AN INVESTIGATION OF THE RELATIONSHIP BETWEEN VULNERABLE POPULATIONS AND HAZARD CASUALTIES IN WARNING DISSEMINATION COVERAGE GAPS

by

Aisha C. Reed Haynes
A Dissertation
Submitted to the
Graduate Faculty
of
George Mason University
in Partial Fulfillment of
The Requirements for the Degree
of
Doctor of Philosophy
Earth Systems and Geoinfomation Sciences

Committee:

______________________________	Dr. Paul Houser, Dissertation Director
______________________________	Dr. Kevin Curtin, Committee Member
______________________________	Dr. Katherine Rowan, Committee Member
______________________________	Dr. Jamese Sims, Committee Member
______________________________	Dr. Donna M. Fox, Associate Dean, Office of Student Affairs & Special Programs, College of Science
______________________________	Dr. Peggy Agouris, Dean, College of Science
Date: ___________________________	Summer Semester 2017 George Mason University Fairfax, VA

An Investigation of the Relationship between Vulnerable Populations and Hazard Casualties in Warning Dissemination Coverage Gaps

A Dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy at George Mason University

by

Aisha C. Reed Haynes
Master of Science
Purdue University, 2006
Bachelor of Science
Jackson State University, 2002

Director: Paul Houser, Professor
Department of Geography and Geoinformation Sciences

Summer Semester 2017
George Mason University
Fairfax, VA

DEDICATION

This dissertation is dedicated to all my family and friends who prayed me through this experience. It is dedicated to those who encouraged and believed in me when doubt crept in and allowed me to question myself and this work. My successes and accomplishments are their successes and accomplishments, because they make me who I am, and I would not be without them.

My husband, Sidney, for being a calming force who assisted me through this process from vetting research topics with me to staying up and working with me through the night.

My daughter, Avery, for joining me during this journey. She attended meetings with my committee members, and she developed and grew with this research. I appreciate her love and words of encouragement.

My mom, Valerie, who is a beacon for all that I would want to be in life. My dad, Charles, for instilling me with a sense of perseverance. My aunts, Donna, Jama, Evelyn, and Debra, for their everlasting support and words of encouragement.

My late grandparents, who believed in me and would move heaven and earth to make me happy. You are missed.

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to my advisor, Prof. Paul Houser for his support of my Ph.D. study, his patience, and knowledge as he guided me through this process. I appreciate that he saw the value in my research idea, and chose to be my advisor after the departure of Prof. Richard Medina, who I must thank for encouraging me to continue down social geography path, when other geoinformation science paths were more popular. In addition to my advisors, I would like to thank the rest of my dissertation committee: Prof. Kevin Curtin, Prof. Katherine Rowan, and Dr. Jamese Sims, for their insightful comments and encouragement, but also for the hard questions which incited me to widen my research from various perspectives.

A very special gratitude goes out to David Caldwell for choosing me to be a NOAA Graduate Sciences Program Scholar, and for Cindy Woods at the National Weather Service for taking me in in his absence. I would like to thank the people in the NOAA Office of Education, Chantell Haskins, Victoria Dancy, and Marlene Kaplan, for their support and encouragement. I would like to thank Victor Hom, Dr. Vankita Brown, the NWS Operations Staff, and other colleagues at the NWS for their support and wealth of knowledge and resources.

My greatest thanks go to my husband, Sidney, for putting up with me through this process. I thank him for the brainstorming sessions, when I tried to develop ‘an original research topic that would be significant to the field.’ I thank him for going through my methodology with me. I thank him for his programming knowledge. There are too many things to thank him for. I thank him for his patience, his knowledge, his encouragement, his support, and just being here as we took this journey.

Finally, I express my very profound gratitude to my parents and friends, especially Crystal and Michelle, for providing me with support and continuous encouragement throughout my years of study and through the process of researching and writing this thesis. Special thanks are extended to my aunt, the librarian, who helped me obtain information from sources and was a second reader of my dissertation.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure Page

ABSTRACT

AN INVESTIGATION OF THE RELATIONSHIP BETWEEN VULNERABLE POPULATIONS AND HAZARD CASUALTIES IN WARNING DISSEMINATION COVERAGE GAPS

Aisha C. Reed Haynes, Ph.D.

George Mason University, 2017

Dissertation Director: Dr. Paul Houser

Many meteorological hazards that occur can be forecast, which allows the population to be warned. The number of warnings that a person receives from different sources play a role in whether an adaptive response is taken. Weather hazard information is communicated via a number of technologies in a variety of ways. The technologies that offer the most promise for reaching all populations are television, radio, phones, the internet, and outdoor sirens/loudspeakers. Whereas these technologies are beneficial in warning the populace, there are several limitations that can hinder a person from getting a warning from these sources. Additionally, people with less accessibility to the latest technologies tend to also be among those most vulnerable to the effects of natural hazards.

This study examined the dissemination of tornado warnings in Mississippi. Using Geographic Information Systems, this identified television, radio, cell phone, and outdoor siren coverage areas by using viewshed analysis and other tools to locate broadcast coverage gaps in order to develop an index that identifies areas of limited to no coverage. U.S. Census data was used to examine demographic information to identify socially vulnerable populations. Tornadoes that resulted in injuries or fatalities were identified along with their warning polygons, if warned. The chi-square test of independence and odds ratio were used to identify relationships between socially vulnerable populations and hazard casualties, respectively, in areas with limited to no coverage. It was hypothesized that socio-economically vulnerable citizens were more likely to reside within coverage gaps, and there were more casualties within warned areas that have coverage gaps.

A Dissemination Technology Coverage Index was developed that displayed areas of No Coverage, Marginal, Fair, Good, or Strong Coverage. Approximately eighty-seven percent of the state has some level of coverage. There was a small association found between coverage areas and socially vulnerable populations. It was also found that the majority of the warned tornadoes with casualties occurred in areas with limited to no coverage.

CHAPTER ONE: INTRODUCTION

The United States is prone to many natural hazards. Most meteorological hazards, such as hurricanes, severe storms and tornadoes, winter storms, and extreme heat can be forecast, which allows the population to be warned of the impending hazard. Despite the warnings, these hazards can cause loss of life, property damage, and result in large scale economic damage. The severity of the loss and damage can depend on the vulnerability of the affected population.

Vulnerabilities to natural hazards refer to the potential for loss and can vary over time and space. There are three principles that are used in determining vulnerability: an exposure model – the identification of conditions that make people or places vulnerable to extreme natural events; “the assumption that vulnerability is a measure of societal resistance or resilience to hazards; and the integration of potential exposures and societal resilience with a specific focus on a particular place or region” (Cutter, Boruff, and Shirley, 2003, p.244). Social vulnerability is characterized by the individual characteristics of people, social inequalities, and place inequalities. There are a number of factors that influence social vulnerability. The factors that are in general consensus of the social science community are

> lack of access to resources; limited access to political power and representation; social capital, including social networks and connections;

> beliefs and customs; building stock and age; frail and physically limited individuals; and types and density of infrastructure and lifelines. The generally accepted characteristics that influence social vulnerability are age, gender, race, and socioeconomic status. Other characteristics identify special needs or those that lack the normal social safety nets necessary in disaster recovery – the physically or mentally disabled, non-English speaking immigrants, the homeless, transients, and seasonal tourists. The quality of human settlement and the built environment are important because they influence the economic losses, injuries, and fatalities from natural hazards. (Cutter et al., 2003, p. 245)

Weather hazard information is communicated via a number of technologies in a variety of ways. The most common technologies are television, radio (AM/FM/weather), telephone and/or cell phones, the internet, and sirens/loudspeakers. Whereas these technologies are beneficial in warning the populace, there are several limitations that can hinder a person from getting the warning from these sources. Some limitations can be as simple as a power outage which will disable television and radio use to no or limited access to cable television, internet or cell phone service. The people with less accessibility to the latest technologies tend to also be among those most vulnerable to the effects of natural hazards (Phillips & Morrow, 2007).

This study seeks to display areas in which people are technologically vulnerable to receiving hazard warnings by using Geographic Information Systems (GIS). Tornadoes are the focus of the study, because they are short-fused events that are sporadic in nature. This creates the need to get warning information to the affected population in a timely manner is imperative to reduce injuries and fatalities. Mississippi is the study area because it is prone to tornadoes, resulting from either severe thunderstorms or hurricanes. Additionally, Mississippi has no defined tornado season with peak tornado occurrences during the “national” tornado season and the winter.

Motivation

“One of the most crucial steps in the tornado warning process is communication of the danger to the public (AMS, 1975).”

Tornado forecasting and tornado warning dissemination has advanced since 1948, when the first tornado was forecast. Tornado warning dissemination has progressed from outdoor sirens, through radio and television, and recently to receiving geo-targeted messages on cell phones. Despite these advances, of the approximate 1,200 tornadoes that occur in the United States annually, on average about 60 people are killed per year and numerous more are injured (Storm Prediction Center, 2015).

There is not one definitive reason why there are still so many deaths associated with tornadoes. Meteorologists are continuously improving their forecasts to have more lead time, to be more precise with their warnings, and to develop graphics that will better display the threat. There has been a broad adoption of new internet and mobile technology to ensure that the public are receiving warnings. Additionally, the expertise of social scientists is being sought to provide information on how to better provide weather information to the public so that they will take protective actions. However, there has been little research that explored if the public is actually receiving this weather information. If people are not receiving the information, then how beneficial is all of this advancement?

Findings presented at a National Academies of Science (NAS) workshop on geotargeted alerts and warnings showed that broadcast signals may not reach intended populations. Broadcast is a terrestrial signal, so coverage is lost due to terrain, less efficient antennas, and building penetration. One example presented at the NAS workshop was a class C FM station in Texas, KVIL-FM with coverage of approximately 24,000 square miles should reach a population of 6,373,000 people. The coverage is represented as a circle; however, when terrain sensitivity and indoor penetration were factored in, the coverage shrinks to ~3,173,000 people. The city of Denton, TX, receives little to no coverage even though it falls within the station’s coverage area (National Research Council, 2013). Given this information, one would wonder if there are other areas with limited to no broadcast coverage which could impede warning dissemination.

This research seeks to explore if the warning messages can reach people given their location. By exploring the coverage of television, radio, and cell tower signals, as well as outdoor warning sirens, this study seeks to locate areas of limited to no coverage, which will impact the public’s receipt of warning messages. Even though the focus of this study is tornadoes, this information will be useful for various types of hazards. This research is not seeking to answer what are the technologies that are most commonly used for receiving warning, what the recipients will do with the information once they receive it (how or if they disperse it), or explore the decision-making process that goes along with the warning receipt.

Hypothesis

Risk communication research has shown that the number of warnings an individual receives increases the chance of an adaptive response (Perry, 1979; Perry, Lindell & Greene, 1982; Dash & Gladwin, 2007; Phillips & Morrow, 2007), so the reduction of sources may affect their reaction to the warning. This study seeks to display areas in which people are vulnerable to receiving hazard warnings by locating coverage gaps in warning dissemination technologies. I hypothesize that socially vulnerable populations are more likely to reside within these coverage gaps compared to other populations. It is presumed that socially vulnerable populations are least likely to receive weather warning communication from all available media because they do not have access to the varied warning communication technologies due to availability and/or affordability. Subsequently, in areas where a warning was issued and a hazard occurred, it is hypothesized that there will be a positive correlation between casualties and coverage gaps.

Structure of paper

This dissertation examines dissemination technologies to locate coverage gaps in warning communications. The paper is outlined as follows. Chapter 2 contains a literature review of the warning process and alerts; the decision-making process; socially vulnerable populations; warning dissemination technologies; and how a technology's coverage area is determined. Chapter 3 provides information on the study area. Chapter 4 details the methods used in identifying coverage gaps in warning dissemination technologies and developing a coverage index. Chapter 5 describes the process in locating socially vulnerable populations and identifying associations between the populations and coverage gaps. Chapter 6 examines past storm warning data to determine if there is a relationship with casualties in warned tornadoes and coverage gaps. Chapter 7 summarizes the research, discusses limitations and possible implementations of the findings, and future research.

CHAPTER TWO: LITERATURE REVIEW

Warning process and alerts

Most meteorological hazards can be forecasted, which allows the population to be warned of the impending hazard. People obtain weather forecasts from a number of sources. Three major groups strongly influence how weather risk messages are created and conveyed: the National Oceanic and Atmospheric Administration (NOAA) National Weather Service (NWS) forecasters at storm centers (Storm Prediction Center, National Hurricane Center, etc.) and local weather forecast offices (WFOs), state/local emergency managers (EMs), and news media (Demuth, Morss, Morrow, & Lazo, 2012). Emergency alerts are also circulated to the public under the auspices of government entities to keep the public informed.

The National Weather Service is composed of 122 weather forecast offices, 13 WFO/River Forecast Centers (WFO/RFC), and 8 NWS National Centers. The NWS is solely responsible for issuing weather forecasts and warnings for the protection of life and property. The NWS has a four-tier approach to alert the public when there is a risk of hazardous weather or hydrologic events that may threaten life and/or property. This four-tier approach consists of outlooks, advisories, watches, and warnings. As the event draws closer, and the confidence in the location and timing of the event increases, the NWS will issue various bulletins that become increasingly more specific. An outlook is a forecast beyond 48 hours that discusses what weather patterns may produce hazardous weather or hydrologic event across any given area. It is intended to provide information to those who need considerable lead time to prepare for the event, such as the emergency managers. A watch is used when the risk has increased significantly, but its occurrence, location, and/or timing is still uncertain. It is intended to provide enough lead time so that those who need to set their plans in motion can do so. A warning is issued when the event is occurring, is imminent, or has a very high probability of occurring. Advisories highlight special weather conditions that are less serious than a warning, but may cause significant inconvenience, and could possibly lead to situations that may threaten life and/or property (National Weather Service, 2009).

The Storm Prediction Center (SPC) in Norman, Oklahoma, issues convective outlooks, forecasts that highlight areas of the contiguous United States with the potential for severe weather, up to eight days in advance. A tornado watch is issued by the SPC when conditions are favorable for the development of tornadoes in and close to the watch area. Prior to the issuance of the tornado watch, the SPC will contact the affected local WFO to discuss the weather conditions, and then issue a preliminary tornado watch that the affected WFO will adjust (by adding or eliminating counties) and then issue it to the public. During the tornado watch, the WFO will keep the public informed on what is happening in the watch area an also let the public know when the watch has expired or been cancelled. A watch is usually issued for duration of 4 to 8 hours. A tornado warning is issued by local WFOs when a tornado is indicated by radar or sighted by spotters (National Weather Service, 2009). As of October 1, 2007, tornado warnings are storm-based warnings (SBW), or threat-based polygon warnings; before, they were issued by county. Storm-based warnings provide more geographic specificity that is not restricted to geopolitical boundaries. The polygons are constructed based on the storm motion and the location of the main updraft. The warning will include where the tornado is located and what towns will be in its path. The polygon's area of coverage is disseminated in the warning by the latitude and longitude of its vertices. SBW can reduce the warning area by as much as 70 percent by not needlessly alarming people outside of the threat area (Nagele & Trainor, 2012). As with a watch, the WFO will update information on the tornado and they will also let the public know when the warning is no longer in effect. Warnings are usually issued for durations of 30-minutes. A tornado emergency is a very rare tornado warning issued when there is severe threat to human life and catastrophic damage from an imminent or ongoing tornado. It is issued when a reliable source confirms a tornado, or there is clear radar evidence of the existence of a damaging tornado, such as the observation of debris (National Weather Service, 2009).

The NWS forecasts and warnings, may reach the public directly through the internet via the NWS and local WFO websites and social media accounts and NOAA Weather Radio (NWR). Due to the broad duties that come along with forecasting, the NWS relies on their public and private sector partners to further disseminate and communicate products and information. They also support private sector efforts to develop complementary services that offer users access to the most complete hydrometeorological information possible. The NWS provides timely access to weather information through a number of systems, including NOAA Weather Wire Service (NWWS), Emergency Managers Weather Information Network (EMWIN), and

NWSChat. The NWWS is a satellite broadcast system that is the primary telecommunications network for near-real time NWS forecasts, warnings, and other products to the mass media, emergency management agencies, and private weather services. The EMWIN is similar to NWWS; however the information can be received from numerous channels, and it is intended to be used primarily by emergency managers and public safety official who need timely weather information to make critical decisions. NWSChat is an Instant Messaging program utilized by NWS forecasters to share critical warning decision expertise and other types of significant weather information essentials in real-time with the news media and emergency management officials who communicate the NWS's hazardous weather messages to the public (NWS, 2014).

State and local emergency managers are employed by government agencies, and their duties are to provide incident management and population protection. They provide incident management by monitoring the NWS impact projections and the watches and warnings in order to anticipate the hazard's future path. Emergency managers provide population protection by recommending, coordinating, and implementing preparedness and public safety activities for their area. Emergency managers operate local warning systems, such as local outdoor warning sirens or reverse 911 systems, which allow emergency managers to telephone landlines or mobile numbers of registered users within a certain area and play a pre-recorded message. They have to decide whether or not an area should evacuate, shelter in place, and have closures (government, etc.) based on the probabilities given by the NWS. If evacuations are to occur, local government agencies must provide traffic management; provide transportation support for those lacking physical mobility or relying on public transportation; and, provide for those who do not have a social support network or lack the funds for commercial hotels/motels by offering shelters. Emergency managers' duties also include advising people what they should be doing and what the consequences are if they fail to do that. They rely on the media to communicate information about the threat and recommended actions to the public (Brotzge & Donner, 2013; Demuth et al., 2012; Lindell, Prater, & Peacock, 2007).

The news media are the most common sources of information for the public. Local television and radio's function is incident management and population protection. The media coordinate with the NWS and emergency managers by monitoring the impact projections and emergency classifications. They also receive information from private sector weather vendors to transmit and post-process NWS data, produce value-added forecast information, and provide a platform for producing graphics for television. The media also synthesize the forecast, preparedness, and response information, and communicate it to their audience. Television and radio broadcasters serve as the primary conduit of weather warning information to the public. They use a number of methods to convey the necessary information, including the use of 'cut-ins," "crawlers," mobile phones apps, Facebook, and Twitter. The media aim to effectively communicate approaching weather threats because it helps them retain audience trust (and therefore market share), and in support of the altruistic goal of protecting their viewers and listeners (Brotzge & Donner, 2013; Coleman, Knupp, Spann, Elliott, & Peters, 2011; Demuth et al., 2012; Lindell et al., 2007).

Additionally, dissemination of geo-targeted warnings is implemented by using NOAA Weather Radio, Specific Area Message Encoding (SAME), Emergency Alert System (EAS) to media outlets in the affected areas, and Wireless Emergency Alerts (WEA) to mobile devices. SAME was the first geotargeted alerting standard, and it allows NWR to target at the Federal Information Processing Standards (FIPS) code level, a code that uniquely identifies counties and county equivalents. The NWR uses dedicated radio frequencies and special-purpose receivers to deliver weather and other hazard alerts to user specified regions that are largely aligned with counties or portions of counties. EAS is a warning system that alerts the public about imminent dangerous weather conditions to specific areas via participating broadcast stations, cable systems, and wireless cable systems; however, cable subscribers that live outside the specified region will also receive the alert. The increase in cell phone usage has led to the development of technologies to increase the reach of alerts and warnings. Wireless Emergency Alerts (WEA) use cellular broadcasting technology to alert people within the warning polygon of an impending hazard without needing to download an app or subscribe to a service. Only cellular towers mapped to a geo-defined region broadcast the message. The message and its metadata are formatted according to the Common Alert Protocol (CAP) standard. CAP supports the use of FIPS code to define the targeted area, and supports the use of polygon vertex coordinates to specify the boundaries of a targeted area (National Research Council, 2013).

Decision making process

The purpose of the tornado watch is to make people aware of the threat; and it is expected that they would review tornado safety rules, and be prepared to move to a safe place if threatening weather approaches. Once the tornado warning has been issued, people should seek shelter immediately. Shelter may be defined as either "in home" or "public." In-home sheltering means to seek refuge in interior rooms with no windows (closets or hallways), underground basements, or personal shelters. Public shelters are typically maintained by local governments, and they may include stand-alone shelters, schools, town halls, or other municipal structures that may become "shelters" during storms (Brotzge & Donner, 2013).

When the warning messages have been disseminated, it is up to the individual to respond and take protective actions. In doing so, there is a decision-making process that entails interpreting the warning message, risk perception, and deciding what types of protective actions to take as a result (Perry, 1979; Perry, Lindell, & Greene, 1982; Dash & Gladwin, 2007; Phillips & Morrow, 2007).

