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Keeping Our Heads above Water: An Exploratory Study on the Equity Opportunities of Coastal Virginia Wireless Emergency Alerts

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Abstract: Economically disadvantaged coastal communities face severe damage and casualties, which can be attributed to storm surges. Excessive amounts of inundation should be considered to a similar level to wind speeds and heavy rains that communities commonly prepare for amidst a hurricane event. Marginalized residents, such as residents of color, disabled residents, elderly residents, and residents occupying low-income housing, suffer from storm surge events. Coastal resiliency plans are bottlenecked by factors, such as residential stability, ability to relocate, and insurance coverage, all of which are inequitably constrained for marginalized communities. This exploratory study reviews the previous literature on wireless emergency alert (WEA) equity critiques and spatial analysis of the WEAs sent to coastal Virginia communities. Two research questions are explored in this paper: (1) How does the previous literature critique equity in wireless emergency alerts? (2) How many households are below the poverty line in areas where storm surge warnings have been sent? To improve the utilization of WEAs for the protection of low-income community members, there is evidence to support the increase in the frequency of message delivery and improving the call-to-action text. This paper sets the stage for future policy analyses and message design experimentation on emergency communication in coastal regions.

Keywords: wireless emergency alerts (WEA); resilience; coastal Virginia; marginalization; storm surge; poverty; visual analysis; equity

1. Introduction

Oftentimes, storm surge events are the most destructive part of a hurricane event, especially in coastal regions and for the marginalized residents within those communities [1–3]. Storm surge is the abnormal amount of seawater that results from a hurricane, in which severity, illustrated in Table 1 below, varies based on the hurricane category and wind speed. Seawater is forced inland due to powerful winds, which can bring devastation and failure to coastal infrastructure [1]. Storm surge events can also cause considerable damage to natural coastal habitats and economic infrastructure. Unfortunately, as climate change continues to increase the surface temperature, the substantial risk for coastal communities to be severely affected by intensified, more frequent natural disasters will continue to rise [4].

Table 1. Storm surge categorization [Reprinted with permission from Ref. [5]. (n.d), NOAA.

Hurricane Category	Storm Surge (Meters.)	Wind Speed (km/h)
1	1.22–1.52	119–153
2	1.83–2.44	154–177
3	2.74–3.66	178–208
4	3.96–5.49	209–251
5	>5.49	>252

1.1. Storm Surge Is One of the Biggest Threats to Coastal Communities

Storm surge places America's coastlines at risk of being damaged by floodwaters. More specifically, illustrated in Figure 1 below, 14 of the 50 largest cities in the United States, indicated in red, are located on or near coastlines. Over time, coastal communities developed around ports. Cities in coastal communities provided many attractive benefits, for example, cultural exchange, transport, and job opportunities [6]. Historic data also points to more people moving to major cities, placing those individuals at a greater risk of being impacted by intensified natural disasters (e.g., storm surges). Namely, in 2017, more than 94 million people (29.1 percent of the US population) lived near coastlines—a 15 percent increase since 2000 [7]. To keep coastal residents safe and informed during natural disasters, FEMA's emergency response system, otherwise known as the Integrated Public Alert and Warning Systems (IPAWS), is currently being used [8]. IPAWS sends wireless emergency alerts (WEAs) to residents located within the high-risk area of the disaster. WEAs can be used to effectively deliver emergency response information to residents, especially marginalized residents (e.g., residents of color, elderly residents, impoverished residents, and disabled residents), as such individuals have historically suffered the most from such disasters [9].
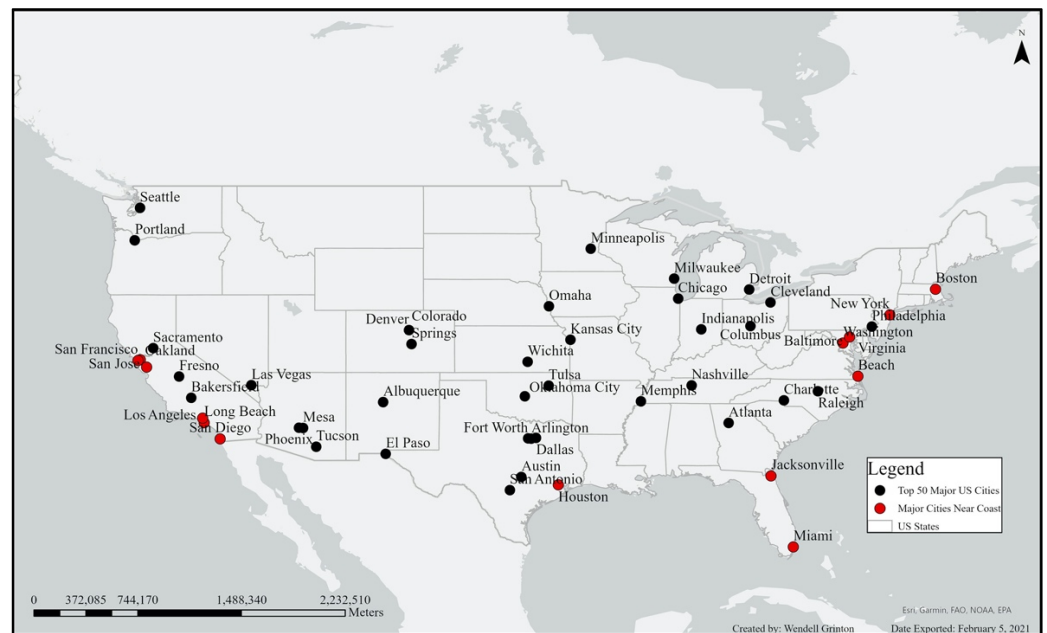

Figure 1. A total of 14 of the 50 largest cities in the US, highlighted in red, are located near coastlines.

