Physical Exposure and Social Sensitivity

Estimating Sea Level Rise Impacts to Transportation through Vulnerability Assessment and Social Media Analysis

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A Research Report from the Pacific Southwest Region University Transportation Center

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The Pacific Southwest Region UTC conducts an integrated, multidisciplinary program of research, education and technology transfer aimed at *improving the mobility of people and goods throughout the region.* Our program is organized around four themes: 1) technology to address transportation problems and improve mobility; 2) improving mobility for vulnerable populations; 3) Improving resilience and protecting the environment; and 4) managing mobility in high growth areas.

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Disclosure

Principal Investigator, Co-Principal Investigators, others, conducted this research titled, "Physical Exposure and Social Sensitivity: Estimating Sea Level Rise Impacts to Transportation through Vulnerability Assessment and Social Media Analysis" at the department of Urban and Regional Planning, University of Hawaii at Manoa. The research took place from Sep 2017 to Dec 2018 and was funded by a grant from the Pacific Southwest Region University Transportation Center in the amount of $ $19,926. The research was conducted as part of the Pacific Southwest Region University Transportation Center research program.

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Abstract

Sea level rise, as one of the most wide-spread and important climate change factors, has become a pressing threat to transportation infrastructures, especially in coastal region. It is particularly a challenge for Hawaii given the geographic and topographic situation of these islands. While many research have been conducted to assess the potential impacts and physical vulnerability of transportation network to sea level rise, it is often difficult to validate the results due to the lack of empirical data. In recent years, social media provides a new opportunity to collect the perishable hazards data, identify the affected areas, and provide useful information for disaster management. Its value in capturing the views, needs, and experiences of the travelling public to support the development of long-term transport policy and transport planning has been acknowledged. However, despite its potential, social media has yet been applied to study the impacts of long-term, gradual hazards on transportation, indicating both a gap and an opportunity. This project proposes to combine traditional transportation vulnerability assessments with social media analysis to assess the potential impacts of sea level rise on transportation and propose adaptation suggestions. Through the examination of past extreme coastal flooding events in Honolulu, it demonstrates how twitter data, community mapping, and transportation vulnerability analysis could complement each other to understand the impacts of sea level rise on transportation from different perspectives and at different geographical scales.

Physical Exposure and Social Sensitivity: Estimating Sea Level Rise Impacts to Transportation through Vulnerability Assessment and Social Media Analysis

Executive Summary

Sea level rise, as one of the effects of climate change, has become a global, regional, and local issue. According to National Oceanic and Atmospheric Administration (*1*), the global sea level has been rising over the past century, approximately 2.6 inches above the 1993 average and it continues to increase at a rate of about one-eighth of an inch per year. In the United States, roughly 40 percent of the population lives in relatively high-population-density coastal areas, where sea level plays a role in flooding, shoreline erosion, and hazards from storms (*2*) Sea level rise and more frequent extreme events are expected to critically affect transportation (*3*). According to National Research Council (*4*), approximately 60,000 miles of coastal roads in the United States are already exposed to flooding from coastal storms and high waves.

This project combines transportation vulnerability assessments with social media analysis and community mapping to understand the potential impacts of sea level rise on transportation and potential adaptive responses. Social media provides a good overview of people's concern and attitude towards flooding's impacts on transportation in general at the global, regional, and state level. Localized transportation vulnerability analysis helps to better understand where and how local communities' transportation accessibilities to different types of opportunities are being affected by sea level rise related flooding. Finally, community mapping and outreach helps to validate and interpret the results of vulnerability analysis and social media analysis, helps transportation researchers and planners to better understand the local problem and engage the local communities in response to sea level rise. The three approaches complement each other and generate the following key findings:

- At the global level, flight cancels and travel delay are the major impact of flood and king tides on the transportation system.
- At the national scale, coastal states have endured more severe impact of flooding hazards on transportation compared to inland states. In another word, coastal flooding has more severe impacts on people's travel than other types of flooding.
- At the local level, for City and County of Honolulu, the vulnerability in terms of accessibility reduction is unevenly distributed spatially. The North part of the island near Kahuku, the east part near Hawaii Kai, and the central part near Honolulu Harbor may experience more impacts from tidal flooding than others. These communities also have a low level of accessibility even without coastal flooding.
- Accessibility reduction correlates positively with the percentage of affected road in the TAZ, the total length of affected roads, percentage of residents in educational, health and social services industries, and percentage of white alone

population, and negatively related with the percentage of residents in public administration, information, and retail industries. Poverty levels, car ownership, age, minority status, and urban rural settings are not significant.

- Work related trips and grocery shopping trips have been more affected than others.
- Finally, despite the dominant concern for sea level rise impacts on future travel, the local community in general considers the impacts of the sea level rise as manageable if appropriate actions are taken.

Introduction

This project proposes to combine transportation vulnerability assessments with social media analysis and community mapping to understand the potential impacts of sea level rise on transportation and potential adaptive responses. Through the examination of past extreme coastal flooding events in Honolulu, it could provide empirical evaluation for potential sea level rise impacts on transportation. The findings not only have practical significance to the case study area, but also have the potential to be generalized to similar coastal regions. The approach and methodology could also be applied to assess coastal hazards impact to transportation in other places.

Study Background

Sea level rise, as one of the most wide-spread and important climate change factors, has become a pressing threat to transportation infrastructure, especially in coastal region (*4*). It is particularly a challenge for Hawaii given the geographic and topographic situation of these islands (*5*). While much research have been conducted to assess the potential impacts and physical vulnerability of transportation network to sea level rise (*6-8*), it is often difficult to validate the results due to the lack of empirical data. In recent years, social media provides new opportunities to evaluate hazard impacts in human perception, identify the affected communities, and identify useful information for disaster management (*9-11*). Social media's potential in collecting information relevant to transportation policies has also been demonstrated (*12*). Its value in capturing views, needs, and experiences of the travelling public to support the development of long-term transport policy and transport planning has been acknowledged (*13*). Despite its potential, social media has yet been applied to study the impacts of long-term, gradual-changing coastal hazards (such as sea level rise) on transportation, indicating both a gap and an opportunity.

Study Objectives

As a result, this project proposes to combine transportation accessibility assessments, community mapping, and social media analysis to assess the potential impacts of sea level rise on transportation by achieving the following objectives.

- Identify the local roadways vulnerable to tidal flooding in City and County of Honolulu. Assess the accessibility reduction with and without the vulnerable road segments to identify the most physically exposed communities.
- Understand from the travelers' perspective the major concern, attitude, and aspects of transportation being affected by flooding and coastal flooding in particular, at global, regional, and city levels through social media analysis and community mapping. Identify the most socially sensitive regions.
- Support the development of adaptation strategies by identifying the most physically vulnerable and socially sensitive areas and discovering people's major concerns in transportation during such events

Report Layout

To achieve the study objectives, this report presents the research details in the following chapters.

Chapter 1 presents the introduction and objectives of the study.
Chapter 2 provides a review of related concepts and knowledge from the literature.

Chapter 3 introduces the case study area, focused sea level rise scenario, and analysis geographical scales.
Chapter 4 describes the data, methodology, and general finding related to flooding's impacts on transportation using social media analysis.
Chapter 5 shows the data, methodology, and results to identify the most physically vulnerable communities in City and County of Honolulu.
Chapter 6 details the data and findings from community mapping activities in City and County of Honolulu.
Chapter 7 summarizes the key findings of the research.

Literature Review

Sea Level Rise and Transportation

According to the IPCC (*14*), since the peak of the last ice age, average global sea-levels have risen by more than 120 meters. Climate change is on track to raise sea level by one to three feet by the end of century (2100) even with the most aggressive emission cutes, due to the Greenhouse Gases already emitted (*15; 16*). The conservative IPCC Fifth Assessment Report (*16*) projects that the earth is expected to experience an additional sea-level rise of 0.26 to 0.82 meters by the end of this century. Semi-empirical models show that higher rate of sea level rise (i.e. 1 to 1.5 meters) is more likely to be reached by 2100 (*17-19*). Although the impacts of sea level rise vary from place to place due to differences in the land elevation and SLR rate, but in general, the physical, economic and social consequences are massive; hence it is widely viewed as a threat to national security.

Studies found climate change has had impacts on land-based transportation, air transportation, and marine transportation such as roads, airports, railways, and ports (*20*). The increase in frequency and intensity of some extreme weather events has increased the risk of delays, disruptions, and damage across the U.S transportation systems (*20*). For land-based transportation system, road networks are significantly vulnerable to sea-level rise impacts, such as 1) erosion and subsidence of road bases, 2) flooding of underground tunnels and low-lying infrastructure, 3) inundation of roads and rail lines, 4) traffic congestion, and 5) infrastructure damage due to increased storm intensity (*21*). Road infrastructure in coastal areas is particularly sensitive to more frequent and permanent flooding from sea level rise and storm surges. SLR has four significant impacts in coastal areas: 1) coastal flooding, 2) coastal erosion, 3) exacerbated land subsidence, and 4) saltwater intrusion (*21*).

Different studies have discussed various impacts of climate change and SLR on transportation infrastructure. Studies have shown that recurrent flooding and inundation have significantly burdened major roads in low-lying areas in Washington D.C, Maryland, Virginia and New Jersey (*22-25*). In Washington D.C., the potential damages from SLR on transportation infrastructures account for 27% of major roads, 9% of the rail line, and 72% of the ports (*21*). The type of impacts includes road closure, detour, and traffic congestion. The extent of effects might be more significant in the future and require relocation of military facilities, for instance, in the case of Hampton Roads. The Hampton Roads areas in Virginia, known as the highly populated center and home to the largest concentration of military capacity and activities in the United States, has been experiencing the highest rates of sea-level rise along the entire U.S East Coast. One of the key findings on the study on sea-level rise in the area has shown that residents could be permanently or regularly inundated by 3 feet or sea-level rise. On the road study, similar 3 feet SLR rate will impact about 877 miles road at the high estimate and 162 miles at the low rating. Sea level at Sewells Point, Norfolks, in the last 80 years has risen 80 percent higher (14.5 inches) than the global average (8 inches) in the previous 140 years (*22; 25*). The subsidence process or the sinking of the land, has also contributed to land being flooded and is projected to remain constant in the region (*22*).

SLR impacts on the West Coast are just as exacerbating as in the East Coast; erosion and flooding are a major concern. The vulnerability analysis of road networks shows that presently, approximately 200 miles of roads are at risk due to the aggravating effects of rising sea levels. San Francisco Bay region is one of the most vulnerable road networks, as well as some low-lying terrain and coastal areas in Florida such as Coral Springs, Sunrise, Pompano, Hollywood, Tama, Kendale Lakes, etc., which has been experiencing inundation and structural damage. With an increase of 1.4 m of SLR, various road networks along the Pacific Coast in California are further at risk (*21*).

In Hawaiʻi, sea level has risen at approximately 1.5 mm/yr (0.6 in/decade) over the past century (*1*). (*26*), on the Development of a Model to Simulate Groundwater Inundation Induced by Sea-Level Rise and High Tides in Honolulu identified tidal flooding as equally damaging in Hawaiʻi, particularly in Waikiki area known as a major tourism center. Flooding that is driven by SLR has become more tangible since the past several years (*26*). Pope in Paradise in Peril shows evidence of the detrimental effect of the king tides along coastal development near Hawaii's shoreline (*27*). In recent month, king tides are said to be higher than average compared to previous years. Further raise could negatively affect the tourism and business industries, coastal residents, and the wildlife ecosystem. Seasonal flooding, coastal erosion, inundation, and interaction with the groundwater table are also the threats that have been apparent in Hawaiʻi. In Mapunapuna industrial district of Honolulu, heavy rains during monthly highest tides have submerged the road a waist deep because storm drains were backed up with high ocean water (*28*).

In 2012 when the superstorm Sandy hit New York, it caused a massive 14-foot storm surge and flooded some subway stations. This transportation service was shut down for days. The effect was much more significant because NYC is home to the most extensive public transportation system in the U.S. The hurricane Sandy provided analog to SLR, and the coastal zone will be increasingly at risk to episodic flood events superimposed on a more gradual rise in mean sea level (*29*). The analysis by Climate Central Research (*30*) aligns closely with the projection made by the NYC Panel on Climate Change projects the local sea level to rise from 0.6 - 1.8 feet by 2050, and 1.9 - 6.3 feet by 2100, using sea level in 2012 as the baseline.