Warnings received from the NWS, emergency managers, and/or the media start the decision-making process. The U.S. disaster warning system assumes either a common shared language (English) and culture or the adaptation of the warning system to a multilingual or multicultural social structure (Fothergill, Maestas, & Darlington, 1999); however, this is not the case. Latinos, who represent the largest minority group in the U.S. with high rates of immigration from Central and South America, have barriers relating to language, literacy, and access, which act as a disadvantage for them to receive warnings (Peguero, 2006; Carter-Pokras, Zambrana, Mora, & Aaby, 2007). As a result, Latinos receive informal information from families and friends based on events they experienced in other countries (Fothergill et al., 1999), which may lead to an ineffective disaster preparedness plan and increase disaster vulnerability (Peguero, 2007).

In order for an adaptive response to occur the threat has to be perceived as real, and this is based on the warning content, prior experience, the number of warnings received, and the warning source. The more specific the warning message, the higher the level of warning belief and the greater the perceived personal risk. Prior disaster experience will motivate compliance, but it also serves as a framework for forming one's current opinion. If a person experienced a disaster, and nothing devastating happened, they may choose to think that later risks are not a real threat (Perry, 1979; Perry et al., 1982; Burnside, & Rivera, 2007; Phillips & Morrow, 2007). However, it has been found that the number of warnings an individual receives increases the chance of an adaptive response. Finally, the more credible the source from which one receives the warning the more likely they are to believe that the threat is real (Perry, 1979). Credibility is based on trust, which is obtained through sustained relationships between the receiver and sender (Phillips & Morrow, 2007). There is a distrust of government messages by racial minorities; so, most warning information is received by media and their social networks (Spence, Lachlan, & Griffin, 2007; Dash & Gladwin, 2007; Smith & McCarty, 2009). Additionally, racial and ethnic minorities are less likely to accept a warning as credible without confirming the message with a number of sources thus causing a delay in response (Fothergill et al., 1999; Spence et al., 2007).

Once the warning has been interpreted and the threat is perceived as real, one must decide what protective actions are viable. A lack of resources often stops or significantly diminishes options, such as personal storm shelters, for those who are socioeconomically marginalized. In such cases, people may look towards local social support networks for assistance (Elliot, Haney, & Sams-Abiodun, 2010) or public shelters. For those who live in mobile homes or other vulnerable structures without shelters, evacuating to a public shelter may be the only option. Traveling to a public shelter maybe dangerous given the rapid and violent onset of some tornadoes. Despite a lack of resources, other factors affect what protective actions can occur. Individuals with disabilities may be physically/mentally unable to take shelter. Some people find shelters to be uncomfortable. Pet owners may be less likely to seek shelter because they are unable to take their pets with them (Paul, Stimers, & Caldus, 2014).

Socially vulnerable populations

One of the goals of this study is to seek out potential physical vulnerabilities to natural hazards that would hinder people from receiving warning messages. Social vulnerability captures the variability within the population to prepare for, respond to, mitigate, and recover from a hazard event. Cutter et al. (2003) made a social vulnerability index that compares the social vulnerability to natural hazards of one place to another among United States counties using socioeconomic data collected from the 1990 U.S. Census. Eleven composite social vulnerability factors were found in their analysis: personal wealth; age; density of the built environment; single-sector economic dependence; housing stock and tenancy; race (African-American, or Black); Hispanic and

Native American ethnicity; occupation; and infrastructure dependence. Lack of wealth is a primary contributor to social vulnerabilities as fewer individual and community resources are available. Race and ethnicity contribute to social vulnerability through the lack of access to resources, cultural differences, and the social, economic, and political marginalization. African Americans, specifically African American female-headed households are among the most vulnerable, along with Hispanic and Native American ethnicities who are most vulnerable to natural hazards. The factor scores were added to the original county file as eleven additional variables and then placed in an additive model to produce the composite social vulnerability index score (SoVI) for each county. The most vulnerable counties appear in the southern half of the nation, stretching from south Florida to California – regions with greater ethnic and racial populations as well as rapid population growth. Counties labeled as the least vulnerable are clustered in New England, along the eastern slopes of the Appalachian Mountains from Virginia to North Carolina, and in the Great Lake states. These counties are relatively homogenous – suburban, wealthy, white, and highly educated – characteristics that lower the level of social vulnerability.

The formulation of the SoVI metric was changed to include more factors, such as family structure, language barriers, etc., and the addition of the U.S. Census Bureau's five-year American Community Service (ACS) estimates for the 2005-09 SoVI. There was also carryover of this more robust metric for the SoVI 2006-10 that combines data from both the 2010 U.S. Decennial Census and five year estimates from the 2006-10 ACS. The SoVI are mapped using quantiles with scores in the top 20% being the most vulnerable counties and scores in the bottom 20% are the least vulnerable counties (Figure 1). In the most recent SoVI, there are seven social vulnerability factors, race and class, wealth, elderly residents, Hispanic and Native American ethnicity, special needs individuals, and service industry employment (HVRI, 2013). There are slight variations between the original SoVI and the current one with the addition of more vulnerable areas in the west.

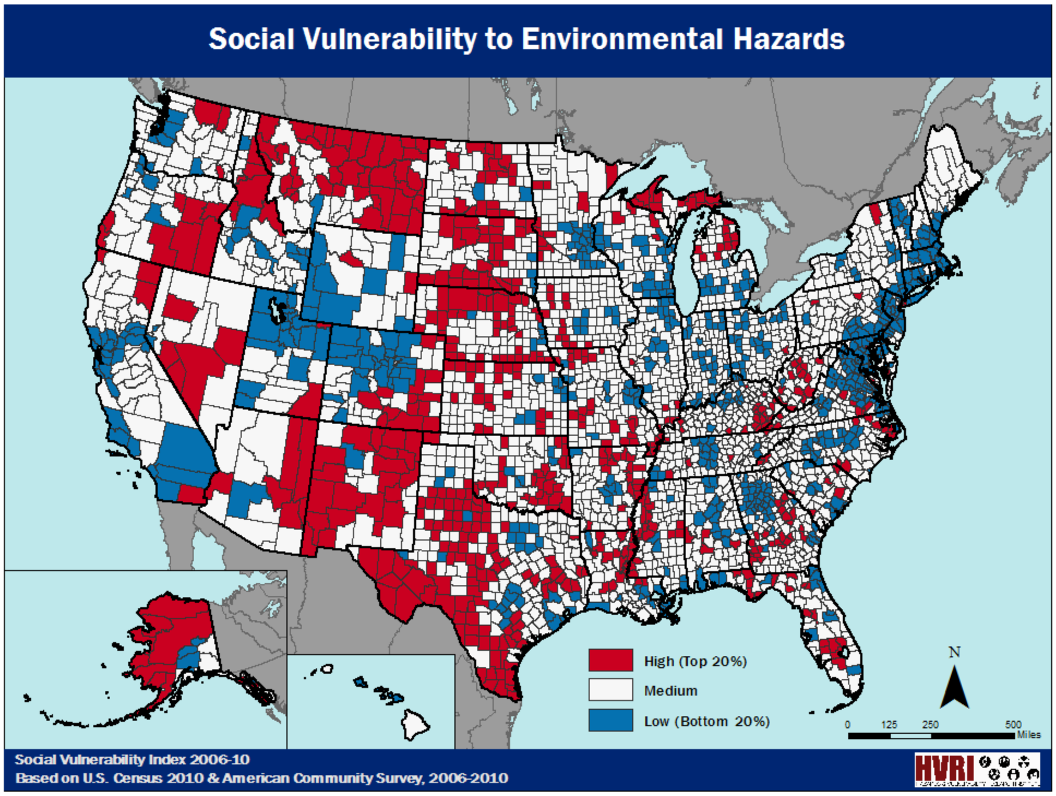


Figure 1: Social Vulnerability Index for the United States. The more vulnerable counties are represented in red and the least vulnerable counties are represented in blue. (HVRI, 2013)

The social vulnerability index has limiting factors. Social vulnerability is context specific. All populations may not be vulnerable to the same hazard, and what makes a group vulnerable in one location may not make a similar group vulnerable in another location. Certain tracts may have numerous vulnerability factors that allow it to have a higher score than tracts that has just one vulnerability factor; however, that one factor alone may be sufficient enough to make the tract vulnerable to certain hazards. Additionally, the index was based on census tract data, so it generalizes vulnerability factors for a larger area and does not look at communities or individuals (Stafford, 2015).

Warning technologies

Lazo, Morss, and Demuth (2009) surveyed a sample representative of the American population to determine how they received daily weather forecasts. The vast majority of the population obtains forecasts from some technological source: television, radio (AM/FM/weather), telephone/cell phone, internet and/or sirens/loudspeakers. More than 70% of the respondents obtained forecasts from local television at least once a day, with cable television and radio as the next most common sources. It was hard for the authors to determine what portion of the weather information is directly from the NWS, with the exception of NWS web pages and the NOAA Weather Radio (NWR), because different sources of weather forecasts sometimes relay unaltered NWS weather forecast information and sometimes provide value-added information. Eighty percent of the respondents rarely or never use NOAA Weather Radio (NWR); and those that did use it obtained weather forecasts a little more than twice a month on average. Emergency managers obtain information from NWR, particularly in potentially hazardous weather situations. At the time of the survey (late 2006), a few respondents were obtaining weather forecasts from cell phones or other portable devices. On average, weather forecasts are obtained from friends, family, coworkers, etc. about 8 times per month.

Weather hazard information is communicated by a number of technologies in a variety of ways. The technologies that offer the most promise to vulnerable populations are television, radio (AM/FM/weather), landline telephones and/or cell phones, the internet, and sirens/loudspeakers. Television offers the broadest dissemination to all members of the public. Radio covers almost as much range as television with messages being received in homes, cars, boats, and other vehicles. Telephone systems provide expansive coverage due to the large percentage of the vulnerable population that has access to landline telephones and cellphones. Internet usage is increasing. Even though there are relatively low rates of computer presence/use among vulnerable populations (Kiefer Mancini, Morrow, Gladwin, & Stewart, 2008), Blacks and Hispanics, for example, mostly use their cell phones to go online (Singer, 2013). Sirens/loudspeakers are simple and time proven means of warning of oncoming hazards and may offer the ability to reach those who lack access to the previously mentioned technologies. Sirens have not been found to be the most effective means of getting the message to the masses; however, they can warn on a more local basis (Coleman et al., 2011; Laidlaw, 2010).

Although these technologies are beneficial in warning the populace, there are several limitations that can hinder a person from getting the warning from these sources. Some can be as simple as a power outage which will disable television and radio use to lack of cable, internet or cell phone service.

Severe weather is one of the leading causes of power outages in the United States. Outages caused by thunderstorms, hurricanes, blizzards, or other severe weather accounts for 58 percent of outages since 2002 (Dept. of Energy, 2013). Each hazard affects the power system differently. Tornadoes and severe thunderstorms affect transmission and local distribution (T&D) lines directly through wind damage and indirectly through downed trees. Thunderstorms are more widespread and consequently more disruptive. High winds, torrential rains, and lightning can wreak havoc on distribution lines. Tornadoes are more likely to cause damage to T&D lines over a small geographic area (U.S. Congress, 1990). Without power, the public cannot receive messages from television, radio, or some outdoor sirens that are not battery operated, thus eliminating most people's preferred warning dissemination option. Not only can these storms affect T&D lines, they can also destroy cell towers and significantly impact the effectiveness of the cellular system. Cellular technology is highly dependent on infrastructure. For example, in northern Colorado in 2008, a tornado damaged towers and transmission lines that affected warning information getting to the public because both electrical power and cell phone signal were lost for most of the day (Schumacher, Lindsey, Schumacher, Braun, Miller & Demuth, 2010).

Outdoor warning sirens are the second most common source of weather warning information for the general public (Laidlaw, 2010). However, there are weaknesses in the outdoor siren system, including sound-limiting geographic features such as wind direction and varying topography; variability in the sound level of a siren for any person; many communities, specifically small towns and rural areas, do not have outdoor sirens;

and, there is an unrealistic societal dependence on them and a desensitization towards them. Additionally, there is no standardized policy for how or when communities activate sirens. Some communities sound sirens for severe thunderstorm warnings in addition to tornado warnings, while others may only do so when a tornado has been confirmed. Also, depending on the geographic location, a siren may warn of different national disasters, i.e. flash floods, strong winds, etc. (Coleman et al., 2011; Laidlaw, 2010).

Some local governments and emergency managers are getting rid of outdoor sirens in their jurisdictions due to the emergence of cell phone alerts. They are finding sirens obsolete, and siren systems are expensive to replace. To replace sirens, emergency managers are using other methods, including Reverse 911 systems and text messages; however, these systems are not without flaws. In order to receive Reverse 911 alerts, one has to subscribe to the service by giving their phone number and address; so if people do not subscribe to the service, that is one less information source. Additionally, the static address that a cell phone user registers can be in an area affected by the hazard, but the user could be elsewhere (Keifer et al., 2008). The various Reverse-911 systems rely on another organization's phone lines or infrastructure, which may not always be efficient or reliable. Additionally, bandwidth limitations or carrier restrictions can cause phone, text, or e-mail warning systems to not work as intended, possibly causing a warning to arrive late or not at all (Laidlaw, 2010). Some emergency managers in Colorado feel that Reverse 911 is not an appropriate mechanism for disseminating warnings for short-fuse hazards, because the threat may be over shortly after, or even before, the message is received. They are also reluctant to use the technology due to the rapidly evolving nature of tornadoes, and the potential for transmission delays (Schumacher et al., 2010).

The entire population does not have the same technology capabilities, due to affordability, availability, accessibility, which limits the sources of information. Some examples of lack of availability are limited or non-existent cable or satellite television access and haphazard cell phone or broadband coverage such as in mountainous or isolated regions of the country (Keifer et al., 2008). The National Telecommunications and Information Administration have found that urban areas have greater access to broadband at faster speeds than rural areas (Beede & Neville, 2013). Not only does the technology have to be available, but it also has to be affordable. The latest technologies, mobile devices, etc, may be beyond the financial reach of many people, especially the most vulnerable populations. The Department of Homeland Security's (DHS's) Commercial Mobile Alert Service (CMAS) program, specifically WEA, is intended to provide alerts and warnings to over 80% of the American population on mobile devices (cell phones and pagers) (National Research Council, 2011), meaning that 20% of the population will not receive the warning.

Research suggests that those who do not receive a warning are considerably less likely to take protective action (Perry, 1979; Perry et al., 1982; Dash & Gladwin, 2007; Phillips & Morrow, 2007). This is the case whether the cause of non-receipt is due to technical failure or situational circumstances, such as being en route during a warning or the storm occurring at night. This research will examine if non-receipt due to being out of the coverage range could be an additional factor that may affect why a warning may not be received.

Dissemination technology propagation

As previously stated, weather hazard information is communicated through a number of technologies, and there are several limitations that can hinder a person from getting a warning from these sources. One such hindrance is the nature in which television, radio, and cellular communications are broadcast via radio waves and how sound waves from outdoor warning sirens propagate. The coverage from these technologies is affected by a number of factors including, the atmosphere, topography, and buildings.

Radio Wave Propagation

Radio waves are a type of electromagnetic radiation that range from 30 Hz to 300GHz (Table 1). Television and FM radio broadcasting and mobile communications are transmitted via the VHF and UHF bands and move through the atmosphere from transmitter to receiver antenna. The waves can travel directly or after reflecting from the Earth's surface to the troposphere. Some limitations are that the waves are limited to the curvature of the Earth and that the waves have line of sight propagation. The former limitation can be overcome by the use of terrestrial repeaters or through the use of communication satellites (Richards, 2008). Radio waves that are propagated in free space will encounter interference from other sources that can result in losses or gains (Mazda, 1996).

Table 1: Nomenclature for radio waves in different bands of frequency

Band	Frequency Range	Wavelength Range
ELF	30 – 300 Hz	10 – 1 Mm
ULF	300 Hz – 3 kHz	1 Mm – 100 km
VLF	3 – 30 kHz	100 km – 10 km
LF	30 – 300 kHz	10 – 1 km
MF	300 kHz – 3 MHz	1 km – 100 m
HF	3 – 30 MHz	100 – 10 m
VHF	30 – 300 MHz	10 – 1 m
UHF	300 MHz – 3 GHz	1 m – 100 mm
SHF	3 – 30 GHz	100 – 10 mm
EHF	30 – 300 GHz	10 – 1 mm

Electromagnetic waves that are transmitted from the antenna may experience a number of interferences as it travels to the receiver. Reflection occurs when the signal reflects off an object such as the ground, water, or a building, and can either decrease or increase the signal at the reception point. Diffraction of the signal occurs when the signal “bends” around objects, such as hilltops or the edges of roofs, causing the radio waves to scatter at the edges and attenuate. Diffraction allows the reception of weakened radio signals when the line of sight conditions is not satisfied, whether in urban or rural environments. Scattering, similar to diffraction, occurs when the original signal encounters objects that are much smaller in size than the wavelength of the signal which causes the signal to disperse in many directions, such as when a signal impinges on foliage, trees, or rough surfaces. Transmission occurs when radio waves propagate through a medium without a change of frequency (Lane, n.d.; Nešković et al., 2000; Sizun, 2005). Building penetration loss is the power loss that occurs as the radio wave propagates from outside a building towards one or several places inside of a building

(Rosu, n.d.; Sizun, 2005). For frequencies lower than 4 GHz, rainfall causes attenuation of the transmitted signal through absorption (Richards, 2008).

Radio propagation models are mathematical formulas that characterize radio wave propagation as a function of frequency, distance, and other conditions with the goal of formalizing the way radio waves are propagated from one place to another. The models predict the path loss in order to determine the effective coverage area of a transmitter (Nešković et al., 2000). The Friis radiation equation gives the power received by one antenna under idealized conditions given another antenna some distance away transmitting a known amount of power. The equation is

$$P_r = \frac{G_r G_t P_t \lambda^2}{(4\pi d)^2} = G_r G_t P_t \left(\frac{\lambda}{4\pi d}\right)^2 \text{ W}$$

where

P_r = received power in watts

P_t = transmitted power in watts

G_t = gain of the transmitting antenna in the direction of the receiving antenna

G_r = gain of the receiving antenna in the direction of the transmitting antenna

λ = wavelength

d = distance between antennas

By converting the equation into logarithmic form, and converting the units to decibels, the last term in the equation becomes free space path loss (FSPL). Free space path loss is the dominant factor in the loss of signal energy as the transmitted signal moves away from the antenna. Verbally, the equation reads “Received power = transmitted power + antenna gains – losses” (Mazda, 1996; Richards, 2008; Shaw, 2013).

The Friis radiation equation displays two important propagation characteristics. For a given frequency the path loss increases with increased distance. A common expression is that the free space path loss increases with the square of the distance between the two antennas. And, for a given distance the path loss increases with increased frequency. Another expression is path loss increases with the square of the increase in frequency (Lane, n.d.).

There are a number of propagation models for path loss that take into account the different attenuation factors. Such models will allow for the effective coverage areas of television, radio, and mobile phone coverage to be displayed.

Sound Propagation

Outdoor warning sirens are used to quickly warn entire populations of natural and man-made emergencies by emitting sound(s). Sound is a form of mechanical energy that moves from a source through air as tiny oscillations above and below the surrounding air pressure. Sound propagation is the transmission of acoustic energy through space. Sound travels at a speed of about 1,000 feet per second through the air, but variations in this speed can be caused by wind, turbulence, humidity, and temperature (Webster, 2014; FEMA, 2006).

Sound spreads through the atmosphere in a similar manner as electromagnetic radiation. Sound waves can be attenuated by barriers due to reflection, absorption, refraction (change direction), and diffraction (bend). Sound waves propagate geometrically, so as sound radiates away from a source, its intensity decreases with distance because its power is distributed over an increasingly large area. Sound is absorbed by the atmosphere and the ground. Acoustic energy is absorbed by the atmosphere as a function of temperature, humidity, and pressure. Sound attenuation can occur when the sound propagation is close to the ground. The magnitude of the attenuation is based on the surface porosity or permeability to the ground: soft, porous surfaces, such as grass or bare soil, cause sound levels to attenuate substantially; whereas, hard or reflective surfaces, such as concrete, asphalt, water, or ice, provide significantly less attenuation. Sound waves can be refracted by temperature and velocity gradients. Sound waves tend to bend upward under calm conditions, causing sound velocity to decrease with height. Due to the refraction, an acoustic shadow forms where the sound is bending upwards, resulting in a reduction of sound. Acoustic shadows can form very close to the source in the upwind direction under extreme conditions. The opposite effect occurs in a temperature inversion, and the same sound source usually sounds louder. Temperature inversions (when the temperature increases with height, and the air is cooler at the surface) typically occur at night, so you can hear sounds louder at night than during the day. Wind influences sound propagation by diffracting sound waves. Wind velocity adds or subtracts from sound velocity depending on whether the sound is moving upwind or downwind. Sound levels decline much less rapidly, and may increase, in downwind areas compared to upwind and crosswind areas. An acoustic shadow can form in the upwind direction. Terrain and other obstructions affect sound propagating outside. The attenuation of sound propagating from hilltops or across valleys depends on geometric spreading and atmospheric absorption. Conversely, a steep hill, ridgeline, or building can act as a barrier causing sound waves to not be directly transmitted (FEMA, 2006; Reed. Boggs, & Mann, 2010; Webster, 2016).