1.2. Do Not Put Your Family in Mourning, Follow the Safety Warning

Due to increases in climate change, hurricanes are intensifying and occurring more frequently [10]. Fortunately, technology is increasing the opportunities to improve the communication of emergency response information to residents. Since 2012, FEMA has sent over 61 thousand WEAs to keep residents safe and informed of natural disasters (e.g., hurricanes, storm surges) and emergencies (e.g., AMBER alerts, COVID-19). WEAs, shown in Figure 2 below, are 360-character, geolocation-based emergency response alerts that notify residents in the geographic area of a disaster or emergency to keep said individuals safe [11]. For emergencies, WEAs can be effective and efficient in communicating needed disaster-related or emergency response information [12]. Though FEMA has increased the use of WEAs since 2012, gaps and limitations still exist in WEAs [13]. For example, the design of WEAs oftentimes overlooks marginalized groups—resulting in said individuals suffering the most from disasters.

Figure 2. Example of a wireless emergency alert (WEA).

1.3. Keeping Our Heads above Water

As a result of climate change, the severity of storm surge events will increase, and the sea level is expected to rise [14,15]. From 1990 to 2015, 13 storm surge events resulted in over 10.7 thousand deaths in North America [14]. More specifically, during Hurricane Katrina, at least 1500 residents lost their life due to storm surges [16]. Since storm surge events are intensifying, the need to keep residents safe and better informed before, during, and after storm surge events is more prevalent now than ever before. Storm surge events generate excessive amounts of flooding (inundation), which can be connected to numerous fatalities after the intense winds of a hurricane subside [17]. Providing residents with simple, concise, and actionable information is critical in disaster mitigation. Furthermore, mitigating impacts on residents who lack resources (e.g., rural broadband, insurance) should be a key part of equitable coastal emergency planning.

WEAs provide residents, including low-income residents, the opportunity to stay safer, to stay more informed, as well as to mitigate infrastructure damage as a result of these intensified natural disasters. The existence of effective communication protocols and networks has been shown to be an effective measure for increasing resiliency, especially perceptions of safety [10].

1.4. Marginalized Communities Suffer from Inequities in Emergency Alerting

While city and government leaders have the leisure to focus on the problems of a whole area and the problems of tomorrow, marginalized communities are barely surviving today. Marginalized residents suffer the most from natural disasters because they lack the necessary resources (e.g., rural broadband, insurance, standard housing, monetary capacity) and knowledge base to mitigate potential infrastructure damages and preserve their life [18–20]. Moreover, marginalized residents suffer because of the inequitable design of current emergency alert systems, such as FEMA's Integrated Public Alert and Warning System (IPAWS). Though IPAWS "intends" to accommodate all residents, oftentimes, this is not the case. Since marginalized residents generally live in lower-income communities, they often lack the financial capacity to be able to afford the more popular telecommunication companies, for example, Verizon Wireless. As an opt-in system, each telecommunication carrier makes decisions on how they upgrade their WEA capacities, which can be a barrier for marginalized residents to get WEAs with the most advanced accessibility features. Ensuring WEAs are equitably improved, therefore, is especially important for marginalized communities because they suffer the most from natural disasters and emergencies. Since residents in low-income communities often lack the knowledge, resources, and monetary capacity to rebuild after disasters, the need for improved emergency messaging is dire because these alerts could be a matter of life and death for such residents.

1.5. Exploring and Identifying Equity Opportunities in Current WEA Delivery

To improve the equity of WEAs in the United States of America, this exploratory research study explores the current opportunities within the IPAWS delivery system managed by FEMA. The use of public alerting is critical in quickly providing the public with important emergency information to protect lives and potentially mitigate property damage [13]. Identifying and closing the equity gaps in the delivery of WEAs provides an opportunity to improve coastal community resilience to intensified, more frequent natural disasters, such as storm surges.

2. Background

FEMA's current emergency alert system (IPAWS) can be effective and efficient in communicating needed emergency response information [12]. Unfortunately, this emergency alert system has blind spots [12]. Though IPAWS was upgraded technologically, blind spots exist that directly impact marginalized residents. For example, the alert standardizations checklists for the IPAWS Emergency Alert System (EAS) and for WEAs, do not include any checklist tasks regarding marginalized residents (e.g., residents of color, elderly residents, disabled residents, functionally illiterate residents, impoverished residents), highlighted in Table 2 below. Because the IPAWS alert standardization checklist does not include tasks specifically related to marginalized residents, this system is inequitable. Accessibility to WEAs is especially difficult for disabled residents and elderly residents, as they must contain specific technologies (e.g., braille readers, sign language interpretation) to receive WEAs.

Table 2. IPAWS alert standardization checklist for EAS and WEAs [Reprinted with permission from Ref. [21]. (n.d.), FEMA.

Emergency Alert System (EAS)	Wireless Emergency Alerts (WEAs)
Determine the appropriate event code	Determine the appropriate event code
Create an alert in English that:	If supported, choose the geo-targeted boundaries
• Provides the alert source	Create a 90- and 360-character English alert that:
• Provides the type of threat or event	
• Provides the affected geographic location	• Provides the alert source
• Provides a protective action for the public to take, how soon they should take action, and how the protective action will reduce potential damage	• Provides the type of threat or event
	• Provides the affected geographic location
• Provides when the threat or event will conclude	• Provides a protective action for the public to take, how soon they should take action, and how the protective action will reduce potential damage
• Provides when new information will be received	
• Alert does not surpass 1800-character limit	Provides when the threat or event will conclude
If needed, create the same alert in Spanish	If needed, create the same alert in Spanish
If needed, and if compatible with software, attach an mp3 audio of the alert (2 min maximum) and/or URL	If needed, include a phone number and/or URL
Review the newly created alert	Review the newly created alert
Send the newly created alert to IPAWS-OPEN	Send the newly created alert to IPAWS-OPEN
Continually monitor event and send additional alert updates or cancelations, if necessary	Continually monitor event and send additional alert updates or cancelations, if necessary
Save lives and protect property	Save lives and protect property