Another non-motorized transportation mode such as bicycle lanes and pedestrian walkway are also prone to the effects of SLR and hence result in a decrease of accessibility/mobility in some low-lying parts (*31; 32*). The impacts have been route closure, detour, or and completely impassable (*31; 32*). In the case of Jacksonville, Florida, the nuisance flooding has occurred a few times a year, for instance, during a spring full moon tides (*32*). The Intracoastal residents have experienced waterfront in front of their houses, causing not only damage to their home and property but also disruption in daily activities (*32*). The high water level has made it difficult to move around, for instance from their house to the mailbox, and limit access to parks, and other locations (*32*). Some residents have forced out their completely flooded neighborhood (*32*). The flooding has had not only physical impact but also emotional because the residents expressed frustration for not able to be mobile (*32*). Besides Jacksonville, the Climate Central Research indicated population living in other low lying areas such as Sacramento, California, Virginia Beach, Virginia, Miami, and New Orleans are coastal and river cities most threatened in the U.S (*32*)

Since the beginning of this century, the Center for Climate Change and Environmental Forecasting at U.S. Department of Transportation began to pay attention to the issue of climate change and transportation. In 2002, it held the first workshop with the intent to explore the potential impacts of climate change on transportation and to delineate the research necessary to better understand these implications. Since then, many studies have been conducted to evaluate the impacts of climate change, particularly sea level rise, on transportation infrastructures (*7; 20; 33-36*). These studies addressed many relevant issues, ranging from sea level rise prediction to the identification of vulnerable transportation facilities and the associated economic costs, providing valuable information for sea level rise adaptation in coastal areas. However, most of these early studies focus on large scale qualitative analysis (*20; 33; 34; 37*); which is not specific or accurate enough to support local adaptation. Later some localized, quantitative studies have been developed. For instance, Bloetscher et al. (*38)* identified vulnerable Florida's state transportation infrastructure in Dania Beach and Punta Gorda under local sea level rise scenarios projected with Army Corps of Engineers' scenario-based methodology, using Florida Department of Transportation (FDOT) information system, satellite imagery, local roadway and hydrologic data. Yet many studies only considers physical exposure rather than system impacts (*8; 38; 39*). To overcome these limitations, some researchers used transportation model to estimate the system impacts (*7; 40-42*). For example, Lu and Peng (*41)* assess Miami's transportation network's vulnerability to projected 2060 sea level rise scenarios using accessibility based index.

Nevertheless, despite all these research efforts, there are two major limitations in sea level rise transportation impact studies. First, given the long-term and gradual nature of sea level rise, such study usually focuses on future extreme scenarios. Therefore, it is difficult to validate the results due to the lack of empirical data. Second, none of the studies discussed travelers' experience, views, and concerns, and hence the social sensitivity to such impacts and the public's major concerns during such events has been little studies and are little understood.

Social Media Analysis

In recent years, social media provides new opportunities to empirically evaluate hazard impacts in human perception. Despite voluminous research in hazard vulnerability and resilience, the understanding and the quantitative assessment of such concept remain difficult. The documented hazard data, such as property loss, injuries or casualties, and the identified social vulnerability indicators (such as income, demographics, and education) are not sufficient to reflect the multifaceted impacts of the hazards to the society (*43-45*). Other important aspects, such as quality of life, social ties, social cohesion, and psychological conditions (*46-48*), which could be used to develop actions and plans to enhance resilience, are not documented in the traditional data sources. Moreover, traditional data have been confined mostly to using static data collected at scheduled time intervals (e.g. census data and health data) (*43; 44*). The lack of timely and fine-resolution information about humans' behaviors and thinking hampered the evaluation of hazard vulnerability and resilience as a dynamic process.

With the development of Web 2.0, social media networks are becoming platforms where numerous users publish and exchange information at any time in any place. In social media, every user acts as an intelligent sensor that collects and shares information about their local environment. The huge amount of real-time information crowdsourced in social media can be used to study individuals' status, thoughts, and behavior related to natural hazards and climate change, which can be a valuable source of information to understand vulnerability as a dynamic process. With the increasing popularity of GPS-enabled mobile devices, more and more messages in social media are associated with geographical locations. These geo-tagged data allow us to uncover not only what people are thinking/doing but also where they are located. With geo-tags (the coordinates), social media data has been advocated to be linked with the socio-economic conditions of the users' locations, which opens a new avenue for spatial, social, and environmental studies. At the same time, more and more people are turning to social media networks to obtain up-to-date information and to share information during emergencies. Social media not only opens another channel of broadcasting messagges to the public, but also allows for two-way communication between emergency managers and the public. In some cases, social media can facilitate the information broadcasting in emergency events and strengthen the social ties within a community, which can potentially strengthen the resilience of the community.

According to (*49*), the utility of social media for hazard response has two fundamental functions: (a) as a tool to monitor emerging crises and events as transmitted by users, and (b) as an effective means of communicating emergency information to a broad audience. In recent years, pioneering work has done to leverage social media data to investigate human dynamics in public celebration (*50*), wildfire (*51*), earthquake (*52*) and tropical storm (*53; 54*). In particular, Kaewkitipong, Chen and Ractham (*10)* demonstrate that social media could be used to meet different information needs in 2011 Thailand flooding disaster. De Albuquerque et al. (*9)* show how georeferenced social media messages enhance the identification of relevant messages related to the 2013 River Elbe Flood in Germany. Dashti et al. (*11)* manifest geo-tagged tweets data could be used to collect data about infrastructure performance and the progression of geological phenomena during and after the 2013 flooding in Colorado. These studies have demonstrated that social media data are potentially a valuable source of information about human behavior and thinking in natural hazards, which is lacking in traditional data sources. So far, a number of techniques for acquiring, mining and analyzing social media data have been developed. The rapid growth of social media users enables us to acquire data representative of a large population. All these advancements in the Big Data era have provided opportunities for gaining new insights to community vulnerability to gradual coastal hazards such as sea level rise which cannot be gained using traditional data. However, more research is needed to develop methodologies, algorithms and tools to transform social media data into useful and actionable information to construct concrete plans and strategies to reduce vulnerability and strengthen resilience.

Social media's potential in collecting information relevant to transportation policies has also been demonstrated (*12*). Its value in capturing views, needs, and experiences of the travelling public to support the development of long-term transport policy and transport planning has been acknowledged (*13*). However, despite its potential, social media has yet been applied to study the impacts of long-term, gradual-changing coastal hazards (such as sea level rise) on transportation, indicating both a gap and an opportunity.

Community Mapping and Outreach

Since the 1960s, urban planning has evolved from the rational approach to incorporate and emphasize the importance of community engagement (*55*). The important features of communities are different for every community member and by better understanding how communities values their surroundings, researchers and policy makers will have a better understanding of the problem and priorities (*55*). To complement the data provided by social media, localized community outreach is needed to help transportation researchers and planners better understand the problem and engage the local communities in response to sea level rise.

Community outreach and engagement can play a pivotal role in helping researchers interpret the results of vulnerability analysis and social media analysis and create shared value within a community to sea level rise. Local knowledge is a valuable resource to foreign academics and cartographers and can mitigate possible dangerous conditions and cultural appropriation (*56; 57*). Utilizing community for the purpose of mapping could help to understand the power dynamic with vulnerable communities, have interpersonal effects, and create positive community outcome beyond the physical mapping of geographic space (*55; 57; 58*). Community mapping is a way planners can use to bridge the gap between theory and practice, empower the local community to understand the problem, build consensus on priorities, and begin to develop responsive plans that will have more community buy-in and foster a sense of place (*55; 59*). Community mapping has been used to map informal and isolated areas of the Global South (*56*). Building community relations, leadership and process centric community mapping are the key factors to success in the process (*57; 58; 60*).

In recent years community mapping has been used as a tool for climate change adaptation and disaster management by building social capital and engaging community in the planning process (*58; 60; 61*). In New Zealand community mapping helped researchers identify individual communities' values and key areas to protect from Sea-Level Rise while the community learned about their vulnerable assets (*58*). The research done in New Zealand was so successful because the researchers focused on the process of community participation and less about specific results (*58*). Community mapping with limited community engagement has less beneficial results for researchers, communities, and policy makers (*62*). Continued engagement with communities seems to be where the most beneficial planning strategies come from (*56-58; 60*).

As a result, this project proposes to combine transportation vulnerability assessments with social media analysis and community mapping and engagement to assess the potential impacts of sea level rise on transportation and explore individual's potential adaptation responses.

Case Study Area Tidal Flooding Scenarios

City and County of Honolulu is selected as a case study given its special vulnerability to sea level rise (*5*). In Hawaii, a 0.15 meter increase of sea level has been observed in the past century with an expected increase of 0.9 meter by 2100 (*63*). Sea level rise may also cause substantial groundwater inundation. (*64*) estimate that "0.6 m of potential sea-level rise causes substantial flooding, and 1 m sea-level rise inundates 10% of a 1-km wide heavily urbanized coastal zone" in Honolulu. The impacts of sea level rise have already revealed in recent years. Data from NOAA tide stations around Hawaiʻi show that observed water levels have been 3–6 inches above predicted tidal heights since early 2016 (*65*). In late April, levels peaked at more than 9 inches above predicted tides at the Honolulu Harbor tide gauge, resulting in the highest daily mean water level ever observed over the 112-year record (*65*). The combination of elevated water levels, seasonally high tides, and a large south shore surf event resulted in flooding on April 28, 2017 (*65*). Despite the severity of the problem, there is a lack of understanding of sea level rise's potential system impacts on Hawaii's transportation roadway network, a lack of empirical study about social sensitivity to such impacts, and a need to identify the most vulnerable communities for adaptation prioritization.

To develop the scenario for analysis, the magnitude of extreme sea level occurrence is extracted from historical tidal records at Station 1612340 Honolulu, HI, provided by NOAA Center Operational Oceanographic Products and Services. The estimation of extreme still water flood exceedance probability levels (i.e. 1%, 10%, 50%, 99% Annual Exceedance Probability) relative to the tidal datum and the geodetic North American Vertical Datum (NAVD88) are also obtained from (*2*). The water levels are then converted to Mean Higher High Water levels to generate the tidal flooding map using the bathtub approach and tidal surface data provided by NOAA (*66*).

To determine the study year for social media analysis, hourly height water level tidal records in recent years (2012-20da18) are searched to extract the duration (Table 3-1) and timing (Appendix A) of tidal water flooding events. Table 3-1 shows that the number of tidal flooding events and durations increase in recent years, especially in terms of annual flooding event. The duration and frequency of transportation network disruption increases with such trend as well. Because of the high frequency and duration of tidal flooding events in 2017, social media analysis is performed to assess people's opinion and perception using 2017 data.

Table 3-1 Duration and Frequency of Coastal Flooding on Oahu 2012-2018

Annual Exceedance Probability Levels (2017)	**Water Level (MHHW datum)**	**Duration of Events (hours)**						
		2012	2013	2014	2015	2016	2017	2018
1%	1.41 ft	0	0	0	0	0	0	0
10%	1.18 ft	0	0	0	0	0	10	0
50%	0.89 ft	0	0	1	0	26	63	11
99%	0.49 ft	33	45	93	48	229	423	46

To get sufficient data to support examination of coastal flooding's impact on transportation specifically and to compare the impacts across different geographical regions, the social media analysis focuses on three geographical scales: the global scale, the state scale in United States, and City and County of Honolulu in specific. The social media analysis results provide an overview of the potential impacts of sea level rise on transportation and help to design localized transportation vulnerability assessment and community mapping afterwards. The GIS-based transportation vulnerability assessment and community mapping analysis helps to better understand the impacts and responses at the local scale.

Social Media Analysis

Data Acquisition and Storage

In this project, twitter data were acquired from the Internet Archive (archive.org), which is a non-profit online library of digital content. Twitter data published in the archive were streamed by a team of volunteers using the streaming API of Twitter. The data represent 1% sample of entire data posted in Twitter at the real time. In this project, the twitter data in 2017 were downloaded, which includes over a billion records (tweets) and occupy 344GB computer storage space. All the downloaded twitter data were stored in MongoDB, which is a document-oriented database system that support distributed data storage, load balancing and map-reduce operations. Stored in MongoDB, twitter data can be queried by keywords, geographic locations and time.

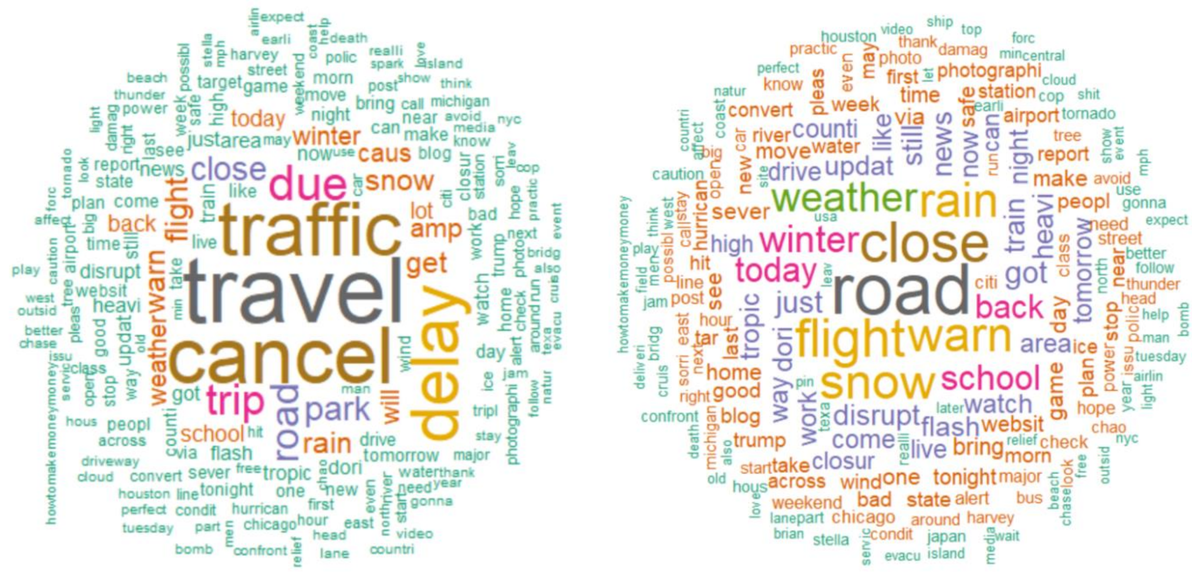
Analysis of Global Data

Two lists of keywords related to hazard and transportation are identified respectively. The hazard keywords include “flood”, “king tide”, and “inundate”. The transportation keywords include "traffic", "congestion", "delay", "travel", "road closure", "parking", "driveway"," trip", "cancel". Tweets that contain at least one word in the hazard keyword list and one word in the transportation keyword list are queried from the database. In total, only 1723 tweets were retrieved. These retrieved tweets contain information about both the hazards and the hazard impacts on travel and transportation. Compared to 462,016 tweets containing only the hazard keywords and 2,458,120 tweets containing only the transportation keywords, the small amount of tweets containing both keywords indicates that very few people talk about hazard impacts on transportation and travel in Twitter.

