INTERNET OF THINGS FOR WATER: REAL-TIME WATER LEVEL SENSING TO SUPPORT FLOODING EMERGENCY MANAGEMENT

IMPACTS OF SEA LEVEL RISE AND FLOODING ON LOW-INCOME COMMUNITIES IN HAMPTON ROADS, VIRGINIA

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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THE PROBLEM

Recently, flooding has become more frequent and damaging as a result of climate change, even in areas far from the coast. As the air in Earth's atmosphere becomes warmer, its water-holding capacity increases, meaning some areas of the world will see increased precipitation (Hausfather, 2018). Furthermore, precipitation will become more intense. The state of Virginia is projected to see an 8% increase in heavy precipitation for every degree Celsius the Earth warms, or a 24% increase by the end of the century (Hausfather, 2018). More frequent heavy precipitation and severe flooding will result in more property damages. Annual flood losses in the U.S. are projected to rise by over 25% to $40.6 billion by 2050 (Wing et al., 2022). The city of Charlottesville, Virginia currently has over 1,200 properties that are at risk of being severely affected by flooding over the next 30 years (Risk Factor, 2022). As heavy precipitation events become more frequent, the University of Virginia becomes more susceptible to dangerous and damaging floods.

The technical part of this paper will address Internet of Things (IoT) water sensors, which are used to monitor water level, rainfall, water flow, and soil moisture. These sensors will be deployed to create a flood monitoring network that university officials could use to respond to flooding on grounds. The Science, Technology, and Society (STS) section of this paper will utilize Langdon Winner's theory of technical arrangements as forms of order to analyze the disproportionate effects flooding has on low-income residents in Hampton Roads, Virginia. While the technical project will focus on the University of Virginia, a similar network of IoT water sensors could be deployed on a larger scale in Hampton Roads so that emergency services could better respond to increasingly frequent flood events.

FLOOD MITIGATION THROUGH IoT WATER SENSORS

The technical goal of the project is to gather water flow, rainfall, water level, and soil moisture content data in order to monitor flooding on grounds the University of Virginia. Water sensors that gather this data will be connected to The Things Network, which will allow for real-time feeds of data relevant to flooding. The Things Network is a global internet of things (IoT) ecosystem that connects devices using LoRaWAN, a long-range wide area network (Selimovic, 2022). Devices connected through LoRaWAN are able to communicate with each other and send data to other devices such as personal computers, creating a flood monitoring network. Plots and graphs of the data from the water sensors can be made through a simple run of Python code. The sensors run on batteries that last for multiple years.

While IoT water sensors do not have the power to stop floods, monitoring real-time data can help minimize damages by creating proactive solutions for communities. With flood sensor networks, emergency response teams can view in real-time when and where roads are flooded, how deep the water is, and the changing conditions of the flood (Semtech, 2021). A sensor network at the University of Virginia would allow emergency services to locate where the most damaging flooding is occurring and respond rapidly. Furthermore, the university could use IoT water sensors to better plan for future storm events. Less severe weather events can give university officials insight into the locations of weak spots on grounds where flooding problems are most likely to occur. Emergency services at the university could use this insight to reinforce those areas of grounds with better stormwater management to minimize the damage during more severe rainfall events.

A flood monitoring network of IoT water sensors similar to the one set to be deployed at the University of Virginia could be implemented on a much larger scale in Hampton Roads. The

Virginia coast is one of the most flood-susceptible regions in the U.S. because of coastal storms and its low sea level (NOAA, 20202). Hampton Roads has a large number of affordable housing units that have a sever risk of flooding (Turken, 2020). Deploying a network of IoT water sensors in low-income communities would give localities critical data to mitigate flood risk. Furthermore, because affordable housing tends to be concentrated (Buchanan et al., 2020), localities could protect a high number of low-income residents with a network of IoT water sensors. As is true with the network at the University of Virginia, a network in Hampton Roads would give emergency response teams real-time data that would help them pinpoint where the most dangerous flooding is occurring. It would also give municipalities data that could be used to make better flood plans for low-income communities, building regulations for affordable housing units, and zoning laws.

FLOODING IN LOW-INCOME COMMUNITIES IN HAMPTON ROADS

Affordable housing in Virginia is among the most vulnerable in the country. Between five and ten percent of homes sold by HUD in Virginia are in flood zones, compared to 0.1 percent of all other homes (Jingnan et al., 2021). The state ranks fourth with nearly 1,500 low-income housing units that will be at risk of flooding by 2050 (Turken, 2020). Some of these housing units are already exposed to as many as four flood events per year (Buchanan et al., 2020). Much of this housing is in Hampton Roads. In fact, 700 of the estimated 1,500 units are in the city of Norfolk alone (Sauer, 2022).

