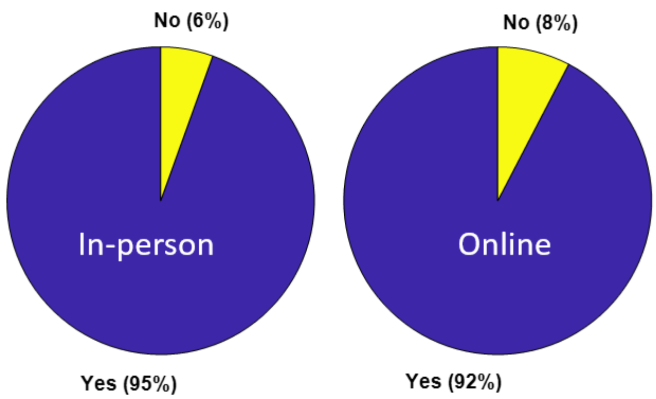

Figure 22: Outdoor Activity Participation

Air Quality

Then next questions focused on air quality notifications and whether or not the participant reduced their outdoor activities based on those air quality notifications. In Figure 4.8, 60% of the public received air quality notifications, where as 65% of the BSU participants reported receiving notifications suggesting they avoid outside activities. In both the in-person participants and online participants, 67% of people sought air quality notifications related to wildfire and smoke notifications, as seen in Figure 4.9 below.

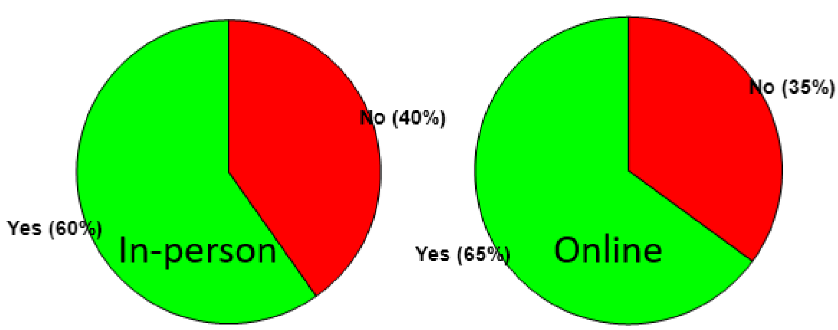

Figure 23: Participants Received Air Quality Notifications to Avoid Outside Activity

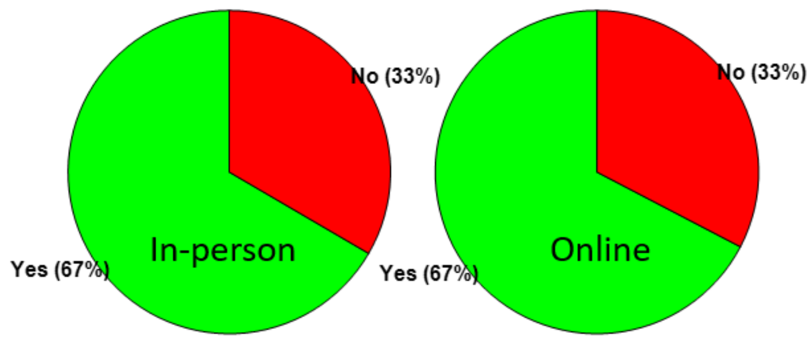

Figure 24: Participants Sought Air Quality Notifications Related to Wild-fire and Smoke

Participants were asked which sources they used to find wildfire smoke notifications and were allowed to check all that applied. The in-person participants mostly used television, social media (like Facebook, Instagram, and Twitter), online news sources, and personal observations. Figure 4.10 shows that the online participants heavily used online news sources, personal observations, and state agencies such as the Department of Environmental Quality website.

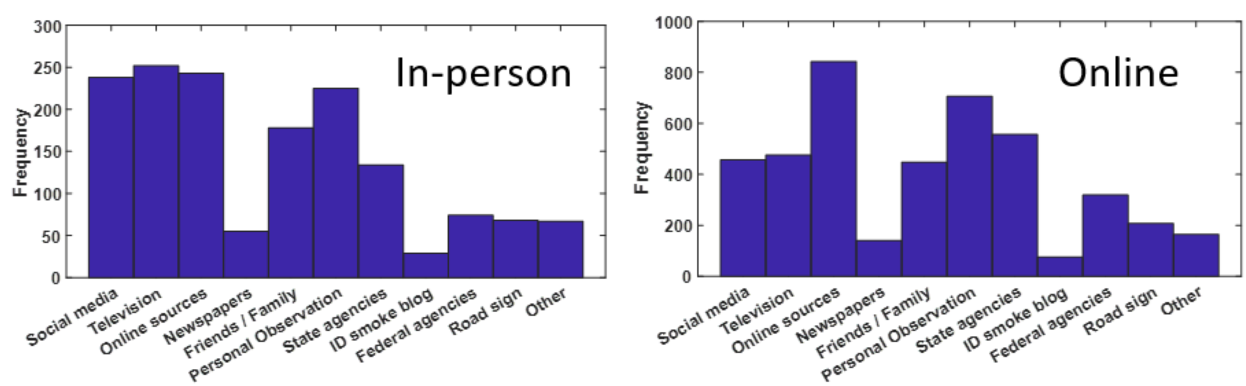

Figure 25: Participants Communication Sources Regarding Air Quality

The next question asked how many days did participants look online (either on a computer, tablet, or smartphone) for smoke-related information, such as air quality, smoke forecasts, or health notices during a smoky week in summer 2018. The public results are that 27% of participants did not look for smoke related information, however for those that did it is almost an even distribution between the options. The online participants were overall more prone to looking for information about 2 days in a week. Both results are in Figure 4.11.

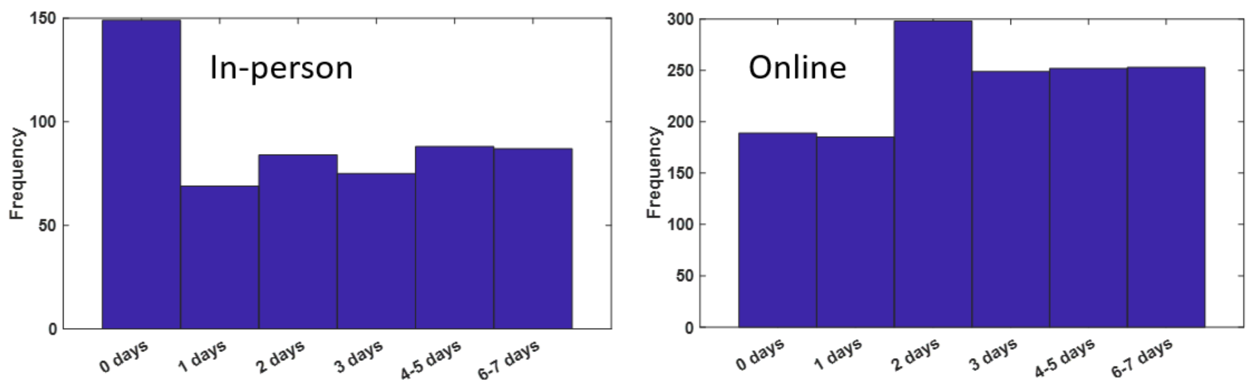

Figure 26: Number of Days/Week Participants Sought On-line Air Quality Information

Participants were asked if they ever reduced their outdoor activities due to wildfire smoke. Figure 4.12 displays that 62% of the in-person and 75% of the online participants reported that they did reduce their outdoor activities.

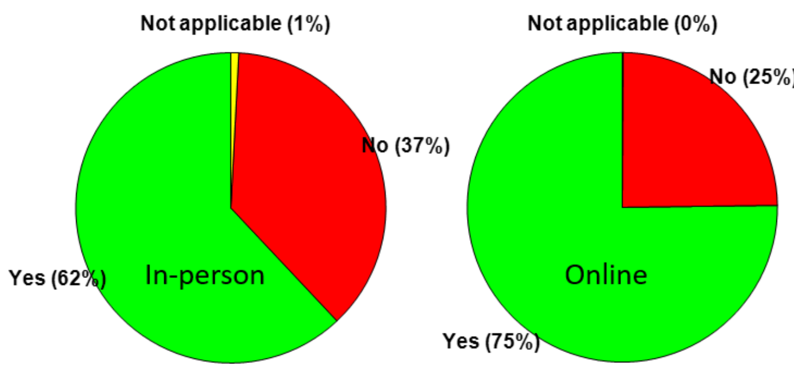

Figure 27: Participants Reduction in Outdoor Activities Due To Air Quality

Next, participants were asked to think of the longest period of consecutive days that they reduced or eliminated their outdoor activities due to a smoke event, and then how many consecutive days they reduced or eliminated those activities. Of the in-person participants about 34% reported that they did not reduce their activities, which aligns with the previous question. Approximately 21% reduced 1-2 days while 14% reduced 6 or more consecutive days. From the online participants, 23% said that they did not reduce their activities, 29% reduced 1-2 days, and 18% reduced more than 6 days. These percentages are illustrated in Figure 4.13 below.

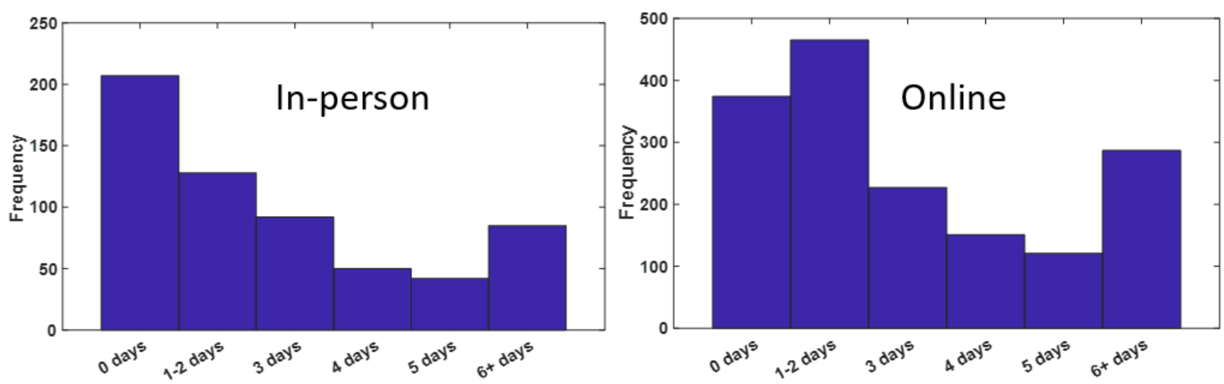

Figure 28: Number of Days Participants Reduced/Eliminated Outdoor Activities

The next set of questions pertained to AQI ratings. Participants were asked at which AQI rating level they would reduce their outdoor activities and then at which level would they eliminate outdoor activities. Figure 4.14 shows the reduction and Figure 4.15 shows the elimination. 37.7% of in-person and 42.7% of online participants will reduce their outdoor activities with an orange AQI warning. 36.8% and 40.8% of in-person and online respectively, reported that they would eliminate their outdoor activities with a red AQI warning. Ten percent of in-person and 4.3% of online participants reported that they were not familiar with the AQI warning system. Of the participants who reported they were not familiar with the AQI system, 60% were men in the in-person group and 44% men of the online group, as expressed in Figure 4.16.