CHAPTER THREE: STUDY AREA

Mississippi is the study area. The state is located in the southeastern United States. It is bordered on the west by the Mississippi River and beyond that by Louisiana and Arkansas, on the north by Tennessee, on the east by Alabama, and on the south by Louisiana and a narrow coast of the Gulf of Mexico. Mississippi is primarily composed of lowlands, the Mississippi Delta in the west and the Gulf Coastal plain in the east (Figure 2). Mississippi has many rivers, creeks, bayous, and other natural drainage networks (Sansing, 2015).

Mississippi has a humid subtropical climate. A number of meteorological hazards occur in the state, such as, extreme heat, flooding, hurricanes, severe thunderstorms, and tornadoes. The state is particularly prone to severe thunderstorms, and subsequently, tornadoes, due to its location between colliding air masses. Locally violent and destructive thunderstorms are a threat on an average of about 60 days each year. Spring produces the greatest number of tornadoes with significant secondary peaks during the late fall-early winter. The cool season peak is likely due to the southward advance of the jet stream over moist air masses produced by the relatively warm adjacent Gulf waters. The average number of tornadoes per year is 30, with an average of 8 deaths per year (Jackson WFO, 2015). Mississippi’s weather is forecast by four WFOs. Forecasts for the southernmost counties bordering Louisiana and the Gulf of Mexico are made by the New

Orleans, LA WFO; five counties in southeast Mississippi are made by the Mobile, AL WFO; for north Mississippi counties are made by the Memphis, TN WFO; and the rest, and majority, of the state is forecast by the Jackson, MS forecast office (Figure 3).

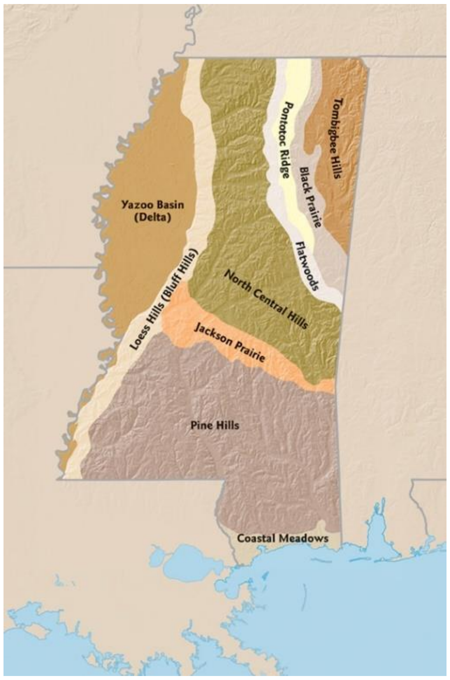


Figure 2: Mississippi Geography (Sansing 2015)

Figure 3: Mississippi Weather Forecast Office boundaries

Mississippi's population is approximately three million people (2,994,079; 2014 est.), with about three-fifths being White, the majority of the remainder is Black, with Hispanics, Asians, and Native Americans each constituting a tiny fraction of the population. Women make up 51.4% of the population. Roughly half of all Mississippians live in rural areas, and the two largest cities are Jackson, the capital, and Gulfport (Sansing, 2015). Mississippi has one of the worst economies in the nation. Mississippi's per capita personal income is second in the nation; and its adjusted median household income is lowest in the nation. The state has been primarily agricultural, but there has been an increase in industrialization. There has been a rapid expansion in the services sector since the late 20th century. Manufacturing and services – primarily government, trade, transportation, and utilities – are the largest sectors of the state's economy. Despite this transition, growth at the regional and national levels has been proportionately greater than Mississippi's growth (Pender, 2017).

CHAPTER FOUR: COVERAGE MAP AND INDEX

Coverage Maps

Given the many hazards that occur in Mississippi, it is important that there are multiple streams of communication that can allow the public to know of any impending hazards. Television, radio, cell phones/mobile devices, and sirens are used to disseminate warning information from pre-authorized national, state and/or local government. These technologies will be the focus of the study, because the EAS messages should be received by all who possess a television or radio, even if they do not have cable or satellite services; and by all who have a WEA-capable phone, without the phone owner having to subscribe to any phone applications (apps). Opportunely, these technologies also act in disseminating warning information from other sources, such as local broadcast meteorologists (television), friends and/or family, subscribed phone apps, mobile internet (cell phones), etc.

Data

The Mississippi Automated Resource Information System (MARIS) website was used to obtain Mississippi geographic data such as county boundaries, census data, urban areas, digital elevation models, major rivers, and highways. The standard projection for the MARIS data is Mississippi Transverse Mercator (MSTM), a customized Transverse Mercator projection designed to evenly distribute convergence and scale-factor. The MSTM is based on the North American Datum of 1983 (MARIS, 2011).

The data used to analyze the warning dissemination coverage was obtained from the NOAA NWS Jackson, MS WFO and the Federal Communications Commission (FCC) GIS site. The locations for all of the outdoor warning sirens in Mississippi were obtained from the Jackson WFO (J. Allen, personal communication, September 19, 2014). The FCC Licensing Database Extracts contains data covering the following communications features: AM Towers, Antenna Structure Registration (ASR), Cellular, Cellular Service Area Boundaries, FM Towers, Land Mobile - Commercial, Land Mobile - Private, Microwave Towers, Paging Stations, TV Towers, and TV Grade B Contours (FCC, 2012).

Methodology

Multiple methods were used to make coverage maps of the different technologies using ArcGIS. Terrain data is used in each approach to account for terrain features and to simulate terrain-based coverage gaps. An algorithm to model radio frequency (RF) propagation based off a study (Jewell, 2014) was used to obtain the coverage for television and FM radio. Both the robustness of the cellular data and the lack of pertinent data led to viewshed analysis to be used instead of RF propagation to obtain the coverage of cell towers. An algorithm was used to determine outdoor warning siren coverage by calculating the degradation of sound over distance.

Terrain is a major factor in the propagation of electromagnetic waves from television, FM radio, and cellular transmitters, and sound waves from outdoor warning sirens. Thus, the Viewshed tool in ESRI ArcGIS is used to determine the line of sight from the transmitter. The Viewshed tool takes a raster input of terrain data and a feature class containing an observer point, transmitter or siren, and returns a raster. Each cell in the output raster receives a value that indicates how many observer points can be seen from each location. If you have only one observer point, each cell that can see that observer point is given a value of 1. All cells that cannot see the observer point are given a value of 0 (ESRI ArcGIS Pro, 2017). The Viewshed tool can be customized to limit the region of the raster being inspected by specifying different attributes in the observer point dataset. In this study, the OFFSET is used to provide a vertical distance of the transmitter from the surface and the RADIUS is used to provide a scanning distance. The observation point elevation (SPOT) and the horizontal and vertical scanning angles (AZIMUTH and VERT) can also be specified (ESRI ArcGIS Pro, 2017).

Television and Radio

A simple model was created using the free space path loss equation derived from the Friis' radiation equation, $P_r = G_r G_t P_t \left(\frac{\lambda}{4\pi d}\right)^2$, to predict the path loss in order to determine the effective coverage area of the television and FM radio transmitters. Converting the Friis' equation to logarithmic terms will express the relationship in an algebraic expression in decibel units. Thus, the equation reads

$$\mathrm{P}_{r,dB} = G_{t,dB} + G_{r,dB} + P_{t,dB} + 20\log_{10}\left(\frac{4\pi D}{\lambda}\right)$$

Free space path loss, denoted as L_{fs}, is the dominant factor in loss of signal energy as the transmitted signal travels over a line of sight path in free space away from the antenna. The loss is dependent on the frequency of the signal being transmitted and the distance from the antenna. Free space path loss is represented as:

$$L_{fs} = \left(\frac{4\pi D}{\lambda}\right)^2$$

or

$$L_{fs} = \left(\frac{4\pi Df}{c}\right)^2$$

D = distance

λ = c/f = wavelength (m)

f = frequency (Hertz)

c = speed of light ($3\text{x}10^8$m/s)

The equation accounts for the signal to decrease in a manner that is inversely proportional to the square of the distance from the source of the radio signal in free space. However, in most terrestrial (non-free space or none line of sight) cases, the exponent value has to be changed to account for the curvature of the Earth and obstacles including hills, trees, buildings, etc., and those values typically range from 2 to 4. Generally, the path loss exponent determines the rate at which the signal decays. Many cellular operators base their calculations for terrestrial signal reduction around the inverse of the distance to the power 4 (Poole, n.d).

The path loss is measured at a reference distance, d_0, resulting in a reference path loss, L_0. The reference path loss is then added to the total path loss, L_p. The equations are as follows:

$$\mathrm{L}_{0,dB} = 20 * \log_{10}\left(\frac{4\pi D}{\lambda}\right)$$

and

$$\mathrm{L}_{p,dB} = (10 * \mathrm{n}) * \log_{10}\left(\frac{4\pi D}{\lambda}\right) + L_0$$

, where n is the path loss exponent.

The effective radiated power (ERP), the power transmitted from an antenna, is the product of the antenna gain and the power accepted by the antenna. The ERP encompasses the G_t, G_r, and P_t terms in the Friis' radiation equation, simplifying the equation to be read as:

$$\mathrm{P}_{r,dB} = \mathrm{ERP} - (10 * \mathrm{n}) \log_{10}\left(\frac{4\pi D}{\lambda}\right)$$

The signal coverage produced by a given ERP is affected by the antenna height, referred to as height above average terrain (HAAT). HAAT is used extensively in FM radio and television, because it may be more important than ERP in determining the range of broadcasts, as they are line of sight transmissions. A station with a low ERP may cover more area than a station with a large ERP, if its signal travels above obstructions on the ground (Vernier, n.d.).

The range of the TV and FM radio broadcast signal is determined by the ERP, HAAT, the FCC's propagation curves, and the station's class. The FM Query and TV Query on the FCC website provide the service contour for the FM or TV station that is protected from interference caused by other stations; even though there is no guarantee that the reception within the service contour will be interference free. Additionally, service can extend beyond the location of the mapped contour, but it is not protected from interference and the interference-free reception becomes less likely at greater distances (Federal Communications Commission, 2015).

A python algorithm is created to model RF propagation in an efficient manner within ArcGIS to make coverage maps for television and FM radio. Terrain data is included in the algorithm to account for terrain features and to simulate terrain-based coverage gaps. The HAAT and the range is input into the respective technology's attribute table to calculate the viewshed analysis, which provides the line of sight of the transmitters. The range is also used to make a buffer around the transmitter, which is used to calculate the Euclidean distance. The calculation used to determine the coverage in regards to terrain is

$$P_R = ERP - (10 * (4.2 - 2 * Viewshed)) * \log_{10}\left(\frac{d}{d_0}\right) - L_0.$$

The received power is calculated as a raster. The resulting coverage rasters for television and FM radio, which is in measurements of decibel-milliwatts, or dBm, are converted to milliwatts, respectively. The rasters are added together in order to make a composite of signal strengths across the state, and then converted back to dBm.

Cellular Coverage

Cellular coverage can be calculated using the RF propagation model; however, it is not used in this study because the frequency data for the cellular transmitters was not readily available. Cellular coverage is determined by using Cellular Geographic Service Areas (CGSA), which is a composite of the service areas of all of the transmitters (cells) in the system and viewshed analysis. The service area is the geographic area that the transmitter should cover. The service area boundary (SAB) is determined by a function of the cell's ERP and antenna center of radiation HAAT (U.S. Government Publishing Office, n.d.). Viewshed analysis is used to take into account terrain in the service areas. The CGSA is used as the radius, and viewshed analysis is run for each transmitter associated with that service area to determine coverage.

Siren Coverage

Outdoor siren coverage is calculated by using a simple sound propagation algorithm. A loss per distance doubled is typically experienced due to atmosphere, terrain, and building or other obstructions frequently present in the sound path. FEMA studies indicate typical ambient sound levels vary by locations as follows: industrial areas: 70+ dB, urban areas: 60 dB, and rural areas: 50 dB. Most of the sirens used in Mississippi are the Federal Signal 2001 outdoor warning siren, a rotating, uni-directional siren. At 100 feet, the sound level is 130dB. Using the 10dB per distance doubled loss factor, the effective range for a typical urban area is 6,400 feet with a 70 dB minimum sound level, and the effective range for a rural area is 11,880 feet with a 50 dB minimal sound level (Federal Signal, 2017).

To determine the siren coverage, the coverage distance is set to 11,880 feet to account for rural areas throughout the state. Euclidean distance is taken from the siren to the coverage boundary, and the change in decibels is calculated between distances using the formula:

$$dB_b = dB_a - 20 \times \log \frac{d_a}{d_b}$$

Results

To display the coverage of the dissemination technologies, composites are made to combine the energies and make single raster layer for each technology for the entire state. In order for the composites to be made, the units of television, FM radio, and outdoor sirens had to be converted. Television and FM radio dBm raster layers are converted into milliwatts, and siren decibel level raster data were converted into sound energy ($sound\ energy\ =\ 10^{\frac{dB\ level}{10}}$). For each technology, the converted raster layer is added together to form one single energy raster for all of the transmitter locations, then the respective raster layers are converted back to their original units. For cellular coverage, the individual viewshed layers are added to make one layer that enumerates the overlap of the transmitters' coverage.

The coverage maps display the combined power of the transmitters from each of the dissemination technologies. There are 31 digital television transmitters (Figure 3), 200 FM radio transmitters (Figure 4), 462 cellular transmitters (Figure 6), and 840 outdoor sirens (Figure 7). The radio frequency from television, FM radio, and cellular transmitters propagate a longer distance than sound waves from the outdoor warning sirens; which explains the number differentials of the transmitters.

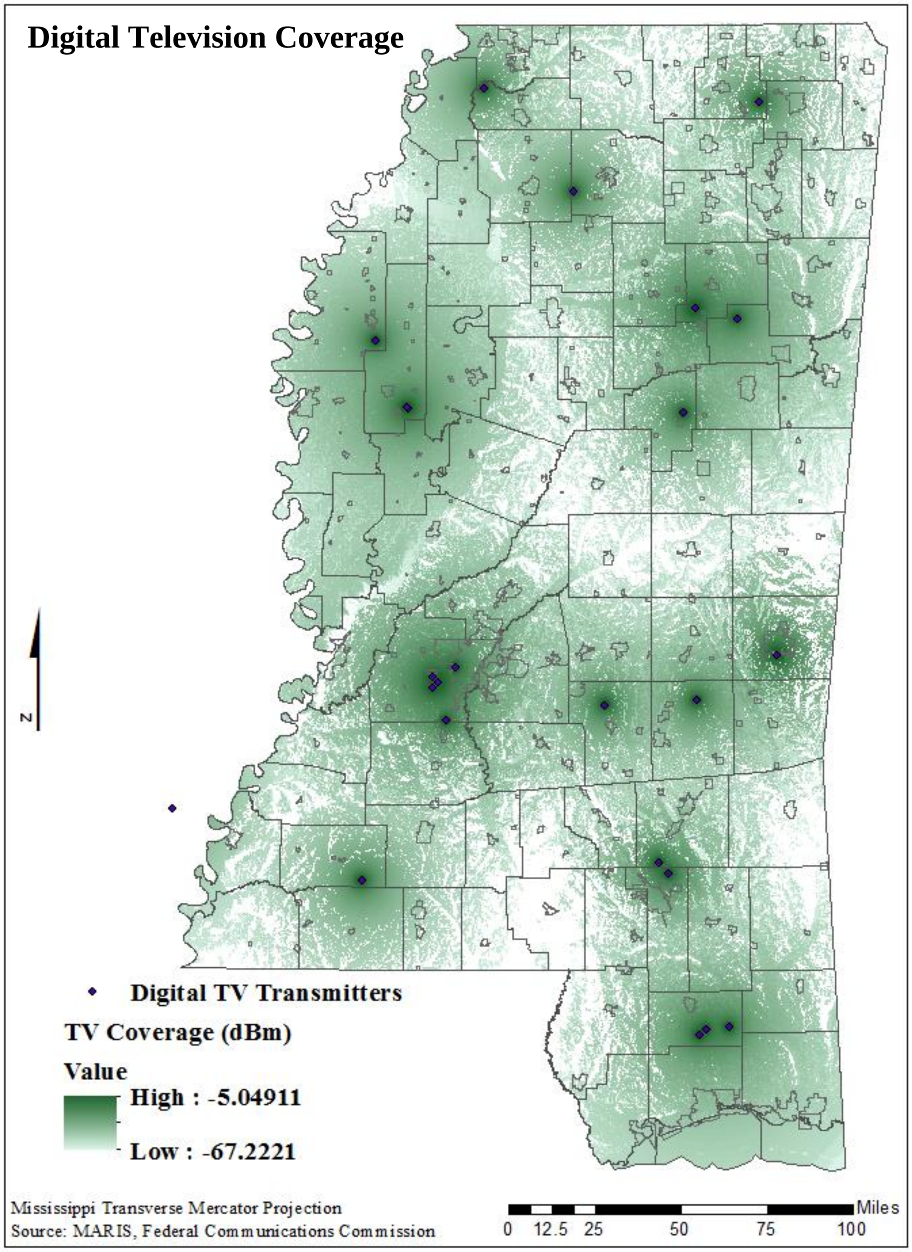


Figure 4: Coverage area of digital television transmitters.

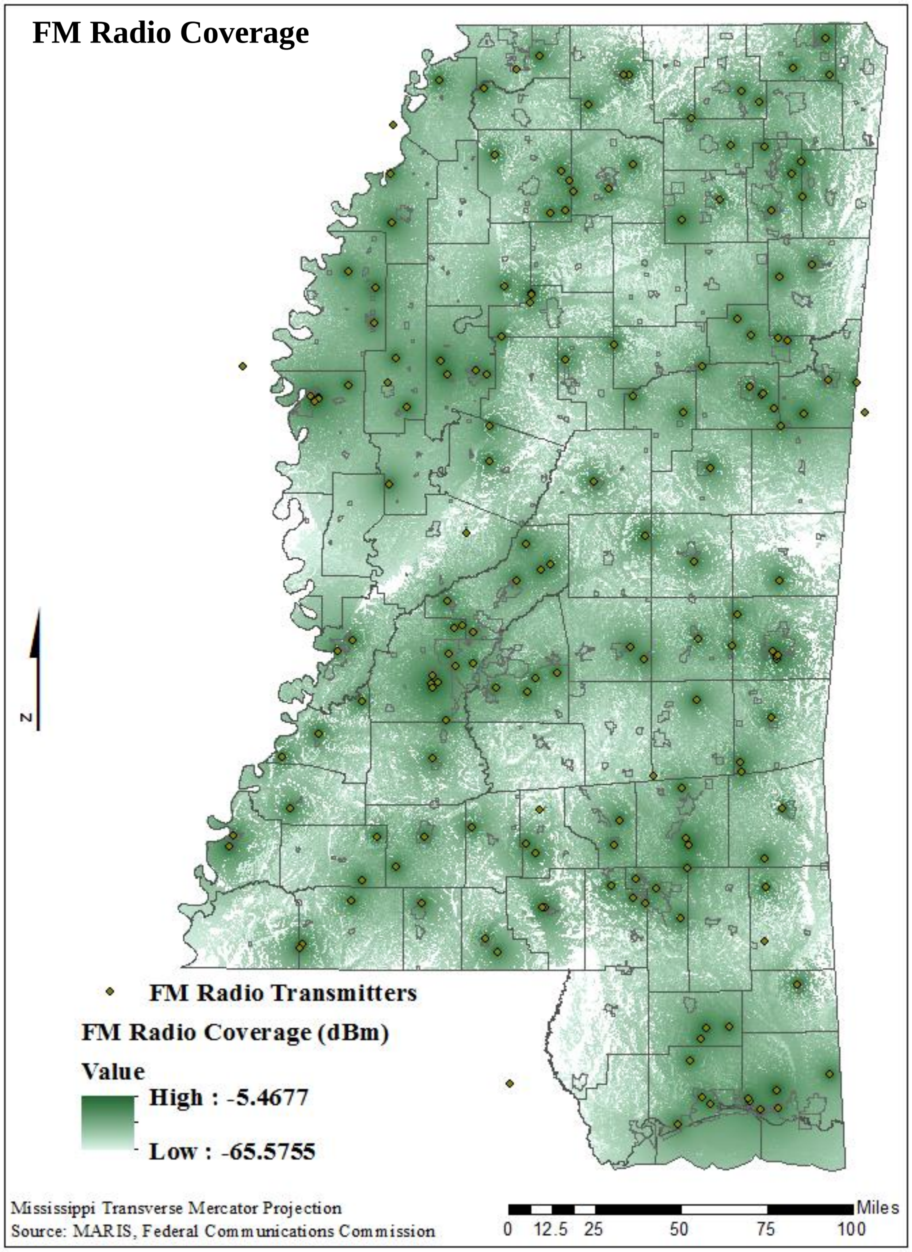


Figure 5: Coverage area of FM radio transmitters.