Along our coastlines, storm surge risks place many coastal Virginia residents in a vulnerable position during a hurricane event [2]. Low-income residents are often the individuals who end up losing their life, irreplaceable positions, and necessities during and after natural disasters [22,23]. For example, the storm surge from Hurricane Katrina devastated New Orleans, Louisiana and the Mississippi coast. Pre-Katrina, 24.5 percent of

the New Orleans, Louisiana (NOLA) residents were below the poverty line (United States average was 13.3 percent), 17.7 percent had a high school or less education (United States average was 15.8 percent), and the total median household income was USD 30,711 (United States average was USD 46,242). Moreover, pre-Katrina, 67.5 percent of the NOLA population were black/African American, 28 percent were white/Caucasian, and 4.5 percent were considered other (e.g., Asian, Hispanic). Post-Katrina, the NOLA population suffered a significant loss of residents due to the high number of black/African Americans who lost their lives during Katrina.

Moreover, Asian and Hispanic individuals increasingly moved to NOLA, which resulted in the demographics of the population now becoming 47 percent black/African American, 42.7 percent white/Caucasian, and 10.3 percent other (e.g., 3.5 percent were Asian, 9.6 percent were Hispanic) [24]. Nearly 53 percent were men (51 percent being Black/African-American men), and nearly 18 percent were Hispanic or Latino [25,26]. Furthermore, the elderly (75 years old and older) were particularly vulnerable post-Katrina due to impaired hospital and health service infrastructure [9,27].

Other cities, for instance, New York City, New York, Miami, Florida, and Virginia Beach, Virginia, are all susceptible to coastal impacts from hurricanes and their associated storm surge [23,28]. Therefore, to improve the equity of FEMA's current WEAs, this exploratory research study identifies equity gaps within the current delivery of WEAs. The use of public alerting is critical in providing the public with important emergency information to protect lives and potentially mitigate property damage [13]. Identifying and closing the equity gaps in the delivery of WEAs can help the public, especially marginalized residents and coastal residents, to be better prepared for future intensified, more frequent natural disasters.

2.1. Vulnerable Residents Will Have Less Time to Prepare for and Recover from Storm Surge Events

Understanding society's vulnerabilities to storm surge events is critical because this change can help foresee and limit future storm surge risks and improve the public's resilience to storm surge events [14]. Since 1900, more than 8 thousand people were killed, and 1.5 million people were affected annually by storm surge events [14]. In the future, the impacts of storm surge events on coastal communities will be magnified by the increasing density of urban areas. For example, previous hurricanes, shown in Figure 3 below, produced storm surge flooding that ranged from 2.45 to 8.53 m above sea level. These storm surge events wreaked havoc on coastal communities and generated billions of dollars in damage that these communities were left to repair.

2.2. The Creation of WEAs and the Process of Sending Alerts to the Public

WEAs are a vital component of America's emergency preparedness protocol [24]. WEAs are geolocation-based, 360-character messages that are delivered to areas that may be impacted by upcoming natural disasters or pandemics to keep the public safe and informed before, during, and after a said natural disaster or pandemic [11]. WEAs can be sent by authorized national, state, or local government officials to alert the public about upcoming safety emergencies (e.g., severe weather, missing children, need for evacuation). To date, these alerts have been utilized over 61 thousand times to alert the public of incoming natural disasters or emergencies [29]. Current WEAs still face design and delivery problems that impact their equitability.

For emergencies, WEAs can be efficient in communicating needed disaster-related information [12]. Unfortunately, WEAs were not always in existence. Though WEAs were established in 2012, prior events had an exponential impact on the creation of WEAs. For example, Hurricane Katrina devastated America in 2005 and exposed America's inability to effectively notify the public of an upcoming natural disaster or pandemic [30]. Executive Order 13407 was the foundation of the creation of WEAs. In Executive Order 13407, President Bush required the Department of Homeland Security (DHS) to combine the United

States' existing and upcoming public alert and warning systems. Moreover, FEMA was instructed to lead the effort and establish standards and protocols to support the Integrated Public Alert and Warning System (IPAWS). IPAWS is a modernized version of the previous and future public alert and warning systems, technologies, and infrastructure. Alerting authorities are federal, state, territorial, tribal, and local government officials who can disperse WEAs. This provides IPAWS with a broader range of messaging opportunities and communication avenues, which can easily and efficiently alert the public before, during, and after a disaster or emergency. This process can be seen in Figure 4 below.
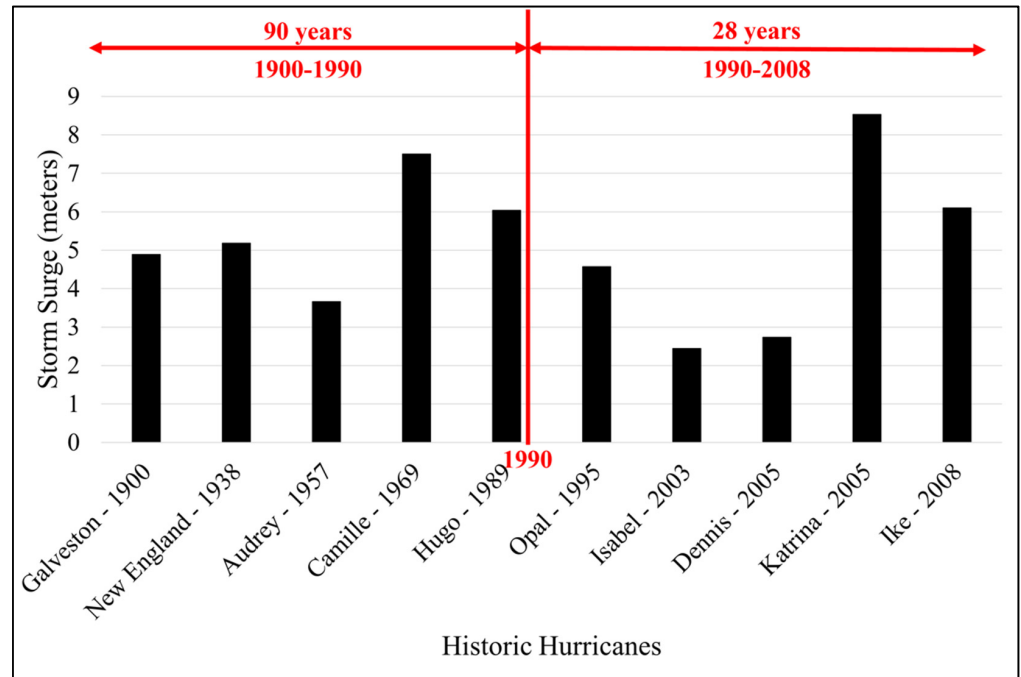