Before analysis, text cleaning will be conducted to remove useless information in the Twitter data. First, using key-word search, only tweets containing hazard-related terms will be selected and noise in the original text message will be cleaned. For example, URLs (such as ‘http://’, ‘"’ ‘&’ etc.), punctuation characters and stop words (e.g. the, is, at, which, and on) will be removed. In addition, spam tweets, such as advertisements or defraud messages, will be removed as well. Then, all words in tweet messages will be converted to a base form. For example, ‘taken’, ‘took’ and ‘takes’ will be all converted to ‘take’. This conversion will ensure that different morphological forms of a word, all of which have similar or identical semantics, are considered identical in the following text mining and analysis. After these processing steps, only the essential terms in tweet messages are retained and converted into consistent forms, which can facilitate the following text mining steps that are mainly based on key-word matching.

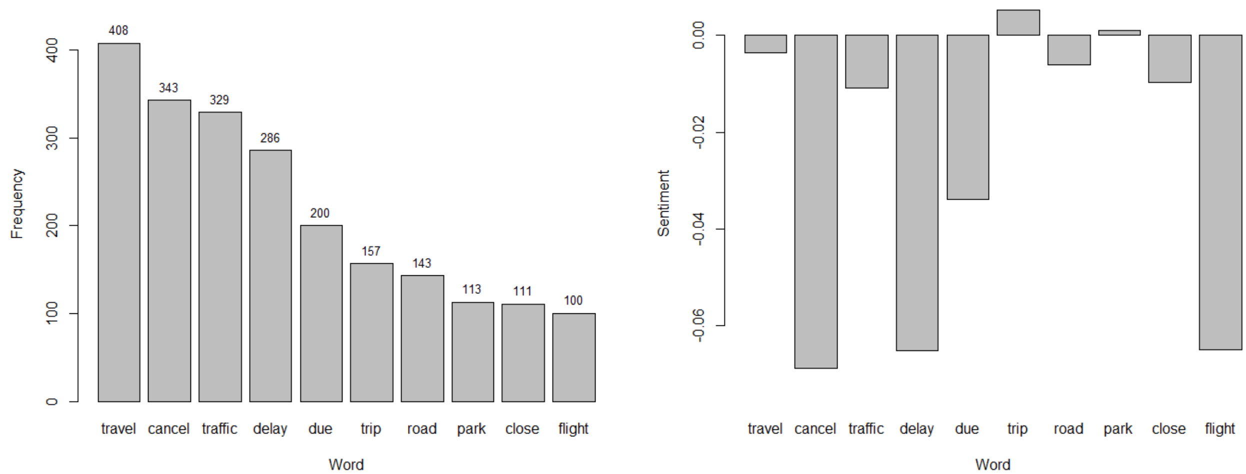
Figure 4-1, Figure 4-2 (a) and Figure 4-3 (a) show the most frequently appeared words in the retrieved tweets, which indicate other issues related to hazards and transportation that people talk about in Twitter. In general, “travel”, “cancel”, “traffic”, “delay” are the most frequently appeared transportation keywords. Excluding the transportation and hazard keywords, ‘flight’, ‘snow’, ‘warn’ and ‘rain’ most frequently appeared in the tweets. Additionally, sentiment analysis was conducted to evaluate people’s attitude and emotional state expressed in the twitter messages. Sentiment analysis is also referred to as opinion mining, which use computational linguistic methods to classify textual contents into a binary opposition. Texts containing words associated with positive/for/happy/optimistic meanings will be assigned a positive sentiment, whereas texts containing negative/against/sad/pessimistic meanings will be assigned a negative sentiment. The sentiment scores range from -1 to 1, where -1 indicate the most negative sentiment and 1 means the most positive sentiment. Average sentiment scores of tweets contain the frequently appeared words are calculated. In the analysis including the keywords (Figure 4-2(b)), tweets that contain 'cancel', 'delay', and 'flight' have much lower lowest sentiment, indicating that people have the most negative opinions to the impacts on flight cancel and delay. In the analysis excluding the keywords, the average sentiment of tweets containing 'warn' is lowest, indicating the panic and pessimistic opinions expressed in tweets that contain warning information. Additionally, tweets that contain weather and winter also have relatively lower sentiment.

Figure 4-1: Word clouds of the retrieved tweets. (a) with the hazard and transportation keywords; (b) without the keywords.



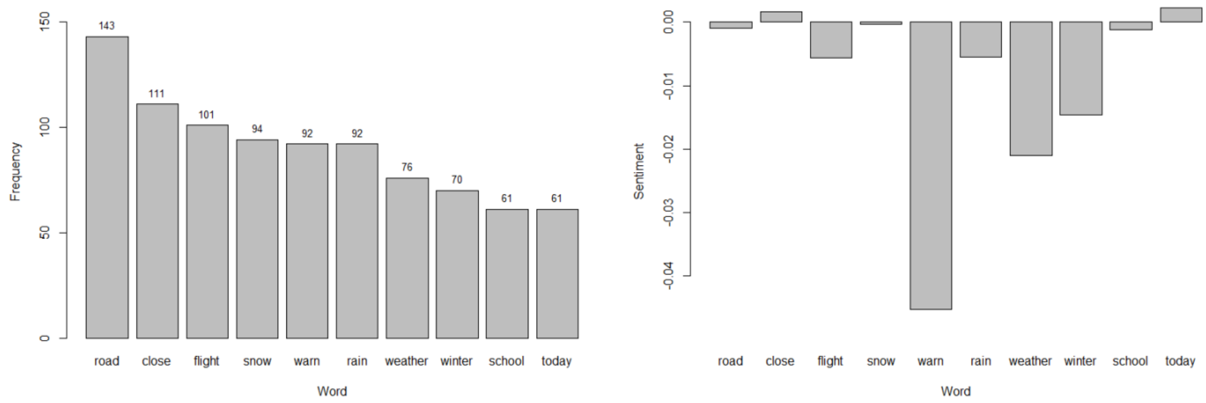
(a) (b)

Figure 4-2: Word frequency and sentiment including the hazard and transportation keywords. (a) Most frequently appeared words in the retrieved tweets. (b) Average sentiment of tweets that contain the keywords in (a).



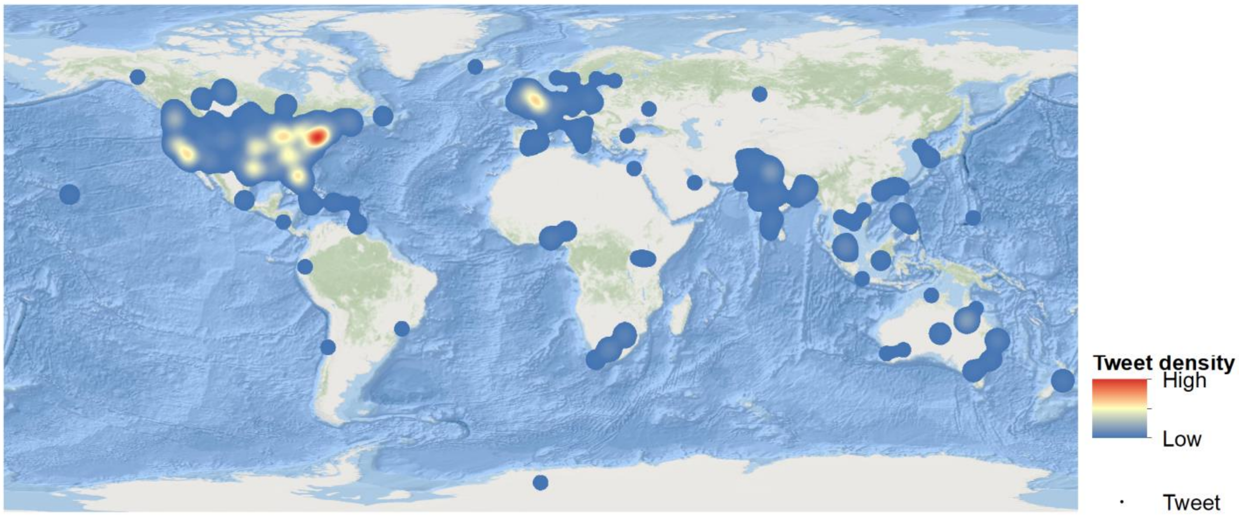
(a) (b)

Figure 4-3: Word frequency and sentiment excluding the hazard and transportation keywords. (a) Most frequently appeared words in the retrieved tweets. (b) Average sentiment of tweets that contain the keywords in (a).



The geographic components (e.g. geotag or user location) of the tweets are geocoded into longitude and latitude coordinates for mapping and spatial analyses. In total, 1106 of the 1723 tweets were geocoded into specific locations. The kernel density map in Figure 4-4 illustrates spatial location of the geocoded tweets. As the queried keywords are in English, most of the high density clusters are distributed in United States and United Kingdom. Within U.S., the clusters can be identified around major cities, where the population density is high.

Figure 4-4: Kernel density map of geocoded tweets containing both hazard and transportation keywords.



Analysis of State Data

To eliminate the effect of population distribution, the ratios of tweets containing the hazard and transportation keywords to the population were calculated within state boundaries (Figure 4-5). In general, coastal states have higher ratios of tweets containing the two sets of keywords compared to inland states. Particularly, the high ratios in Florida, Oregon and Delaware are noticeable, indicating the hazard impacts on transportation are more discussed in social media in these states. Figure 4-6 illustrates the average sentiment of tweets containing the two sets of keywords. The average sentiment in coastal states are generally lower than the inland states. Particularly, the states along the Gulf Coast except Florida have the most negative sentiment, indicating that negative, pessimistic and said sentiment are often associated with tweets containing the hazard and transportation keywords. The negative sentiment in the Gulf Coast would further indicate that the hazard had more severe impacts on transportation and people's lives in 2017, when multiple hurricanes (including Harvey and Irma) struck this region. The relatively positive sentiment in Florida, compared with other Gulf Coast states, would be attributed to the better economic conditions and different demography in the state. Additionally, the negative sentiment in Montana and North Dakota, which are inland states, is worth-noting and deserves further investigation. In general, both the distributions of ratios and average sentiment at the state level revealed that the hazard impact on transportation is more severe in coastal counties than inland. Compared with all states, the ratio of the retrieved tweets in Hawaii ranked 33th and the average sentiment in Hawaii ranked 9th (positive), indicating that Hawaii is not as affected as other coastal counties in the U.S.

Figure 4-5: Ratio of tweets containing the hazard and transportation keywords to population in United States.

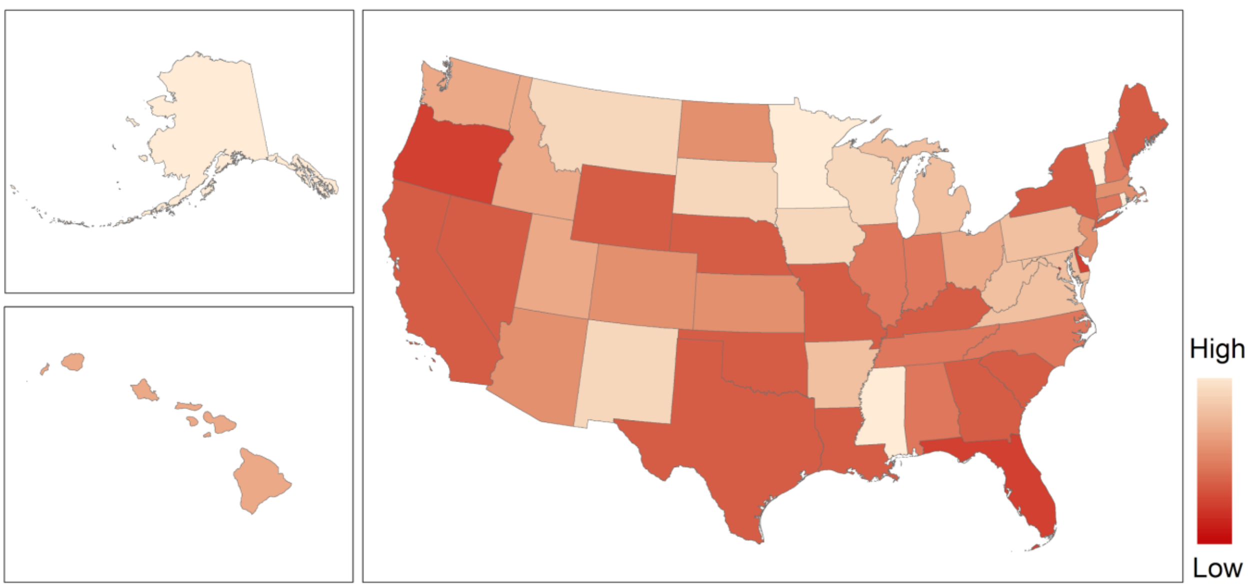
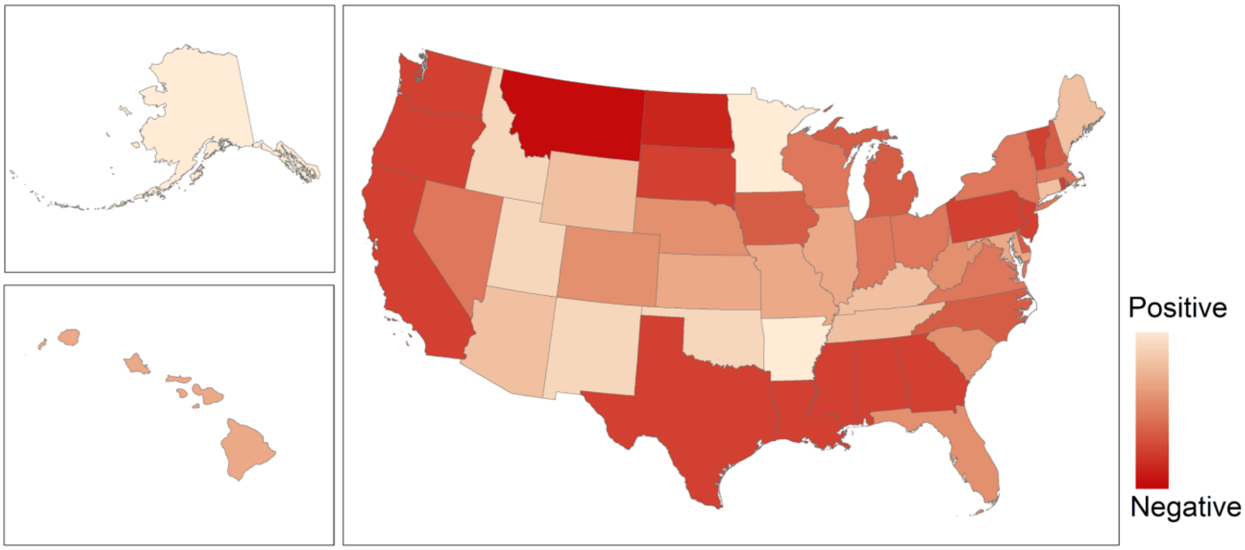