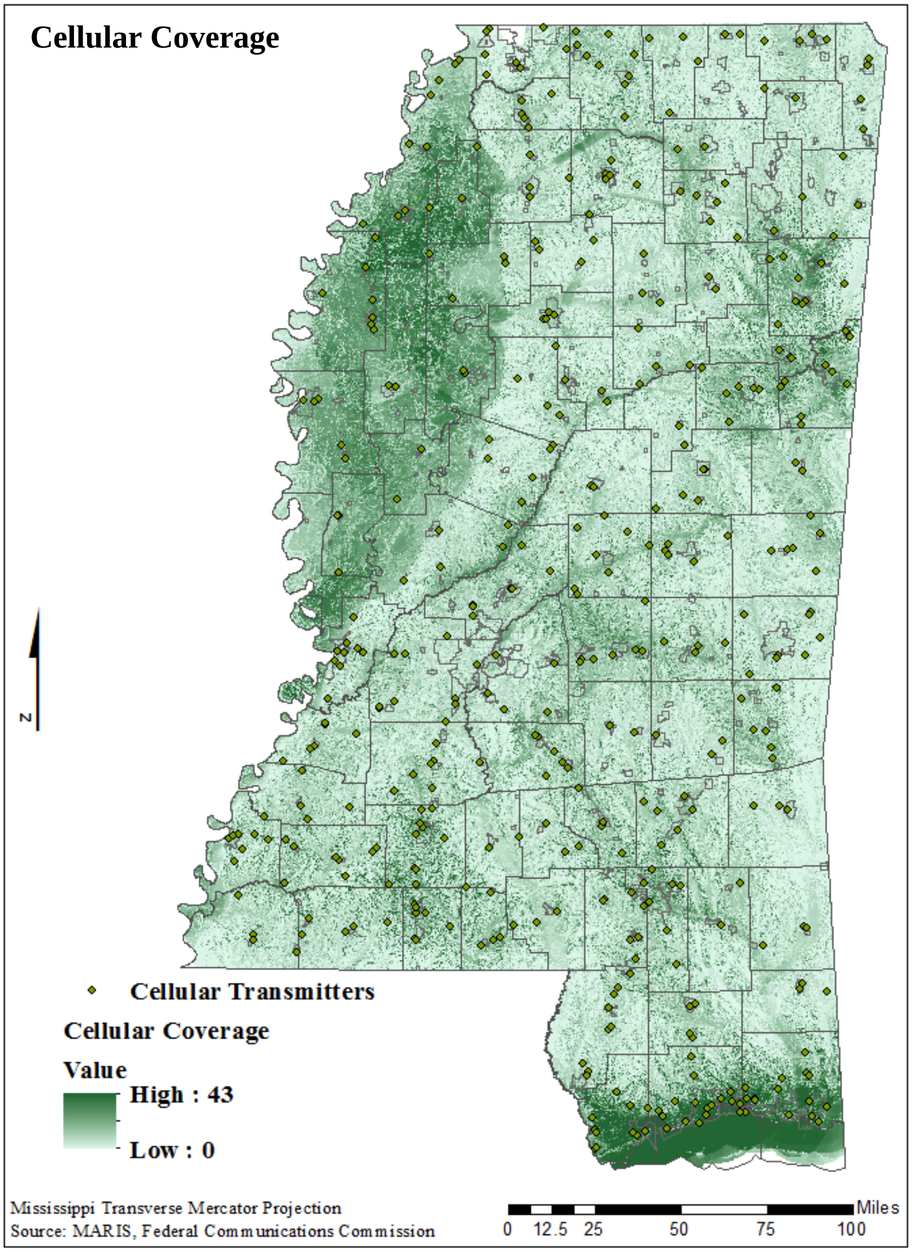


Figure 6: Coverage of cellular transmitters.

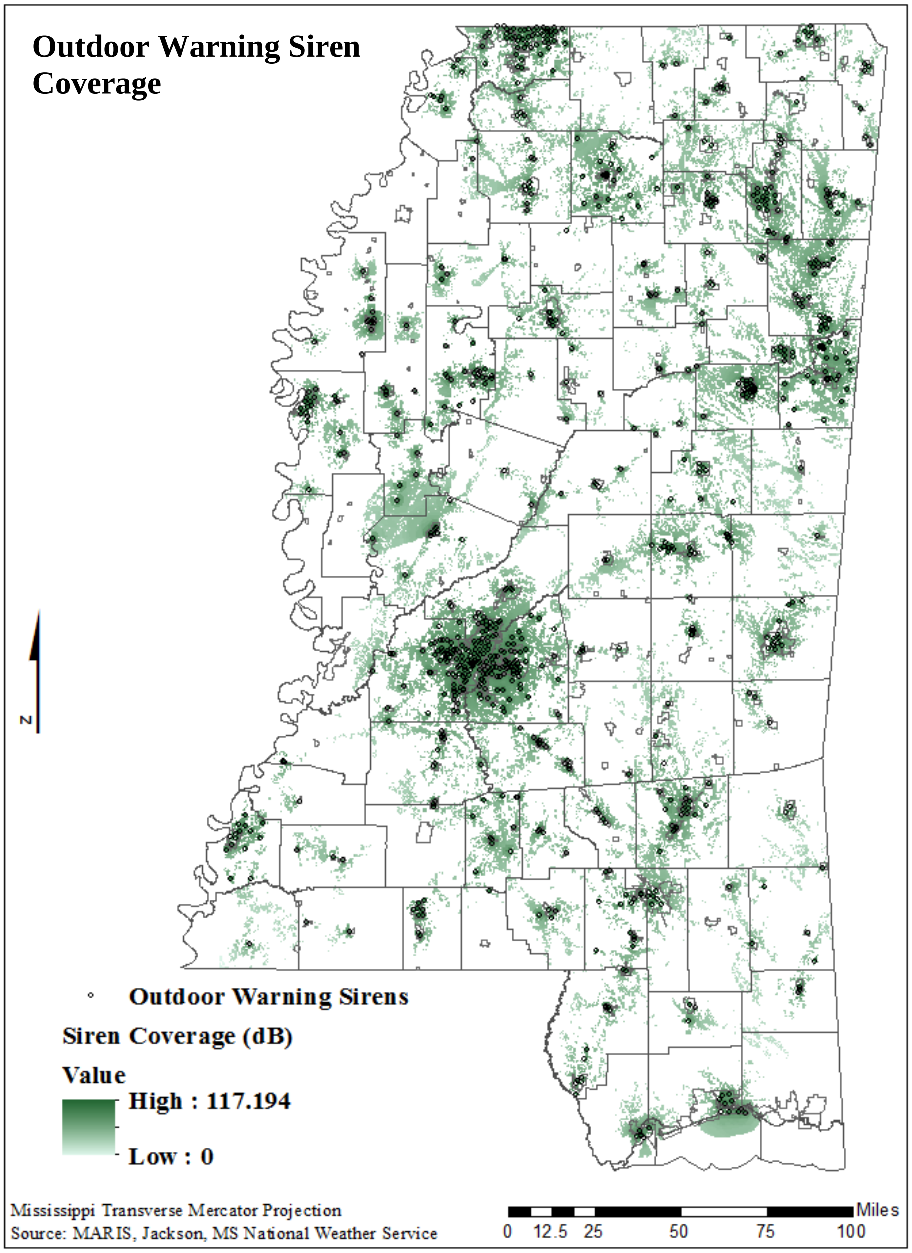


Figure 7: Coverage of outdoor warning sirens.

The values with the exception of cellular coverage indicate the radio and sound propagation over the state. Television receivers may process signals from approximately -5 dBm to about -65 dBm; and FM radio from -5 dBm to -65 dBm. The positive values immediately around the transmitters are too strong to be processed. The minimum signal depends on the receiver sensitivity and local conditions, so some television and radio receivers may be able to process signals lower than -65 dBm, but that value is the required minimum. The values on the coverage maps extend to -65 dBm due to the coverage range boundaries that were obtained from the FCC, the television and radio signals may be received beyond the boundaries given. Sound propagates at a shorter distance from the transmitter; however, multiple sirens can combine their sound energy together to create a higher decibel level. The decibel levels from the sirens range from 130 dB, which is harmful to the human ear, to 0 dB, the weakest sound detectable by the human ear. The range for the sirens was set at 11,880 feet, which is the effective range for 50 dB. Based on the local atmospheric conditions, i.e. the wind, the sound waves can exceed or not accomplish that coverage range.

The cellular transmitter data is not as robust as the data for digital television and FM radio, so the basis of how cellular transmitters work is used to measure coverage. Factors that can limit one’s ability to use their cell phone are topography, network architecture, and capacity – how many callers are communicating with the same cell site at a given time. Topography and network architecture are what is used to qualitatively determine the coverage map, so the quantifying factor will be capacity. Each cell can maintain a certain capacity, so when a large call volume is high, the capacity is limited.

When people are moving, a call may drop due to a weakening signal as they travel to an area with few or no cell sites. In quantifying the coverage, the assumption is the more overlapping coverage areas present, the better the signal because the areas will be able to maintain a higher capacity. There are areas with no coverage, which is represented as 0, up to raster cells with 43 overlapping cells. It appears that most of the state has no coverage, but the color bar does not representatively differentiate between 0 and the other low values. An area of exceptional coverage in comparison to the other technologies, can be seen in the northeastern portion of the state, which is the Mississippi River Delta region, where there is very flat land, thus no topographic obstructions.

Most of the transmitters are located within urban centers that ensure large numbers of the population are covered. The presence of outdoor warning sirens in a location varies due to jurisdiction. Of the 82 counties, 12 do not own or operate sirens in the county. The cellular transmitters in this study do not represent all of the transmitters that are present in the state, only those that are reported to the FCC. Most cellular transmitters are located on towers, water tanks, or other elevated structures at heights of 50 – 200 ft. If an antenna structure is taller than 200 feet above ground or may interfere with the flight path of a nearby airport, then it has to be reported to the FCC.

Index

Approach

After the coverage maps are made, a Dissemination Technology Coverage Index, or coverage index, was devised to represent the varied ranges of coverage throughout the state from strong coverage to no coverage. The coverage index is developed using the

ArcGIS Weighted Sum tool, a type of overlay analysis that allows different types of information to be weighted and combined for multiple factors to be visualized and evaluated at once. To use the tool, three steps need to be taken. First, criteria layers with different numbering systems/ranges need to be reclassified into a common preference scale. Next, layers are weighted based on importance. Finally, the criteria layers are multiplied by the weights and added together to produce the result.

The coverage data was classified into a common scale to make an index. The values for each technology were normalized from 0 to 1. The signal power for television and radio, sound intensity for outdoor warning sirens, and the overlapping cellular coverage areas were used to identify ranges of coverage. Television and radio receivers will process signals from -5 dBm (strong) to about -65 dBm (weak). The range of sound intensity used in the classification is 0 – 120 dB, siren sounds greater than 123 dB are damaging to the ear (Smith, 1998). The cellular classification was made based on the counts of the overlapping coverage areas. Table 2 illustrates the reclassification of the original values.

Table 2: The classification scale and the reclassified values for each dissemination technology.

	Television (dBm)	**FM Radio (dBm)**	**Outdoor Warning Siren (dB)**	**Cellular**
Classification				
No Coverage	0	0	0	0
Marginal	-65 - -60	-65 – -60	--	1 – 3
Fair	-60 - -50	-60 – -50	--	3 – 6
Good	-50 - -35	-50 – -35	50 - 60	7 – 11
Strong	-35 - -5	-35 – -5	> 60	12 – 43

Results

The following maps (Figure 8 - Figure 11) represent the classified maps. The maps show a better representation of the collective coverage of each technology. The coverage amounts for each dissemination technology vary(Table 3). Cellular phones have the largest coverage area, conversely only 49.2% of the coverage is fair or better. Even though the majority of the cellular coverage is weak, the technology can still be useful as a dissemination tool, because, text messages require less capacity than voice calls, so they can still send information when a voice call cannot be made. To reiterate, this is not a complete representation of the cellular coverage, so the coverage of the state is better than this. FM radio has the second greatest coverage followed by digital television. It should also be noted that the digital television coverage is for digital antennas only, satellite or cable television is not being considered in coverage. Outdoor warning sirens had the least coverage for the whole state, but they sufficiently cover the cities/towns where they are located.

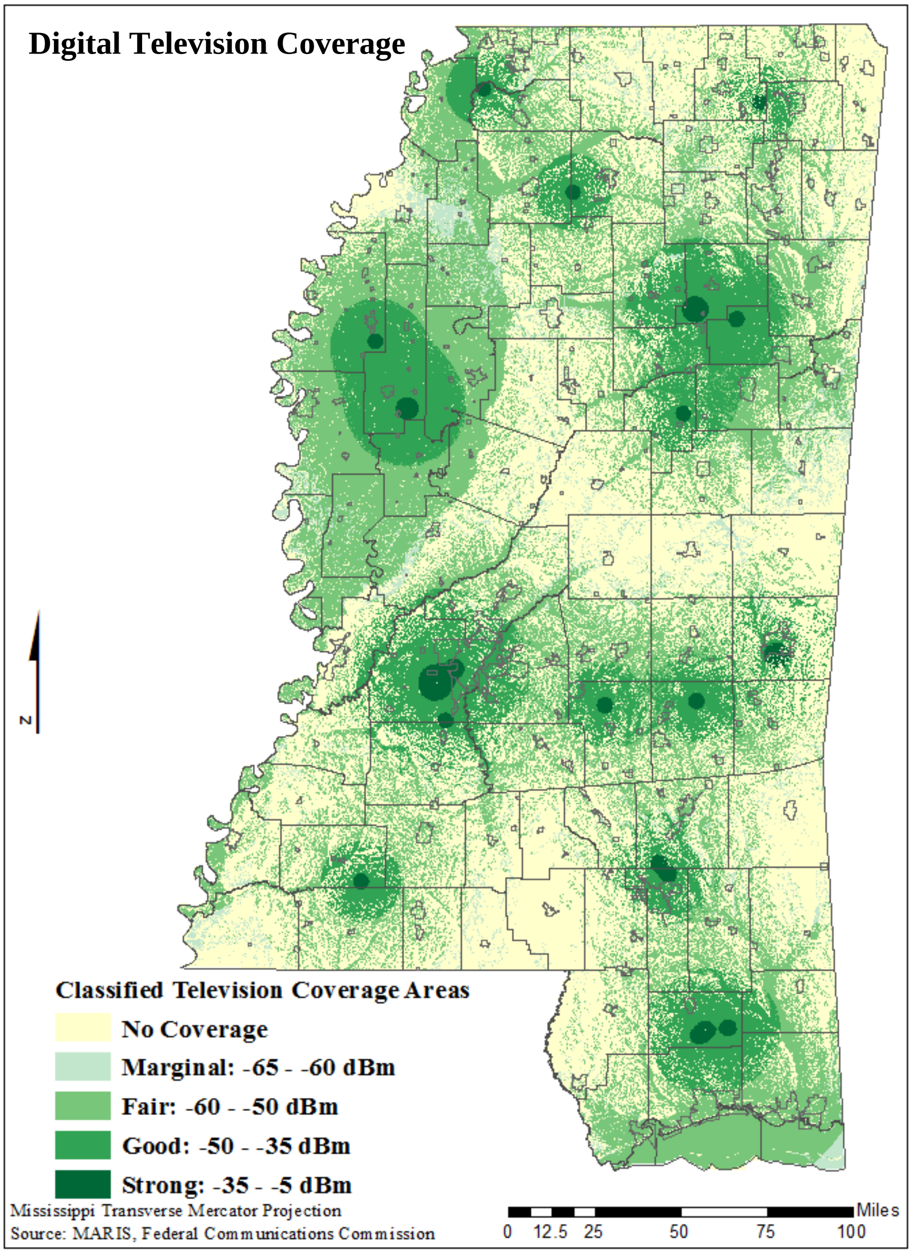
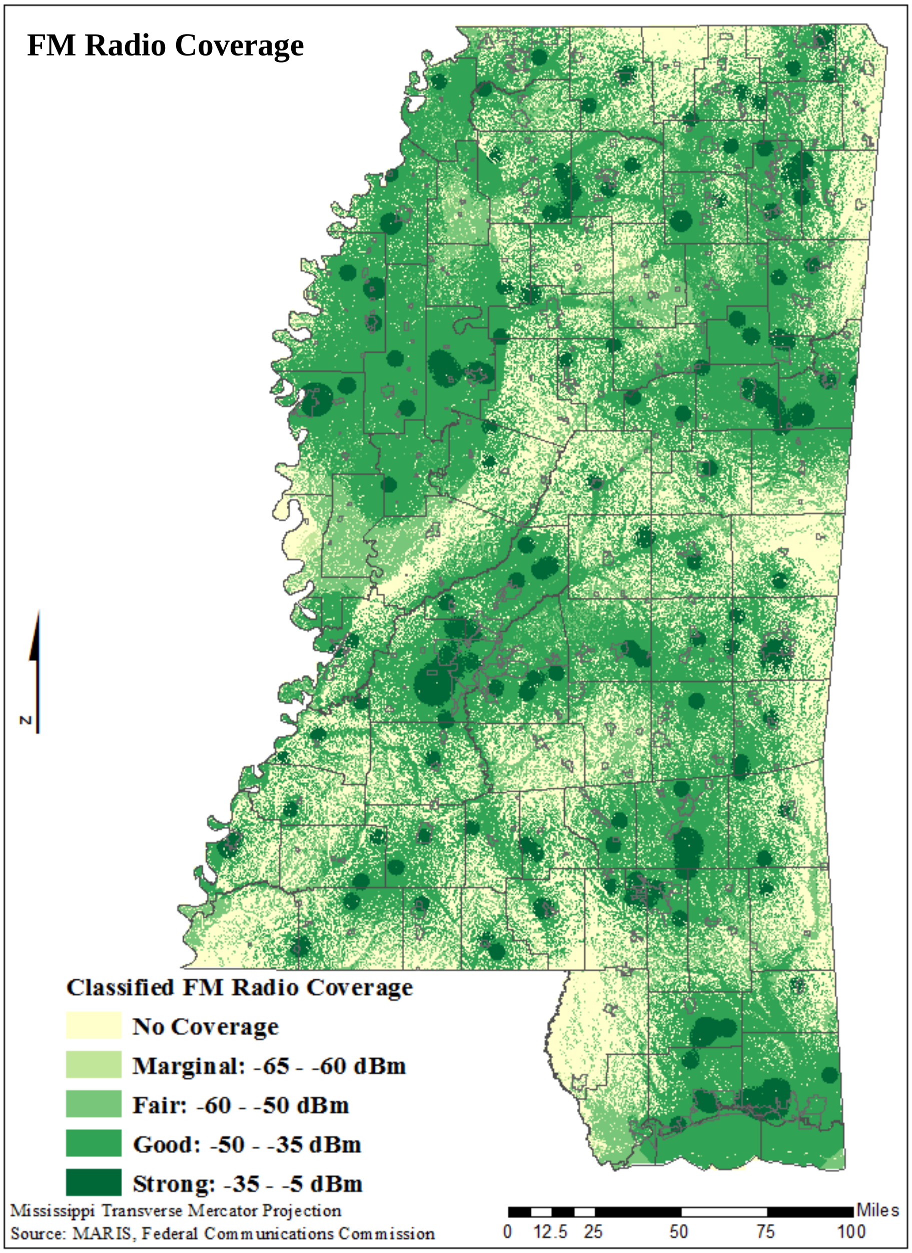


Figure 8: Classified coverage values for digital television transmitters.