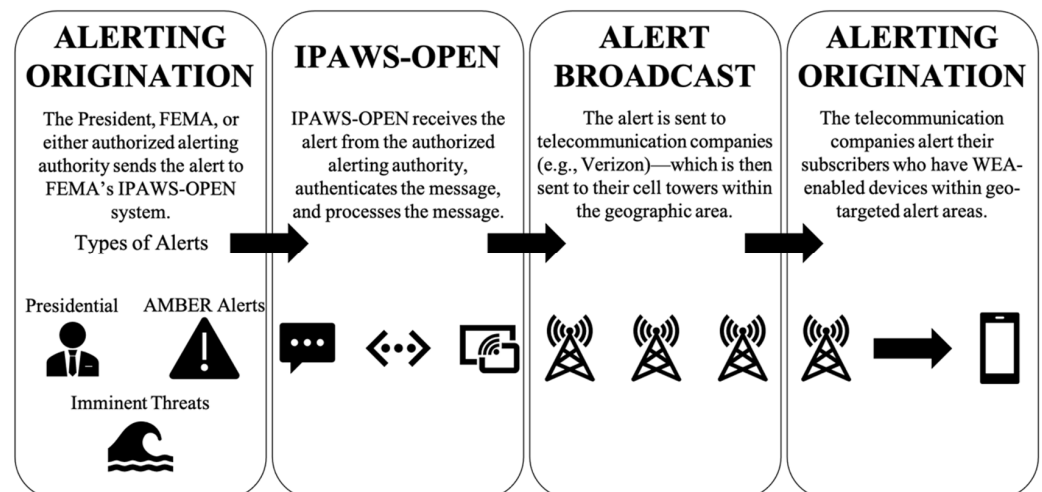**Figure 3.** Historic storm surge events.

Figure 4. Delivery process of WEAs.

Though WEAs have been delivered to residents over 61 thousand times since 2012 to alert the public of upcoming natural disasters or emergencies, the recent pandemic, COVID-19, exposed the need for improving current WEAs. COVID-19 is one of the deadliest pandemics in human history, claiming the lives of more than 5.7 million people since its appearance in 2019 [31,32]. The issue with COVID-19, however, was that initially, no one

was properly alerted on how dangerous COVID-19 was, how to prevent the spreading of COVID-19, or how to protect yourself and others from COVID-19. The CDC provided minimal information about COVID-19, but even then, no concrete actionable recommendations were provided that residents could take. Moreover, through the duration of COVID-19 and as more information surfaced about the virus, the CDC was then able to release more information to the public. Further, when natural disasters and emergencies arise, marginalized residents tend to be impacted the most due to a lack of resources or a lack of literacy about safety protocol. Therefore, to make WEAs more equitable, this research study identifies the current gaps and leverages a variety of qualitative and quantitative methods (e.g., content analysis, GIS, literature analysis).

2.3. These Systems Have Blind Spots, Especially for Marginalized Communities

Current systems, namely FEMA's emergency response and preparedness system (IPAWS) are inequitable [33]. Oftentimes, emergency response and preparedness systems (IPAWS) are intended to accommodate everyone, but marginalized residents are typically left out. This results in marginalized residents suffering the most from natural disasters, such as storm surges. Marginalized residents also make up the majority of natural disaster casualties. However, the marginalized residents that survive often lack the monetary capacity to rebuild what the disaster just destroyed. Similarly, a plethora of marginalized residents have expressed that enacted legislation did not adequately accommodate their needs post-disaster, which hindered the recovery of marginalized communities [12]. In contrast, it is common that marginalized residents are unable to move away from high-risk areas; some marginalized residents appreciate useful information that will help them be more resilient to increasing natural disasters [34]. Furthermore, to better communicate WEAs to marginalized residents, this study leverages GIS to illustrate a visual analysis of the geolocation of WEAs to marginalized residents and the ways in which WEAs can be better communicated to marginalized residents.

3. Methods

This exploratory study looked to highlight the equity opportunities of storm surge warning WEAs (SSW WEAs) sent to coastal Virginia. More specifically, this exploratory study leveraged a brief literature review, Python 3.0, Microsoft Excel, and GIS. A brief literature review can help understand what research and improvements have been done surrounding WEAs, as well as highlight the limitations or equity gaps in such alerts. Correspondingly, Microsoft Excel and Python 3.0 were used to clean and sort the storm surge WEA dataset. Further, GIS was used to create a visual analysis of where storm surge WEAs were sent in correlation with the geographic location of marginalized communities in coastal Virginia. In doing this, future WEAs can be improved and restructured to better accommodate coastal communities and marginalized residents in those communities.