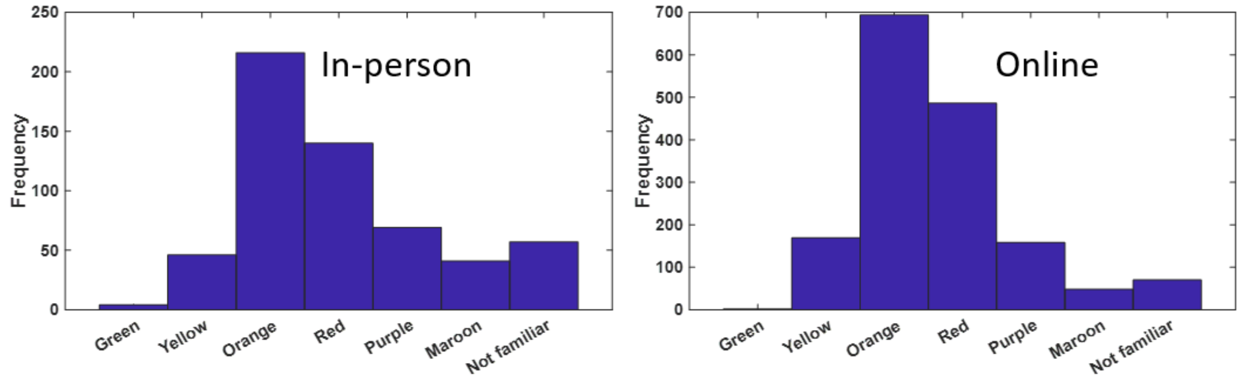

Figure 29: AQI Rating Level Causing Participants to Reduce Outdoor Activities

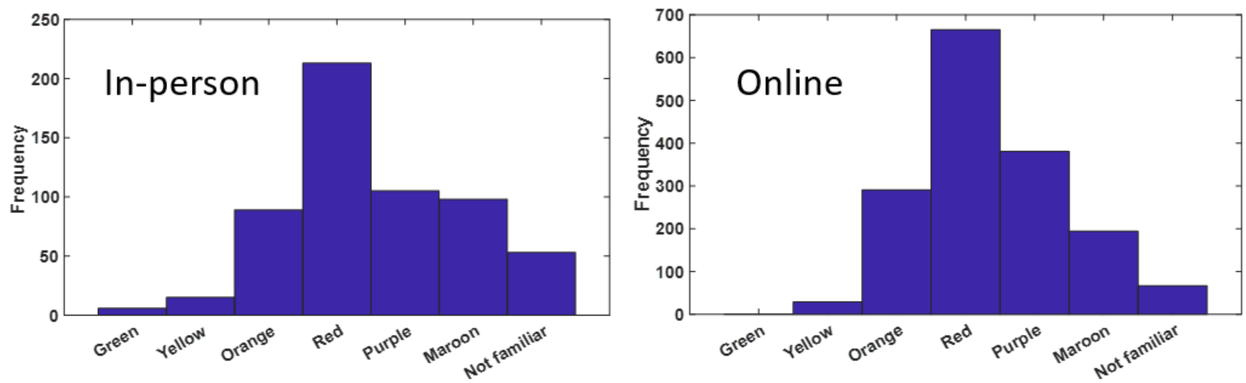

Figure 30: AQI Rating Level Causing Participants to Eliminate Outdoor Activities

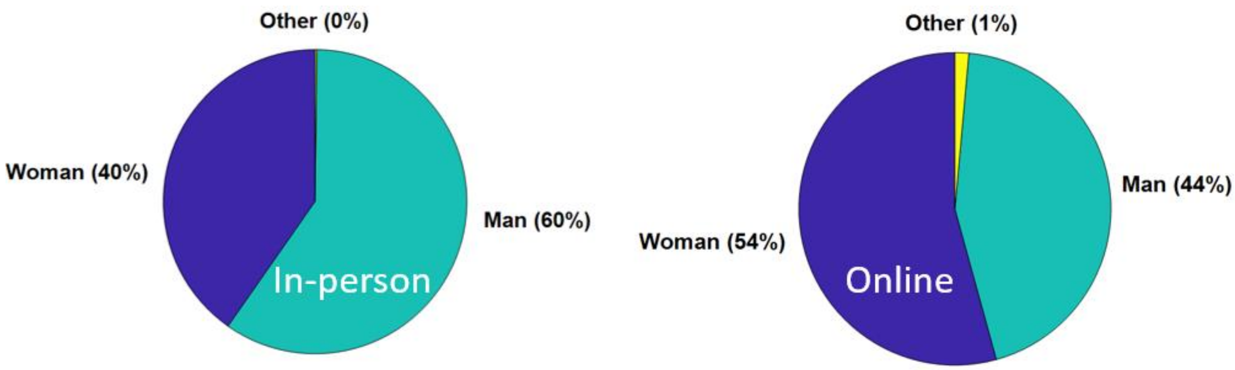

Figure 31: Gender of Participants Unfamiliar with AQI Rating Levels

Next, the questions focused on warning messages. For participants that decided to limit their outdoor activity during the smoke event, they were asked what type of information motivated their decision. Both groups, seen in Figure 4.17, reported that their own visual observations (seeing the smoke outside) and air quality information were most prominent in their decision making.

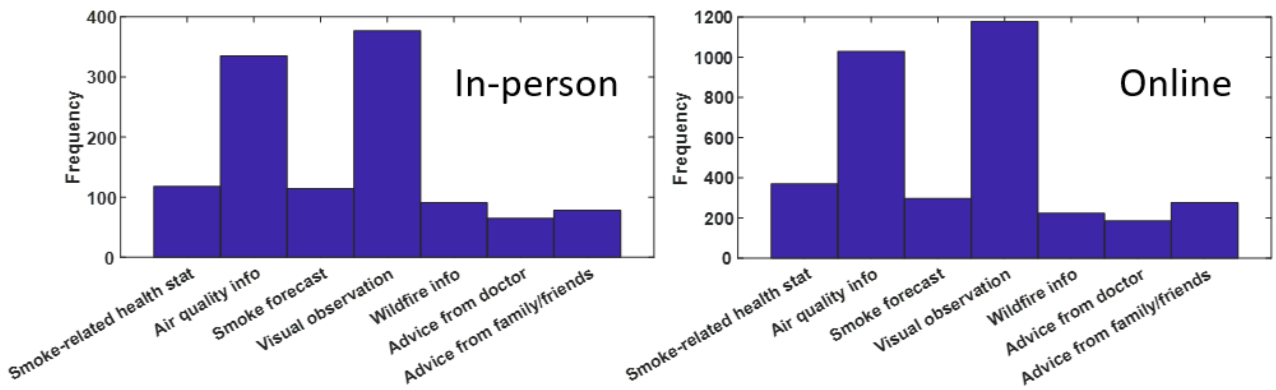

Figure 32: Factors Causing Participants to Limit Outdoor Activities

Participants were then asked what type of message could motivate or did motivate them to take action to mitigate the risk of issues related to wildfire smoke, such as staying indoors or leaving the area. Although participants could select more than one answer, both groups reported that emergency alerts and text messages were the best types of messaging and that phone calls had the least amount of responses. This is displayed in Figure 4.18.

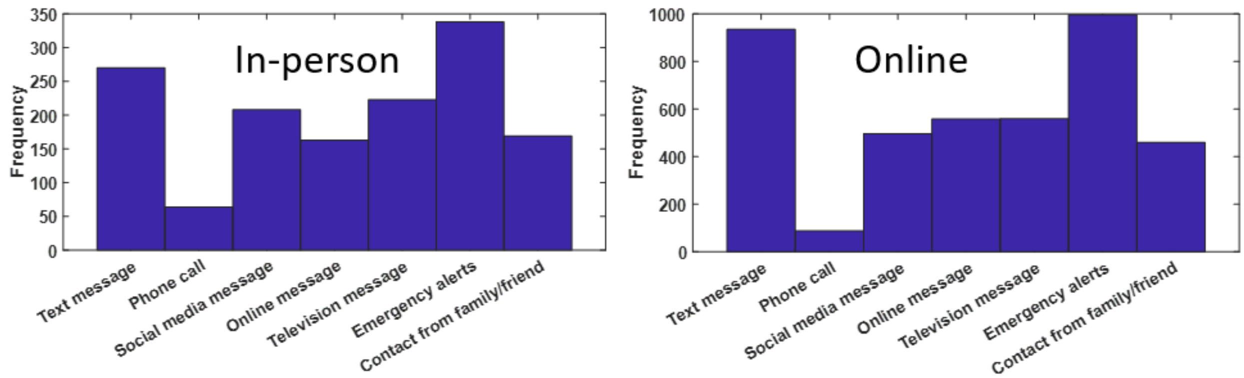

Figure 33: Type of Message Motivating Participant to Take Action to Reduce Risk

Participants were asked about the content of messages that motivated them to take action. A majority of the respondents stated a *short warning with one sentence about the risk* was the most effective. The second and third prominent responses were a *short warning with some statistics* about the risk and *visual infographics or pictures*. Figure 4.19 confirms that responses were very similar between both survey groups.

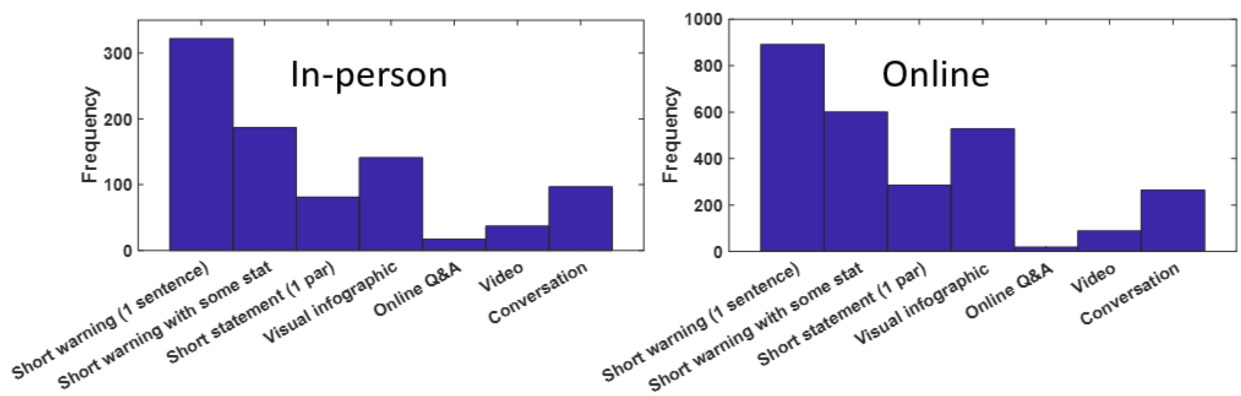

Figure 34: Message Content Motivating Participant to Take Action to Reduce Risk

The timing of the messages is important, thus, the next question asked participants when participants would prefer to receive a smoke warning message that would impact their decision to limit or avoid outdoor activities that same day. Comparing both groups in Figure 4.20, 50.5% of the in-person and 52.1% of the online participants replied that a message before 9 a.m. and 35.4% of the in-person and 36.3% of the online respondents expressed that messages even the day before would impact them the most.

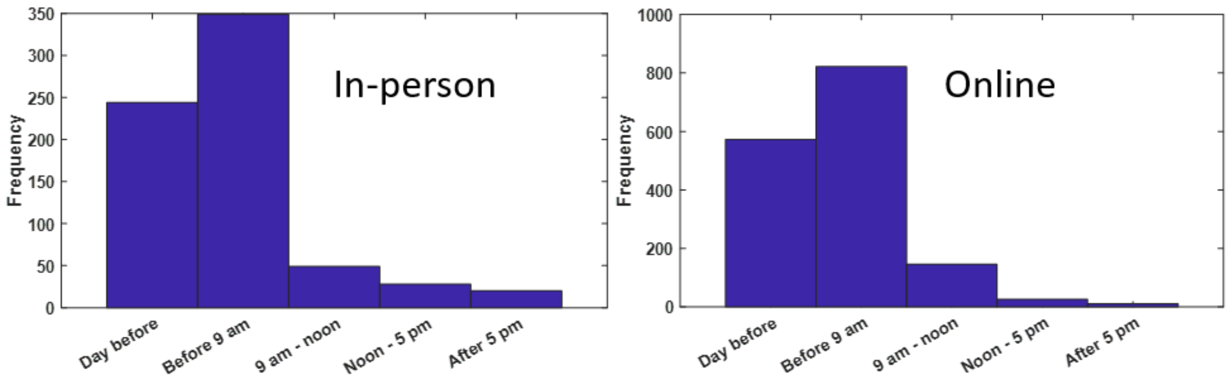

Figure 35: Timing of Warning Messages Encouraging Participants to Limit/avoid Outside Activities

Participants were asked if they would take preventative actions to reduce smoke-related health impacts in the future. The in-person group reported 42% yes they would, whereas the online group reported 50%. An interesting point is that 44% of both groups were unsure if they would take any kind of preventative actions, as seen in Figure 4.21. Comparing this question with those that experienced smoke-related illnesses, Figure 4.22 was compiled. Approximately 25% of in-person participants have experienced health related illnesses and will take preventative actions in the future. Almost 40% of online participants have experienced health related illnesses and also will take preventative actions.

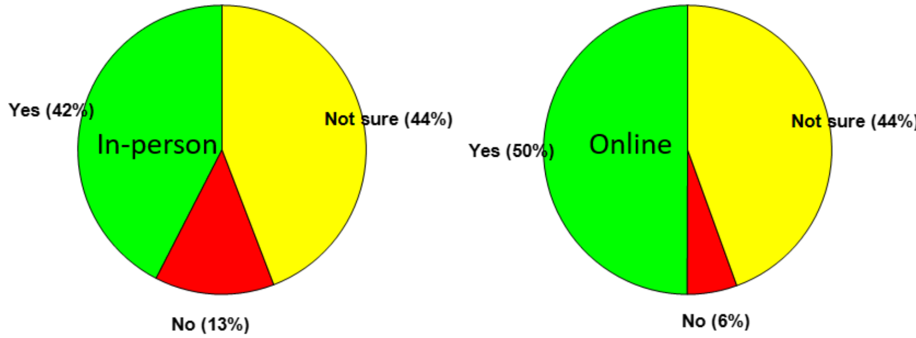

Figure 36: Participants Would Take Preventative Measures in the Future

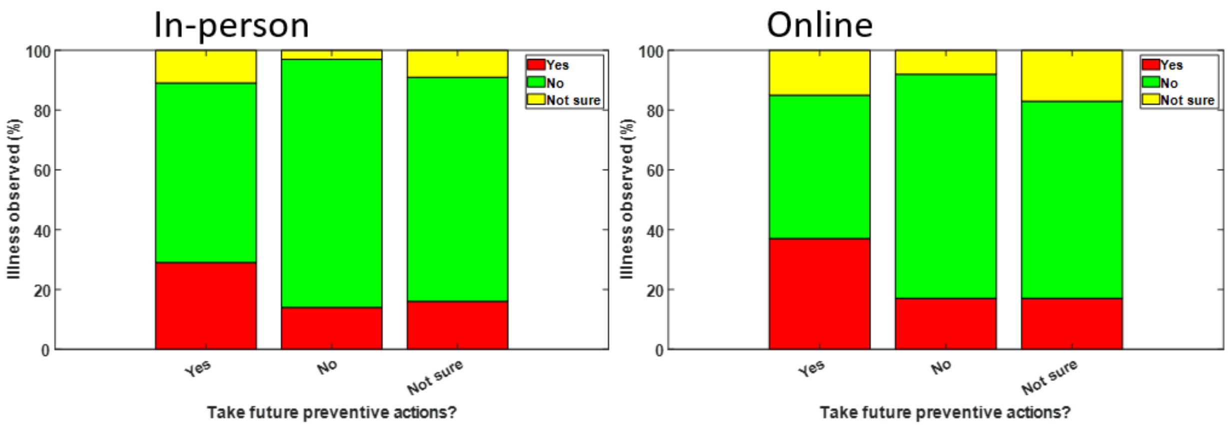

Figure 37: Participants Experiencing Air Quality Related Illness Will Take Preventative Measures in Future

Natural Hazard

The next part of the survey pertains to the perceptions of natural hazards. Participants were asked if they considered wildfire smoke events a natural hazard. Eighty-one percent and 80% of the in-person and online respectively, agreed that wildfire smoke is a natural hazard, as illustrated in Figure 4.23.