Mississippi Transverse Mercator Projection
Source: MARIS, Federal Communications Commission

Figure 9: Classified coverage values for FM radio transmitters.

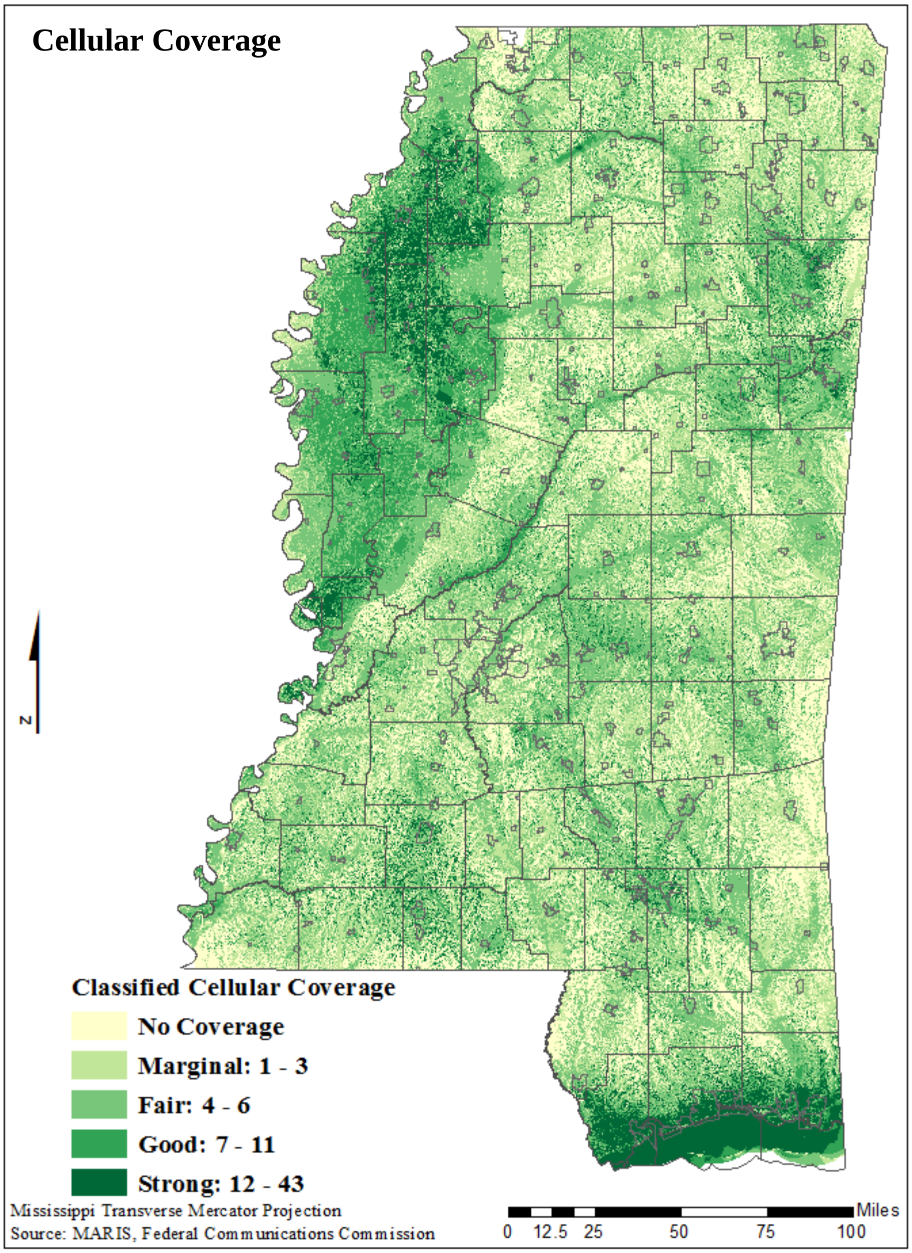


Figure 10: Classified coverage values for cellular transmitters.

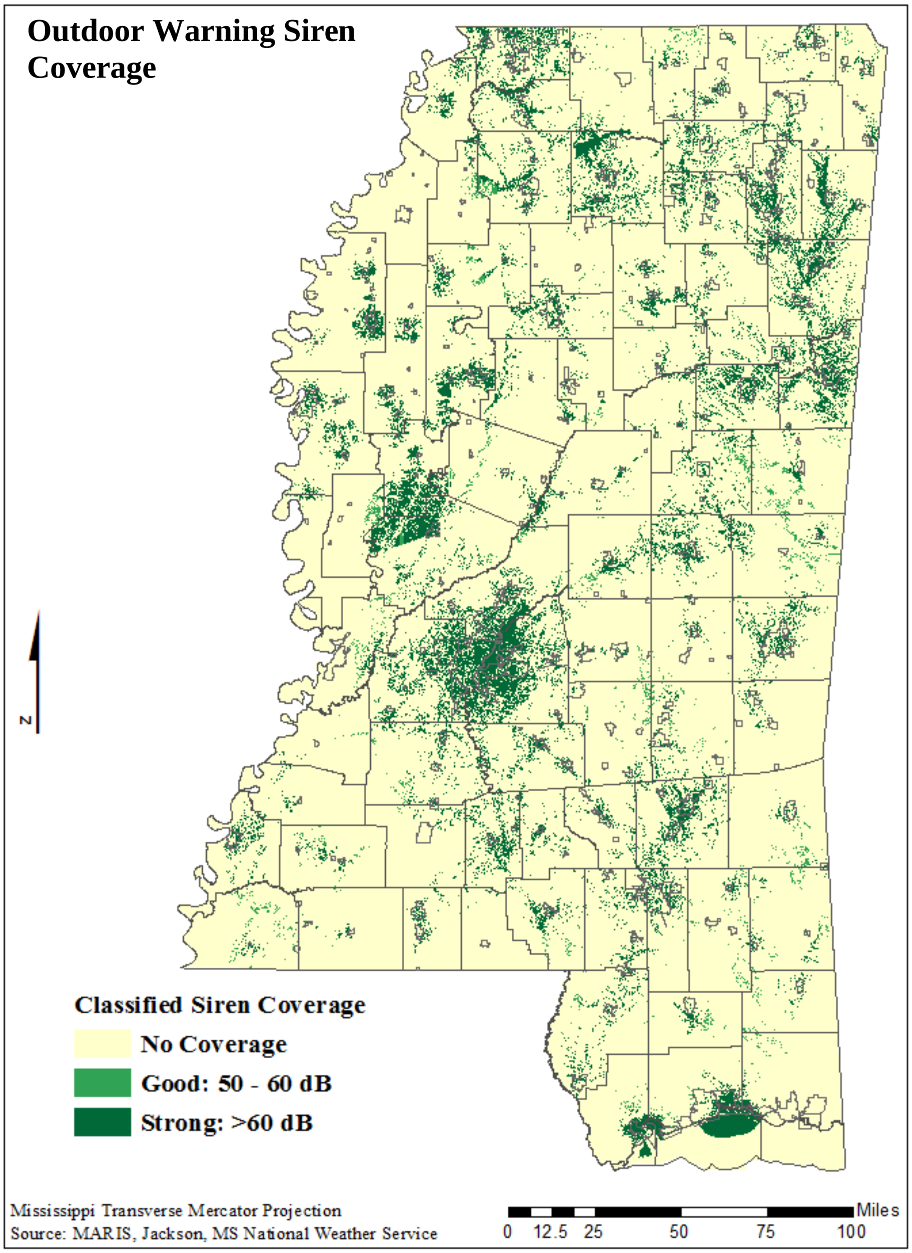


Figure 11: Classified coverage values for outdoor warning sirens.

Table 3: The coverage area in square miles of each dissemination technology by index value and the coverage percentage.

	Television	**Cellular**	**FM Radio**	**Outdoor Warning Siren**
0 – No Coverage	22,075.910	10,023.481	13,777.934	43,434.227
1 - Marginal	2,532.011	13,217.007	459.983	---
2 – Fair	15,708.157	16,545.283	7,757.182	---
3 – Good	7,627.408	5,327.677	23,279.742	398.376
4 – Strong	493.517	3,185.605	3,162.186	4609.568
% Covered	54.423%	79.247%	71.555%	10.34%
% Fair Coverage	49.196%	51.882%	70.605%	10.34%
Total	48,437.002	48,299.053	48,437.027	48,442.171

The weights for the Dissemination Technology Coverage Index were subjectively given because there have been few, if any, studies that have explicitly reviewed the dissemination sources that are commonly used to get warning information. As a result, each technology was weighted equally. The formula used when determining the weighted overlay is as follows:

$$\sum(.25 \times Television + .25 \times Cellular + .25 \times FM\ Radio + .25 \times Sirens)$$

The cell values of each input raster are multiplied by the raster's weight (or percent influence). The resulting cell values are added to produce the Dissemination Technology Vulnerability Index (Figure 12). The most covered areas are shown in dark green. Lighter green areas represent good coverage, orange represent fair coverage, dark red represents marginal, or weak, coverage, and white areas have no coverage.

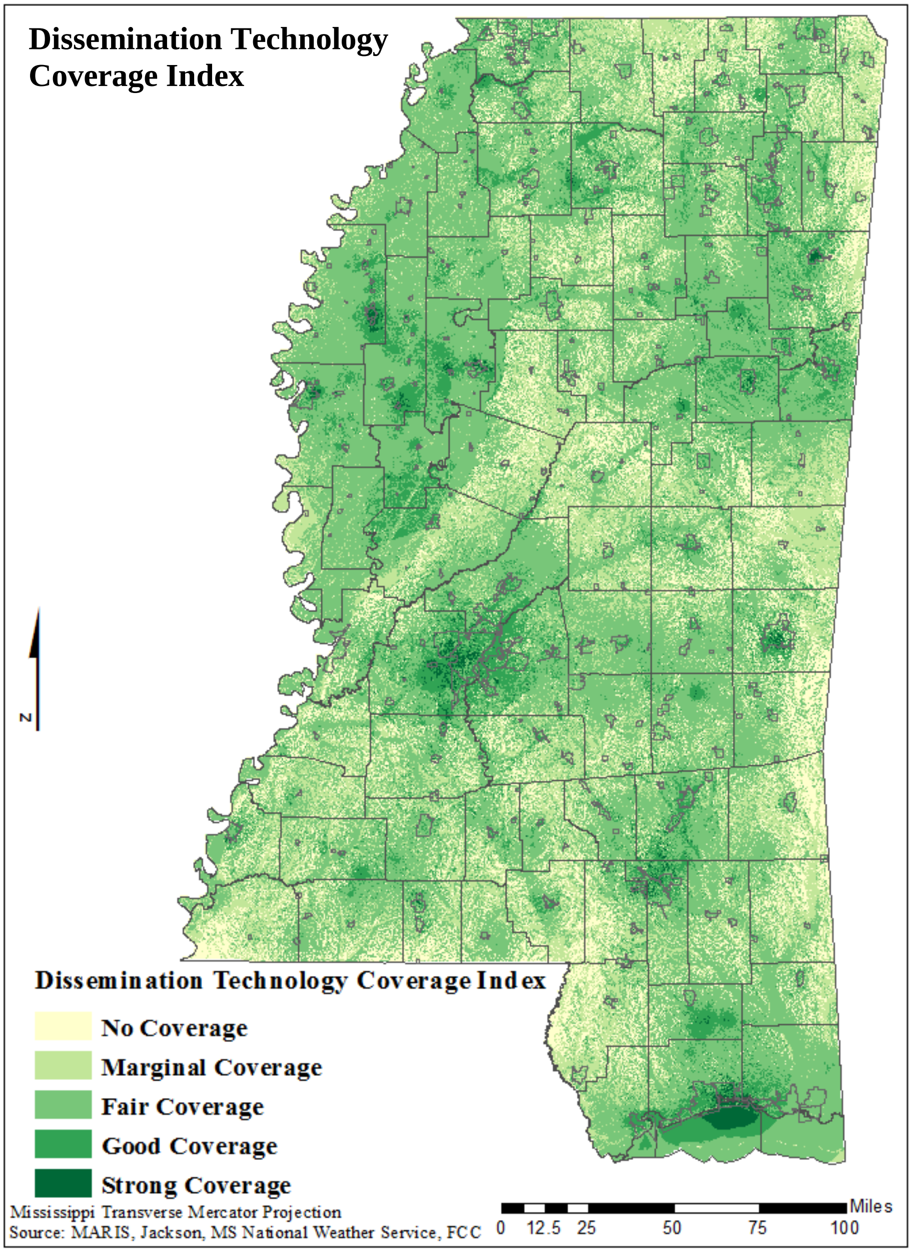


Figure 12: The Dissemination Technology Coverage Index

The area of Mississippi is 48,434 square miles. The Dissemination Technology Coverage Index covers 48,431 square miles, close to 100% of the state. The remaining 3 square miles may have been lost in the conversion from raster to vector data. The majority of the state has some range of coverage: 22.3%, or 10,813 square miles, have marginal/weak coverage, 55.1%, or 26,684.34 square miles have fair coverage, 9.4%, or 8,895 square miles, have good coverage, and .69%, or 334 square miles, have strong coverage. There is no coverage in 12.5%, or 6,060 square miles, of the state.

All of the cities in the state have some coverage with most of them having good coverage. There are some areas in the cities that have marginal/weak coverage, and some cities close to the border have marginal/weak coverage. The cities along the border could be a part of the respective neighboring state's market and those transmitters were not included in this dataset. There are small areas of the state that has strong coverage, and those areas are located in the very flat parts of the state. Some of the strong coverage areas are along the fringe areas of cities, and the largest percentage of strong coverage are over the waters along some coastal cities.

Summary

A Dissemination Technology Coverage Index is developed using four common hazard warning dissemination technologies: television, FM radio, cell phones, and outdoor warning sirens. The coverages of each technology were calculated taking into account terrain. The data is classified, aggregated, and weighted to develop the index. The Technology Dissemination Coverage Index categorizes the coverage as No

Coverage, Marginal (weak), Fair, Good, and Strong. Approximately 87% of the state should be able to obtain a hazard warning from at least one dissemination technology.

CHAPTER FIVE: SOCIAL VULNERABILITY

Mississippi’s demographic and socioeconomic characteristics may cause certain populations to be vulnerable to hazards. Lack of wealth, gender, age, race and ethnicity, occupation, housing stock and tenancy, and single-sector dependence are some factors that contribute to social vulnerability; that it is a higher potential for loss or other adverse effects (Cutter et al., 2003). This section seeks to identify where socially vulnerable people reside in the state, and if people who reside in areas that have weak to no coverage are more vulnerable than those who reside in areas with fair to strong coverage.

Data

The characteristics that influence social vulnerability are age, gender, race, and socioeconomic status. Twenty-three variables from the U.S. Census Bureau’s 2010 U.S. Decennial Census and the five-year American Community Service (ACS) estimates for 2006 – 2010 at the census tract scale are used to determine social vulnerability. The variables have been normalized as percentages, per capita values, or density functions. The 23 variables are classified in Table 4.

Table 4: The demographic and socio-economic variables that are used to examine social vulnerability.

Description
Median age
Percent of population under 18 years old
Percent of population over 65 years old
Median dollar value of owner occupied housing
Median rent (in dollars)
Percent of African American
Percent American Indian or Alaska Native
Percent Asian
Percent Hispanic
Percent of civilian labor force unemployed
Average number of people per household
Percent of households earning more than $75,000
Percent living in poverty
Percent renter-occupied housing units
Percent of housing units that are mobile homes
Percent of population 25 years or older with no high school diploma
Percent of population participating in the labor force
Percent females participating in civilian labor force
Percent urban population
Percent females
Percent female-headed households, no spouse present
Mean Social Security Income
Percent of population with no vehicle

Methodology

Principal component analysis (PCA) is used to explore the social vulnerability in the state. PCA is a statistical tool and type of factor analysis that is used to reduce the number of variables to a smaller number of uncorrelated variables, called principal components. The methodology is similar to Cutter et al.'s (2003) methodology with the exception of smaller census units and fewer independent variables.

The analysis is made using IBM SPSS Statistics. The 23 variables are standardized using z-score standardization to produce variables with a mean of 0 and standard deviation of 1. The PCA is performed using a varimax rotation to reduce the tendency for a variable to load highly on more than one factor and Kaiser criterion for component selection. The extraction of factors is determined by using Eigenvalues greater than 1 and examining the scree plot. The resulting factors are studied to determine the representation and influence on the social vulnerability by inspecting the factor loadings, or correlation coefficients, for each variable in each factor. Once the factors are extracted they are named based on the variables with factor loadings greater than .500 or less than -.500. Next, based off of the tendency of the factor to increase or decrease vulnerability, a directional adjustment of +, -, or || is applied to ensure that the signs of the defining variables are appropriate. The factor scores with the adjustments are calculated to generate the overall social vulnerability index score for the place. The index is mapped objectively using quantiles with scores in the top 20% being the most vulnerable census tracts and scores in the bottom 20% are the least vulnerable census tracts.

Principal Component Analysis is performed for the entire state to identify vulnerability factors in order for a social vulnerability index to be constructed. The social vulnerability index is used to examine if there is a relationship between vulnerable populations and coverage areas.

The chi-square test of independence is used to determine if there is a relationship between the coverage areas and the social vulnerability. The statistic determines whether there is an association between two nominal variables by comparing the observed frequencies in the cells to the frequencies you would expect if there was no association between the two variables. The further the observed frequencies are to the expected frequencies, the larger the test statistic, the greater the association and the more likely a statistically significant result. The chi-square test of independence will find evidence against the null hypothesis, that the two variables are independent, by calculating a significance value. If the p-value is sufficiently small (usually $p < .05$), it presumes that there is an association between the two variables (Laerd Statistics, 2016a).

The chi-square test of independence informs you whether you can reject the null hypothesis of independence; however, if the null hypothesis is rejected, it does not provide the strength/magnitude of any association or the details of which cells deviate from independence. Cramer’s V is used to measure the nominal association of chi-square tests. Cramer’s V equals 0 when there is no relationship between two variables, and has a maximum value of 1 when there is a very strong relationship. Cramer’s V can be used to compare the strength of association between crosstabulation tables. Residuals, the difference between the expected frequencies and observed frequencies, are analyzed to determine which cells in the table deviate from independence. The larger the residual, the further the observed frequency is from its expected frequency. The residuals are standardized to avoid having larger values cells with higher expected or observed frequencies. Positive standardized residuals indicate that there are more observed frequencies than expected frequencies given the null hypothesis of independence; and negative standardized residuals indicate there are less observed frequencies than expected frequencies given the null hypothesis of independence (Laerd Statistics, 2016a).

The chi-square test of independence and the subsequent analysis is performed on three subsets of the state: north, central, and south Mississippi in IBM SPSS Statistics. The data was prepared for the statistic by using ArcGIS tools. The Spatial Join tool was used to join the Dissemination Technology Coverage Index values with the values of the social vulnerability index for the state. In the statistics program, an integer value was given to represent the categories of the nominal values, and then the analysis was run.

Results

Principal Component Analysis

For the state of Mississippi, the PCA extracted five components that accounted for 68.013% of the variance. Table 5 displays the factors and variable loadings, with loadings less than .50 omitted. Most of the components extracted contained multiple vulnerability indicators instead of each component focusing on one vulnerability indicator as was observed in Cutter et al.'s (2003) research.

Table 5: The factors, variables and factor loadings of the PCA.