3.1. Understanding Past Literature Can Help Design and Dictate Future Equitable Storm Surge Issues

To better understand the equitability of current storm surge WEAs, this exploratory study leveraged a literature review. Given the disciplinary stratification and limited amount of papers on wireless emergency alerts, we consider this literature review to be preliminary. Although this paper does not provide an extensive literature review, the examination of select academic papers from the time frame that WEAs were established (2012) provides useful equity insights. The papers selected were intentionally included for their inclusion of equity-related dimensions.

3.2. Leveraging Microsoft Excel and Python 3.0 to Clean and Sort Storm Surge WEA Data

To improve the communication of storm surge WEAs to marginalized residents in coastal Virginia, researchers received a publicly available Microsoft Excel spreadsheet of every WEA sent from June 2012 until April 2021 from FEMA's chief engineer of IPAWS.

Such WEAs included but were not limited to the time the WEAs were sent, the location, the emergency alert system (EAS) category, as well as the short-text and long-text versions of each WEA. This Microsoft Excel spreadsheet included more than 61 thousand WEAs. When the WEAs were sent from FEMA, the latitude and longitude geo-coordinates for each WEA were placed in one cell per WEA. Further, once the latitude and longitude geo-coordinates were placed in their respective columns, the sort and filter function on Microsoft Excel was used to filter the data to only show storm surge warning (SSW) WEAs that were sent to Virginia. Once the SSW WEAs were filtered to alerts only sent in Virginia, the filtered dataset was then imported to GIS.

3.3. Leveraging GIS to Create a Visual Analysis of Storm Surge WEAs in Correlation with Coastal Communities with High Volumes of Households below the Poverty Rate

To help coastal communities and marginalized residents living in coastal communities stay safer and better informed before, during, and after storm surge events, this study uses Microsoft Excel, GIS, and Python 3.0. Microsoft Excel, Python 3.0, and GIS helped to visualize where past WEAs have been sent across the United States and if the WEAs geolocation polygons included areas with marginalized communities. To do so, researchers filtered the WEA Microsoft Excel spreadsheet to only show the 395 storm surge WEAs (SSW WEAs) that have been sent to residents across the United States since 2012. The geolocation polygons that included the latitude and longitude points for each WEA—which show where each WEA was sent—were all submerged within one cell. Unfortunately, GIS is unable to plot the geolocation points in this format, therefore, Python 3.0 was used to clean and sort the geolocation polygons so that each WEA contained a column of latitude values and a column of longitude values, which is receptive to GIS. Next, the newly edited Microsoft Excel spreadsheet was imported into GIS and the polygons were overlaid on a US map—which will be discussed further in the results. Here, researchers can make observations, correlations, and conclusions about where past WEAs were sent and where future WEAs must be sent to mitigate economic damage, mitigate infrastructure damage, mitigate damage to coastal habitats and ecosystems, as well as preserve human life.

3.4. Author's Positionality

To help readers of this paper to understand the importance of creating more equitable policy and emergency alert systems, the authors of this paper have lived experiences that shaped the need to better accommodate marginalized individuals. Author Grinton is an African American male who comes from a middle-class family and has many family members and friends who have been affected by or live in poverty. Author Paige is a Black male who lived in a household below the poverty line and a coastal city for many years of his youth. While working on this study, both authors Grinton and Paige considered the reality of reflexivity and reflected on their feelings in relation to the marginalized individuals who experience the inequities that natural disasters bring, or the inequities that previous and current emergency alert systems contain. Both authors believe that this paper and study is a valuable effort to leverage our voices to support marginalized groups and individuals who deserve improved policies and technologies.

4. Results

Prior literature discussed and critiqued the equity issues related to current WEAs. Such literature highlights that current WEAs are not equitable. Therefore, this exploratory study sought to further highlight the inequities in WEAs by leveraging GIS to create a spatial analysis to highlight where SSW WEAs have been sent in correlation with poverty-stricken communities in coastal Virginia.

4.1. How Does Previous Literature Critique Equity in Wireless Emergency Alerts?

To date, research has been focused on FEMA's WEAs and on the resilience of coastal and marginalized communities to storm surge inundation [12,35,36]. This exploratory,

mixed-methods research study builds on prior literature surrounding the equity gaps in the current design and delivery of WEAs.

One 2015 study, which prioritized disabled people, assessed disabled people's awareness and understandability of WEAs [35]. This study was conducted from October 2013 until February 2014. The Rehabilitation Engineering Research Center for Wireless Technologies dispersed a survey to the public, in which 1830 people responded (1818 to the English survey version and 12 to the Spanish survey version). Of the 1830 respondents, 321 people reported they had a disability, and 202 people reported they were a caregiver to a disabled person. Further, the age range for this study fell between the ages of 18 to 92 and the average age of respondents was 50. Researchers from this study found gaps in the effectiveness of WEAs that must be addressed. For example, the results from this study highlighted that: (1) the public is unaware of WEAs, (2) WEAs' geo-targeting capabilities need improvements, and (3) WEAs need additional features to increase effectiveness. Furthermore, researchers from this study found that: (1) more than 33 percent of the sample population of 1830 found out about the existence of WEAs after receiving one and 27 percent were unaware if their cell phone was compatible with WEAs; (2) nearly 25 percent of the participants that received a WEA during this study took action and nearly the same amount did not take action because they were not near the event; (3) over 70 percent of the participants requested to see the choice architecture of the messages improved (e.g., more icons, graphs, or maps) embedded within the WEAs and 67 percent of participants requested links to more information. Moreover, participants in Bennett's study expressed their support for WEAs because these alerts were faster and more immediate than alerts from entities, such as the NOAA weather radio.