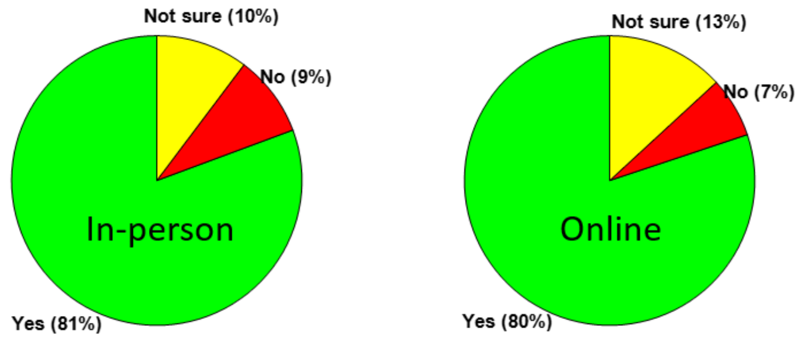

Figure 38: Participants Consider Wildfire Smoke a Natural Disaster

Next, participants were asked to compare wildfire smoke events to other natural disasters, such as hurricanes or tornadoes, in terms of a public health threat. As seen in Figure 4.24, the in-person results show that about 42.6% believe that smoke events are *about as important* and 32.5% believe that they are *somewhat less important* as other natural disasters. The online group was split with 39.4% reporting *somewhat less important* and 38.5% reporting *about as important* compared to other natural disasters.

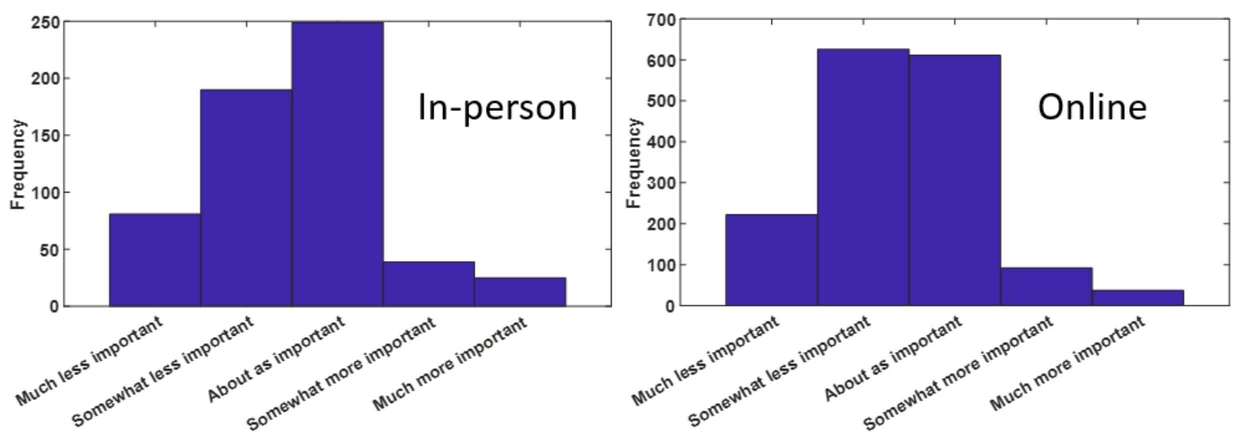

Figure 39: Participants Comparison of Wildfire Smoke to Other Natural Disasters

The final natural hazard question asked participants if they would consider evacuating their home only because of the wildfire smoke. As demonstrated in Figure

4.25, overwhelmingly most participants would not consider evacuating with 64.7% of in-person and 61.2% of online. 30.4% of in-person and 35.1% of online would consider it.

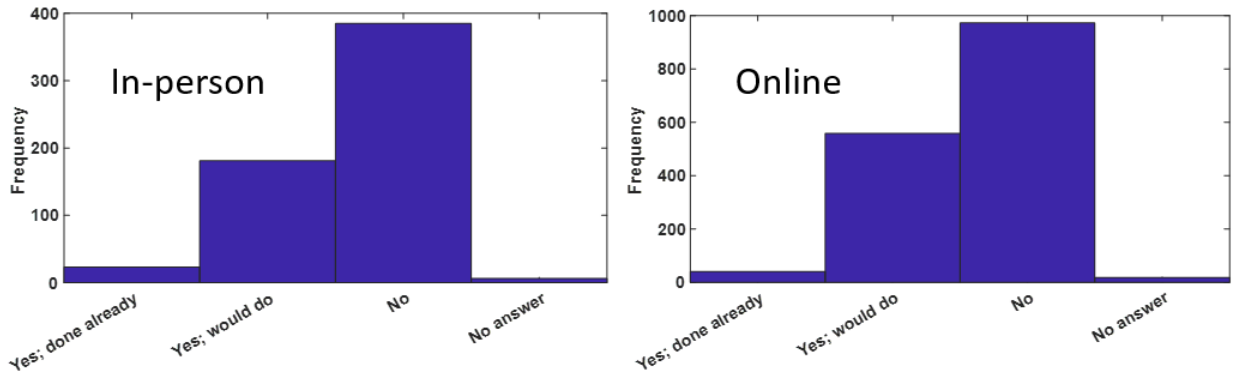

Figure 40: Participants Consideration of Evacuating Home During Wildfire Smoke Event

Health

The final questions focused on health. Participants were asked if they, or anyone living in their household, experienced wildfire smoke-related illnesses. Twenty-one percent of the in-person group reported that they experienced wildfire smoke-related illnesses, 70% reported that they had not and 9 % were unsure if they had. The online group reported that 27% had experienced an illness, 58% had not experienced one and 15% were not sure, which is illustrated in Figure 4.26 below.

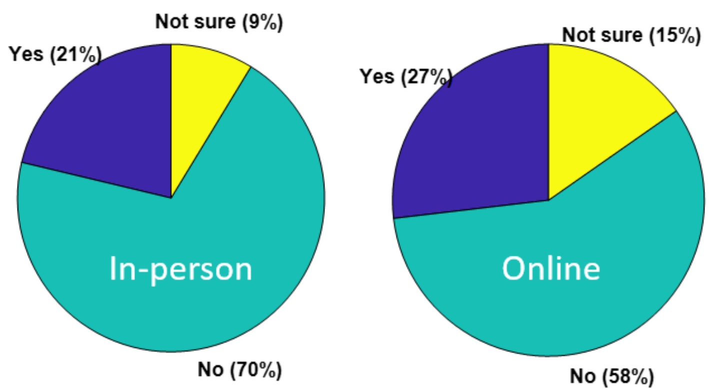

Figure 41: Participants Experiencing Wildfire Smoke-Related Illnesses

Participants were asked if they had any of the following symptoms during or a few days after one of the smoke events in the summer of 2018 in the Boise area / Treasure Valley. Participants were allowed to check all that applied. In both groups participants reported having eye, sinus, and irritated throat problems, as well as headaches, as shown in Figure 4.27. Using the participant's answers, 93% of the public observed having at least one symptom due to wildfire smoke and 81% of the online group reported the same observation.

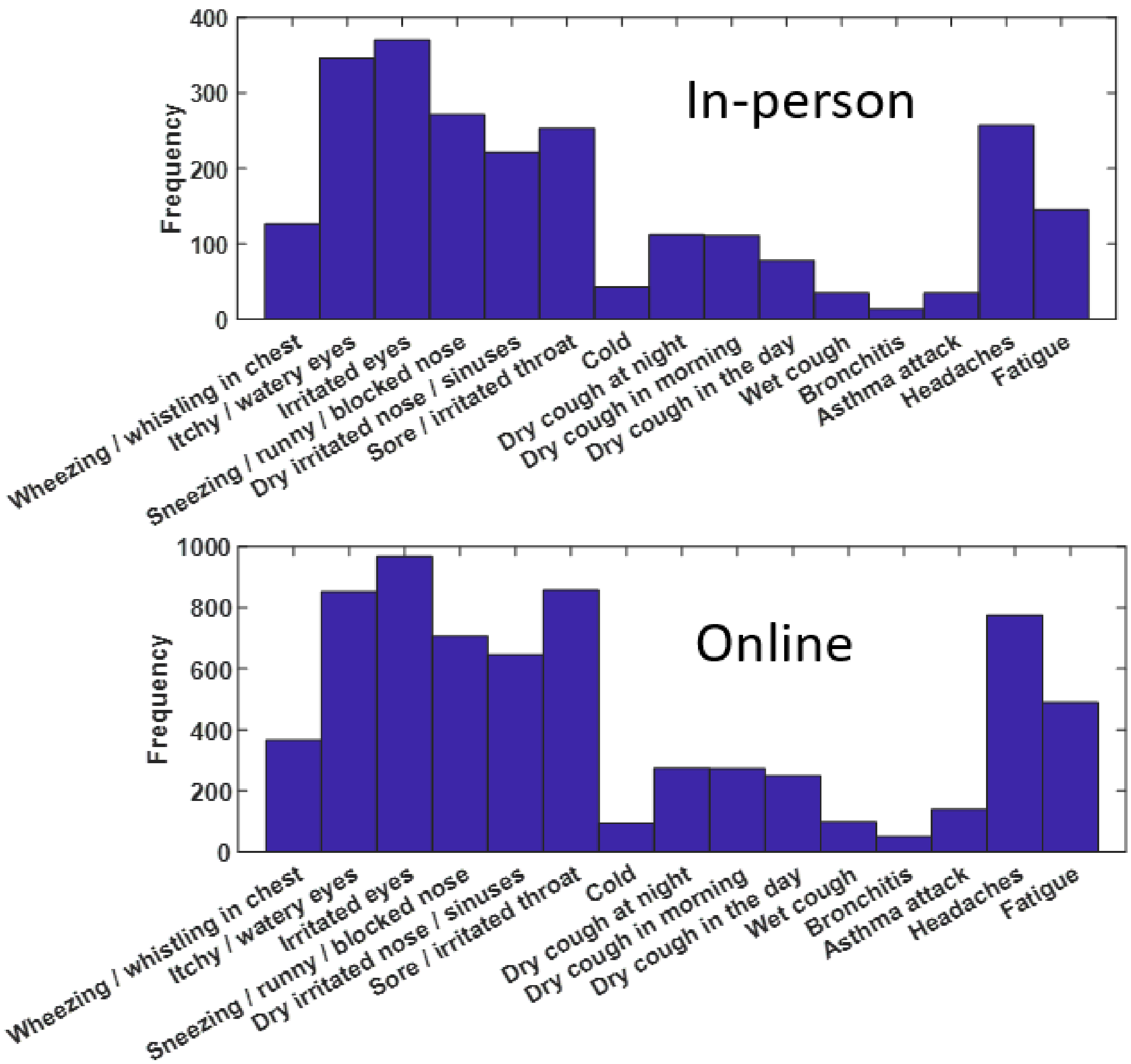

Figure 42: Symptoms Participants Experience during Wildfire Smoke Event

The final question asked how participants mitigated any symptoms. Twenty percent of in-person participants consumed medications, 14% reported they took longer showers, and 15% used personal air filtration systems in their homes or went to public buildings. The online group had similar results with 30% consumed medications, 21% reported they took longer showers, and 17% used personal air filtration systems in their homes or went to public buildings. The full results are shown in Figure 43.

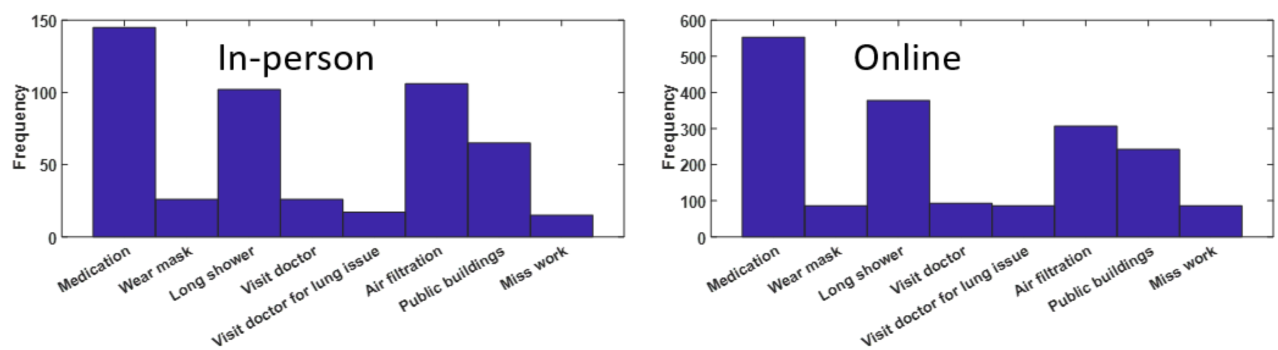

Figure 43: How Participants Mitigated Symptoms during Wildfire Smoke Event

This list of answers has given insight to how the participants, both public and those affiliated with Boise State, perceived wildfire smoke and their awareness about warning messages.

4.3 Research Question Analysis

The focus of this thesis was to research the social behavioral aspects of wildfire smoke using the public surveys acquired in the Treasure Valley. Three research questions were developed prior to surveying the public. The questions were:

1. Do people reduce their outdoor activities and do most people only reduce for 2-3 consecutive days?
2. Do most people receive warnings mostly from social media and are short direct warning messages the most effective?

3. Are younger and more educated people more active with adhering to smoke warnings by reducing their outdoor activities?

4.3.1 Research Question One

Research Question One was designed to determine if people reduce their outdoor activities and if most people only reduce for 2-3 consecutive days. Questions 15 and 16 of the survey were used to determine the answer to this research question. Question 15 of the survey was developed to determine if people reduced their outdoor activities during the smoke event. Figure 4.12, on page 54, indicates that 62% of in-person and 75% of the online participants reported that they did reduce their outdoor activities.