Sign adjustment	Factor	Name and Variance	Dominant Variables	Factor Loading
+	1	Socioeconomic Status, Family structure and Race 31.749%	Income > $75,000	-0.871
			Below Poverty	0.862
			Per Capita Income	-0.849
			Female-led households	0.836
			Black	0.797
			No vehicle	0.758
			Median Home Value	-0.754
			Social Security Income	-0.733
			No High School Diploma	0.717
			Unemployed	0.630
			Service Occupations	0.611
||	2	Urban & Housing	Urban	0.887

Sign adjustment	Factor	Name and Variance	Dominant Variables	Factor Loading
		16.712%	Mobile Home	-0.842
			Renter	0.618
			Agriculture	-0.547
-	3	Employment and Age 8.477%	Labor Force	0.745
			Female Civilian Labor Force	0.729
			Population Over 65	-0.703
			Median Age	-0.595
			Population Under 18	0.506
| |	4	Gender and Hispanic 6.888%	Female	0.783
			Hispanic	-0.604
+	5	American Indians, and Family size 4.187%	Average Family Size	0.674
			American Indian	0.653

The first factor component accounts for 31.749% and encompasses Socioeconomic Status, Family structure and Race. The socioeconomic variables include personal wealth measured by percentage of households earning more than $75,000 per year, per capita income, and median house value; and lack of wealth measured by percentage below poverty, over 25 with no high school diploma, unemployed, and service occupations. Lack of wealth increases vulnerability because the poor are less likely to have the resources to take protective actions and recover after a hazard. The female-led household, representing family structure, increases vulnerability because they are considered to be of lower socioeconomic status, and they are solely accountable for all caretaker responsibilities. Blacks have increased vulnerability because they are marginalized socially, economically, and politically, resulting in less access to resources (Cutter et al., 2003; Flanagan et al., 2011) The variables indicating wealth that decreases vulnerability load negative in this component, and all factors that increase vulnerability load positive. The cardinality on this factor is positive because the signs for the individual variables are consistent with their tendency on social vulnerability.

The second factor component represents urban areas and accounts for 16.712% of the variance. The component's variables include percentage of urban, mobile home residents, renters, and agriculture. The component was characterized as Urban due to the positive loading of percentage of urban areas and renters and negative loading of percentage of agriculture and mobile homes, meaning that latter variables would not coexist with the former. All of the variables increase vulnerability. People in urban areas are vulnerable due to the high-density area and the difficulty in getting out of harm's way. Renters may lack financial resources to own a home, be transient, and/or lack access about information to recover. Those who have an occupation in agriculture are vulnerable to weather conditions that may damage crops, and subsequently affect their income. Additionally, those in agriculture may live in rural areas which are vulnerable due to lower incomes and lack of resources. Mobile homes are vulnerable to severe weather, typically found outside of metropolitan areas, and are often clustered in communities (Cutter et al., 2003; Flanagan et al., 2011). Since all the variables have tendency to increase vulnerability, absolute value is applied to this factor to dissolve the negative signs and maintain the cardinality of the variables with non-negative loadings.

The third component represents Employment and Age and accounts for 8.477% of the variance. The variables for employment, labor force and female civilian labor force, should decrease vulnerability; however, the type of employment may increase vulnerability. Populations less than 18 and over 65 increase vulnerability because they require extra assistance. This factor is indicating that the elderly are not in the workforce. The cardinality on this factor component is negative to adjust the sign of the negative loadings on age which act to increase vulnerability.

The fourth component represents gender and ethnicity, specifically Hispanic, and accounts for 6.888% of the variance. Both of these variables increase vulnerability. Women often make lower wages than men and have family care responsibilities. Ethnic groups are also marginalized in the same manner as race. Additionally, they may also encounter language and literacy barriers. Women loads positively and Hispanics load negatively, so the directional adjustment was absolute value. The fifth component represents ethnicity, American Indians, and family size and accounts for 4.187% of the variance. The larger the family size the more vulnerable the family due to their needing more resources to take protective actions and recover. Both of these factors load positively, so the cardinality is positive.

Mapping Social Vulnerability

The social vulnerability index was visualized by mapping the social vulnerability factors on to census tracts using an additive model that was constructed using the directional adjustment of the PCA factors. The map displays the less vulnerable areas in shades of blue and the more vulnerable areas in shades of red. The map (Figure 13) represents the social vulnerability of the state. The social vulnerability ranges from -3.7 (low vulnerability) to 18.2 (high vulnerability) with a mean score of 1.54 and standard deviation of 2.1. There is a concentration of more vulnerable areas across central Mississippi into the Mississippi Delta in the west, and in southwest Mississippi along the Louisiana border. There are areas of less vulnerability along most of the northern counties bordering Tennessee, northeastern counties bordering Alabama, portions of the tri-county area surrounding the capital city of Jackson, and a few counties in the south.

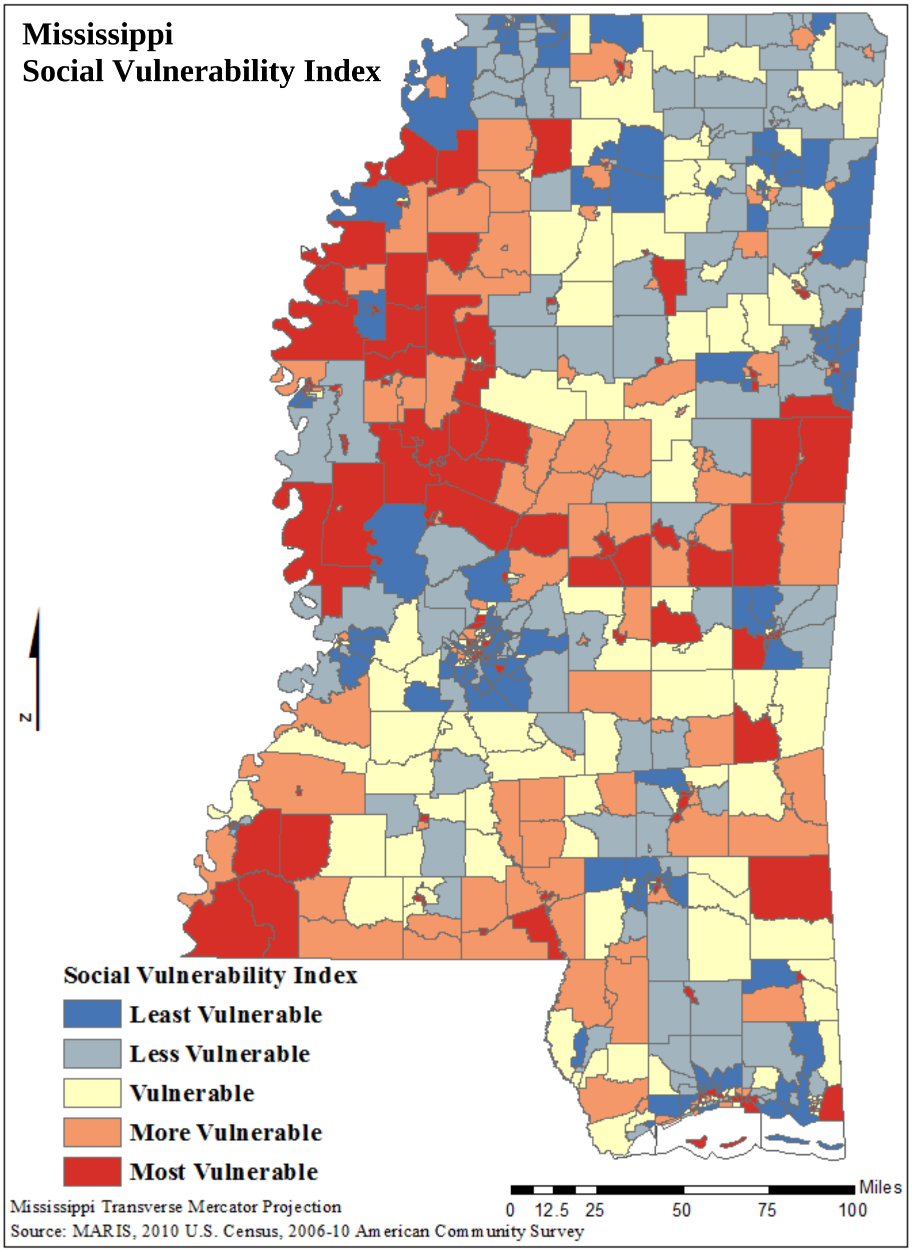


Figure 13: Social Vulnerability Index for the state of Mississippi. The most vulnerable areas are dark red and the least vulnerable are dark blue.

Coverage Relationship

A chi-square test of independence was conducted between the social vulnerability indices and the Dissemination Technology Coverage indices for portions of northern, central, and southern Mississippi. The null hypothesis is H_0: social vulnerability and coverage area are independent. The alternative hypothesis is H_A: there is an association between social vulnerability and coverage areas. All expected cell frequencies were greater than five, one of the assumptions that have to be met to run to properly interpret the analysis.

The chi-square test of independence for central Mississippi shows that there was a statistically significant association between social vulnerability and coverage areas. The Pearson Chi-Square statistic is 261,920.507; and, to determine whether the test was statistically significant, the chi-square distribution with 20 degrees of freedom found that the p-value for the test is < .0005, or $\chi^2(20) = 261{,}920.507$, $p < .0005$. The association was small, Cramer's V = .112. Table 6 displays the observed counts of occurrences, and the standardized residual values are beneath the observed values in parenthesis. The residuals show the largest differences are in the least and more vulnerable populations in coverage areas. The highest standardized residuals were found in the least vulnerability index. There were less observed frequencies in marginal and fair coverage areas, and more observed frequencies than expected in good and strong coverage. Conversely, there were less observed frequencies in the more and most vulnerable populations for good coverage, and a higher occurrence of more vulnerable populations in marginal coverage areas.

Table 6: Crosstabulation of Social Vulnerability Index and the Dissemination Technology Coverage Index for Central Mississippi. Standardized residuals are in parenthesis beneath the observed values.

	Dissemination Technology Coverages				
Social Vulnerability	No Coverage	Marginal Coverage	Fair Coverage	Good Coverage	Strong Coverage
Least Vulnerable	7,152 (-28.6)	48,878 (-176.7)	252,278 (-152.1)	142,191 (433.3)	9,864 (106.3)
Less Vulnerable	20,252 (-2.6)	180,122 (-53.6)	629,174 (3.5)	127,618 (56.8)	9,784 (24.8)
Vulnerable	28,850 (27.5)	238,869 (-12.1)	788,579 (47.7)	118,351 (-62.0)	7,706 (-22.8)
More Vulnerable	25,631 (29.8)	273,021 (173.6)	657,512 (-18.6)	64,781 (-189.9)	4,004 (-54.4)
Most Vulnerable	10,982 (-39.2)	156,155 (23.9)	501,199 (86.8)	50,023 (-135.1)	4,124 (-25)

The chi-square test of independence for northern Mississippi also showed that there was a statistically significant association between the two variables, $\chi^2(16) = 29,289.275$, $p < .0005$. Therefore, the null hypothesis was rejected, and the alternative hypothesis accepted; however, the association was very small, Cramer's V = 0.053. Table 7 displayed that the largest residual value showed that there were less observations than expected for the most vulnerable populations in marginal coverage areas.

Table 7: Crosstabulation of Social Vulnerability Index and the Dissemination Technology Coverage Index for North Mississippi. Standardized residuals are in parenthesis beneath the observed values.

	Dissemination Technology Coverages				
Social Vulnerability	No Coverage	Marginal Coverage	Fair Coverage	Good Coverage	Strong Coverage
Least Vulnerable	6,295 (-4.8)	45,260 (-45.2)	289,972 (0.3)	54,394 (48.9)	1,360 (8.6)
Less Vulnerable	14,853 (27.4)	113,350 (52.1)	524,336 (-36.6)	81,075 (-12.3)	1,134 (-23.6)
Vulnerable	14,330 (13.3)	129,155 (88.7)	548,882 (-63.0)	86,129 (-12.8)	2,080 (-2.0)
More Vulnerable	5,376 (-16.0)	300,379 (56.0)	300,379 (56.0)	40,922 (-21.0)	186 (-29.6)
Most Vulnerable	2,656 (-34.6)	22,138 (-102.9)	232,748 (79.5)	34,287 (4.2)	2,427 (60.1)

There was a statistically significant association between the two variables in southern Mississippi, $\chi^2(16) = 127{,}838.690$, $p < .0005$. Cramer’s V was .139, indicating a small association. Table 8 shows that the largest residuals were found in the marginal coverage area and good coverage area. In the marginal coverage area, there were fewer observed occurrences of the less and least vulnerable populations, and more observed occurrences for the other populations. Conversely, there were more occurrences in good coverage for the less and least vulnerable and fewer occurrences for the vulnerable population.

Table 8: Crosstabulation of Social Vulnerability Index and Dissemination Technology Coverage Index for Southern Mississippi. Standardized residuals are in parenthesis beneath the observed values.

	Dissemination Technology Coverages				
Social Vulnerability	No Coverage	Marginal Coverage	Fair Coverage	Good Coverage	Strong Coverage
Least Vulnerable	2,606 (-31.6)	14,818 (-148.4)	153,374 (44.0)	36,420 (108.8)	5,910 (85.3)
Less Vulnerable	8,735 (-26.9)	49,553 (-199.6)	371,071 (80.4)	79,854 (145.8)	5,073 (-3.8)
Vulnerable	12,307 (33.9)	111,389 (130.8)	293,126 (-25.5)	23,481 (-129.2)	1,983 (-44.8)
More Vulnerable	8,712 (10.6)	92,543 (116.1)	236,415 (-50.2)	26,985 (-68.3)	2,469 (-24.4)
Most Vulnerable	3,179 (14.3)	39,627 (140.8)	66,788 (-77.6)	4,858 (-71.8)	1,604 (12.3)

Summary

The chapter identifies areas of social vulnerability in the state to discover if there is a correlation between socially vulnerable populations and no to limited dissemination technology coverage areas. A social vulnerability analysis was developed using 23 demographic and socioeconomic factors to develop a social vulnerability index. The most prominent social vulnerability factor for the state describes socioeconomic status (poverty), family structure (female-led households), and race (Black). The most vulnerable areas of the state are central Mississippi into the Mississippi Delta in the west and in southwest Mississippi along the Louisiana border.

The knowledge of the locations of socially vulnerable populations allowed for analysis to be done to observe if there is a relationship between populations and coverage areas. This study found that there is a small association between socially vulnerable populations and coverage areas in the different sample areas. In the central and southern parts of the state, it was observed that the less and least vulnerable populations had fewer observations than expected in marginal coverage areas and more in good coverage areas. In contrast, the more and most vulnerable populations had more observations than expected in marginal coverage areas and less in areas of good coverage. These findings support the hypothesis that socially vulnerable populations are more likely to reside in areas of limited coverage than other populations.

CHAPTER SIX: WARNED TORNADO CASUALTIES

Tornado warnings are issued when a tornado is indicated by radar or sighted by spotters in Mississippi. Once the tornado warning has been issued, it is intended that people seek shelter immediately to avoid harm. The number of warning sources an individual has access, and thus hazard information that they receive, increases the chance of an adaptive response, so the reduction of sources may affect their reaction to the warning. Tornado casualty data was observed to determine if there is a relationship between casualties and lack of dissemination coverage.

Data

The tornado data for Mississippi was obtained from the NOAA SPC severe report database for the time period 1950 through 2015 (Storm Prediction Center, 2016). The tornado database contains information by state for the time of observation (year, month, day, time), state, county, F-scale, injuries, fatalities, estimated property loss, estimated crop loss, beginning and end latitude and longitude, track length (in miles) and width (in yards), and tornado segment information. Not all data are available for all tornadoes recorded in the database. Archived NWS tornado warning polygons and NWS Storm Based Warning Verifications were obtained from the Iowa Environmental Mesonet (IEM) (IEM, 2016). The tornado warning polygon database includes the issuing WFO, the time that the product was issued and expired, the type of warning, and the area of the polygon in square kilometers.

Methodology

Tornadoes are observed that occurred from 2013 – 2015. The timeframe begins in 2013, because all tornado dissemination technologies were active at that time. (Wireless Emergency Alerts were not issued until mid-2012.) The tornadoes that resulted in injuries and/or deaths were extracted from the tornado data, and, if warned, the warning polygons were extracted for the tornado tracks.

The odds ratio (2 x 2) statistic is utilized to examine the relationship. The odds ratio is used to measure associations between two dichotomous variables by using a 2 x 2 contingency table. It is common to define the variables as independent and dependent, even though it is not required. The odds ratio represents the odds that an outcome will occur given a particular exposure, compared to the odds of the outcome occurring in the absence of that exposure, defined as

$$Odds\,ratio = \frac{odds\ of\ X\ in\ exposed\ group}{odds\ of\ X\ in\ unexposed\ group}.$$

If the odds ratio is greater than 1, the odds of X in exposed group is greater in the exposed group, whereas if the odds ratio is less than 1, the odds are less in the exposed group. An odds ratio of 1 means that the odds are the same (Laerd Statistics, 2016b).

In this study, the technology coverage index is defined as the independent variable and casualties (injuries and/or death) are the dependent variables. To be dichotomous, the technology coverage index was divided into low and high coverage with low coverage encompassing no to marginal coverage and high coverage encompassing fair to strong coverage. The casualties were classified as yes for occurring along the tornado track and no for occurring in a portion of the tornado warning polygon. The entire area of the polygon was not used in the analysis, because the no data would overwhelm the yes data given the area of the warning polygon and the area of the tornado.

ArcGIS tools are used to prepare the data for analysis. The Buffer tool was used to place a buffer around the tornado tracks to depict the width of the tornadoes. Another buffer measuring .75 mile was placed around the tornado track width to represent a portion of the warned area that was in close proximity to the tornado. The Clip tool was used on both buffers to extract coverage areas into the desired size to get coverage values. The Join tool was used to join the casualty data to the tornado track buffer. The tornado track buffer was joined to the .75-mile buffer, which represents no casualties, using the Spatial Join tool in order to combine all of the values together: the coverage values and the casualty values. In SPSS Statistics, an integer value was given to represent the categories of the nominal values and the statistic was run.

Results

There were 31 tornadoes in 2013, 6 of which resulted in 2 deaths and 88 injuries; in 2014, 11 out of 40 tornadoes resulted in 16 deaths and 209 injuries; in 2015, 2 out of

45 tornadoes resulted in 11 deaths and 64 injuries; and, in 2016, 2 out of 46 tornadoes resulted in 1 death and 2 injuries. All of the tornadoes were warned except for 1 tornado in 2014 (Figure 14).

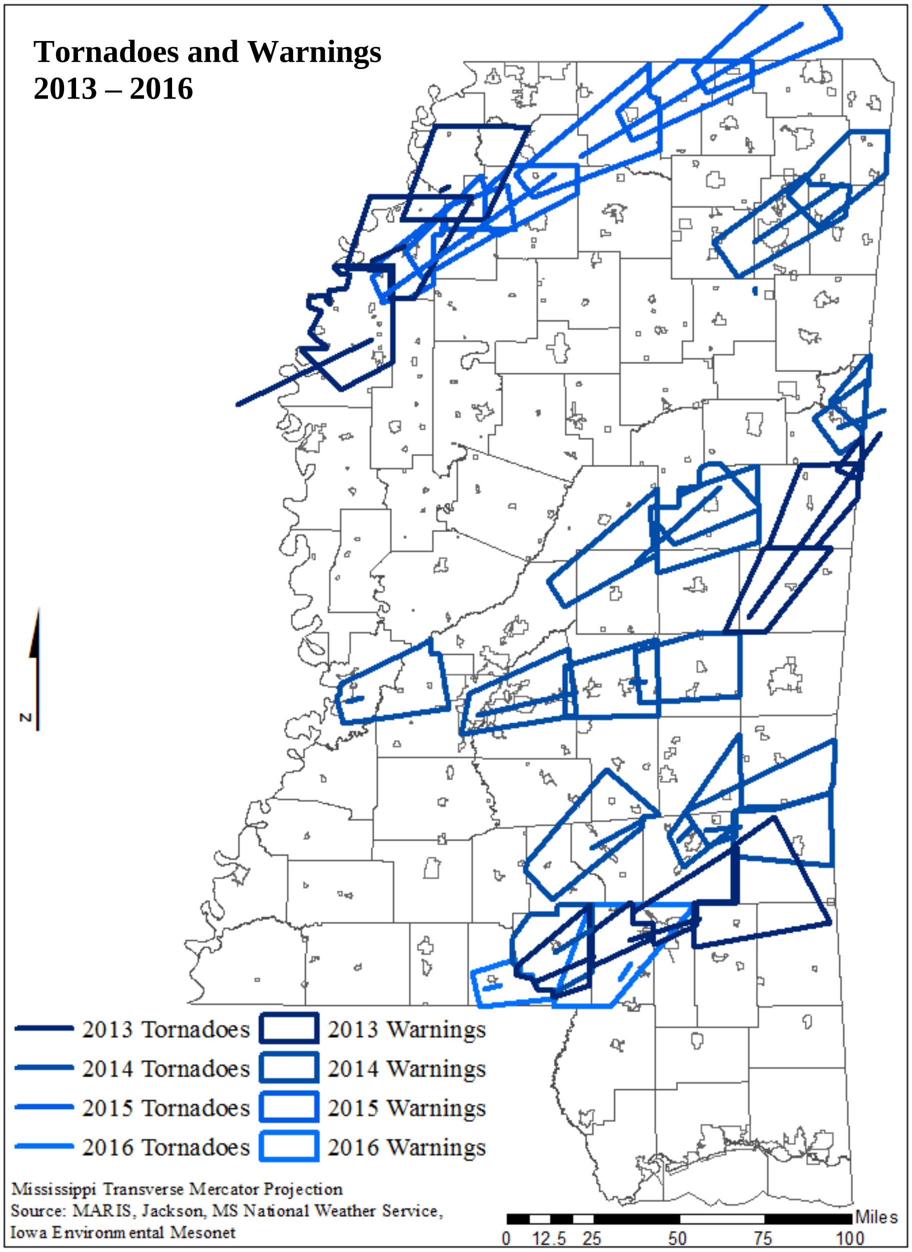


Figure 14: Tornadoes that caused casualties in 2013 - 2015 with their subsequent warning polygons.