Next, a 2016 research study was conducted on how optimizing the accessibility of WEAs can be beneficial for marginalized residents [36]. Researchers from this study define marginalized residents as people who have been disproportionately affected by disasters (e.g., disabled people, elderly people, economically disadvantaged people, women, children, and immigrants). The findings from this study were based on a 2015 national WEA survey that was conducted by the Georgia Institute of Technology (Georgia Tech), which highlighted how disabled people respond to WEAs. Results from this study highlight that increased awareness and more exposure to WEAs increased disabled people's trust in and response to WEAs. Further, researchers measured the statistical significance using a Chi-squared test of variables, such as the behavioral response to WEAs, disability, and WEA awareness. More specifically, the Chi-squared analyses highlighted people without a disability were seven times more likely to own a cell phone compared to disabled people ($p < 0.001$). Moreover, though there were some discrepancies in the statistical results, as household income increased, so too did the likelihood of the ownership of a mobile phone. While cell phone use is becoming more abundant, WEAs are still inequitable.

Further, a 2018 research study highlighted the overall need for improved WEAs [12]. Researchers conducted a study on WEAs from the perspective of the alerting authorities (AOs). By understanding the perspective of the AOs, researchers explored the efficacy of potential extensions to FEMA's WEAs. The extensions address the importance of user context and to improve awareness of critical emergency response information. To do so, researchers from this study evaluated these potential extensions through two public usability trials. Researchers found that to increase the effectiveness of WEAs, WEAs needed (1) longer messages (upgrading from 90 to 360 characters), (2) improved geo-targeting aspects of WEAs, and (3) restructuring WEAs from a warning alarm to a rich information service. Still, none of these research studies focused specifically on persons of color.

4.2. What Is the Connection between Coastal Virginia Communities Experiencing High Rates of Poverty and Where WEAs Have Been Sent?

Results highlight that during hurricane season in Virginia (i.e., June 1st to November 30th), alerting authorities have leveraged FEMA's IPAWS system to deliver 9 SSW WEAs to coastal Virginia. To provide scale, from the creation of FEMA's IPAWS system in 2012 until

the present, Virginia communities received a total of 672 WEAs. Table 3 below illustrates the various types of WEAs that Virginia has received and the frequency of each WEA type. Moreover, Table 3 below highlights the small amount of SSW WEAs sent to coastal Virginia compared to other types of WEAs. For example, flash flood warning (FFW) WEAs and tornado warning (TOR) WEAs have been leveraged heavily, which highlights the opportunity to increase the number of SSW WEAs that are delivered to poverty-stricken coastal Virginia communities.

Table 3. Virginia WEA Frequency from September 2012 to April 2021.

WEA Type	EAS Alert Code	Frequency
Child Abduction Emergency	CAE	14
Civil Danger Warning	CDW	1
Civil Emergency Message	CEM	8
Flash Flood Warning	FFW	361
Local Area Emergency	LAE	23
Law Enforcement Warning	LEW	4
Required Monthly Test	RMT	3
Shelter In Place Warning	SPW	1
Storm Surge Warning	SSW	9
Severe Weather Statement	SVS	1
Tornado Warning	TOR	245
Winter Storm Warning	WSW	1
Hurricane Warning	HUW	0

Since storm surge is commonly associated with hurricanes, to get an estimate of the number of messages that could have been sent during hurricane events, we included hurricane warning WEAs (HUW WEAs) in this analysis to find that 0 HUW WEAs were sent. There was a total of 772 HUW WEAs (0 to Virginia) that have been delivered across the nation since 2012, compared to the 394 SSW WEAs (9 to Virginia). By including the number of HUW WEAs sent to Virginia and comparing it to the number of SSW WEAs that were sent to Virginia, we are highlighting the number of HUW WEAs sent to coastal Virginia should be the same or similar to the number of SSW WEAs sent to coastal Virginia. Further, this inconsistency in the HUW WEAs and SSW WEAs highlights that coastal communities are not being warned frequently.

As illustrated by the darker areas in Figure 5 below, coastal Virginia communities contain high amounts of households below the poverty level. Coastal cities, including, but not limited to, Southampton, Franklin, and Surry contained some of the fewest households below the poverty line. In contrast, coastal cities, such as Virginia Beach, Norfolk, and Chesapeake all contained high amounts of households that were below the poverty line.