In Question 16, participants were asked how many consecutive days did they reduced or eliminated activities. Figure 4.13, on page 55, presents the results of both the in-person and online data. From the in-person group 34% reported they did not reduce their activities, 21% reduced 1-2 days, 15% reduced 3 days, 8% reduced 4 days, 7% reduced 5 days, and 14% reduced 6 or more consecutive days. The online group reported 23% did not reduce activities, 29% reduced 1-2 days, 14% reduced 3 days, 9% reduced 4 days, 7% reduced 5 days, and 18% reduced 6 days or more.

4.3.2 Research Question Two

The second research question focused on warning messages and the source from which those messages were received. Was social media the medium that people obtained their warning messages from; and were short, direct messages the most effective? Survey Question 13 was used to explore the social media aspect of the research question, while survey Questions 20 and 21 were used to analyze messaging types and content.

Figure 4.10 on page 53, relates to Question 13 where participants were asked which sources they used to find wildfire smoke notifications. The in-person participants mostly used television, online news sources, social media, and personal observations. Online participants heavily used online news sources, personal observations, state agencies, television and then social media.

Two more in-depth assessments were completed comparing the results from Question 13 with the demographic information focusing on age and education levels. Question 2 provides the participant's age, included in Figure 4.1 on page 48, and Question 6 furnishes the participant's education level, shown in in Figure 4.5 on page 50. The in-person participants were primarily between 20 and 50 years old and a majority of the online participants were between 18-22 years old. The level of education of the public ranged from a few completing some high school to those who have achieved a Ph.D., M.D., J.D, or similar education level. The online participants provided their level of schooling or how they were classified at Boise State as staff or faculty.

Figure 4.29 (Q2/Q13) is a graphical representation of the age distribution within each possible answer from Question 13. The red line depicts the median age of participants who answered this question. The median age of in-person participants who used social media was approximately 38 years old and is shown by the red line. The blue box encompasses 50% of participant's (rand between 25th and 75th percentiles) who said social media was the medium they used as their smoke warning medium. Participants above the box, represent the top 25% by age of those who use social media. Participants below the box, represent the lower 25% by age of those who use social media. Using the in-person group and Social Media from Figure 4.29, the upper 25% limit is approximately 48 years old and the lower 25% limit is approximately 28 years old. Therefore, 50% of participants who responded that they used social media were between the ages of 28 and 48. The highest and lowest participant age is represented by a flat black line on the top or bottom of the answer option. Again, using the in-person group and Social Media the lowest age was below 20 and the highest age was about 75. Looking at the median age for all possible sources of smoke notifications, the in-person median age ranges from about 35 to 45 years old for the in-person groups whereas the online groups varies significantly between 28 and 51 years old.

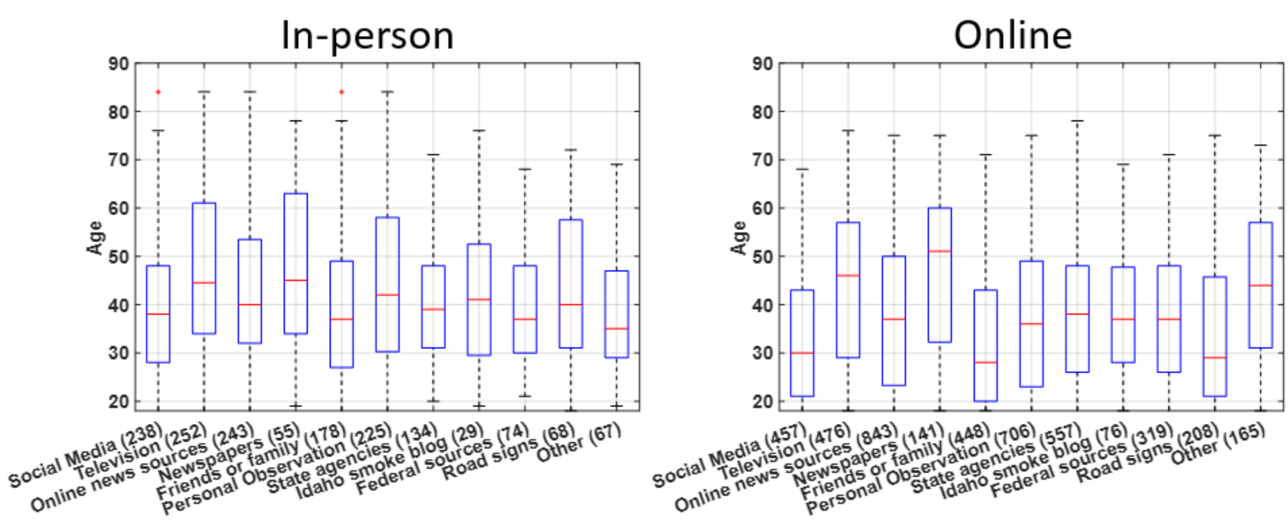

Figure 44: Age and Source of Air Quality

Figure 4.30 (Q6/Q13) is a graphical representation of the education distribution within each possible answer from Question 13. These figures use a multi-color spectrum to depict the percentage of participants who selected the possible answer option with each education level. Using the online undergraduate freshman / sophomore group, approximately 15% used social media, about 11% used television, 19% used online new sources, and maybe 1% or less used the newspaper as their source of smoke notifications. The online group conveys that minimal notifications were received via the Idaho Smoke

Information Blog, Federal sources such as AIRnow.gov website, dynamic road signs, or newspapers. The in-person group results are similar, with the addition of State agencies such as the IDEQ website not being used by those who have an education level below a Bachelor's degree. However, those with a Bachelor's degree and higher do use the IDEQ website for notifications.

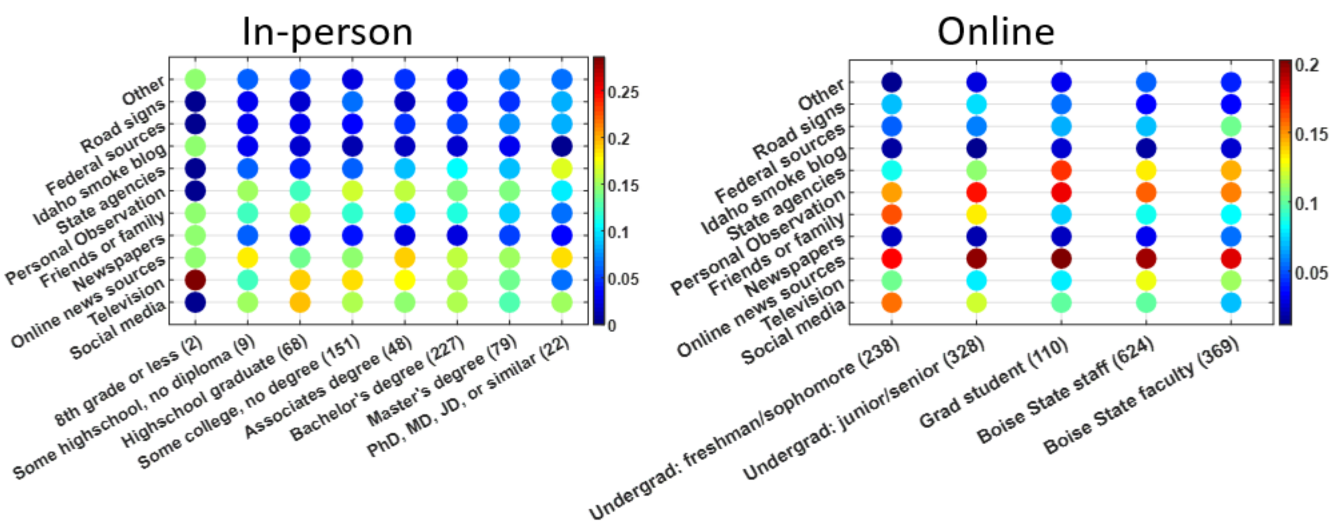

Figure 45: Education and Source of Air Quality

Figure 4.18 on page 58 is associated with Question 20, where participants were asked about the type(s) of message that motivated them to take action. Although participants could select more than one answer, both groups reported that emergency alerts and text messages were the best types of messaging.

Another assessment was conducted by comparing the results from Question 20 (message meduim) with participants age. Figure 4.31 (Q2/Q20) is a graphical representation of the age distribution within each possible answer from Question 20. According to the in-person results, participants in their 50s and 60s prefer TV messages, a phone call, emergency alert, and social media messages, whereas the online group show only TV messages. The median age for those who felt a social media message would motivate them to take action were 39 for the in-person group and 29 with the online group.

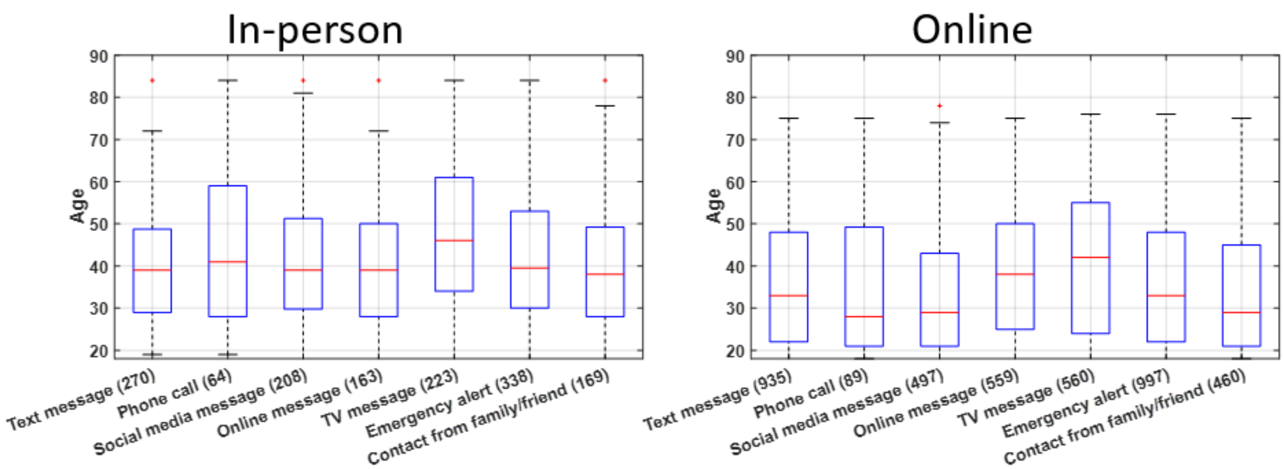

Figure 46: Age and Message Medium

Question 21 focused on the content of the messages, with results shown in Figure 4.19 on page 58. Thirty-seven percent of in-person participants and 33% of online participants prefer a short, one line message about the risk. Twenty-two percent of both groups would like a short message that includes health or other statistical information. A visual infographic or picture was selected by 16% of the in-person group and 20% of the online group.

4.3.3 Research Question Three

Research question three focused on age and education levels as an indicator of adhering to smoke warnings. The age and education level demographic information was cross referenced with four other questions. Question 11 inquired if the participant received air quality notifications, Question 12 asked if they searched for wildfire and smoke notifications, Question 15 asked if they reduced outdoor activities because of smoke, and Question 16 asked how many consecutive days they reduced activities.

Figure 4.8 on page 52 relates to Question 11, in which it was determined that 60% of the public did receive air quality notifications, as well as 65% of the BSU participants. The integration of participants that received air quality notifications (Question 11) and their age are depicted in Figure 4.32 below. The median age of those who did receive notifications are similar, with an age of 41 for the in-person group and an age of 40 for the online group. However, for those who did not receive messages, the median age is 36 for the in-person group and 28 for the online group.

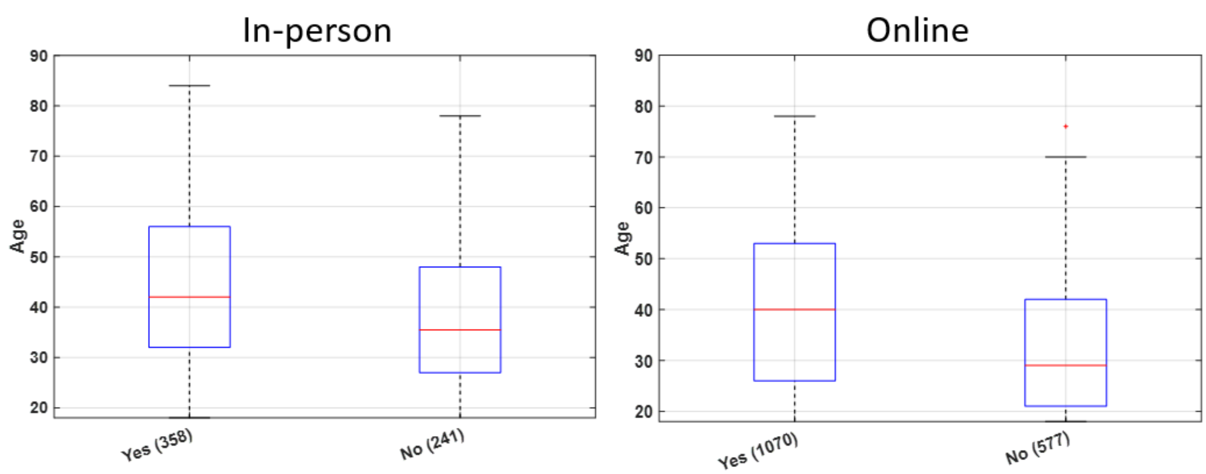

Figure 47: Age and Received Air Quality Information

The integration of participants that received air quality notifications (Question 11) and education levels are depicted in Figure 4.33. Of the in-person group nearly 60% of participants with Associate's and Bachelor's degrees did receive notifications and 70% of Master's participants. From the online group, about half of the undergraduate groups received notifications, 60% of the graduate students, and nearly 70% of the Boise State staff and faculty.