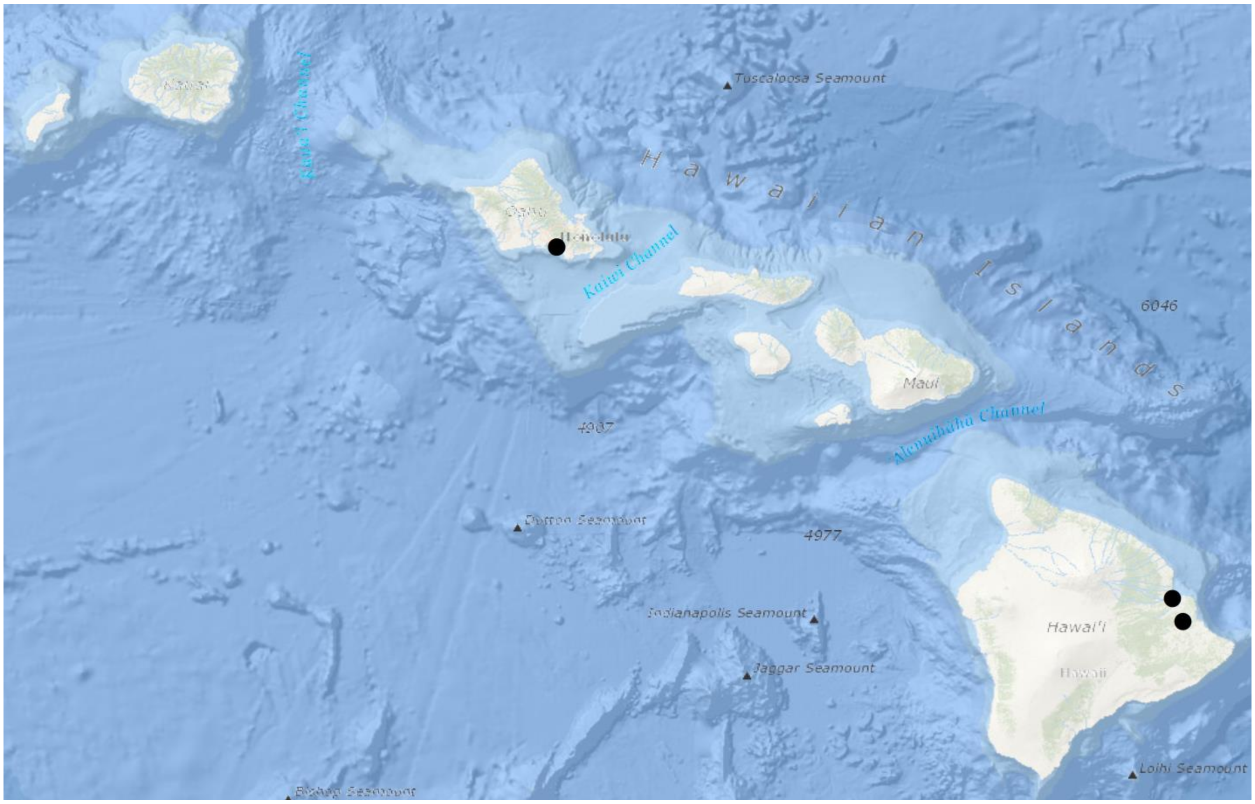
Figure 4-6: Average sentiment of tweets containing the hazard and transportation keywords in United States.



Analysis of Data in Hawaii

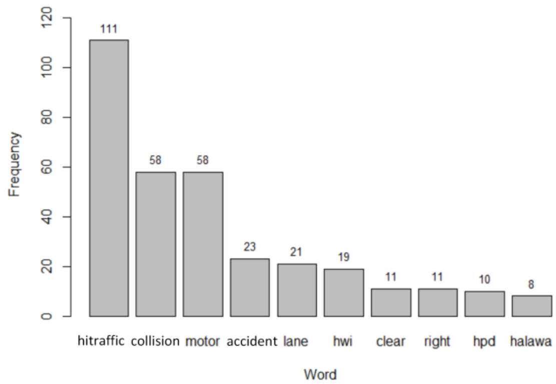
Due to the low sampling rate of the twitter data from the International Archive, only 16 tweets with the hazard and transportation keywords can be found in Oahu. In addition, the tweets, although geotagged, are associated with large geographical bounding box, which makes their location information insufficient for local impact analysis (Figure 4-7). Thus, a different approach was used to query and analyze the data in Oahu. First, tweets that have geotags located in Oahu are retrieved from the database. Second, tweets that have a user location containing 'Oahu' or 'Honolulu' were retrieved. Combining the two retrieved tweet sets lead to 343,089 tweets that can be located in Oahu, either by geotag or user location. Note tweets do not necessarily contain the traffic or transportation keywords described in the previous section. Next, the Oahu tweets in the king tide days in 2017 were selected. In this project, the king tide days are defined as days when the tide level is above 50% annual probability and there were 29 king tide days in 2017 (Appendix A). As the traffic volumes in Oahu has seasonal and weekly pattern, and also related to school semesters, vacations and holidays, only tweets on the days before and after the king tide days are selected as the control group to be compared with the tweets on the king tide days. Finally, the ratios and average sentiment of tweets containing the transportation keywords in the king tide days are compared with those not on the king tide days were compared to evaluate the impact of king tide on transportation reflected in Twitter. The paired student's t-test was applied to compare the quantities on king tide days and control days.

Figure 4-7: Geotag of Related Hawaii Tweets.

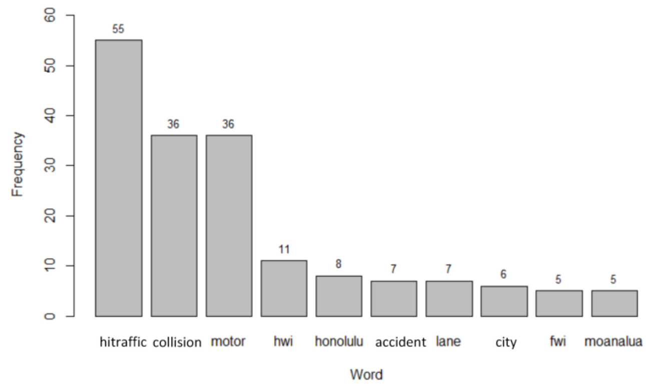


The analysis results show that the average ratio of tweets containing the transportation keywords on the king tide days is 0.264%, which is almost equal to the average ratio on the control days (0.256%). This result suggests that people do not tweet more about transportation in the king tide days compared to regular days. Additionally, the average sentiment of tweets containing the transportation keywords (0.046) is slightly lower than the average sentiment on the control days (0.050). However, this difference is not statistically significant (p=0.30). Both results indicate that the impact of king tide on transportation is not apparent in twitter. From the most frequent tweets shown in Figure 4-8, we can see that the major discussions about transportation in twitter are hitraffic (a hashtag), collision, and accident. Halawa and Moanalua are places near the intersection of H1 and H3, which is a traditional hotspot of traffic congestion.

Figure 4-8: Most frequent words in tweets on the king tide days (a) and control days (b).



(a)



(b)

Transportation Vulnerability Assessment

Analysis Framework

While social media analysis provides a good overview of people's concern and attitude towards flooding's impacts on transportation in general, localized vulnerability analysis is needed to better understand where and how local communities are being affected by sea level rise related flooding. As mentioned in the literature, exposure to flooding would not only reduce road capacity, cause closure and damage, but also affect broad community's accessibility to essential services (*32*). To identify the vulnerable road under the extreme tidal water levels (i.e. 1%, 10%, 50%, 99% annual exceedance probability level), spatial analyses in Geographical Information System (GIS) are performed. Appendix B shows the flooding maps and affected roadways under each scenario. Table 5-1 summarizes the number and length of affected roadways. The maps and table show that there are no significant differences among the extent and impacts of different tidal flooding levels (1%, 10%, 50%, 99% annual exceedance probability levels) on transportation road network on Oahu. Therefore, the 1% annual exceedance extreme scenario is selected to perform detailed vulnerability analyses.

Table 5-1 Summary of Affected Roadways

Annual Flood Exceedance Probability	Number of Road Segments Affected	Length of Affected Roads (miles)
1%	161	33.11
10%	160	32.2
50%	154	31.54
99%	154	30.32

To assess how communities are affected by the impacts of tidal flooding on transportation roadway network so as to identify the most physically vulnerable communities, network analysis in ArcGIS are performed to evaluate region's accessibility with and without tidal flooding. The notion of accessibility is defined as the ease for individuals from specific locations to access opportunities in other locations using a transport system (*67*). Because of its ability to capture the relationship between land use and transportation, the spatial separation, and the interests of people (*68*), it has often been used as a transportation performance measure in transportation vulnerability studies (*41; 69*). For example, Chang and Nojima (*70)* used total distance-based accessibility and areal distance-based accessibility to measure transportation system performance after the 1995 Kobe earthquake. Sohn (*71)* developed an accessibility measure based on population weighted travel distance and traffic volume to evaluate the significance of highway network links under the flood damage. Taylor, Sekhar and D'Este (*69)* used a number of standard indices of accessibility, including the generalized travel cost, the Hansen integral accessibility index, and the Australia ARIA index, to assess the socio-economic impacts of network degradation. Taylor, Sekhar and D'Este (*69)* defines transportation vulnerability as the reduction of accessibility caused by the loss of transportation node or link. For instance, Lu and Peng (*41)* developed a location based accessibility index to assess the impacts of sea level rise on transportation network in Hillsborough County, Florida.

Among the many accessibility indices developed, the most commonly used is the Hansen integral accessibility index (*72*), which measures the accessibility of zone i by

$$A_i = \sum B_j f(c_{ij}), \tag{1}$$

Where A_i is accessibility in zone i, B_j is the opportunities at zone j for a given purpose, $f(c_{ij})$ is the impedance functions, c_{ij} is the generalized travel cost such as time, distance or economic cost.

Normalized Hansen index $A_i = \frac{\sum B_j f(c_{ij})}{\sum_j B_j}$ and population weighted Hansen index $A_i = P_i \sum B_j f(c_{ij})$ are two common variations of the Hansen accessibility measure. Because of its simplicity yet intuitive grasp of the concept, easy-to-interpret to community members, and data availability, we used the Hansen accessibility index to understand the transportation vulnerability in terms of accessibility changes with and without tidal flooding for census traffic analysis zones(TAZs) on the island of Oahu. We choose the normalized Hansen formula over the population weighted one to avoid the over weight of densely populated regions from an equal opportunities perspective (*73*), which is especially important with the geographic context of an island community. We adopted an opportunity-based approach to assess the vulnerability from multiple aspects (*74*). We measure the accessibility as

$$A_i = \frac{\sum B_j f(c_{ij})}{\sum_j B_j} \tag{2}$$

where B_j, is the opportunity in zone j, including employment, K-12 school, university, grocery stores, and recreational parks. $f(c_{ij}) = d_{ij}^{-\alpha}$, which represents the separation between two locations and is formulated as the inverse of shortest travel distance from zone i to zone j d_{ij} . α is a constant, which should be calibrated using local data. Due to lack of data, we take α from an existing study as 2.0347 for work and school related trips, 2.5000 for grocery shopping related trips, and 3.0751 for recreational related trips (*75*). We use regression to analyze how transportation vulnerability in terms of accessibility reduction are related to socioeconomic characteristics of each TAZ.

Vulnerability Analysis Results

The accessibilities for employment, education, grocery, recreation are calculated as below using data from 2006-2010 Census Transportation Planning Program (CTPP), which is generated from U.S. Census Bureau, 2006-2010 American Community Survey 5-Year Estimates.