Hurricane Dorian lasted from 24 August 2019 to 7 September 2019. Authorized users utilized FEMA's IPAWs system to send out storm surge warning WEAs to alert coastal residents in the geographic area of Hurricane Dorian. However, they only sent SSW WEAs to coastal Virginia nine times, but each of the nine messages was sent at the same time (4 September 2021, at 5:41 PM EST). Namely, coastal Virginia cities, including Chesapeake, Hampton/Poquoson, Newport News, Virginia Beach, Norfolk/Portsmouth, Suffolk, Isle of Wright, Surry, and James City, all received an SSW WEA. This alert said the following "NWS: Life-threatening STORM SURGE danger. FOLLOW THE INSTRUCTIONS OF LOCAL OFFICIALS." These WEAs were also delivered to coastal Virginia residents on 4 September 2019, the same time period that Hurricane Dorian struck Virginia. The geolocation of each SSW WEA that was sent on 4 September 2019 can be seen in Figure 6 below.
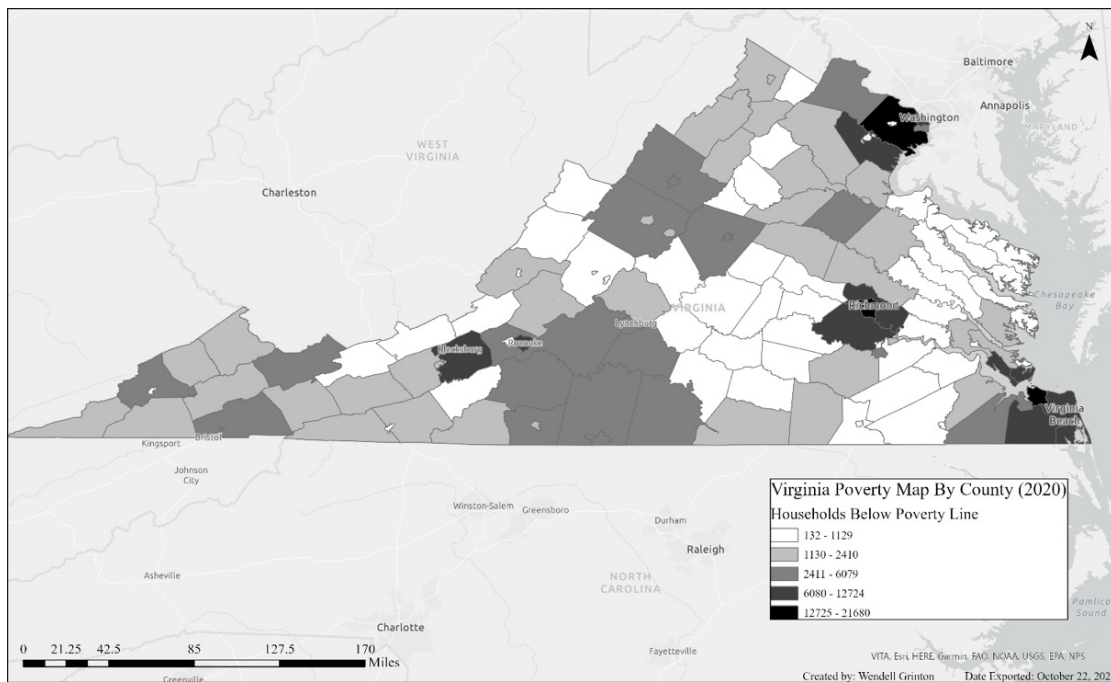
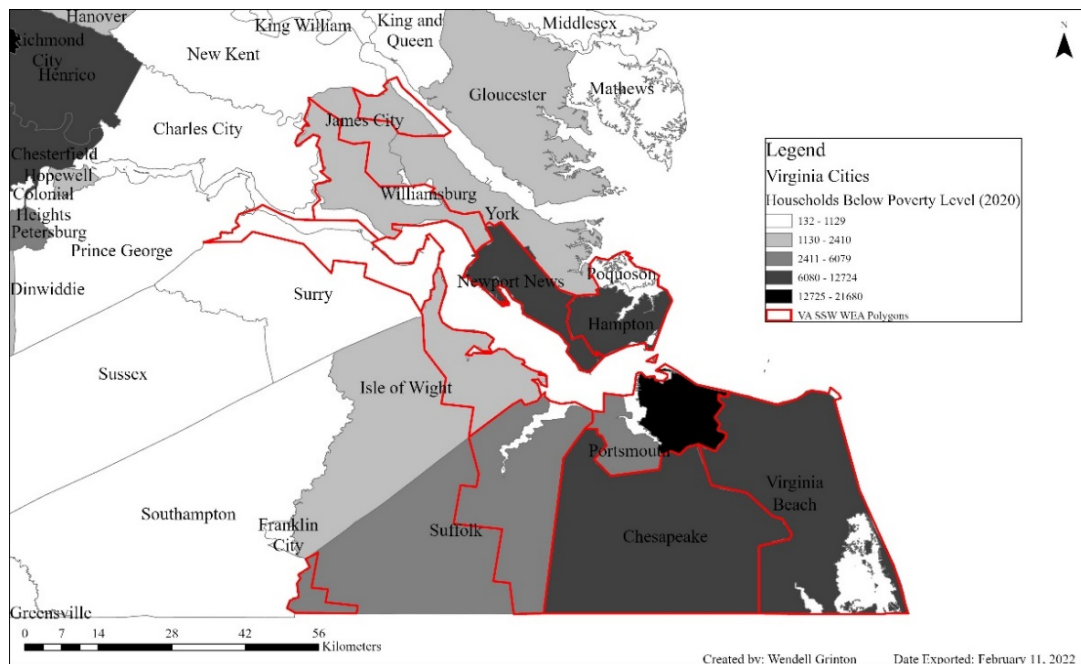**Figure 5.** Virginia poverty map per county in 2020.

Figure 6. Where SSW WEAs were sent in relation to households below the poverty level in 2020.

Figure 6 above highlights the geolocation of SSW WEAs in association with poverty-stricken coastal Virginia cities. The color of the cities varies based on the number of households below the poverty line. The lighter shaded cities are cities with the lowest number of households below the poverty line, while cities with the highest number of households below the poverty line are shaded black. Cities, such as Norfolk (19.2 percent), Williamsburg (15.9 percent), and Portsmouth (15.8 percent) contained the highest percentages of households below the poverty line. Contrastingly, cities such as Poquoson (5.1 percent), York (5.7 percent), James City (7.3 percent), and Virginia Beach (7.6 percent) contained the lowest percentages of households below the poverty line.

5. Discussion

The prior literature on WEAs describes opportunities for improved utility for marginalized groups [12,35,36]. Moreover, prior literature highlights the opportunity to make SSW WEAs more equitable. Similarly, coastal Virginia communities that are experiencing high amounts of poverty have received SSW WEAs. Further, as income increased, the likelihood of smartphone ownership increased [36], which indicates that residents in a lower-income class would be less likely to own a WEA-enabled smartphone—which would limit their ability to receive and leverage WEAs.

Previously sent SSW WEAs were sent to the coastal region of Virginia, as shown in Figure 6 above. Further, the SSW WEAs that were sent to coastal Virginia were to alert residents in high-risk areas of Hurricane Dorian. Moreover, the regions that were sent the storm surge warning WEAs contained high amounts of poverty.