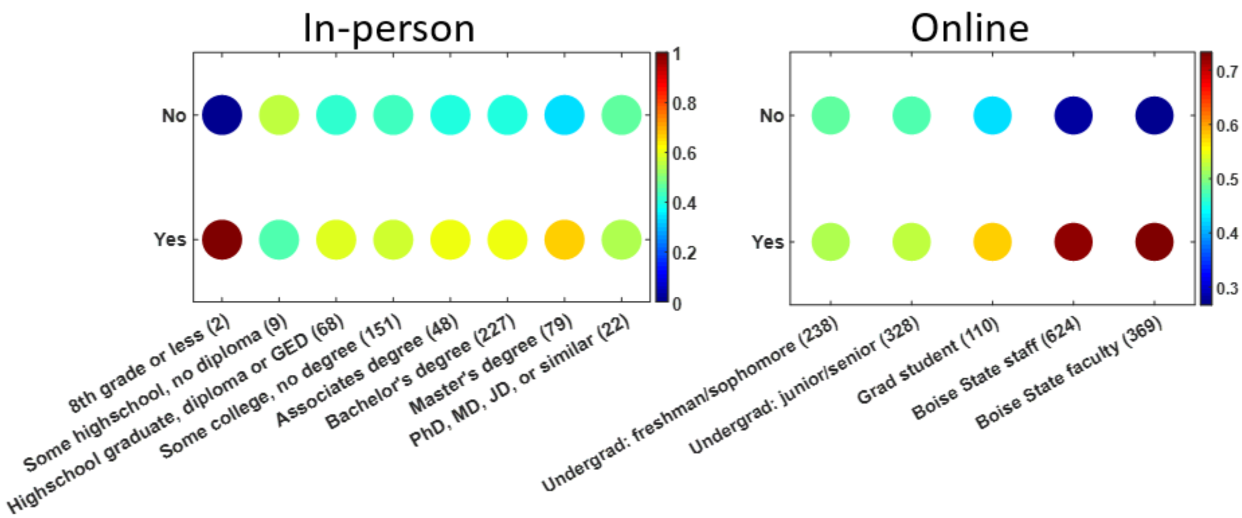

Figure 48: Education and Received Air Quality Information

Sixty-seven percent of both the in-person and online participants searched for air quality notifications related to wildfire and smoke notifications, as seen in Figure 4.9 on page 53 (Question 12). An incorporation of those who looked for air quality notifications along with their age level is depicted in Figure 4.34. The in-person group median age was approximately 39 for those who took an active role in searching, while the median age of those who did not was 40. The online group was more diverse, with the median age of those who did search being 38 and those who did not 29.

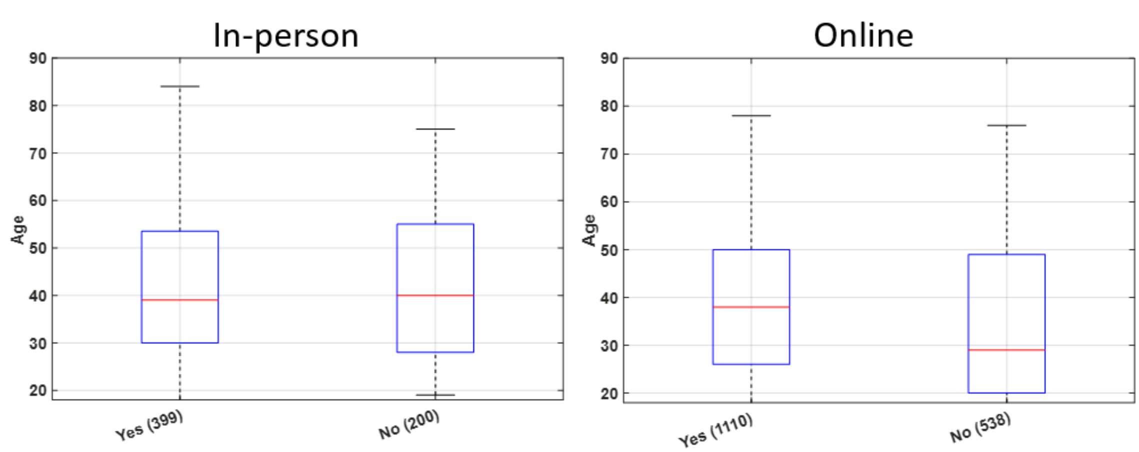

Figure 49: Age and Sought Air Quality Information

The integration of participants that sought air quality notifications (Question 12) and education levels are depicted in Figure 4.35 below. Fifty percent of the in-person group with a high school diploma or equivalent searched for information. Percentages increased to 60% for those with some college and rise to 70% for Associate degree participants and 73% for Bachelor's degree and above education levels.

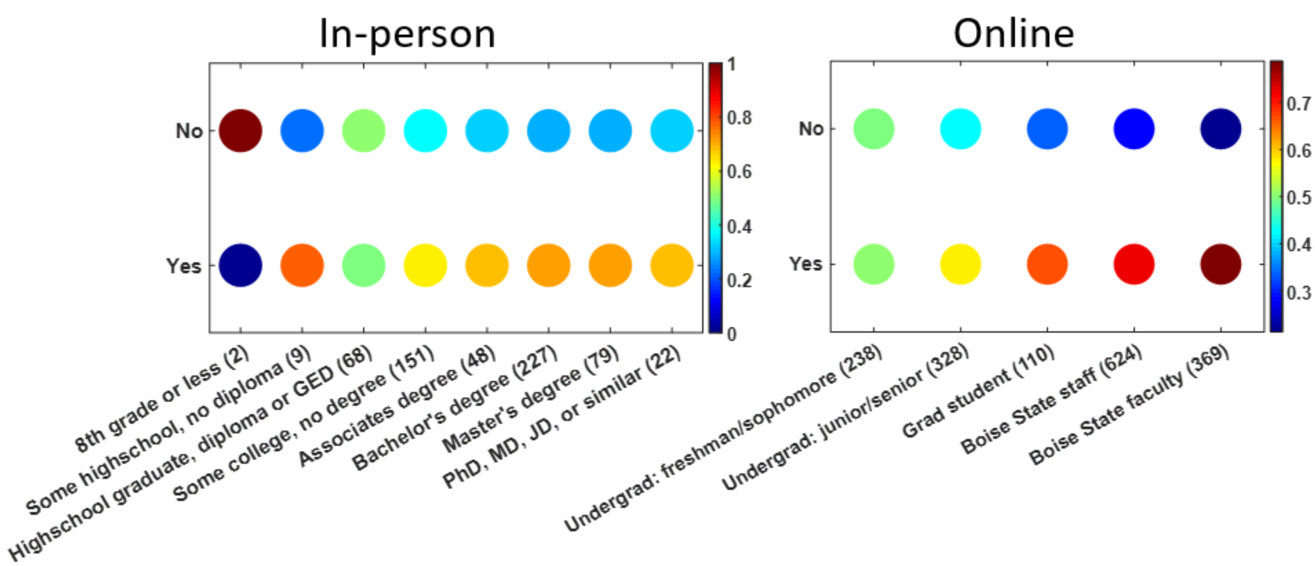

Figure 50: Education and Sought Air Quality Information

Figure 4.12 on page 54 relates to Question 15 where participants were asked if they reduced their outdoor activities due to wildfire smoke. Sixty-two percent of in-person and 75% of the online participants reported that they did reduce their outdoor activities. Merging this question with participant age results in Figure 4.36. The in-person group has similar median ages, with 41 years old for those who did reduce outdoor activities and 38 years old for those who did not. Of the online group the median age difference is about 9 years, with those who did reduce had a median age of 38, while those who did not had a median age of 29.

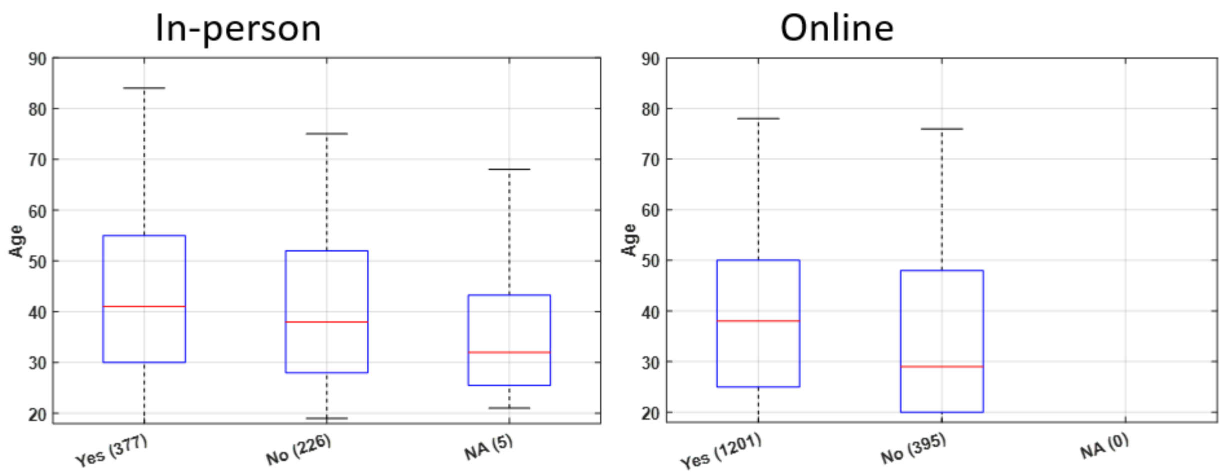

Figure 51: Age and Reduced Activities

Incorporating those who reduced their outside activities with their level of education is represented in Figure 4.37. Approximately 42% of the in-person group with a high school diploma or equivalent reduced their outside activities. For those with some college, the percent increases to 60% and increases even more for Associate participants to about 70%. The Bachelor's participants reported a 65%, Master's a 70% and the PhD a 75% reduction of outdoor activities. The online group results were similar with freshman/sophomores reducing about 60%, junior/seniors approximately 65%, graduate students 77%, BSU staff 70% and BSU faculty reduced over 80%.

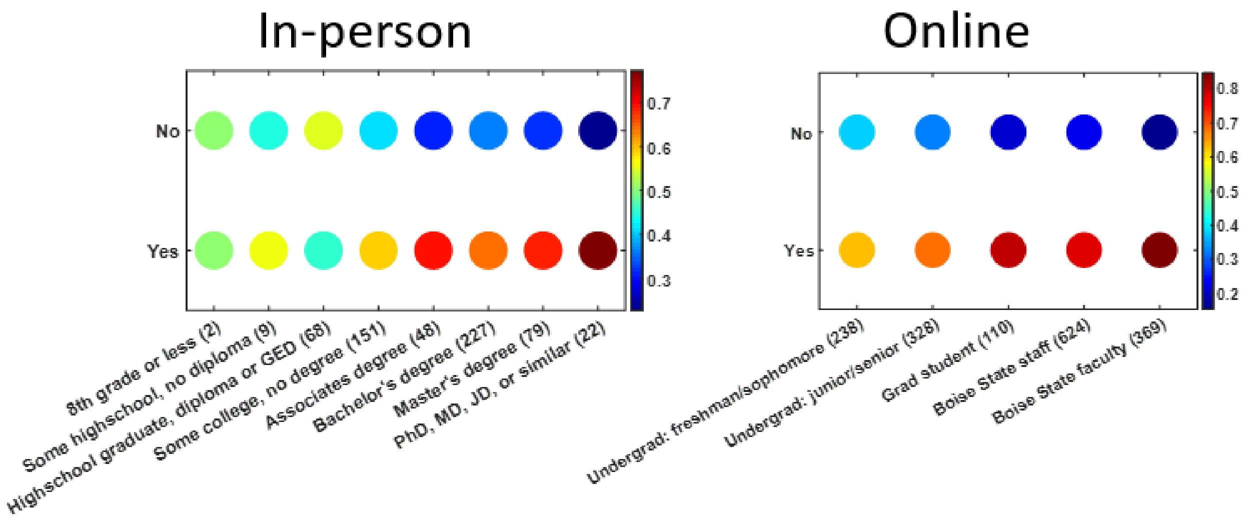

Figure 52: Education and Reduced Activities

Participants were also asked how many consecutive days they reduced or eliminated outdoor activities in Question 16 (refer to Figure 4.13 on page 55). Integrating this question with participant's age is presented in Figure 4.38. The in-person group has similar median ages with 39 years old for those who did not reduce outdoor activities, 39 years old for those who reduced 1-2 days, 40 years old for those who reduced 3 or 4 days, 42 years old for those who reduced 5 days, 42 years old for those who reduced 6 or more days. Results from the online group showed the median age ranged from 30 years old for those who did not reduce outdoor activities to 39 years old for those who reduced 5 or more days.