Table 9 displays the odds ratio results for each of the warned tornadoes that occurred along with the date of occurrence and number of casualties. Figure 15 through Figure 18 show where they are located. Thirteen of the 20 tornadoes had odds ratios greater than 1, indicating that the odds were greater for casualties to occur in low coverage areas. There were 25 fatalities and 228 injuries attributed to the tornadoes that occurred in areas with low coverage. The remaining tornadoes had odds ratios less than 1 indicating that those tornadoes occurred in areas where there was high coverage, with one tornado being solely located in an area with high coverage. Of those tornadoes, two had odds ratios approximately .01 away from 1, indicating that there could be an almost equal mixture of high and low coverage areas along the tornado track. The tornadoes that were warned in areas with high coverage had 5 deaths and 135 injuries; and, of those casualties, 2 deaths and 60 injuries were located in both low and high coverage areas.

Table 9: The odds ratio results for the odds of low coverage areas resulting in casualties.

Tornado	**Date**	**Casualty**		**Odds Ratio -- 95% Confidence Intervals**
		Injury	**Fatality**	
2013				
1	2/10/13 - 16:23	3	0	1.970 -- 1.576 – 2.463
2	2/10/13 – 17:03	71	0	0.807 -- 0.451 – 1.446
3	4/11/13 – 10:35	9	1	1.413 -- 1.242 – 1.609
4	12/21/13 – 16:51	2	0	1.656 -- 1.319 – 2.079
5	12/21/13 – 17:19	2	1	1.448 -- 0.931 – 2.251

Tornado	**Date**	**Casualty**		**Odds Ratio -- 95% Confidence Intervals**
		Injury	**Fatality**	
6	12/21/13 – 17:40	1	0	0.593 -- 0.143 – 2.456
2014				
1	4/7/2014 – 1:02	8	0	1.177 -- 0.953 – 1.453
2	4/28/2014 – 13:38	32	0	.988 -- 0.750 – 1.302
3	4/28/14 – 14:51	84	10	1.271 -- 1.077 – 1.500
4	4/28/14 – 15:56	1	0	1.429 -- 0.967 – 2.111
5	4/28/14 – 17:27	10	1	1.339 -- 0.902 – 1.988
6	4/28/14 – 17:38	5	0	2.127 -- 1.095 – 4.131
7	4/28/14 – 18:36	3	0	All in high coverage
8	4/28/14 – 20:40	15	0	1.061 -- 0.764 – 1.474
9	12/23/14 – 14:20	50	3	1.815 -- 1.400 – 2.353
10	12/23/14 – 15:22	0	2	0.361 -- 0.088 – 1.472
2015				
1	12/23/15 – 14:54	28	2	0.985 -- 0.826 – 1.175
2	12/23/15 – 16:10	36	9	1.497 -- 1.303 – 1.721
2016				
1	02/15/16 – 13:15	2	0	2.300 -- 1.422 – 3.719
2	02/23/16 – 16:15	0	1	0.810 -- 0.614 – 1.068

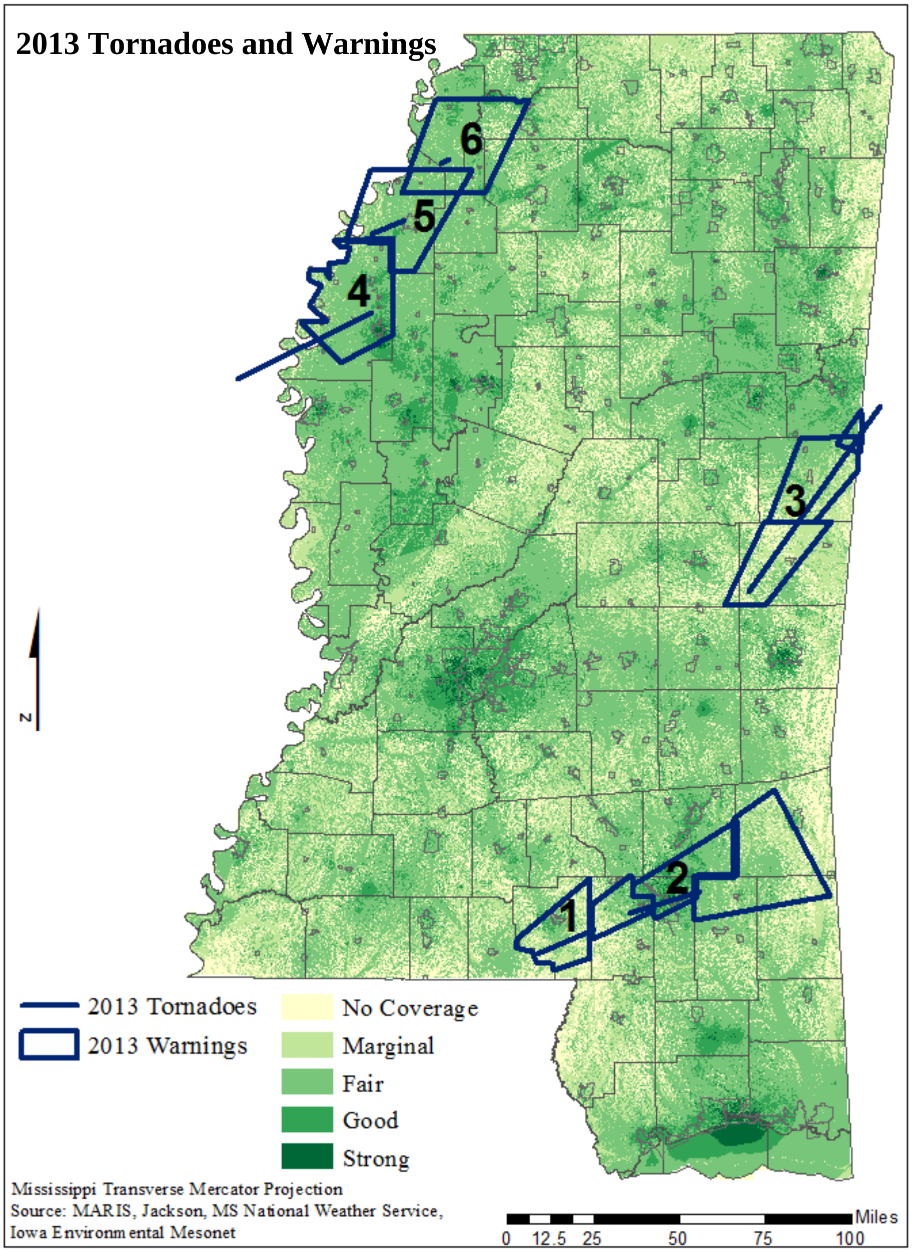


Figure 15: The locations of 2013 tornadoes and warnings on the Dissemination Technology Coverage Index.

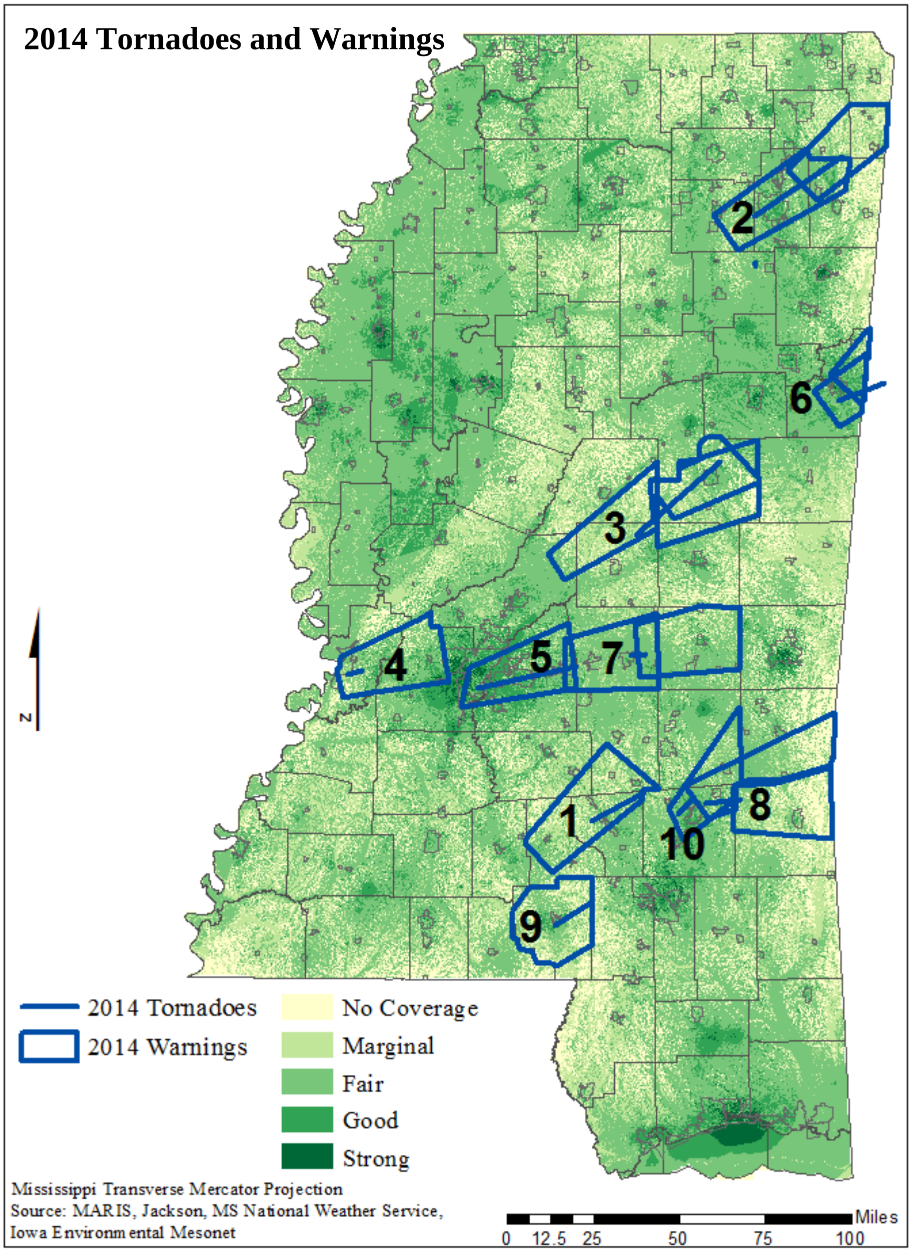


Figure 16: The locations of 2014 tornadoes and warnings on the Dissemination Technology Coverage Index.

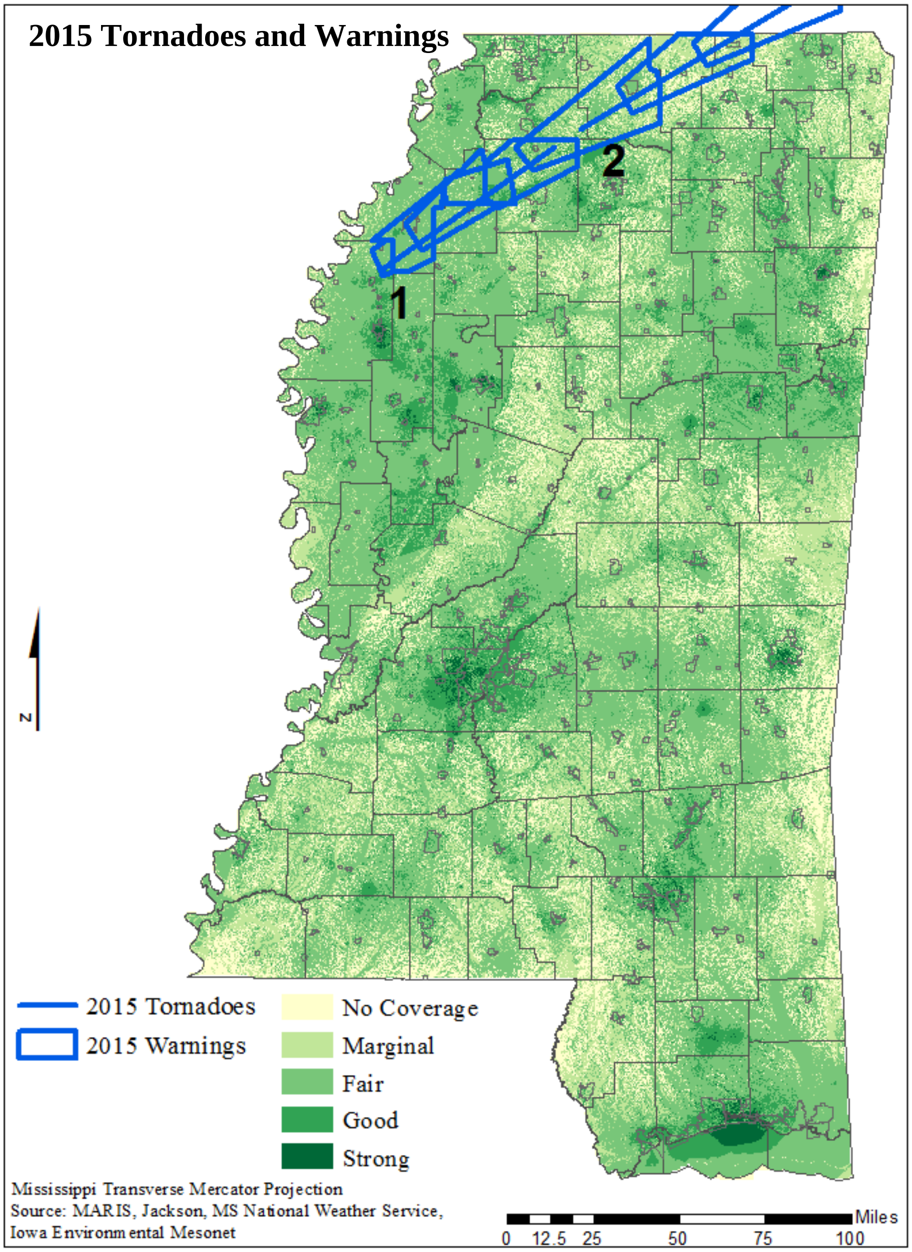


Figure 17: The locations of 2015 tornadoes and warnings on the Dissemination Technology Coverage Index.

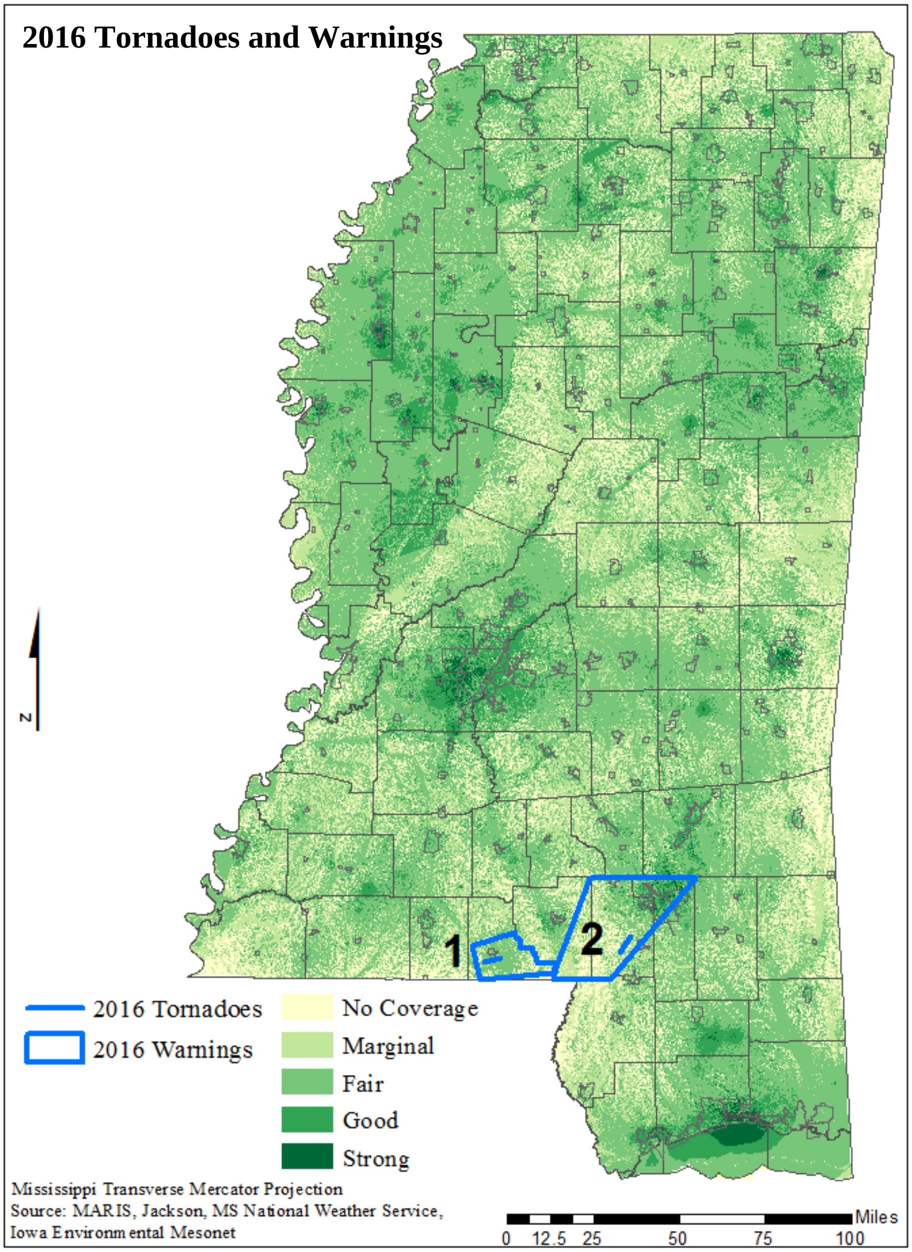


Figure 18: The locations of 2016 tornadoes and warnings on the Technology Dissemination Coverage Index.

Summary

This chapter incorporated the Dissemination Technology Coverage Index with past tornado warnings to examine casualties. Warned tornadoes that resulted in injury and/or death were examined to reveal if there is a correlation between casualties and coverage areas. The odds ratio was used to calculate the odds of tornado casualties for warned tornadoes in low coverage areas. The study found that 13 of the 20 warned tornadoes from 2013 – 2017 occurred in areas of low coverage, resulting in 228 injuries and 25 fatalities.

The results show that there is a relationship between coverage gaps and tornado-warned casualties. Although the research supports my hypothesis, it should be noted that this is a very limited dataset of four years, and a longitudinal study should be performed to see if the results persist. Additionally, the lack of dissemination coverage may not be the cause of the casualties. Factors such as the time of tornado occurrence, the person's location, whether in a car or a mobile home, along with other factors may have affected the chances of the injury or fatality.

CHAPTER SEVEN: CONCLUSION

This research sought to explore the effectiveness of tornado warning messages by locating coverage gaps in commonly used dissemination technologies. A Dissemination Technology Coverage Index was developed using the coverage from reclassified, aggregated, and weighted digital television, FM radio, and cellular signals, and outdoor warning sirens. The coverage index categorizes coverage as No Coverage, Marginal (weak), Fair, Good, and Strong.

The Dissemination Technology Coverage Index was used to test the hypothesis that socially vulnerable populations are likely to reside in areas with no to marginal coverage. A social vulnerability index was developed for the state using 23 demographic and socioeconomic variables. The chi-square test of independence statistic was run for portions of northern, central, and southern Mississippi to discover if social vulnerability and coverage areas were independent. For each portion of the state, the chi-square test of independence showed that there was a statistically significant association between social vulnerability and coverage areas; however, the Cramer's V showed that the associations were small. The association in northern Mississippi was the smallest. To determine which cells deviated from independence, standardized residuals were examined. In central Mississippi, there were less observed occurrences than expected in areas of good coverage for the more and most vulnerable populations, and a higher occurrence of more vulnerable populations in marginal coverage areas. Additionally, in southern Mississippi, there were higher observations of vulnerable to most vulnerable populations in marginal coverage areas. In central and southern Mississippi, the higher occurrences of the more and/or most vulnerable populations in the marginal coverage area supports the hypothesis.