Most of the areas that received SSW WEAs during the time of Hurricane Dorian contain a large number of households below the poverty line. This highlights that such areas contain more marginalized communities. Often, the residents in these communities struggle financially (e.g., live paycheck-to-paycheck) or may experience homelessness. If a storm surge event were to impact these marginalized communities, the substandard infrastructure in these communities would either be completely destroyed or heavily damaged. Because marginalized residents lack the financial capacity or the lack of insurance, they must rely on governmental emergency funding sources, such as FEMA's grants and loans, but such financial assistance may take weeks or months to arrive. Moreover, if marginalized residents receive financial assistance from the government, it may take them years to pay for damages sustained by storm surges or other natural disasters. On the other hand, residents of a higher socio-economic class often suffer the most financially, due to their assets being damaged, but can recover and rebuild faster than lower-income residents. Since natural disasters such as storm surge present social inequities, WEAs can help to reduce the social inequities that accompany natural disasters.

Authorized users have leveraged FEMA's IPAWS system to send 672 WEAs to Virginia, 9 of which were SSW WEAs to coastal Virginia from September 2012 to April 2021. With the lack of SSW WEAs sent to coastal Virginia and the high amounts of TOR and FFW WEAs sent to Virginia, an opportunity exists for FEMA to encourage authorized users to not only send future alerts more frequently but to improve the content embedded within SSW WEAs. Sending more alerts will give marginalized communities the opportunity to act fast and be better prepared for upcoming and more frequent natural disasters or emergencies.

In the dataset of WEAs from FEMA, only nine SSW WEAs had been sent to coastal Virginia during Hurricane Dorian; and each message was sent to a different coastal city in Virginia at the same time. Each SSW WEA that was sent to coastal Virginia cities read as "NWS: Life-threatening STORM SURGE danger. FOLLOW THE INSTRUCTIONS OF LOCAL OFFICIALS." Though Hurricane Dorian did not cause any confirmed causalities in Virginia, the results could have been much worse. This further highlights the dire need for WEAs to be sent more frequently to coastal communities before, during, and after a natural disaster, so that the devastation similar to or worse than Hurricane Katrina is minimized. With natural disasters increasing in frequency and intensity, the opportunity to send more WEAs, which can provide quick, efficient information to residents is critical.

Additionally, the content embedded within SSW WEAs is effective, but lacking at the same time. The first half of the SSW WEAs that were sent to coastal Virginia (e.g., "NWS: Life-threatening STORM SURGE danger . . . ") is effective in driving home the sense of urgency of this event by using language, such as "life-threatening" and "danger", as well as the use of capitalized text (e.g., "STORM SURGE"), however, the call-to-action (e.g., " . . . FOLLOW THE INSTRUCTIONS OF LOCAL OFFICIALS.") is lacking. The call-to-action is problematic because residents, especially marginalized residents, may be unaware of who their local officials are, and how to find the proper instructions to follow, or they may be in a frantic state, leaving them unable to make a quick, safe, and effective contextual decision. Moreover, future SSW WEAs can and should utilize more plain language because many

residents, especially those who are marginalized or impoverished, may have no idea what the storm surge is or how to prepare for it.

Moreover, SSW WEAs should also be customized to specify the local officials' names, highlighting the radio station, including a hyperlink to the website, or including the office location. Including specific information about the local officials can help marginalized residents who may be unaware of their local officials' contact information. Moreover, specifying how residents can contact or get in touch with their respective local officials can be critical in keeping residents safe and informed.

Current WEAs are unintentionally and inadvertently inequitable. Standardizing improvements to WEAs can reduce equity impacts. By creating more equitable WEAs, marginalized communities can leverage such alerts to become better informed and safer before, during, and after a natural disaster or emergency.

6. Conclusions

Current WEAs are unintentionally and inadvertently inequitable. Standardizing improvements to emergency alerting can create more equitable WEAs. Moreover, by creating more equitable WEAs, natural disaster casualties can be reduced. Further, though the prior literature discussed equity issues related to WEAs, this exploratory study builds on those ideologies to highlight that more storm surge warning WEAs (SSW WEAs) must be sent to not only coastal Virginia but similar areas experiencing issues with increased natural disaster events and poverty-stricken communities near coastlines. Wireless emergency alerts (WEAs) are a key component of FEMA's Integrated Public Alert and Warning System (IPAWS) that can benefit residents, especially marginalized residents, to stay safer and better informed before, during, and after a natural disaster or emergency. Though FEMA's IPAWS system can quickly send WEAs to residents in high-risk areas of natural disasters or emergencies, such alerts still contain equity gaps—which bottleneck WEAs' ability to protect vulnerable populations. These inequities often lead residents in low-income areas to suffer severe damage, simply because they were unaware of or unprepared for an upcoming natural disaster. Such severe damage is detrimental for marginalized residents, as a lot of these residents live from paycheck-to-paycheck, may experience homelessness, may have disabilities, may lack the necessary knowledge about natural disasters and relief opportunities for such disasters, or may not have the necessary insurance to help them rebuild. Some marginalized residents may have a disability surrounding their vision, hearing, speech, or cognitive impairment, which also puts such individuals at greater risk of being negatively impacted by intensified, more frequent natural disasters. Though WEAs can help coastal residents and marginalized residents be aware of and better prepared for upcoming natural disasters that are predicted to be intensified and more frequent, this exploratory study is a stepping stone to creating more equitable WEAs.

Future work will explore specific methods (e.g., customizing verbiage used, improving the call-to-action of each alert, improving the accessibility of WEAs for individuals with disabilities or who do not have access to current WEAs, and increasing the public's awareness of WEAs) that can be leveraged to improve the application and equity of WEAs. Further, future work can explore ways in which the methods from this study can be reproduced in other areas of the United States or internationally. Additionally, future work can leverage a weather analysis to track weather patterns over a given period of time and send specific WEAs to geo-targeted areas based on the weather conditions. Leveraging weather patterns can act as a predictor for the best time to disperse WEAs, as well as a quantitative trigger emergency alerting-based system.

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