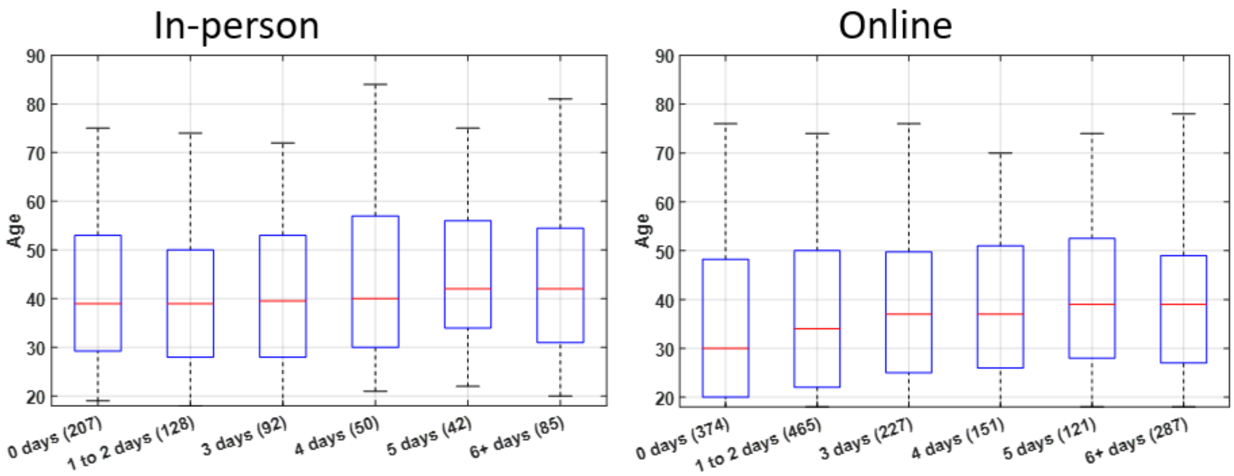

Figure 53: Age and Number of Days Reduced Activities

Incorporating the number of days participants reduced their outside activities and education levels are represented in Figure 4.39. The highest percentage of reduction for those with some college was 1-2 days at about 22%. Twenty-eight percent of Associate degree holders reduced 1-2 days, 22% of Bachelors reduced 1-2 days, 24% of Masters also reduced 1-2 days, and 28% of those with a Ph.D. also reduced 1-2 days. About 22% of the Ph.D. group reduced 3 days and about 18% reduced 6 or more days.

The online participants reported that most reduced 1-2 days with 27% for freshman and sophomores, 30% for juniors and seniors, 28% for graduate students and BSU staff, and 29% for BSU faculty. However, 15% of juniors and seniors, 22% of graduate students, 18% of staff and 22% of faculty also reduced 6 or more days.

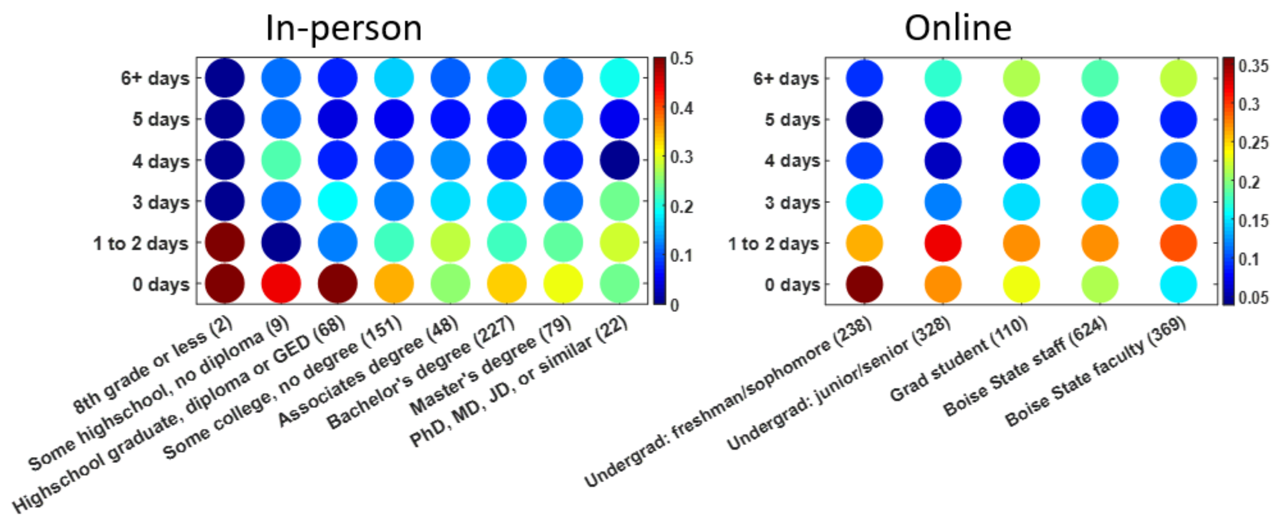

Figure 54: Education and Number of Days Reduced Activities

Analysis was completed to determine social behavioral response of the Treasure Valley public to wildfire smoke. Section 4.4 discusses the results from the survey analysis and the research questions.

4.4 Results and Discussion

The demographic data indicates that the in-person group were between 20 and 50 years old and the online group was much younger, with a majority of the participants in their late teens and early twenties. Most of the respondents' were Caucasian females. Many participants live within the Treasure Valley, have some college education, and have a household income above $100,000. More than 90% of the participants engaged in outdoor activities like hiking, fishing, or gardening.

Air quality notification data indicates that participants do receive and search for information related to wildfire and smoke. Participants gain wildfire smoke notifications from television, social media, online news sources, state agencies, and personal observations. About 25% of public participants and about 11% of online participants did not look online for smoke information however, while many looked for updates more than 6 days. Most people reduced their outdoor activities by 1-2 days, and some reduced their activities more than 6 days because of smoke. When given AQI ratings, most participants will reduce their outdoor activity with an orange rating and eliminate activities with a red rating. Nearly 10% of the in-person and 4% of the online population were not familiar with the AQI warning system. This suggest that more education about the system would be necessary.

Participants who limited their outdoor activities used their own visual observations and air quality information to make their decision. Emergency alerts and text messages were the best types of messaging that would motivate people to mitigate the risks related to wildfire smoke. The majority of people would like short, one sentence warnings or short warnings with some statistics or visual pictures. The best time for sending notifications to limit or avoid outdoor activities was in the early morning before 9 am or the day before. As stated in their responses, in the future 42% of the public and 50% of the online participants will take preventative actions to reduce smoke-related health impacts.

Approximately 80% of both participant groups consider wildfire smoke a natural hazard. However, when comparing wildfire smoke to other natural disasters like hurricanes or tornadoes in terms of a public health threat, the results are different. Of the in-person population, 43% believe that smoke is *about as important* and 33% believe that it's *somewhat less important* as other natural disasters. The online group was evenly split with 39.4% reporting *somewhat less important* and 38.5% reporting *about as important.*

Although the survey questions were designed not to lead participants to one specific answer, two hurricanes hit the United States during the time of data collection.

Hurricane Florence made landfall in North Carolina as a Category 1 hurricane on September 14, 2018 and Hurricane Michael made landfall in the Florida panhandle as a Category 4 hurricane on October 10, 2018 and was the strongest storm of the 2018 season (CNN Library 2018). In-person survey collections were conducted between August 28, 2018 and September 15, 2018 and online collections were conducted between September 25, 2018 and October 16, 2018. It can be assumed that Hurricane Florence had minimal influence on the in-person surveys as 95% of the surveys were collected by September 12, 2018. It is undeterminable if the news of either hurricane could have influenced the online population, but it is worth noting the timing.

Most participants would not consider evacuating their home because of wildfire smoke. The in-person group reported 64% would not while 30% would and 61% of online would not evacuate and 35% would consider it.

Participants were asked if they, or anyone in their household, had experienced smoke-related illnesses. Twenty-one percent of the in-person group said they had and 27% of the online group had also experienced smoke-related illnesses. In both groups, participants reported having eye, sinus, sore irritated throat, and headaches with 93% of the in-person group and 81% of the online group observing at least one symptom due to wildfire smoke. To mitigate symptoms, participants consumed medications, took longer showers, and used personal air filtration systems or went to public buildings.

The research as to the social behavioral aspects were incorporated into three questions. First, do people reduce their outdoor activities and do most people only reduce for 2-3 consecutive days? Second, do most people receive warnings mostly from social media and are short direct warning messages the most effective? And third, are younger and more educated people more active with adhering to smoke warnings by reducing their outdoor activities?

The first question focuses on if people reduced their outdoor activities and for how many consecutive days. Sixty-two percent of in-person and 75% of the online participants reported that they did reduce their outdoor activities, Figure 4.12 on page 54. When asked how many days they reduced in Question 16, Figure 4.13 on page 55, 66% of the in-person group and 77% of the online group said that they reduced more than one day. Using both of these results, yes, people do reduce their outdoor activities.

The most common reduction was 1-2 days with 21% of the in-person group and 29% of the online group answering as shown in Figure 4.13 on page 55. Fifteen percent reduced 3 days and 14% reduced 6 or more days from the in-person group. Eighteen percent of the online group reduced 6 or more days. Overall, the majority of people only reduced 1-2 days.

The second question asked whether or not most people receive warnings from social media and are short direct warning messages most effective? Using only Question 13 in Figure 4.10 on page 53, the conclusion would be “no”, other sources are used more than social media to receive smoke warnings. The in-person participants mostly used television, online news sources, social media, and personal observations, which suggests that social media is the third highest choice of the public as a source of warnings. Online participants heavily used online news sources, personal observations, state agencies, television and then social media, while approximately 10% of the online participants used social media for warnings. The target median age group for social media users based on this study is between 21 and 48 as shown in Figure 4.29 on page 67. However, when comparing education with medium of warning, Figure 4.30 on page 68, 20% of those with a high school diploma prefer social media. Those with some college, have an Associate's degree or Bachelor's degree use social media for warnings about 15% and those with a Master's degree reduces to about 10%. When looking at the online community, about 15% of freshman and sophomores used social media for warning and then the percentages decline to about 13% for juniors and seniors, 10% for graduate students and staff, and continues to decline to 7% for faculty.

In regard to most effective messages, both groups prefer emergency alerts and text messages. When focusing on participant age groups, participants over 50 rely on television, phone calls, emergency alerts and some social media. For participants in their 20s, 30s and 40s, all medium messaging is acceptable using Figure 4.31 on page 69.

The results show that short, one line messages about the risk are most preferred by both groups in Figure 4.19 on page 58. The age of the group is important when determining which method to convey warnings to people, each type can target different age groups.

The third question asks whether younger and more educated people are more active with adhering to smoke warnings by reducing their outdoor activities. This question was broken into age and education. It was shown in this analysis that the overall median age within both groups was between 38 and 41 years old for those that received or searched for air quality notifications, and for those that reduced their outdoor activities. This median age was slightly higher than the expected late 20s and early 30 year olds as seen in Figure 4.32 on page 70.

When comparing the level of education, it is apparent that the more education people have, the more likely it is that they reduced outdoor activities as shown in Figure 4.37 on page 74. Participants who received warnings increased as the education level increased, and the same trend was observed in those who sought out air quality information. About 42% of high school graduates reduced outdoor activities which increased to 75% for those with a Ph.D. The online group also had the same trend with 60% of the undergraduate freshman and sophomore group reducing activities which increased to 77% for graduate students. Therefore, the more educated more often do follow warnings and reduced their outdoor activities.

Chapter 5 provides a conclusion to this thesis work.

CHAPTER FIVE: SUMMARY

5.1 Summary

Wildfire activity and the resulting smoke have increased significantly in the Western United States, which impacts millions of people every year. An average of 339,000 people die worldwide each year because of exposure to wildfire smoke (Johnston et al. 2012). Global warming and climate change have created warmer, shorter winters and hotter, longer summers. Thus the fire season has lengthened and these seasonal changes promote large uncontrollable fires, as dry vegetation awaits one spark. Whether the spark is by lightning or human caused, the subsequent fire may be the next inferno that takes out a city and thousands of acres of land. With projections of an increase of 78% area burned by Spracklen et al., the future will be filled with fires and consequently smoke (Spracklen et al. 2009).

When dealing with smoke, many people look towards public safety officials and resource managers to guide the public as to their actions for health and safety. The communication between agencies and the public needs to be transparent, and should encourage household level risk mitigation. Those in the expert role must be able to adjust to each community and support their understanding of the fire and smoke risks (Calkin et al. 2011; Olsen et al. 2014; Slovic 1987; Wilson, McCaffrey, and Toman 2017).

Our health will be impacted as smoke increases the levels of PM in our air. The small and fine PM are easily transported thousands of miles away from fires and have the ability to be taken deeper into our lungs. Thousands of people in the United States have been admitted to the hospital for respiratory and cardiovascular problem as well as having thousands of deaths attributed to short term exposure to $PM_{2.5}$ (Fann et al. 2018).

Analysis of air quality trends in the Treasure Valley was completed in this thesis utilizing both ground level monitoring and satellite observations. Air quality has deteriorated in the fire season (July through September) over the last 20 years as shown by ground level monitoring. The inversion and non-fire and no-inversion seasons have seen some improvement in air quality, which is documented as a reduction in the AQI ratings. However, during fire season the average and maximum AQI trends both increased. The maximum AQI values are significantly higher, showing a trend that continues to worsen over time. The AOD observations of the Northwestern US also show an increase in poor air quality during fire season over the last 37 years. The frequency of days with AOD values above the 90^{th} (99^{th}) percentile the Treasure Valley AOD increase 17% (36%).

The research of this thesis used the increase in poor air quality to focus on the social behavioral aspects of wildfire smoke. The areas of focus within the social behavioral aspects of wildfire smoke include public health messaging and content, and acceptance of smoke from various sources and its perception as a hazard. Collaboration with the Bureau of Land Management, IDEQ, and the Nez Perce Tribe was done to open communication with the agencies that are experts in the field of fire, smoke, and resource managers, as well as public safety officials. A public survey was created; comprised of demographic data, activity data, air quality notifications, natural hazards, and finally, health questions.

In-person and online surveys were conducted between August 28 and October 16, 2018, which resulted in 2,237 completed questionnaires. Analysis of the surveys indicated that most of the in-person participants were between 20 and 50 years old and the online participant group were in their late teens and early twenties. Overall, most of the respondents' were Caucasian females. Many participants live within the Treasure Valley, have some college education, and have a household income above $100,000 and engaged in outdoor activities like hiking, fishing, or gardening.

Air quality notification analysis indicates that participants do receive and search for information related to wildfire smoke, and most people reduce their outdoor activities by 1-2 days, while some even reduce their outside activities more than 6 days because of smoke. Most participants will reduce their outdoor activity with an orange AQI rating and eliminate activities with a red AQI rating. Emergency alerts and text messages were the best types of messaging that would motivate people to mitigate the risks related to wildfire smoke with a short sentence warnings about the risk before 9 a.m.