Virginia’s Hampton Roads is facing the highest rates of sea level rise along the Atlantic seaboard and is second only to New Orleans as the largest U.S. population center at rise (NOAA, 2022). Rates of sea level rise continue to accelerate, with recent projections estimating a rise of

1.7 feet by 2050 (Coutu, 2020). That number is projected to increase to 3 feet by 2080 and at least 4.5 feet by 2100. (Coutu, 2020). Furthermore, the acceleration at the majority of tide stations suggests that Hampton Roads may end up facing the higher end of sea level projections in the coming decades (Coutu, 2020). Three feet of sea level rise would impact between 59,000 and 176,000 people and cause between 162 to 877 miles of road to be inundated, either permanently or regularly (NOAA, 2022).

The increasing threat of flooding for residents of affordable housing and low-income communities has damaging effects. First, as affordable housing units are exposed to flooding more frequently, property damages will rise. These damages will likely be multiplied because of the lack of financial resources available to low-income residents (Foudi et al., 2017). Second, flooding can have a negative effect on the mental health of individuals who are frequently exposed to flooding (Foudi et al., 2017). As low-income neighborhoods in Hampton Roads experience worse flooding because of sea level rise, mental health problems are likely to become worse. Finally, flooding increases microbial and chemical loads in surface waters, which can lead to a serious health risk for residents (Yard et al., 2014). Surface water collected during flood events can contain higher level of pathogens like *E.coli* and enterococci (Yard et al., 2014). Increased flooding in low-income communities means residents will likely be more exposed to pathogens.

A major concern with regards to deploying a flood mitigation network of IoT water sensors is where they will be placed. In “Do Artifacts Have Politics?” Langdon Winner discusses the idea of technical arrangements as forms of order. Winner explains how technological change expresses human motives like the desire to dominate over others (Winner, 1980). He continues by discussing how the very process of technical development is so thoroughly biased that it regularly produces outcomes counted as breakthroughs by some and setbacks by others (Winner, 1980). This can be seen in flood-susceptible communities around the U.S. as well as in Hampton Roads. Martinich et al. (2012) found that socially vulnerable populations are more likely to experience disproportionate impacts of sea level rise and bear disproportionate costs of adaptation. Areas at risk of sea level rise but low levels of social vulnerability are more likely to have their shores fortified (Martinich et al., 2012). Nearly all the land was abandoned in the highest social vulnerability category, while almost all the land was armored in the lowest social vulnerability category (Martinich et al., 2012). So, while localities are investing in mitigation techniques for areas prone to flooding, these areas are generally not where socially vulnerable residents live. This can be seen in Hampton Roads, where expensive oceanfront properties are fortified while low-income residents are ignored as sea levels rise in their neighborhoods (Sauer, 2022). Similar techno-politics could occur with the introduction of a network of IoT water sensors. Social conflicts generally occur with the implementation of adaptation technologies when there is an uneven distribution of public money (Hinkel et al., 2018). Wealthier residents of localities generally have a louder public voice which can influence governments away from aiding low-income residents (Hinkel et al., 2018). If the network is deployed in oceanfront and high-income neighborhoods, socially vulnerable residents will once again be ignored. Localities in Hampton Roads must ensure that the flood mitigation network is deployed in low-income communities to aid residents who are the most socially and economically vulnerable.

RESEARCH QUESTIONS AND METHODS

One research question that will be explored is: What are local leaders in Hampton Roads doing to combat the disproportionalities that low-income residents face with respect to flooding?

This question is important because it targets the root of the problem. It is known that localities in coastal Virginia have promoted building and investment in infrastructure in areas that will not be viable in 50 years (Belt, 2019). It is also known that low-income residents are facing disproportionate effects from flooding, so it is essential to know why they are put into vulnerable positions in the first place. The question will be answered through a content analysis of policy documents from localities in Hampton Roads including comprehensive plans, hazard mitigation plans, floodplain maps, and affordable housing plans. Insight can also be gained through interviews of residents of affordable housing to see what the localities have done in response to increased flooding. The analysis will be assessed ethically and consequentially to discover if the plans and policy documents are equitable and consider the consequences of flooding and sea level rise in low-income areas.

A second research question that will be explored is: How does the Department of Housing and Urban Development evaluate the feasibility of potential sites for affordable housing? Similar to the first, this question targets another root of the problem. The federal government is placing affordable housing units in flood zones at 75 times the rate of other homes (Jingnan et al., 2021). The question will be answered through a content analysis of HUD documents about the process of evaluating site feasibility, and if that process involves looking at flooding potential over the next three decades. This analysis will be assessed ethically to discover if HUD's process for assessing new affordable housing sites are fair to the residents who will be occupying them.

CONCLUSION

Flooding has and will become more frequent and more damaging because of climate change, even in areas far from the coast, and especially in low-income communities. This will lead to significant economic loss and physical damages that disproportionately affect low-income residents. IoT water sensors offer a proactive solution for communities to mitigate flooding by giving real-time data to emergency service officials. This will allow for better planning for and responses to severe flood events. The technical goal of the research project is to create a flood mitigation network of water sensors that can be used by the University of Virginia and mimicked on a larger scale. The goal of the research paper is to gain insight into how localities in Hampton Roads are working to combat the disproportionate effects flooding has on low-income communities, as well as discover the process the Department of Housing and Urban Development uses to assess the feasibility of potential affordable housing sites.

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