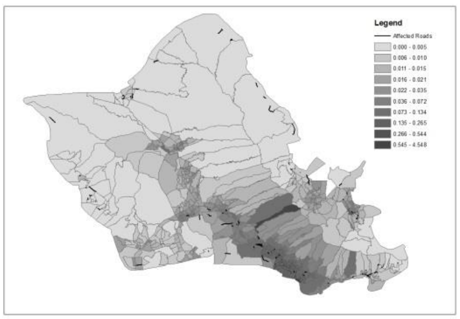
- Employment accessibility, B_j is number of employment at workplace from CTPP data in TAZ j.
- Education accessibility
  - K-12 School accessibility, B_j is the total number of K-12 school enrollment in each TAZ. Public and charter school enrollment is collected from State of Hawaii Department of Education. Private school enrollment is collected from Hawaii Association of Independent Schools. Location data is collected from State of Hawaii Office of Planning.
  - University accessibility, B_j is the total number of university enrollment in each TAZ. The data is collected from university's website and US news high education report for the year 2017-2018.

- Grocery accessibility, B_j is the total number of grocery store and supermarket in each TAZ. The data is collected from google map.
- Recreational accessibility, B_j is the total number of parks to represents the number of recreational attractions in each TAZ. The data is collected from City and County of Honolulu Open Geospatial Data Portal.

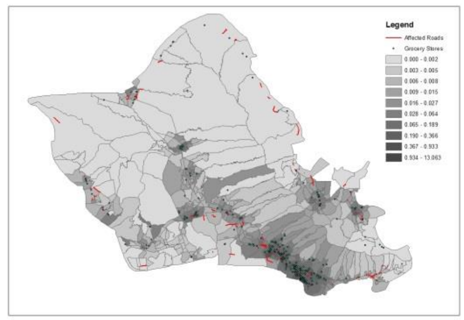
Using equation (2), the accessibility for each TAZ on the island of Oahu is calculated and mapped in Figure 5-1.

Figure 5-1 Accessibility by TAZ on the Island of Oahu

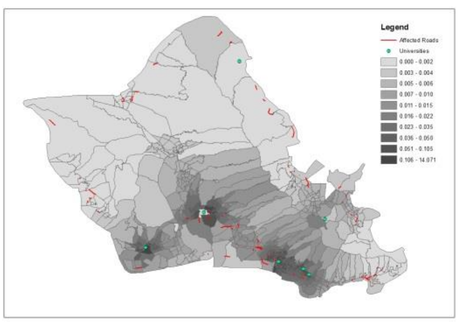
a) Employment Accessibility



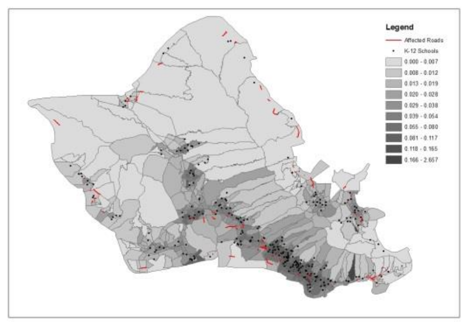
b) Grocery Accessibility



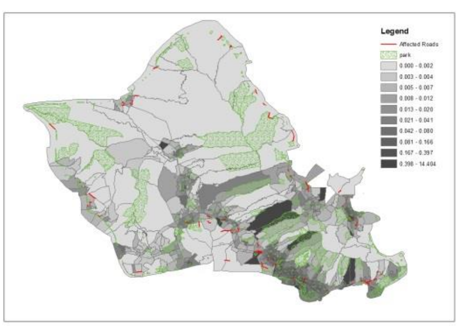
c) University Accessibility



d) K-12 School Accessibility



e) Recreational Accessibility



With the affected road blocked, the reduction of accessibility for each opportunity in percentage are calculated as

$$R_i = (A_i^b - A_i^a)/A_i^b * 100 \quad (3)$$

Where A_i^b is the original accessibility without flooding, A_i^a is the accessibility with flooding event. The change of accessibility is summarized in Table 5-1and Figure 5-2 and mapped in Figure 5-3. The table and figures show that the vulnerabilities are distributed unequally across the island and across trip purposes. On average, work related trips and access to universities may be affected most and recreational purposes are least affected, while grocery and school access would be in between. While majority of the TAZs are experiencing minimal accessibility reduction, i.e. 3%-6% reduction on average, there are a few TAZs experiencing up to 100% accessibility reduction.

Table 5-1 Summary of Accessibility Reduction in Percentage

Statistics		Employment Accessibility Reduction	Grocery Accessibility Reduction	School Accessibility Reduction	University Accessibility Reduction	Recreational Accessibility Reduction
N		753	753	753	753	753
Mean		4.154	4.186	3.671	6.043	2.959
Median		.750	.310	.320	.780	.260
Minimum		.00	.00	.00	.00	.00
Maximum		100.0	100.00	100.00	99.99	77.34
Percentiles	**25**	.300	.110	.120	.260	.060
	50	.750	.310	.320	.780	.260
	75	1.760	1.105	1.170	2.970	1.330

Comparing Figure 5-1 and Figure 5-3, it is found that the TAZs experiencing the highest amount of accessibility reduction locate in the North part of the island near Kahuku, the east part near Hawaii Kai, and the central part near Honolulu Harbor. In general, these places are also TAZs have low original accessibility to all kinds of opportunities. To find out household and population with what kind of socio-demographic characteristics or living in what type of TAZs are experiencing more impacts that others, regressions analyses are conducted to explore the relationships between transportation vulnerability and residence characteristics and road network characteristics using 2006-2010 CTPP data. The results of the regression are presented in Table 5-3 to Table 5-7. The models show that accessibility reduction in general increase with the % length of affected road and the total length of affected roads rather than the decrease of network density. Accessibility reduction is positively related with the cluster of residents in educational, health and social services industries, and negatively related with the cluster of residents in public administration, information, and retail compared with other industries. Poverty levels, car ownership, age, and urban rural settings are not significant. Also, to our surprise, the accessibility reduction are correlated with the increase of white alone population rather than Native Hawaii population. To validate the model results, we conducted outreach and community mapping in the vulnerable communities identified by vulnerability assessment.

Figure 5-2 Histogram of Accessibility Reduction

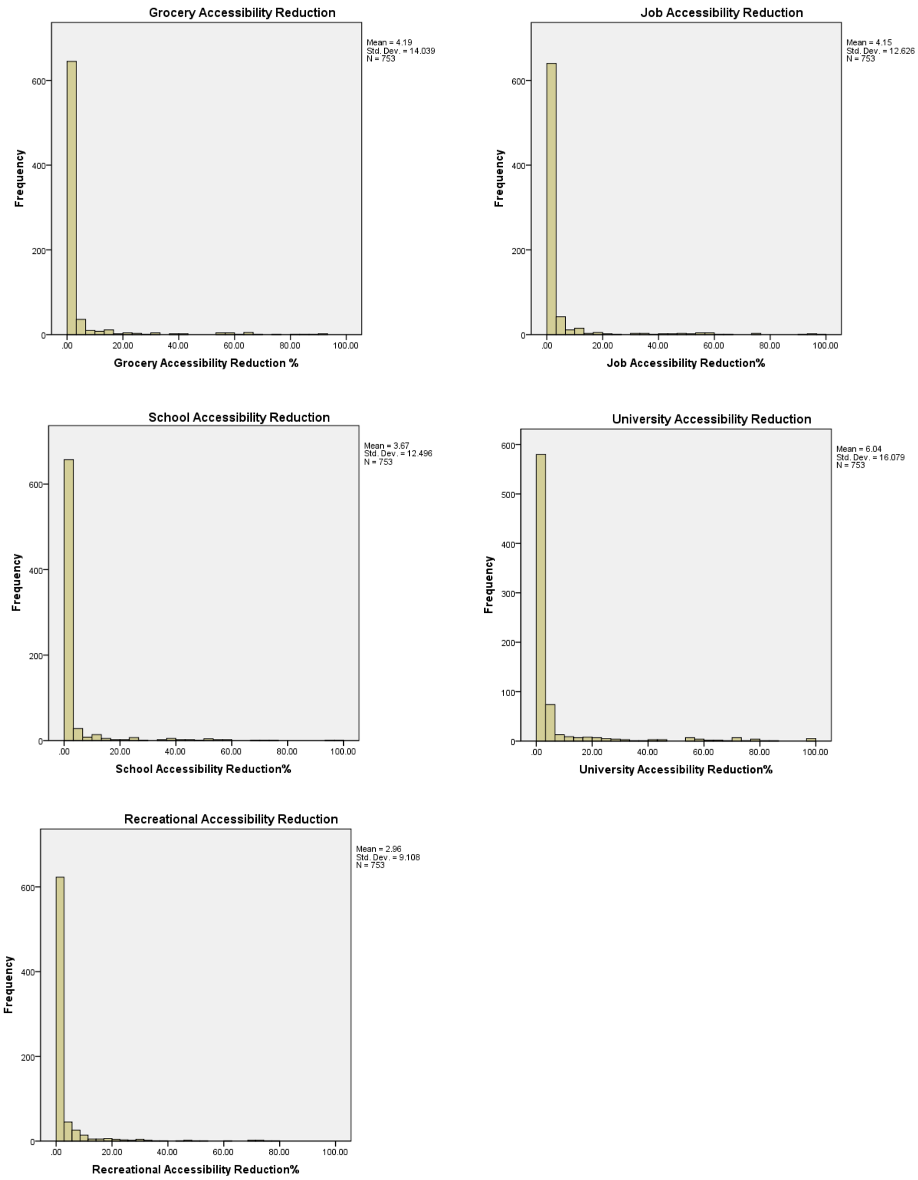
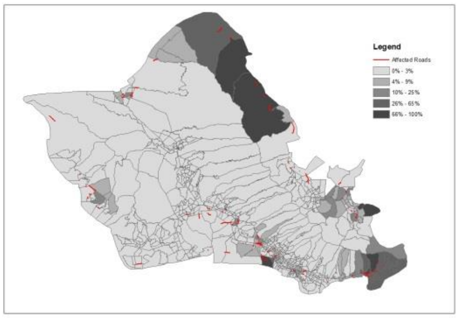


Table 5-2 summarizes the dependent and independent variables for the regression models.

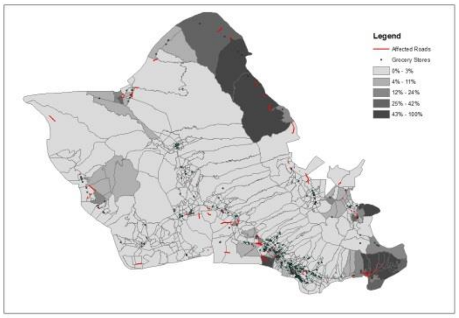
Dependent variables	Independent Variables	
	Demographic Variables	Network Variables
Employment accessibility reduction	Worker (residence), rural population percentage, race (white alone, Native Hawaiian), industry type by worker residence, poverty (percentage of household below 100% poverty), workers per car/truck/van	TAZ size, Mileage of affected road, % of affected road, total mileage of roads, road density (miles per sq miles)
Grocery accessibility reduction	Number of ousehold, race (white alone, Native Hawaiian), rural population percentage, elderly (over 75) percentage, youth percentage (under 16), poverty (percentage of household below 100% poverty), percentage of household without a car, average household size	TAZ size, Mileage of affected road, % of affected road, total mileage of roads, road density (miles per sq miles)
K-12 School accessibility reduction	K-12 enrollment by residence, race (white alone, Native Hawaiian), rural population percentage, race (white alone, Native Hawaiian), percentage of household without a car, poverty, household size, poverty (percentage of household below 100% poverty)	TAZ size, Mileage of affected road, % of affected road, total mileage of roads, road density (miles per sq miles)
University accessibility reduction	College/Professional enrollment by residence, rural population percentage, poverty (percentage of household below 100% poverty), race (white alone, Native Hawaiian), percentage of household without a car, average household size	TAZ size, Mileage of affected road, % of affected road, total mileage of roads, road density (miles per sq miles)
Recreational accessibility reduction	Population, poverty, race (white alone, Native Hawaiian), rural population percentage, percentage of household without a car, household size	TAZ size, Mileage of affected road, % of affected road, total mileage of roads, road density (miles per sq miles)

Figure 5-3 Accessibility Reduction by TAZ on the Island of Oahu.