Eighty percent of participant groups consider wildfire smoke a natural hazard and 43% of the in-person group believes that smoke is *about as important* as other natural disasters. The online participant group was evenly split with 39.4% reporting *somewhat less important* and 38.5% reporting *about as important* as other natural disasters. However, most participants would not consider evacuating their home because of wildfire smoke.

Twenty-one percent of the in-person group and 27% of the online group had experienced smoke-related illnesses. Both group participants reported having eye, sinus, sore irritated throat, and headaches with, 93% of the in-person group and 81% of the online group observing at least one symptom due to wildfire smoke. To mitigate symptoms, participants consumed medications, took longer showers, and used personal air filtration systems or went to public buildings.

The focus of the social behavioral aspects were incorporated into three questions. First, do people reduce their outdoor activities and do most people only reduce for 2-3 consecutive days? It was determined that a majority of the population did reduce their outdoor activities by 1-2 days. Second, do most people receive warnings mostly from social media and are short direct warning messages the most effective? Most participants did not receive their warnings from social media but short messages were the most effective. Third, are younger and more educated people more active with adhering to smoke warnings by reducing their outdoor activities? Overall, median age for those that received or searched for air quality notifications, and for those that reduced their outdoor activities was between 38 and 41 years old. The more education that participants had, the more that they reduced their outdoor activities.

The purpose of this study was to gather and analyze information about the publics' level of outside activity during smoke event(s), their source of air quality information and their effective messaging preferences, their perception of wildfire smoke as a hazard, and their smoke-related health experiences. This work provides crucial policy-relevant smoke-related social behavioral information to decision-makers, and believe such information should be integrated into risk mitigation decision-making processes. This is critical because decision-makers need such information to mitigate the negative impacts of smoke.

The collaboration with the BLM, IDEQ, and the Nez Perce Tribe was done to open communication with the agencies. Survey results were presented to the collaborators at the 2018 Wildfire Interagency After Action Review meeting on November 29, 2018. Final results from this thesis were also presented at the University of Montana on April 8, 2019 and will be presented at the 2019 EPA Sponsored Smoke Management Northwest Meeting on May 29, 2019. Another goal of this thesis was to provide the collected data freely to researchers, thus the manuscript entitled "A Dataset on Human Response to Wildfire Smoke" was submitted to Nature and is currently under revision.

5.2 Future Research

This section describes recommendations for future research that can be continued from this thesis.

The analysis of the complete data set can be continued going in more depth with each of the demographic background information and each of the questions to provide a predictive model to analyze the human behavior. We will provide feedback to BLM, IDEQ, and the Nez Perce Tribe about the analysis results, and suggest potential ways to integrate this information into their policies and procedures during smoke events. Also we suggest that further public education and/or transparent conversations are needed based on survey results.

Redoing this survey to determine if there are trends or change in behavior or perception in the future is also recommended, with some minor modifications. First, ensure some possible answer (N/A, none, etc.) for each question so that analysis can be completed knowing that participant did see every question. Also if surveys use a paper format, ensure that the last question is not on the last page by itself and print single sided. This leads to determining if participants in fact did see the question (Question 29) but did not select an answer, or if the participant did not see the question. If a digital format can be developed for the public surveys, it would reduce the time required to manually enter and quality check each paper survey. A digital format was not used for the public surveys because of potential lack of wireless internet, potential logistical problems with needing personal email addresses or personal information of participants to use the online survey program, and resources for which to collect digital surveys (i.e. ipad or tablet). Finally, consider how terms, such as illness, could be interpreted by survey participants. Illness can be defined as something serious like cancer, but intended for a range of minor symptoms like irritated eyes.

REFERENCES

Abatzoglou, John T., and A. Park Williams. 2016. "Impact of Anthropogenic Climate Change on Wildfire across Western US Forests." *Proceedings of the National Academy of Sciences*.

Abatzoglou, JT., CA. Kolden, JK. Balch, and BA. Bradley. "Controls on Interannual Variability in Lightning-Caused Fire Activity in the Western US." *Environ Res Lett* 11(4): 045005.

Achen, Christopher H. 1975. "Mass Political Attitudes and the Survey Response." *American Political Science Review* 69(4): 1218–31. https://doi.org/10.2307/1955282.

AghaKouchak, Amir et al. 2018. "How Do Natural Hazards Cascade to Cause Disasters?" *Nature* 561(7724): 458–60. http://www.nature.com/articles/d41586-018-06783-6 (February 11, 2019).

Balch, Jennifer K. et al. 2017. "Human-Started Wildfires Expand the Fire Niche across the United States." *Proceedings of the National Academy of Sciences* 114(11).

Balshi, Michael S. et al. 2009. "Vulnerability of Carbon Storage in North American Boreal Forests to Wildfires during the 21st Century." *Global Change Biology* 15(6): 1491–1510.

Barbero, R. et al. "Climate Change Presents Increased Potential for Very Large Fires in the Contiguous United States." *Int J Wildland Fire* 24(7): 892–99.

Black, Carolyn, Yohannes Tesfaigzi, Jed A. Bassein, and Lisa A. Miller. 2017. "Wildfire Smoke Exposure and Human Health: Significant Gaps in Research for a Growing Public Health Issue." *Environmental Toxicology and Pharmacology*.

Blades, Jarod J., Steven R. Shook, and Troy E. Hall. 2014. "Smoke Management of Wildland and Prescribed Fire: Understanding Public Preferences and Trade-Offs." *Canadian Journal of Forest Research*.

Bowman, David M J S et al. 2009. "Fire in the Earth System." *Science (New York, N.Y.)* 324(5926): 481–84. http://www.ncbi.nlm.nih.gov/pubmed/19390038 (April 2, 2019).

Brown, Timothy J., Beth L. Hall, and Anthony L. Westerling. 2004. "The Impact of Twenty-First Century Climate Change on Wildland Fire Danger in the Western United States: An Applications Perspective." *Climatic Change* 62(1–3): 365–88. http://link.springer.com/10.1023/B:CLIM.0000013680.07783.de (February 11, 2019).

Burns, Robin, Priscilla Robinson, and Penelope Smith. 2010. "From Hypothetical Scenario to Tragic Reality: A Salutary Lesson in Risk Communication and the Victorian 2009 Bushfires." *Australian and New Zealand Journal of Public Health*.

Calkin, David C et al. 2011. "Progress towards and Barriers to Implementation of a Risk Framework for US Federal Wildland Fire Policy and Decision Making." *Forest Policy and Economics* 13: 378–89. http://www.wfmrda.org/NFDSC.html (February 28, 2019).

CITI Program. "Human Subjects Research." https://about.citiprogram.org/en/series/human-subjects-research-hsr/ (June 21, 2018).

CNN Library. 2018. "2018 Atlantic Hurricane Season Fast Facts." https://www.cnn.com/2018/05/10/us/2018-atlantic-hurricane-season-fast-facts/index.html (March 17, 2019).

Dennison, Philip E., Simon C. Brewer, James D. Arnold, and Max A. Moritz. 2014. "Large Wildfire Trends in the Western United States, 1984-2011." *Geophysical Research Letters* 41(8): 2928–33. http://doi.wiley.com/10.1002/2014GL059576 (February 11, 2019).

Eiser, Richard J. et al. 2012. "Risk Interpretation and Action: A Conceptual Framework for Responses to Natural Hazards." *International Journal of Disaster Risk Reduction*.

Fann, Neal et al. 2018. "The Health Impacts and Economic Value of Wildland Fire Episodes in the U.S.: 2008–2012." *Science of the Total Environment* 610–611: 802–9.

Firewise.org. "NFPA - Firewise USA®." https://www.nfpa.org/Public-Education/By-topic/Wildfire/Firewise-USA (June 2, 2018).

Fish, Jennifer A. et al. 2017. "Effectiveness of Public Health Messaging and Communication Channels during Smoke Events: A Rapid Systematic Review." *Journal of Environmental Management* 193: 247–56. https://www.sciencedirect.com/science/article/pii/S0301479717301160 (February 28, 2019).

Flannigan, Mike D. et al. 2009. "Implications of Changing Climate for Global Wildland Fire." *International Journal of Wildland Fire*.

Glik, Deborah C. 2007. "Risk Communication for Public Health Emergencies." *Annual Review of Public Health*.

Gordon, S. 2014. "Respiratory Risks from Household Air Pollution in Low and Middle Income Countries." *The Lancet Respiratory Medicine* 2(10): 823–60. https://doi.org/10.1016/S2213-2600(14)70168-7.

Holstius, David M., Colleen E. Reid, Bill M. Jesdale, and Rachel Morello-Frosch. 2012. "Birth Weight Following Pregnancy during the 2003 Southern California Wildfires." *Environmental Health Perspectives* 120(9): 1340–45.

Johnston, Fay H. et al. 2012. "Estimated Global Mortality Attributable to Smoke from Landscape Fires." *Environmental Health Perspectives*.

Jolly, W. Matt et al. 2015. "Climate-Induced Variations in Global Wildfire Danger from 1979 to 2013." *Nature Communications* 6(1): 7537. http://www.nature.com/articles/ncomms8537 (February 11, 2019).

Kaulfus, Aaron S. et al. 2017. "Biomass Burning Smoke Climatology of the United States: Implications for Particulate Matter Air Quality." *Environmental Science & Technology* 51(20): 11731–41. http://pubs.acs.org/doi/10.1021/acs.est.7b03292 (February 11, 2019).

Knowlton, Kim. 2013. Where There's Fire, There's Smoke: Wildfire Smoke Affects Communities Distant from Deadly Flames. http://rmgsc.cr.usgs.gov/outgoing/ (March 2, 2019).

Kolbe, Anthony, and Kim L. Gilchrist. 2009. "An Extreme Bushfire Smoke Pollution Event: Health Impacts and Public Health Challenges." *New South Wales Public Health Bulletin* 20(2): 19.

Koster, Randal D et al. 2016. Technical Report Series on Global Modeling and Data Assimilation, Volume 45 The MERRA-2 Aerosol Assimilation.

Kulemeka, Owen. 2015. "A Review of Wildland Fire Smartphone Applications:A Classification Study from Australia, USA, Canada and South Aftrica." *International Journal of Emergency Services* 4(2): 258–70. https://doi.org/10.1108/IJES-07-2014-0010.

Künzli, Nino et al. 2006. "Health Effects of the 2003 Southern California Wildfires on Children." *American Journal of Respiratory and Critical Care Medicine*.

Littell, JS., D. McKenzie, DL. Peterson, and AL. Westerling. "Climate and Wildfire Area Burned in Western U.S. Ecoprovinces, 1916-2003." *Ecol Appl* 19(4): 1003–21.

Lundgren, E. R., and H.A. McMakin. 2009. "Risk Communication: A Handbook for Communicating Environmental, Safety, and Health Risks, Vol. 1." *The Institute of Electrical and Electronic Engineers Inc.*

McCaffrey, Sarah. 2015. "Community Wildfire Preparedness: A Global State-of-the-Knowledge Summary of Social Science Research." *Current Forestry Reports*: 81–90. https://link.springer.com/content/pdf/10.1007%2Fs40725-015-0015-7.pdf (February 28, 2019).

McClure, Crystal D., and Daniel A. Jaffe. 2018. "US Particulate Matter Air Quality Improves except in Wildfire-Prone Areas." *Proceedings of the National Academy* *of Sciences* 115(31): 7901–6. http://www.pnas.org/lookup/doi/10.1073/pnas.1804353115 (February 11, 2019).

Meadow, A. M. 2018. "Considering Research Ethics and Design for Participatory Research Projects." *Northwest Climate Adaptation Science Center*. https://vimeo.com/291801158 (September 25, 2018).

National Aeronautics and Space Administration: Goddard Space Flight Center. 2019. "Modern-Era Retrospective Analysis for Research and Applications, Version 2." https://gmao.gsfc.nasa.gov/reanalysis/MERRA-2/ (March 14, 2019).

National Aeronautics and Space Administration. 2019. "A Brief History of NASA." https://history.nasa.gov/factsheet.htm (March 17, 2019).

National Aeronautics and Space Administration, Applied Remote Sensing Training. 2016. "Introduction to Satellite Remote Sensing for Air Quality Applications, Webinar Session 3: NASA Aerosol Products for Particulate Matter Air Quality."

National Interagency Fire Center. "Communicator's Guide." https://www.nifc.gov/prevEdu/comm_guide/ch2.html.

Nunes, Karine Vila Real, Eliane Ignotti, and Sandra de Souza Hacon. 2013. "Circulatory Disease Mortality Rates in the Elderly and Exposure to PM2.5 Generated by Biomass Burning in the Brazilian Amazon in 2005." *Cadernos de Saúde Pública* 29(3): 589–98.

Olsen, Christine S., Danielle K. Mazzotta, Eric Toman, and A. Paige Fischer. 2014. "Communicating about Smoke from Wildland Fire: Challenges and Opportunities for Managers." *Environmental Management*.

Olsen, Christine S., Eric Toman, and Stacey Frederick. 2017. "A Multi-Region Analysis of Factors That Influence Public Acceptance of Smoke from Different Fire Sources." *International Journal of Wildland Fire*.

Pope, C. Arden, Majid Ezzati, and Douglas W. Dockery. 2009. "Fine-Particulate Air Pollution and Life Expectancy in the United States." *New England Journal of Medicine* 360(4): 376–86.

Price, Colin, and David Rind. 2004. “Possible Implications of Global Climate Change on Global Lightning Distributions and Frequencies.” *Journal of Geophysical Research* 99(D5): 10823.

Radeloff, V C et al. 2005. 15 Communications Ecological Applications *THE WILDLAND-URBAN INTERFACE IN THE UNITED STATES*. http://www.silvis.forest.wisc.edu/projects/WUI.