The Dissemination Technology Coverage Index was also used to test the hypothesis that casualties from warned tornadoes are more likely to occur where the area being warned has marginal to no coverage. There were 20 warned tornadoes that occurred from 2013 – 2016 that resulted in 253 casualties. The odds ratio was used to calculate the odds of tornado casualties for warned tornadoes in low coverage areas. The results showed that 13 of the 20 tornadoes occurred in areas with low coverage, and the other 7 occurred in areas with high coverage. Additionally, the low coverage areas had a higher number of casualties than those in high coverage areas. This validates the hypothesis because there is a positive correlation between warned tornadoes with casualties and areas with low coverage. There are many factors that can contribute to casualties in severe weather; this study attempts to observe if the lack of dissemination coverage is one of these factors.

This study is important in that there have been few, if any, warning dissemination research that examines the availability of warning sources to the public. There has been research that focused on whether or not a warning was issued, the warning lead times, and false alarm rates. People have been surveyed on the sources they received information from, but are less likely to have been asked what sources they have available to them. This research can be used to improve coverage, increase warning dissemination prior to and during a hazard, and as a research tool. Additionally, the coverage index can be used by emergency managers, meteorologists, or other hazard scientists, and the media.

Limitations

This study had some limitations that could have enhanced the research, but did not adversely affect the results. As previously discussed, one limitation was the extent of the coverage studied, specifically the cellular coverage. The cellular data use is not the entire cellular network for the state, since the FCC data does not include cellular towers that are under 200 feet. Additionally, the cellular coverage was not calculated using the RF propagation model, because the frequency data for the cellular transmitters was not readily available. However, the coverages for the cellular towers were represented by the Cellular Geographic Service Areas, which is a composite of the service areas of all of the transmitters. Another limitation is that the television coverage is for digital antennas only; satellite or cable television was not considered in the coverage, so a larger number of people are getting a television signal that are not being accounted for. Finally, the areas along the border could be a part of the respective neighboring state’s market and those transmitters were not included in this dataset.

Second, the social vulnerability index has limiting factors. There are agreed upon variables that may define one as being socially vulnerable, such as socioeconomic status, age, race and ethnicity, gender, and disability. In developing the social vulnerability index for Mississippi, all of the variables that have been used in the development of other vulnerability indexes, such as disability, nursing home occupants, and specific employment industries, were not used in the development of this index. The inclusion of those factors in the Principal Component Analysis would not produce an identity matrix, which shows that the sample data is inadequate for analysis. As previously stated, the index was based on census tract data, so it generalizes vulnerability factors for a larger area and does not look at individual communities.

Finally, there were some limitations with the casualties associated with warned tornadoes. The range of years for examining the casualties for warned tornadoes was limited due to the time frame in which all four observed technologies were disseminating warning information. Additionally, assumptions were made when determining the location of the tornado-related casualties. The storm reports do not list the exact location of the injury or fatality, so the injuries or fatalities were assumed to have occurred along the path of the tornado.

Despite these limitations, the research goals were accomplished, and the findings can be used to enhance warning dissemination.

Applications

The Dissemination Technology Coverage Index identifies exposures to vulnerabilities by displaying gaps in dissemination coverage. The city of Tulsa, Oklahoma, has demonstrated how research of this kind can be used to improve coverage. In Tulsa, emergency managers exposed gaps in tornado siren coverage, and are now seeking to add more sirens so that the entire city would be within the range of a siren

(Wade, 2015). Other jurisdictions could use the index in a similar manner to identify gaps and find ways to fill them.

The National Weather Service has the Weather-Ready Nation initiative whose purpose is to save more lives by ensuring that the nation is prepared “to protect, mitigate, respond to and recover from weather-related disasters.” To accomplish this goal, the NWS is expanding its reach by incorporating new partners, enhancing its operational initiatives, upgrading radar and satellite technologies, and improving its risk communication. A specific operational initiative is to increase severe weather warning lead times and improve how the weather is communicated to the public. The NWS’s partners, including other government agencies, emergency managers, the private sector, non-profits, and the media, work to get these weather messages out (NWS, 2011). As the NWS works to build a Weather Ready Nation, the information gathered from this research can be utilized. For example, the Dissemination Technology Coverage Index can be used by Warning Coordination Meteorologists at local weather forecast offices as a tool to use when hazardous weather will be impacting their county warning area. This research can act as a reference to where there are areas with limited dissemination coverage, and allow them to reach out to partners to ensure that the hazard information is available to more people. Additionally, the social vulnerability index can be used to locate where the more socially vulnerable populations are, and information, such as shelter locations and other resources, can be shared with them so that they are aware of their options for protective actions during hazardous weather. Using both the Dissemination Technology Coverage Index and a social vulnerability index will provide the NWS with instances of both place and social vulnerability, and allow them to hone in on areas that are more at risk to hazards.

The coverage index can be a tool used to encourage the utilization of other information sources. It has been shown that areas with no to limited coverage can play a factor in casualties and that they may have more socially vulnerable populations. When a hazard is impending and the affected area is located where there is limited technology dissemination coverage; emergency managers and/or broadcasters could encourage family and friends to reach out to those in the threat area, and act as an additional information source. Additionally, neighborhood associations, local civic organizations, and/or religious institutions could be made aware of the threat, and they can take action to ensure that the areas that they serve are aware of the risk and what protective actions to take, which ties into the NWS Weather Ready Nation initiative.

Future research

There are several ways in which this research can be extended. The research only examined four dissemination technologies, which was due to two factors: computing time/power and information availability. The Dissemination Technology Coverage Index could add more technologies, such as NOAA Weather Radio, broadband internet, and all of the cellular transmitters. Additionally, the coverage maps are based on mathematical applications. Field studies could be performed to test the accuracy of the results from the Free Space Path Loss and sound propagation equations. This will allow the coverage index to be more accurate.

This research does not take into account other factors that that could hinder the warning messages from reaching the targeted populations, such as power outages. As previously stated, tornadoes and severe thunderstorms affect transmission and local distribution (T&D) lines directly through wind damage and indirectly through downed trees. Partnerships can be developed with the power companies to determine if there are locational trends for power outages during certain hazards. For example, Dominion Power in northern Virginia has the capability to know where (according to zip code) there are outages and how many people are affected. Such locations, if they exist, could be highlighted in the coverage index as areas with the potential to have decreased communication. This method can be helpful both proactively and during the event.

Social vulnerability indices can be powerful tools for decision-making in pre-disaster planning, post-disaster response, and resource allocation. Since it was found that there is a small relationship between areas with no to limited coverage and socially vulnerable populations, an index can be developed on a smaller scale to locate vulnerable populations. For the index to be most effective, it should take into account quantitative approaches and qualitative approaches. The qualitative approach may be more time consuming, because it will require communicating with local officials and/or community members. This method could lead to the development of a social vulnerability index that will take into account what hazards are more vulnerable to areas, and what specific variables may make a community vulnerable. If this social vulnerability index were developed and used in conjunction with the Dissemination Technology Index, emergency managers and hazard scientists (meteorologists, geologists, etc.) will know where to direct communication to ensure that the populace is getting hazard information, are aware of available resources, and know what protective actions to take.

The coverage index can be made into an interactive application (app) that covers the United States and is packaged for hazard scientists and emergency managers to be used when a hazard is imminent or occurring. The app can allow the respective users to know where there may be limited messaging before the event, and include a social vulnerability index. Additionally, if partnerships could be brokered with power companies, a tool could be added to the app to include active power outages. With this information, some of the recently stated uses of the Technology Dissemination Coverage Index can be utilized to inform the at-risk population of the hazard. Regardless of the approach, it is hoped that hazard warning disseminators could have some influence in ensuring that all populations receive adequate warning information.

REFERENCES

Beede, D. and Neville, A. (2013). Broadband availability beyond the rural/urban divide: Broadband brief no. 2. Retrieved from http://www.ntia.doc.gov/files/ntia/publications/broadband_availability_rural_urban_june_2011_final.pdf

Brotzge, J. and Donner, W. (2013). The tornado warning process: A review of current research, challenges, and opportunities. *Bulletin of the American Meteorological Society*, 94, 1715 - 1733

Burnside, R., Miller, D.S., and Rivera, J.D. (2007). The impact of information and risk perception on the hurricane evacuation decision-making of greater New Orleans residents. *Sociological Spectrum: Mid-South Sociological Association*, 27, 727 – 740.

Coleman, T.A., Knupp K.R., Spann, J., Elliott, J.B., and Peters, B.E. (2011). The history (and future) of tornado warning dissemination in the United States. *Bulletin of the American Meteorological Society*, 92, 567–82.

Carter-Pokras, O., Zambrana, R.E., Mora, S.E., and Aaby, K.A. (2007). Emergency preparedness: knowledge and perceptions of Latin American immigrants. *Journal of Health Care for the Poor and Underserved*, 18, 465 – 481.

Cutter, S.L., Boruff, B.J., and Shirley W.L. (2003). Social vulnerability to environmental hazards. *Social Science Quarterly*, 84, 242 – 261.

Dash, N. and Gladwin, H. (2007). Evacuation decision making and behavioral responses: Individual and household. *Natural Hazards Review*, 8, 69 – 77.

Department of Energy. (2013). Economic benefits of increasing electric grid resilience to weather outages. Retrieved from http://energy.gov/sites/prod/files/2013/08/f2/Grid%20Resiliency%20Report_FINAL.pdf

Demuth, J., Morss, R.E., Morrow, B.H., and Lazo, J.K. (2012). Creation and communication of hurricane risk information. *Bulletin of the American Meteorological Society*, 93, 1133 – 1145.

Elliott, J.R., Haney, T.J., and Sams-Abiodun, P. (2010). Limits to social capital: Comparing network assistance in two New Orleans neighborhoods devastated by Hurricane Katrina. *The Sociological Quarterly*, 51, 624 – 648.

ESRI ArcGIS Pro. (2017). Using Viewshed and Observer Points for visibility analysis. Retrieved from http://pro.arcgis.com/en/pro-app/tool-reference/3d-analyst/using-viewshed-and-observer-points-for-visibility.htm

Federal Communications Commission. (2012). Federal Communications Commission Geospatial Data (Data file). Retrieved from http://wireless.fcc.gov/geographic/index.htm?job=licensing_database_extracts

Federal Communications Commission. (2015). General information about FM and TV service contour maps and map data. Retrieved from https://www.fcc.gov/media/radio/general-info-fm-tv-maps-data

Federal Emergency Management Agency. (2006). Outdoor Warning System: Technical Bulletin (Version 2.0). Retrieved from http://www.midstatecomm.com/PDF/FEMA_guide.pdf

Federal Signal. (2017). Models 2001-130, Equinox, and 508-128 Sirens: Installation, Operation, and Service Manual. Retrieved from https://www.fedsig.com.resource-document/file/9371

Flanagan B.E., Gregory, E.W., Hallisey, E.J., Heitgard, J.L., and Lewis, B. (2011). A social vulnerability index for disaster management. Journal of Homeland Security and Emergency Management, 8(1), Article 3.

Fothergill, A., Maestas, E.G.M. and Darlington, J.D. (1999). Race, ethnicity, and disasters in the United States: A review of the literature. *Disasters*, 23, 156 – 173.

Hayes, J.L. (2011). NOAA NWS Service Assessment: The Historic Tornadoes of April 2011. Retrieved from https://www.weather.gov/media/publications/assessments/historic_tornadoes.pdf

Hazards and Vulnerability Research Institute (HVRI). (2013). Social vulnerability index for the United States – 2006-10. Retrieved from http://webra.cas.sc.edu/hvri/products/sovi.aspx.

Iowa Environmental Mesonet. (2016). Archived NWS Watch/Warnings (Data file). Retrieved from https://mesonet.agron.iastate.edu/request/gis/watchwarn.phtml

Jewell, V.R. (2014). Use of GIS in readio frequency planning and positioning applications. Retrieved from https://vtechworks.lib.vt.edu/bitstream/handle/10919/50499/Jewell_VR_T_2014.pdf?sequence=1

Keifer, J.J., Mancini, J.A., Morrow, B.H., Gladwin, H., and Stewart, T.A. (2008). Providing access to resilience-enhancing technologies for disadvantaged communities and vulnerable populations. Oak Ridge, TN: Community and Regional Resilience Initiative, Oak Ridge National Laboratories.

Laerd Statistics. (2016a). Chi-square test for independence using SPSS Statistics. *Statistical tutorials and software guides.* Retrieved from https://statistics.laerd.com/

______. (2016b). Calculating an odds ration using SPSS Statistics. *Statistical tutorials and software guides.* Retrieved from https://statistics.laerd.com/

Laidlaw, E. 2010. The controversy over outdoor warning sirens. *Weatherwise* 1:16 – 25.

Lane, B. (n.d.). Tech topic 17: Propagation characterization. Retrieved from http://transition.fcc.gov/pshs/techtopics/techtopics17.html

Lazo, J.K., Morss, R.E., and Demuth, J.L. (2009) 300 billion served: Sources, perceptions, uses, and Values of Weather Forecasts. *Bulletin of the American Meteorological Society,* 90(6), 785 – 798.

Lindell, M.K. and Perry, R.W. (2012). The protective action decision model: The theoretical modifications and additional evidence. *Risk Analysis*, 32, 616 – 632.

Lindell, M.K., Prater, C.S., and Peacock, W.G. (2007). Organizational communication and gecision making for hurricane emergencies. *Natural Hazards Review*, 8, 50 – 60.

Mazda, F. (Ed.). (1996). Principles of radio communication. Oxford: Focal Press.

Mississippi Automated Resource Information System. (2011). Mississippi Statewide Data and 2010 Census (Data File). Retrieved from http://www.maris.state.ms.us/HTM/Data.html

Nagele, D.E. and Trainor, J.E. (2012). Geographic specificity, tornadoes, and protective action. *Weather, Climate, and Society*, 4, 145 – 155.

National Research Council. (2011). Public response to alerts and warnings on mobile devices: Summary of a workshop on current knowledge and research gaps. Washington, D.C., The National Academies Press, pp. 102.

______. (2013). Geotargeted alerts and warnings: Report of a workshop on current knowledge and research gaps. Washington, D.C., The National Academies Press, pp.79.

National Weather Service. (2009). Glossary. Retrieved from http://w1.weather.gov/glossary/

______. (2010). Weather-ready nation: Strategic plan 2011. Retrieved from http://www.nws.noaa.gov/com/weatherreadynation/files/strategic_plan.pdf

______. (2014). Dissemination Services. Retrieved from http://www.nws.noaa.gov/os/disemsys.shtml

Nešković, A., Nešković,N., and Paunović, D. (2000). Modern approaches in modeling of mobile radio systems propagation environment. IEEE Communications Survey. Received from http://www.researchgate.net/profile/Natasa_Neskovic/publication/224084444_Modern_approaches_in_modeling_of_mobile_radio_systems_propagation_environment/links/54fcc5d00cf20700c5e96eda.pdf.

Paul, B.K., Stimers, S. and Caldus, M. (2014). Predictors of compliance with tornado tarnings issued in Joplin, Missouri, in 2011. *Disasters*, 39, 108 – 124.

Peguero, A.A. (2006). Latino disaster vulnerability: The dissemination of hurricane mitigation information among Florida's homeowners. *Hispanic Journal of Behavioral Sciences*, 28(5), 5 – 22.

Pender, G. (2017, February 17). 13 things you need to know about the state economy. *The Clarion-Ledger*. Retrieved from http://www.clarionledger.com/story/news/politics/2017/02/16/state-economic-briefing/97993092/

Perry, R.W. (1979). Evacuation decision making in natural disasters. *Mass Emergencies*, 4, 25 – 38.

Perry, R.W., Lindell, M.K., and Greene, M.R. (1982). Crisis communication: Ethnic differentials in interpreting and acting on disaster warnings. *Social Behavior and Personality*, 10, 97 – 104.

Phillips, B.D. and Morrow, B.H. (2007). Social science research needs: Focus on vulnerable populations, forecasting, and warnings. *Natural Hazards Review*, 8, 61 – 68.

Poole, I. (nd). Free space path loss: details, formula, calculator. Radio-Electronics.com. Retrieved from http://www.radio-electronics.com/info/propagation/path-loss/free-space-formula-equation.php

Reed, S.E., Boggs, J.L., and Mann, J.P. (2010). SPreAD-GIS: an ArcGIS toolbox for modeling the propagation of engine noise in a wildland setting. Version 2.0. The Wilderness Society, San Francisco, CA.

Richards, J.A. (2008). Radio wave propagation: An introduction for the non-specialists. Berlin: Springer.

Rosu, I. (n.d.). Basics of radio wave propagation. Retrieved from http://www.qsl.net/va3iul/Antenna/Basics_of_Radio_Wave_Propagation.pdf

Sansing, D.G. (2015). Mississippi. *Encyclopedia Britannica*. Retrieved from http://www.britannica.com/EBchecked/topic/385567/Mississippi

Schumacher, R.S., Lindsey, D.T., Schumacher, A.B., Braun, J., Miller, S.D., and Demuth J.L. (2010). Multidisciplinary analysis of an unusual tornado: Meteorology, climatology, and the communication an interpretation of warnings. *Weather and Forecasting*, 25, 1412 – 1429.

Shaw, J.A. (2013). Radiometry and Friis transmission equation. American Journal of Physics. 81(33): 33 – 37.

Singer, H. (2013). Is the US losing the broadband race? As it turns out, we look a like Danica Patrick. *Forbes*. Retrieved from http://www.forbes.com/sites/halsinger/2013/02/26/is-the-u-s-losing-the-broadband-race-as-it-turns-out-we-look-a-lot-like-danica-patrick/

Sizun, H. (2005). Radio wave propagation for telecommunication applications. Berlin: Springer.

Smith, K.S. and McCarty, C. (2009). Fleeing the storm(s): An examination of evacuation behavior during Florida’s 2004 hurricane season. *Demography*, 46, 127 – 145.

Smith, S.W. (1998). The scientist and engineer’s guide to digital signal processing. Retrieved from http://www.dspguide.com/ch22/1.htm

Spence, P.R., Lachlan, K.A., and Griffin, D.R. (2007). Crisis communication, race, and natural disasters. *Journal of Black Studies*, 37, 539 – 554.

Stafford, S. (2015). Comparing methods for identifying social vulnerability to environmental hazards: A case study of coastal Virginia (PDF document). Retrieved from https://coast.noaa.gov/socialcoast/ppt/Stafford.pdf

Storm Prediction Center. (2015). The online tornado FAQ: Frequently asked questions about tornadoes. Retrieved from http://www.spc.noaa.gov/faq/tornado/

__________. (2016). Storm Prediction Center SVRGIS (Data file). Retrieved from http://www.spc.noaa.gov/gis/svrgis/

U.S. Congress, Office of Technology Assessment. (1990). Physical vulnerability of electric system to natural disasters and sabotage, OTA-E-453. Washington, DC: U.S. Government Printing Office. Retrieved from http://ota.fas.org/reports/9034.pdf

U.S. Government Publishing Office (n.d.) Cellular Geographic Service Areas. Retrieved from https://www.gpo.gov/fdsys/pkg/CFR-2013-title47-vol2/pdf/CFR-2013-title47-vol2-sec22-911.pdf

Vernier, D. (n.d.) Interference on the FM band. Retrieved from http://www.v-soft.com/wp-content/uploads/2012/04/Interference_on_the_FM_Band.pdf

Wade, J. (2015, May 15). Covering tornado warning gaps: Tulsa emergency officials seek funding to add four more sirens. *Tulsa World*. Retrieved from http://www.tulsaworld.com/news/local/covering-tornado-warning-gaps-tulsa-emergency-officials-seek-funding-to/article_42f13d92-42e3-5dfc-8c63-0b267e2abe63.html

Webster, B. (2014). Emergency siren sound propagation and coverage optimization analysis (Master's thesis, University of Redlands). Retrieved from http://inspire.redlands.edu/gis_gradproj/223

BIOGRAPHY

Aisha C. Reed Haynes graduated with an International Baccalaureate Diploma from Jim Hill High School, Jackson, MS in 1998. She received her Bachelor of Science from Jackson State University in 2002, and her Master of Science from Purdue University in 2006.