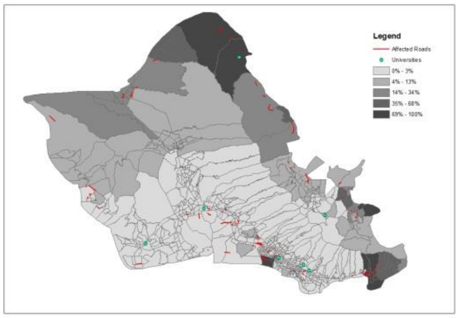
a) Employment Accessibility Reduction



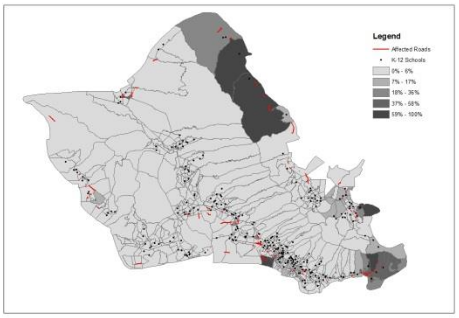
b) Grocery Accessibility Reduction



c) University Accessibility Reduction



d) K-12 School Accessibility Reduction



e) Recreational Accessibility Reduction

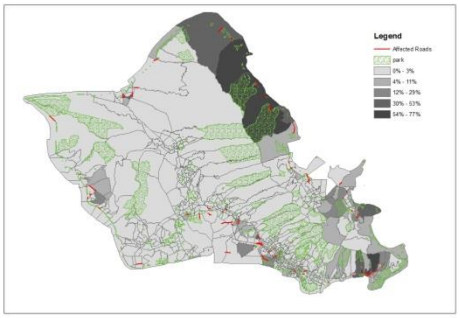


Table 5-3 Employment Accessibility Regression Model Results

Dependent Variables	Unstandardized Coefficients	Standardized Coefficients	p
Length of Affected Roads(miles)	5.401	.128	.004
Educational, health and social services	.852	.427	.000
% of White Alone	.078	.134	.000
Public administration	-.743	-.149	.009
% length of affected road	.133	.103	.019
Information	-1.829	-.120	.021
Retail trade	-.347	-.103	.036
Adjusted R Square			.105

Table 5-4 Grocery Accessibility Regression Model Results

Dependent Variables	Unstandardized Coefficients	Standardized Coefficients	p
Length of Affected Roads(miles)	8.284	.177	.000
% of White Alone	.068	.105	.004
Road Network Density (Miles per sq miles)	-.053	-.085	.019
Adjusted R Square	.056		

Table 5-5 K-12 School Accessibility Regression Model Results

Dependent Variables	**Unstandardized Coefficients**	**Standardized Coefficients**	**p**
Length of Affected Roads(miles)	7.433	.178	.000
% of White Alone	.060	.103	.004
Road Network Density (Miles per sq miles)	-.052	-.094	.009
Adjusted R Square	.058		

Table 5-6 University Accessibility Regression Model Results

Dependent Variables	Unstandardized Coefficients	Standardized Coefficients	p
% of White Alone	.160	.215	.000
Length of Affected Roads(miles)	7.834	.146	.000
Road Network Density (Miles per sq miles)	-.077	-.108	.003
% of household without a car	-.080	-.076	.032
Adjusted R Square			.100

Table 5-7 Recreational Accessibility Regression Model Results

Dependent Variables	Unstandardized Coefficients	Standardized Coefficients	p
Length of Affected Roads(miles)	4.386	.144	.002
Area(sq miles)	.350	.116	.002
% of White Alone	.040	.095	.007
% length of affected road	.109	.116	.009
Adjusted R Square			.086

Community Mapping and Outreach

Community Outreach

We conducted community mapping and outreach in the identified vulnerable North and East part of the island to get a better understanding of how local communities are currently being impacted by sea level rise, their primary concerns and response, and their perceived risk of the future. The outreach and mapping help us to validate the social media and vulnerability analysis results and get more in-depth understanding of the problem from the field.

Because community engagement plays a vital role in the success of community mapping (*56-58; 60; 62*), we focused on building relationship through formal and informal talks and conversations in community meeting and activities, which led to engaged communication between community members and the researchers. It has taken time to communicate and engage with the community, but by following the principles of community participation the results have been encouraging for continued participation. Table 6-1 summarized the community meetings and activities we attended to build the outreach relationship.

Table 6-1 Community Outreach Activities

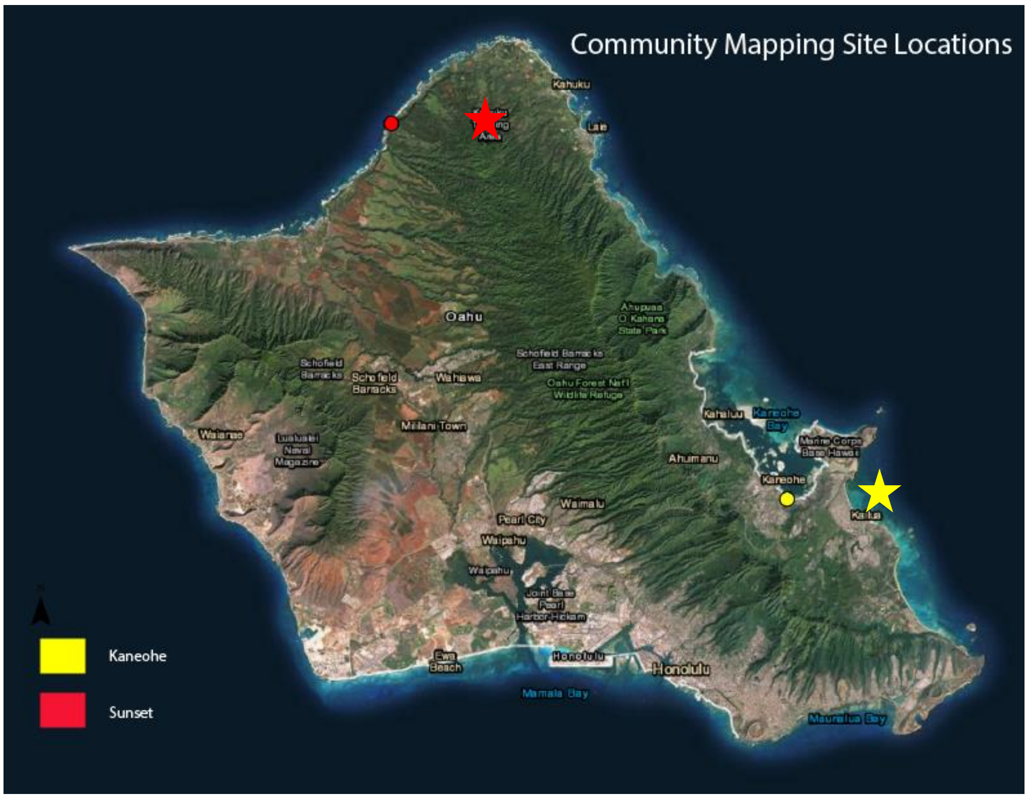
Event	Location	Date and Time	Number of Participants
Kahuku Point Restoration	Kahuku point near Turtle Bay	Saturday November 10th, 9:00am	18
Keehi Small Boat Harbor	Kalihi	Monday November 12th, 5:00pm	6
Kahuku Public Library	Kahuku Intermediate/High School	Tuesday November 13th, 4:30pm	35
Kahaluu Neighborhood Board Meeting	Key Project	Wednesday November 14th, 7:00pm	42
Kahuku Point Restoration	Kahuku point near Turtle Bay	Saturday November 10th, 9:00am	18
Keehi Small Boat Harbor	Kalihi	Monday November 12th, 5:00pm	6
Kahuku Public Library	Kahuku Intermediate/High School	Tuesday November 13th, 4:30pm	35
Kahaluu Neighborhood Board Meeting	Key Project	Wednesday November 14th, 7:00pm	42
Waiahole Bridge Meeting	Key Project	Monday November 19th, 5:00pm	34
Keehi Small Boat Harbor Regatta	Kalihi	Wednesday November 28th, 5:00pm	30

After building the community relationship and letting the local communities know about our research, community mapping data was collected by reaching out to non-profit and faith based community organizations in the vulnerable communities in North shore sunset beach and Kaneohe (Table, 6-1, Figure 6-1). Using paper maps and questionnaires (Appendix C), we asked the participants to identify where they experience the coastal flooding impacts on transportation and how their travels have been affected. We also asked questions to understand their perceptions of sea level rise and their current responses or suggestions for adaptation.

Table 6-1 Community Mapping Events

	Location	Date and Time	Number of Participants	Number of Responses
Sunset Beach Christian Church	Haleiwa Near Ke'iki Beach Road	Sunday November 18th, 9:00am	35	25
La Ohana Loko I'a Workday	Paepae o He'eia Fish Ponds	Saturday November 24th, 6:00am	40	24

Figure 6-1 Site locations for community mapping



Community Mapping Analysis

In total we got 48 participants from community mapping activities, 25 from Sunset and 23 from Kaneohe. The 48 participants identified a total of 165 vulnerable transportation infrastructure they either currently experienced flooding or where they were concerned about flooding in the future (Figure 6-2). Of 48 responses, over 50% respondents chose storm surge and coastal erosion as number one most frequently experience coastal hazard conditions, and followed by king tide and inland groundwater inundation contains 6.2% response each (see figure 6-3). The type of impacts associated with these hazards conditions vary, but the most prevalent are flooding and inundation of the origin/ destination and along the trip route, and detour due to road closure (Figure 6-4). Other coastal flooding, on the other hand, caused the least impact. Almost all participants could drive a car and had at least one car per household, although there were also numerous complaints of experiencing costal erosion and storm surge over bike paths and pedestrian walkways.

Figure 6-2 Compete results from both community mapping events

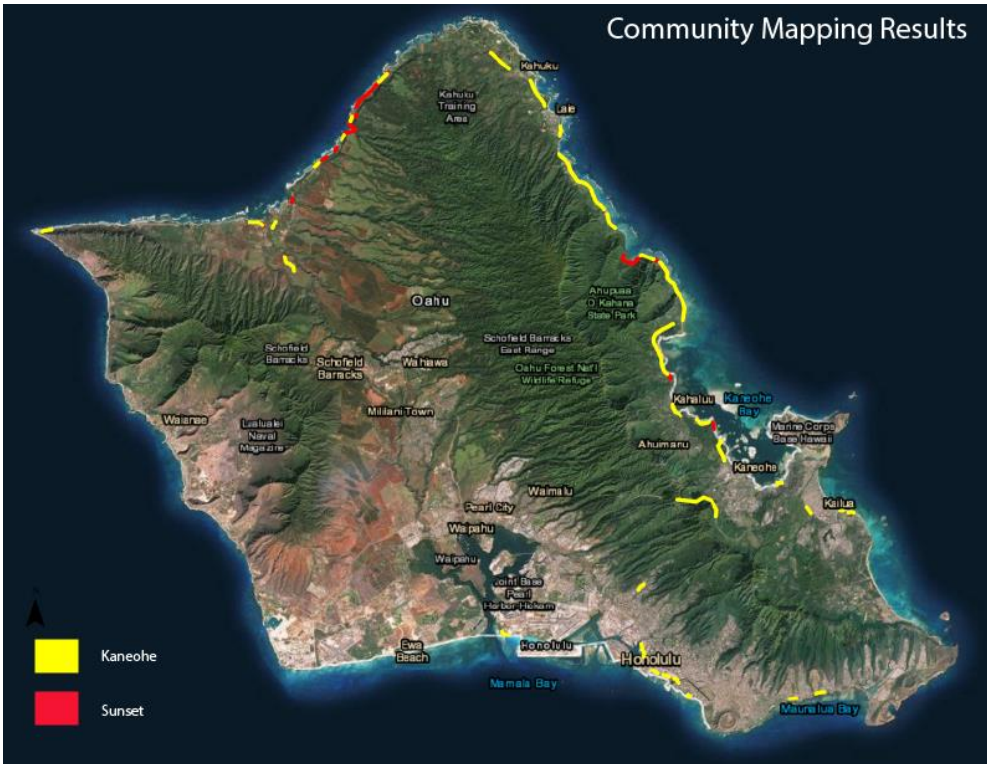


Figure 6-3 Experience of Hazard Conditions

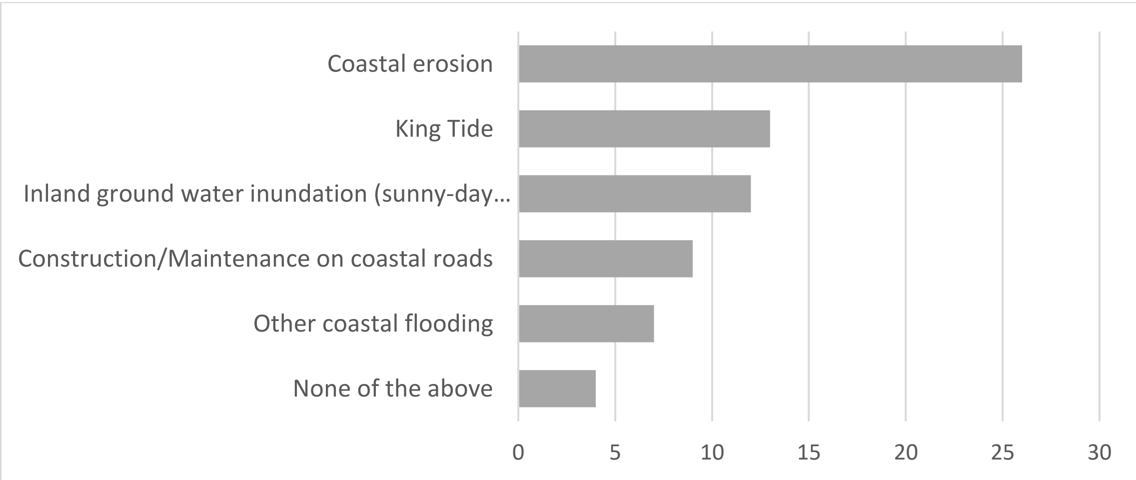
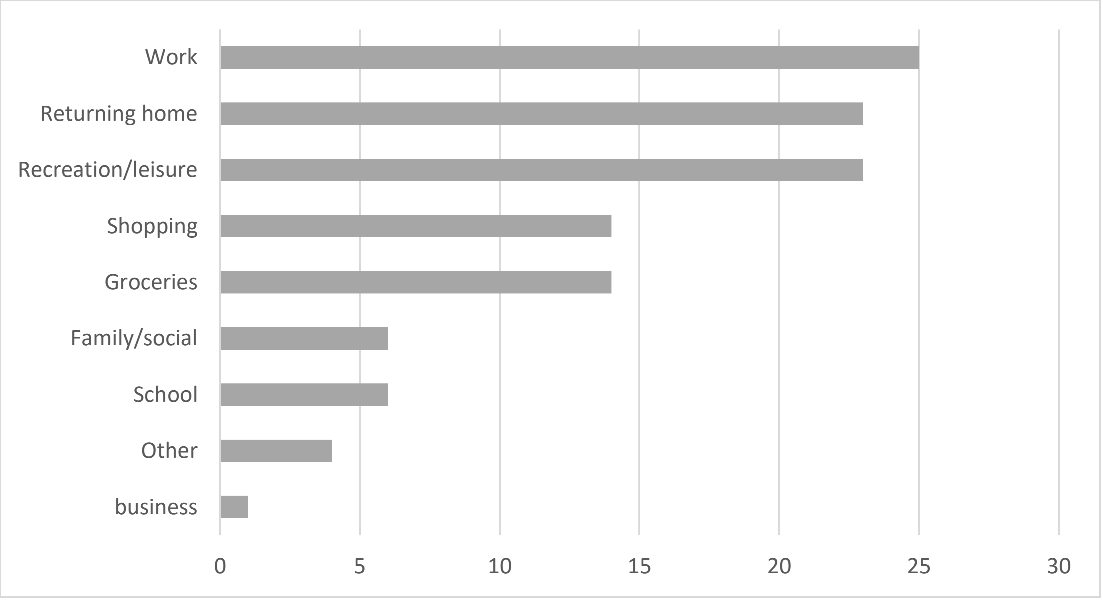