Rappold, Ana G. et al. 2012. “Cardio-Respiratory Outcomes Associated with Exposure to Wildfire Smoke Are Modified by Measures of Community Health.” *Environmental Health: A Global Access Science Source*.

Reid, Colleen E. et al. 2016. “Critical Review of Health Impacts of Wildfire Smoke Exposure.” *Environmental Health Perspectives* 124(9).

Shaposhnikov, Dmitry et al. 2014. “Mortality Related to Air Pollution with the Moscow Heat Wave and Wildfire of 2010.” *Epidemiology* 25(3): 359–64.

Slovic, P. 1987. “Perception of Risk.” *Science* 236(4799): 280–85. http://science.sciencemag.org/content/236/4799/280.abstract.

Spracklen, D. V. et al. 2009. “Impacts of Climate Change from 2000 to 2050 on Wildfire Activity and Carbonaceous Aerosol Concentrations in the Western United States.” *Journal of Geophysical Research* 114(D20): D20301. http://doi.wiley.com/10.1029/2008JD010966 (February 11, 2019).

Sugerman, David E et al. 2012. “Emergency Health Risk Communication During the 2007 San Diego Wildfires: Comprehension, Compliance, and Recall.” *Journal of Health Communication* 17(6): 698–712. https://www.tandfonline.com/action/journalInformation?journalCode=uhcm20 (February 28, 2019).

Theobald, David M., and William H. Romme. 2007. “Expansion of the US Wildland–urban Interface.” *Landscape and Urban Planning* 83(4): 340–54. https://www.sciencedirect.com/science/article/pii/S0169204607001491 (February 11, 2019).

Tourangeau, Roger, Lance J. Rips, and Kenneth Rasinski. 2012. *The Psychology of Survey Response*. Cambridge University Press. https://doi.org/10.1017/CBO9780511819322.

United States Environmental Protection Agency - 1. 2019. “Evolution of the Clean Air Act.” https://www.epa.gov/clean-air-act-overview/evolution-clean-air-act (January 9, 2019).

United States Environmental Protection Agency - 2. 2019. “Air Data Basic Information.” https://www.epa.gov/outdoor-air-quality-data/air-data-basic-information (January 9, 2019).

United States Government, AIRNOW. 2016. “Air Quality Index (AQI) Basics.” https://airnow.gov/index.cfm?action=aqibasics.aqi (November 2, 2018).

Van Der Werf, Guido R. et al. 2008. “Climate Controls on the Variability of Fires in the Tropics and Subtropics.” *Global Biogeochemical Cycles* 22(3).

Weisshaupt, Brad R et al. *Acceptability of Smoke From Prescribed Forest Burning in the Northern Inland West: A Focus Group Approach*. https://academic.oup.com/jof/article-abstract/103/4/189/4598622 (March 5, 2019).

Westerling, A. L. et al. 2003. “Climate and Wildfire in the Western United States.” *Bulletin of the American Meteorological Society* 84(5): 595–604. http://journals.ametsoc.org/doi/10.1175/BAMS-84-5-595 (February 11, 2019).

Westerling, A L, H G Hidalgo, D R Cayan, and T W Swetnam. 2006. “Warming and Earlier Spring Increase Western U.S. Forest Wildfire Activity.” *Science (New York, N.Y.)* 313(5789): 940–43. http://www.ncbi.nlm.nih.gov/pubmed/16825536 (February 11, 2019).

Westerling, Anthony Le Roy. 2016. “Increasing Western US Forest Wildfire Activity: Sensitivity to Changes in the Timing of Spring.” *Philosophical Transactions of the Royal Society B: Biological Sciences*.

Wilson, Robyn S., Sarah M. McCaffrey, and Eric Toman. 2017. *Wildfire Communication and Climate Risk Mitigation*.

APPENDIX

Survey Questionnaire

Mojtaba Sadegh and Mariah Fowler Consent Form

Title: Human Response to Wildfire Smoke Survey

Study Information Sheet

The study is being conducted by Mojtaba Sadegh, assistant professor, and Mariah Fowler, graduate student of Civil Engineering, at Boise State University. The purpose of this study is strictly for research purposes. The researchers are not affiliated in any way with any organization other than Boise State University.

The purpose of this study is to assess human response to wildfire smoke. During the study, you will answer some survey questions and read a brief text. This survey should take you less than 10 minutes to complete. You must be at least 18 years old to complete this survey.

This study involves no foreseeable risks. You may discontinue the study at any time. Your responses are completely anonymous and cannot be linked to you in any way.

For this research project, we are requesting demographic information. Though it is unlikely, it is possible that the combined answers to these questions may make an individual person identifiable. The researchers will make every effort to protect your confidentiality. However, if you are uncomfortable answering any of these questions, you may leave them blank.

CONTACTS FOR QUESTIONS OR PROBLEMS

Contact Information: If you should have any questions about this research study, please contact Mojtaba Sadegh at 208-426-3774 or mojtabasadegh@boisestate.edu. For additional information about your rights as a research participant in this study, please feel free to contact the Boise State University Institutional Review Board Office. You may reach the board office between 8:00 AM and 5:00 PM, Monday through Friday, by calling (208) 426-5401 or by writing: Institutional Review Board, Office of Research Compliance, Boise State University, 1910 University Dr., Boise, ID 83725-1138.

In consideration of all of the above, I give my consent to participate in this research study.

In consideration of all of the above, I DO NOT consent to participate in this research study. [EXIT IF NO CONSENT]

DEMOGRAPHIC DATA

If you are uncomfortable answering any of these questions, you may leave them blank.

1. Do you consent to participate in this research study?
   - ☐ Yes
   - ☐ No – If you do not consent to participate, please do not complete this survey

2. What is your age?

   Fill in the blank _______

3. Which gender do you identify with?
   - ☐ A woman
   - ☐ A man
   - ☐ Other _____________

4. What racial or ethnic group best describes you?
   - ☐ White / Caucasian
   - ☐ Hispanic or Latino
   - ☐ Black or African American
   - ☐ Native American / American Indian or Alaskan Native
   - ☐ Asian / Pacific Islander
   - ☐ Other _______

5. What is the ZIP Code where you currently live?

   Fill in the blank _______

6. What is the highest degree or level of school you completed? If currently enrolled, highest degree received.
   - ☐ 8th grade or less
   - ☐ Some high school, no diploma
   - ☐ High school graduate, diploma or GED
   - ☐ Some college, no degree
   - ☐ Associates degree
   - ☐ Bachelor's degree
   - ☐ Master's degree
   - ☐ Ph.D, M.D., J.D. or similar

7. What is your total household income, including income from all members of your family, in 2017 before taxes? This figure should include salaries, wages, pensions, dividends, interest, and all other income.
   - ☐ $25,000 or less
   - ☐ $25,000 to $49,999
   - ☐ $50,000 to $74,999
   - ☐ $75,000 to $99,999
   - ☐ $100,000 or more

ACTIVITY DATA

8. Would you say that in general your health is:
   - ☐ Excellent
   - ☐ Good
   - ☐ Fair
   - ☐ Poor
9. During summer of 2018, have you engaged in any outdoor activities, such as hiking, biking, fishing, gardening, running, or any other outdoor activity?
   - ☐ Yes – Please list the activities ___________________
   - ☐ No (skip to question 11)
10. During the summer of 2018, how often would you say you've engaged in the outdoor activities you've listed above?
    - ☐ Daily
    - ☐ A few times per week
    - ☐ Once per week
    - ☐ Less than once per week, but more than once per month
    - ☐ Rarely – A few times during the summer
    - ☐ Never

AIR QUALITY NOTIFICATION

11. During the summer of 2018, have you ever received an air quality notification message suggesting you avoid outside activity?
    - ☐ Yes
    - ☐ No

12. Do you ever seek out information related to wildfire and smoke notifications?
    - ☐ a. Yes
    - ☐ b. No (if you answered no to both questions 11 and 12, please skip to question 15)

13. Which source do you use to find wildfire smoke notifications? [Check all that apply]
    - ☐ Social media (like Facebook, Instagram, Twitter)
    - ☐ Television
    - ☐ Online news sources
    - ☐ Newspapers
    - ☐ Friends or Family
    - ☐ Personal observation
    - ☐ State agencies such as Department of Environmental Quality website
    - ☐ Idaho Smoke Information Blog
    - ☐ Federal sources such as AIRnow.gov website
    - ☐ Dynamic road sign displays (such as the signs on I-184 or I-84)
    - ☐ Other _______

14. In a smoky week in summer 2018, about how many days did you look online (either on a computer, tablet, or smartphone) for smoke-related information, such as air quality, smoke forecasts, or health notices?
    - ☐ 0 days
    - ☐ 1 days
    - ☐ 2 days
    - ☐ 3 days
    - ☐ 4-5 days
    - ☐ 6-7 days.

15. During summer of 2018, did you *ever* reduce your outside activities due to wildfire smoke?
    - ☐ Yes
    - ☐ No
    - ☐ Not applicable
16. During summer of 2018, think of the *longest* period of consecutive days you reduced or eliminated your outdoor activities due to a smoke event. <u>How many consecutive days</u> did you reduce or eliminate activity?
    - ☐ 0 days
    - ☐ 1 to 2 days
    - ☐ 3 days
    - ☐ 4 days
    - ☐ 5 days
    - ☐ 6 days and more

17. What is the *minimum* air quality index rating that would cause you to <u>reduce your outdoor activity</u> on a particular day?
    - ☐ Green – Good
    - ☐ Yellow – Moderate
    - ☐ Orange – Unhealthy for Sensitive Groups
    - ☐ Red – Unhealthy
    - ☐ Purple – Very Unhealthy
    - ☐ Maroon – Hazardous
    - ☐ I am not familiar with this rating

18. What is the *minimum* air quality index rating that would cause you to <u>eliminate your outdoor activity</u> on a particular day?
    - ☐ Green – Good
    - ☐ Yellow – Moderate
    - ☐ Orange – Unhealthy for Sensitive Groups
    - ☐ Red – Unhealthy
    - ☐ Purple – Very Unhealthy
    - ☐ Maroon – Hazardous
    - ☐ I am not familiar with this rating

19. If you decided to limit your outdoor activity during a smoke event, what type of information motivated your decision to do so? [Check all that apply]
    - ☐ Smoke-related health problem statistics
    - ☐ Air quality information
    - ☐ Smoke forecasts
    - ☐ Your own visual observation (seeing the smoke outside)
    - ☐ Wildfire information
    - ☐ Advice from your doctor
    - ☐ Advice from family and friends

20. What type of message could motivate / motivated you to take action to mitigate the risk of issues related to wildfire smoke, such as staying indoors or leaving the area? [Check all that apply]
    - ☐ Text message
    - ☐ Phone call
    - ☐ Social media message
    - ☐ Online message
    - ☐ Message seen on television
    - ☐ Emergency alerts
    - ☐ Contact from family or friends

21. What was the *content* of the message(s) that motivated you to take this action to mitigate the negative health impacts of wildfire smoke? [Check all that apply]
    - ☐ A short message warning about the risk (1 line of text)
    - ☐ A short message warning about the risk that included health or other statistics
    - ☐ A short statement (roughly 1 paragraph)
    - ☐ A visual infographic or picture
    - ☐ An online Q&A session (Facebook Live or Instagram Live)
    - ☐ A video
    - ☐ A conversation (either online, via phone, or in person)

22. When would receiving a smoke warning message be most likely to impact your decision to limit or avoid outdoor activities *that same day?*
    - ☐ I would prefer to know the day before
    - ☐ Early morning (before 9 AM)
    - ☐ Late morning (9 AM – noon)
    - ☐ Afternoon (Noon – 5 PM)
    - ☐ Evening (5 PM or later)

23. Will you take preventive actions to reduce smoke-related health impacts in the future?
    - ☐ Yes – Please list the actions you might take ______________
    - ☐ No
    - ☐ Not sure

NATURAL HAZARD QUESTIONS

24. Do you consider wildfire smoke events a natural hazard?
    - ☐ Yes
    - ☐ No
    - ☐ Not sure
25. As a public health threat, are wildfire smoke events more important, less important, or about as important as other natural disasters, such as hurricanes or tornadoes?
    - ☐ Much less severe/important
    - ☐ Somewhat less severe/important
    - ☐ About as severe/important
    - ☐ Somewhat more severe/important
    - ☐ Much more severe/important
26. Would you consider evacuating your home only because of the wildfire smoke?
    - ☐ Yes, I have done this in the past.
    - ☐ Yes, I would consider it
    - ☐ No
    - ☐ Prefer not to answer

HEALTH QUESTIONS

27. Have you, or anyone in your household, experienced wildfire smoke-related illness?
    - ☐ Yes
    - ☐ No
    - ☐ Not sure

28. Did you have any of the following symptoms during or a few days after one of the smoke events in the summer of 2018 in the Boise area / Treasure Valley? [Check all that apply]
    - ☐ Wheezing or whistling in the chest
    - ☐ Itchy or watery eyes
    - ☐ Irritated eyes
    - ☐ Sneezing or a runny or blocked nose
    - ☐ Dry irritated nose / sinuses
    - ☐ A sore or irritated throat
    - ☐ A cold
    - ☐ A dry cough at night
    - ☐ A dry cough first thing in the morning
    - ☐ A dry cough at other times of the day
    - ☐ A wet cough (congestion in the chest or phlegm production)
    - ☐ Bronchitis
    - ☐ An asthma attack
    - ☐ Headaches
    - ☐ Fatigue

29. Did you use/do any of the following to help with any symptoms during the smoke event? [Check all that apply]
    - ☐ Take medication
    - ☐ Wear a mask to protect your lungs
    - ☐ Take long showers
    - ☐ Visit a doctor or nurse
    - ☐ Visit a doctor's office for asthma or smoke-related lung issues
    - ☐ Use a personal air filtration system in your home or office
    - ☐ Go to buildings that have air filtration systems like the mall or public library
    - ☐ Miss work due to health problems