Figure 6-4 Affected Transportation Modes

100% responses placed trip to work has been interfered and 80% responses indicated that flooding hindered recreational activity and returning to home trip (Figure 6-5). Trip to school and for business purpose is not as affected as much, but it would be interesting to investigate the reason behind it. Regarding risk perception, which is the subjective judgement that people make about the characteristics and severity of a risk, 45 out of 48 people agree to some degree that sea level rise increased coastal flooding. In addition to it, these respondents think that flooding will likely to affect future travel.

Figure 6-5 Affected Transportation Modes



With the mapping results we found very high consistency among participants in identifying problem locations, especially at Sunset (Figure 6-5). All five people that identified where they experienced coastal erosion at Sunset said that Sunset Beach specifically was eroding causing reduced service for vehicles and pedestrians as well as reduced parking (Figure 6-6). No storm surge areas were identified by participants in Kaneohe, but the nine locations of coastal erosion that were identified in Kaneohe covered a much larger area along the East Side of Oahu than the responses from sunset on the North

Shore of Oahu. Interestingly, one person in Kaneohe did mentioned a part of Kamehameha Hwy. that is no longer in service due to coastal erosion at Kaena Point which is the most western part of Oahu. Consistency was found on the East side as well with several people referring to the Southern side of Kahana Bay near Crouching Lion where the area is experiencing coastal erosion that is resulting in construction, reduced service, and a reduction in parking.

Figure 6-5 Areas participants identified as experiencing storm surge or coastal erosion

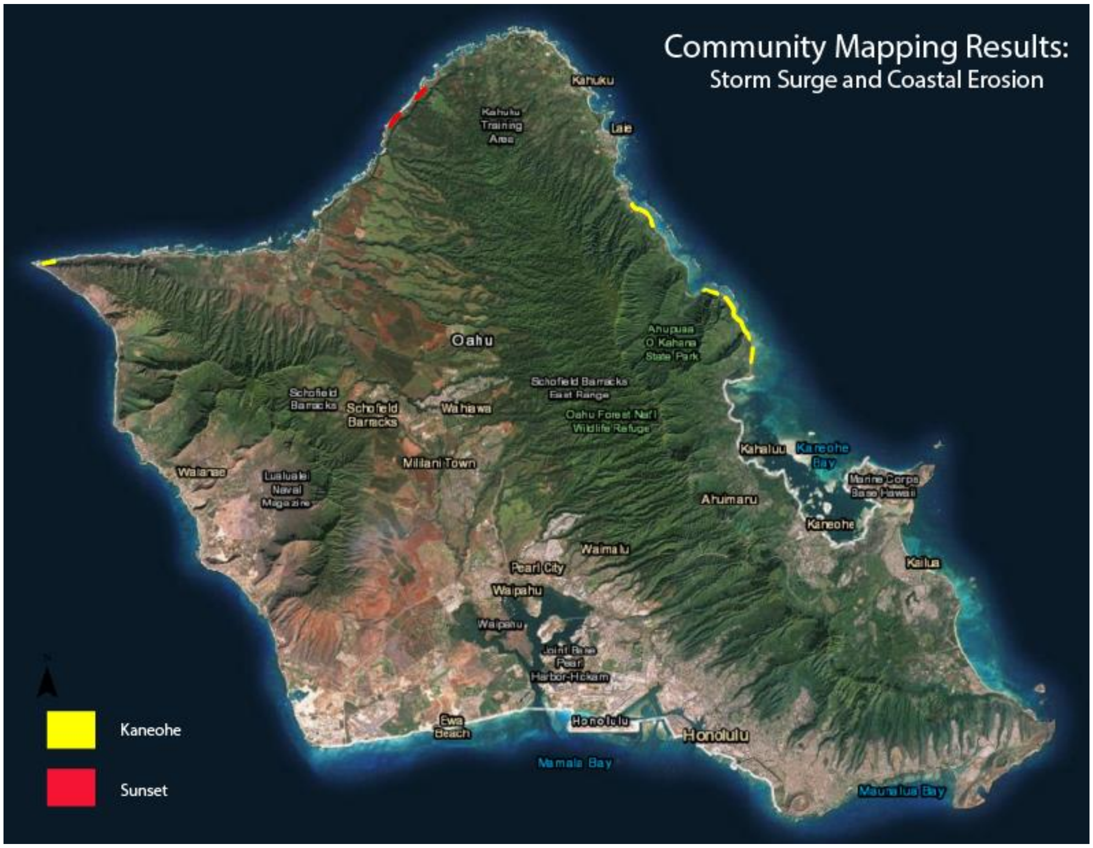


Figure 6-6 Bike path, beach parking, and road are eroding into the ocean at Sunset Beach

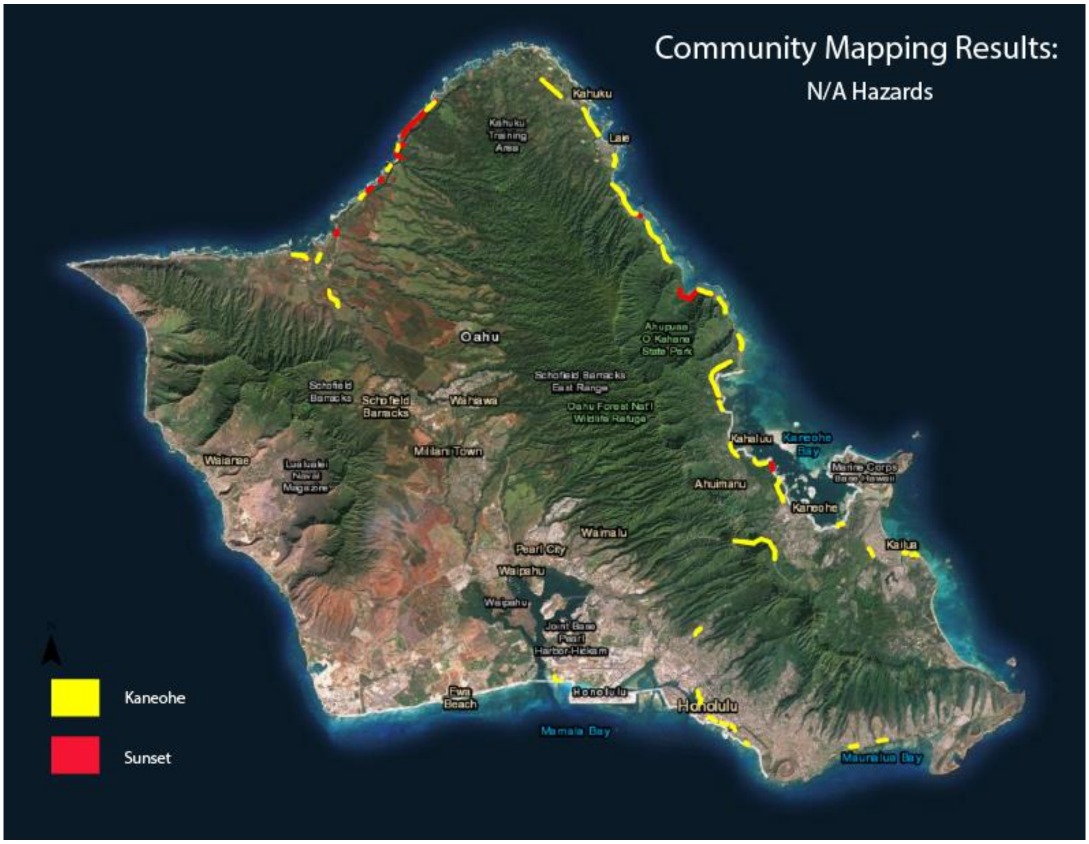
The Sunset location was the only group that referenced specific locations (6) of coastal flooding (Figure 6-7). Only one participant mentioned Laniakea about coastal flooding, but Laniakea frequently came up as a concern for future travel or as an issue with an unidentified hazard. Laniakea is one of the locations that even during this study had aggressive storm surge that inundated the road and covered it with debris (Figure 6-8). Laniakea is notorious for its “turtle traffic” because the road is dangerously close to the ocean and tourist frequently cross the road to observe the turtles. At this location it would be hard for locals to decipher the difference between daily traffic and traffic that is related to other coastal hazards.

Figure 6-7 Areas participants identified as experiencing coastal flooding

Figure 6-8 Storm surge crossing the road at Laniakea on November 26th 2018

It seems that locals understand their transportation infrastructure is in danger in the face of coastal hazards, but they are mostly unclear about what types of hazards are threatening their roads. An overwhelming 69 out of the 99 features identified by the Sunset group were classified as unidentified hazards, while Kaneohe was strikingly similar with 56 out of the 66 features identified were classified as unidentified hazards (Figure 6-9). Continued community outreach is needed to facilitate the information sharing between the communities, the scientists, and the local agencies to help them better understand the causes of the problems, the hazards they face with sea level rise, and work with the community to come out the possible solutions and develop action plans.

Figure 6-9. Problem areas communities identified as experiencing unidentified coastal hazard



Conclusion and Recommendation

This project demonstrates how twitter data, community mapping, and transportation vulnerability analysis could complement each other to understand the impacts of sea level rise on transportation from different perspectives and at different geographical scales.

Social Media data provides a good overview of the problem at the large geographical scale, i.e. globally and nationally. It could help researchers to develop future research questions, select case study areas and conduct comparative studies. The global analysis indicates flight cancels and travel delay are the major impact of flood and king tides on the transportation system, which is reflected from the frequently appeared words and sentiment of tweets containing the words. At the national scale, coastal states have endured more severe impact of hazards on transportation compared to inland states, which are reflected from the ratio and average sentiment of tweets containing the hazard and transportation keywords. However, the impact in Hawaii is not as high as other coastal states. At the local level, the analysis did not discover significant difference of tweets about transportation between the king tide days and regular days in Oahu. The common traffic instances (e.g. accident and collision) are still the major topics in Twitter. The impacts of king tide days on transportation are not identifiable in Twitter data at this scale of study.

Transportation vulnerability analysis helps to understand and compare the systematic impacts at the city level. It could provide researcher and planning practitioners an in-depth examination of the spatial patterns of various types of impacts with socioeconomic and build environment data. For the case study area, City and County of Honolulu, the results show spatially the vulnerability in terms of accessibility reduction is unequally distributed. It reveals that the residents at the North part of the island near Kahuku, the east part near Hawaii Kai, and the central part near Honolulu Harbor may have experienced more impacts from tidal flooding than others. These communities also have a low level of accessibility to employment, school, grocery, and recreational opportunities even without coastal flooding. On average, work related trips and access to universities may be affected most, followed by grocery trips, and recreational as the least. In general, accessibility reduction increases with the percentage of affected road in the TAZ, the total length of affected roads, percentage of residents in educational, health and social services industries, and percentage of white alone population, which indicate the important role infrastructure protection could play in reduce vulnerability. The accessibility reduction is negatively related with the percentage of residents in public administration, information, and retail industries. Poverty levels, car ownership, age, minority status, and urban rural settings are not significant.

Community mapping, on the another hand, helps to validate the analysis results with field data from the community's perspective at the neighborhood scale, which facilitate the information communication between academia, community, and public agencies to facilitate the conversation for adaptation actions. The community mapping results confirms the findings from the social media analysis and transportation modelling for the types of impacts and locations of the impacts. For example, community mapping confirms that delays, cancel, detour are the major impacts experienced by participants and some locations identified as vulnerable in the analysis. It also confirms that work related trips and grocery shopping trips have been greatly affected. It also provides interesting findings that diverge from the analysis. For example, it found that the participants' recreational trips has been heavily affected, which is different from the model results. Continued engagement and more outreach is needed to understand whether these difference are because of the location of the participants or because of the community's value preference. Finally, community mapping get the communities' inputs for adaption actions.

Despite the majority (i.e. 43 out of 48) of the community mapping participants are concerned with sea level rise impacts on future travel, 78 percent of participants think the impacts of the sea level rise could be manageable if appropriate actions are taken. The community mapping activity gathers community's suggestions for adaptation, including 1) prevent construction in flooding zone, 2) undertake maintenance including road and drainage system, 3) advocate for elevated development or retreat, 4) create new roads/ emergency access, 5) create barrier, and 6) level monitoring of high/ low tides, as well as monitoring of dirt and sand and soil erosion in critical areas. Several participants suggest that development should not be allowed in the areas where flooding is prevalent. Taking occurrence of flooding events into consideration, the development limitation approach helps to prevent further loss in infrastructure, property and assets. We suggest the implementation of regulatory planning tools that align with this adaptation recommendation such as floodplain regulation and rebuilding restriction to prevent future loss from happening in places with large portion of infrastructure affected and expensive protection costs. Other respondents suggest relocation of the roadway or infrastructure, moving out from harm's way. This is similar to managed retreat, in which human development is relocated and moved out from the flood defended area. This is especially important, in the long run, for vulnerable communities with potential 100% accessibility reduction if sea level rise and coastal erosion lead to permanent inundation or damage to their only accessible roads. In the near term for remote communities already experiencing severe impacts whose emergent access might be blocked and for highly developed urban areas, we suggest hard structure protection. Continued community outreach and further studies are needed to identify the suitable locations, understand the social capital in vulnerable communities, and legal and institutional framework for the successful implementation of different types of adaptation strategies.

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Data Management Plan

Products of Research
This project utilized publicly accessible tidal records and digital elevation models, from United States National Oceanic and Atmospheric Administration, open source twitter data, United States census data, and transportation network data from the city and county of Honolulu. The sources of the publicly available data are documented in the final report.

Data Format and Content
This project collected participatory mapping data from selected communities on the island of Oahu in Hawaii to assess the impacts of sea level rise on transportation. The spatial data collected through participatory mapping process are processed anonymously and stored in digital format using standard spreadsheet and spatial data format (i.e. excel, shapefile, geodatabase) and metadata standard. The participant background information (e.g., socio-demographic) are processed anonymously and aggregately. The participatory mapping questions and process have been approved by the University of Hawaiʻi Human Studies Program Institutional Review Board. The data collection did not collect any information related to personal identity and confidential information.

Data Access and Sharing
The findings from the processed community mapping data are visualized and shared to the public through project website (http://www2.hawaii.edu/~yiqiang/utc/) and public meetings in image and map formats. The spatial data related to the project are stored in a web server hosted by the Geography department at the University of Hawaii Manoa for a year.

Reuse and Redistribution
The spatial data related to the impacts of coastal flooding will only be visualized and shared at the aggregated level through the project website to protect the Privacy and Confidential of the survey participants according to the research data collection protocol.

Appendix

Appendix A

Dates and Time for Honolulu Tidal Flooding Events (2012-2018)

Annual Exceedance Probability Levels (2017)	Water Level (MHHW datum)	2014	2016	2017	2018
10%	1.18 ft	0	0	5/26/2017 2:00:00 AM 6/24/2017 2:00:00 AM 8/19/2017 12:00:00 AM 8/20/2017 12:00:00 AM – 2:00:00 AM 8/21/2017 1:00:00 AM – 3:00:00 AM 8/22/2017 1:00:00 AM – 4:00:00 AM	0
50%	0.89 ft	9/7/2014 12:00:00 AM	12/16/2016 4:00:00 PM 12/15/2016 3:00:00 PM 12/14/2016 2:00:00 PM – 4:00:00 PM 12/13/2016 2:00:00 PM 12/12/2016 1:00:00 PM	12/31/2017 1:00:00 PM 12/4/2017 2:00:00 PM— 4:00:00 PM 11/7/2017 5:00:00 PM 11/6/2017 4:00:00 PM 11/5/2017 3:00:00 PM	6/14/2018 2:00 am – 3:00am 6/15/2018 3:00 am-4:00am 2/1/2018 3:00 pm-4:00pm 1/31/2018 2:00:00 PM – 4:00:00 PM 1/30/2018 1:00:00 PM – 3:00:00 PM

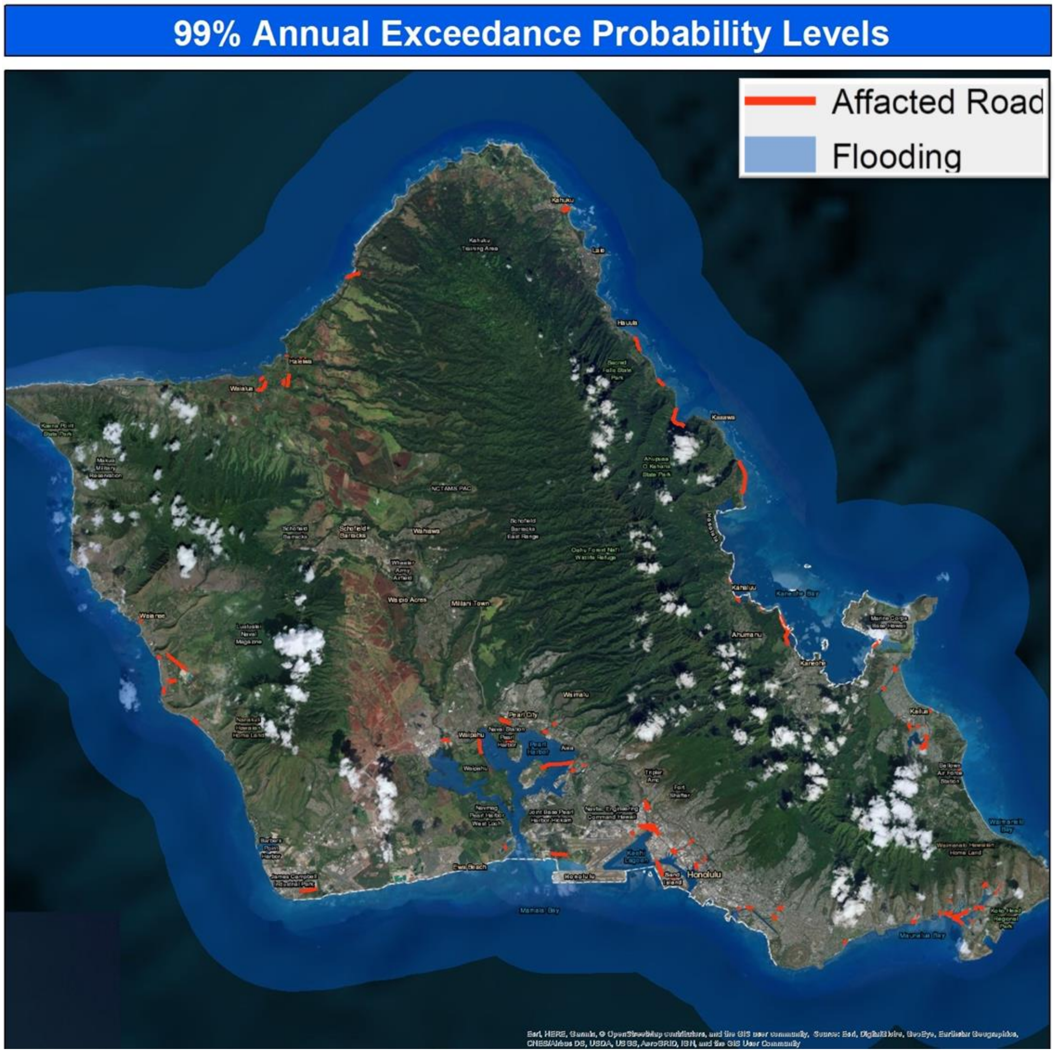
Annual Exceedance Probability Levels (2017)	**Water Level (MHHW datum)**	**2014**	**2016**	**2017**	**2018**
50%			11/16/2016 3:00:00 PM 11/15/2016 2:00:00 PM— 4:00:00 PM 11/14/2016 2:00:00 PM 10/18/2016 3:00:00 PM 10/17/2016 3:00:00 PM 7/6/2016 3:00:00 AM 7/5/2016 2:00:00 AM – 4:00:00 AM 7/4/2016 1:00:00 AM – 4:00:00 AM 7/3/2016 12:00:00 AM – 2:00:00 AM 6/6/2016 2:00:00 AM – 4:00:00 AM 6/5/2016 1:00:00 AM – 4:00:00 AM 6/4/2016 1:00:00 AM	8/23/2017 2:00:00 AM – 5:00:00 AM 8/22/2017 1:00:00 AM – 4:00:00 AM 8/21/2017 12:00:00 AM – 4:00 AM 8/19/2017 11:00:00 PM – 3:00 AM 8/18/2017 11:00:00 PM – 2:00:00 AM 8/17/2017 10:00:00 PM – 1:00:00AM 7/24/2017 3:00:00 AM 7/23/2017 2:00:00 AM 7/22/2017 1:00:00 AM 6/26/2017 3:00:00 AM – 5:00:00 AM 6/25/2017 2:00:00 AM – 5:00:00 AM 6/24/2017	1/29/2018 12:00:00 PM – 2:00:00 PM 1/3/2018 3:00:00 PM 1/2/2018 2:00:00 PM – 4:00:00 PM 1/1/2018 1:00:00 PM – 3:00:00 PM

Annual Exceedance Probability Levels (2017)	Water Level (MHHW datum)	2014	2016	2017	2018
50%				1:00:00 AM – 4:00:00 AM 6/23/2017 1:00:00 AM – 3:00:00 AM 6/22/2017 12:00:00 AM – 2:00:00 AM 5/28/2017 3:00:00 AM – 5:00:00 AM 5/27/2017 2:00:00 AM – 5:00:00 AM 5/26/2017 1:00:00 AM – 4:00:00 AM 5/25/2017 1:00:00 AM – 3:00:00 AM 5/1/2017 6:00:00 AM 4/30/2017 4:00:00 AM – 7:00:00 AM 4/29/2017 3:00:00 AM – 6:00:00 AM 4/28/2017 3:00:00 AM – 5:00:00 AM	

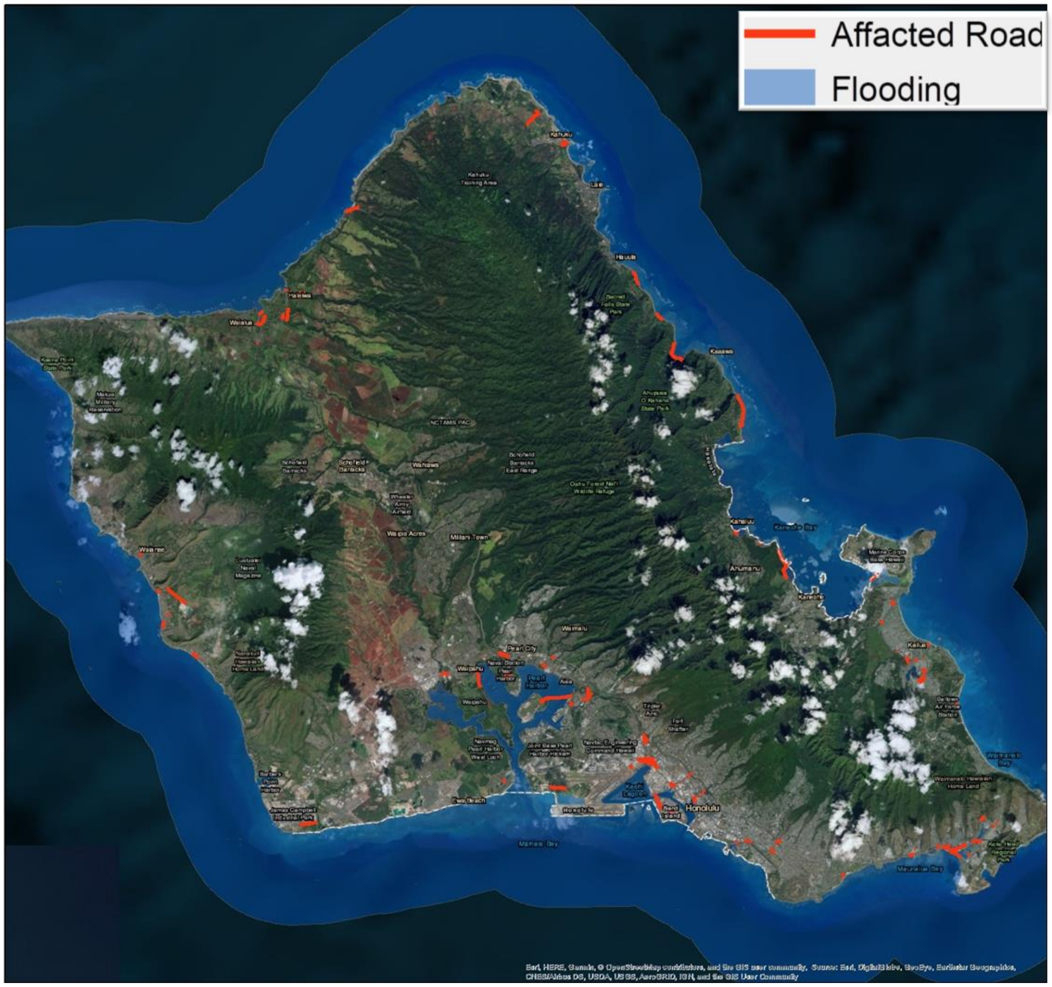
Annual Exceedance Probability Levels (2017)	Water Level (MHHW datum)	2014	2016	2017	2018
50%				4/27/2017 2:00:00 AM – 4:00:00 AM 1/12/2017 2:00:00 PM	

Appendix B

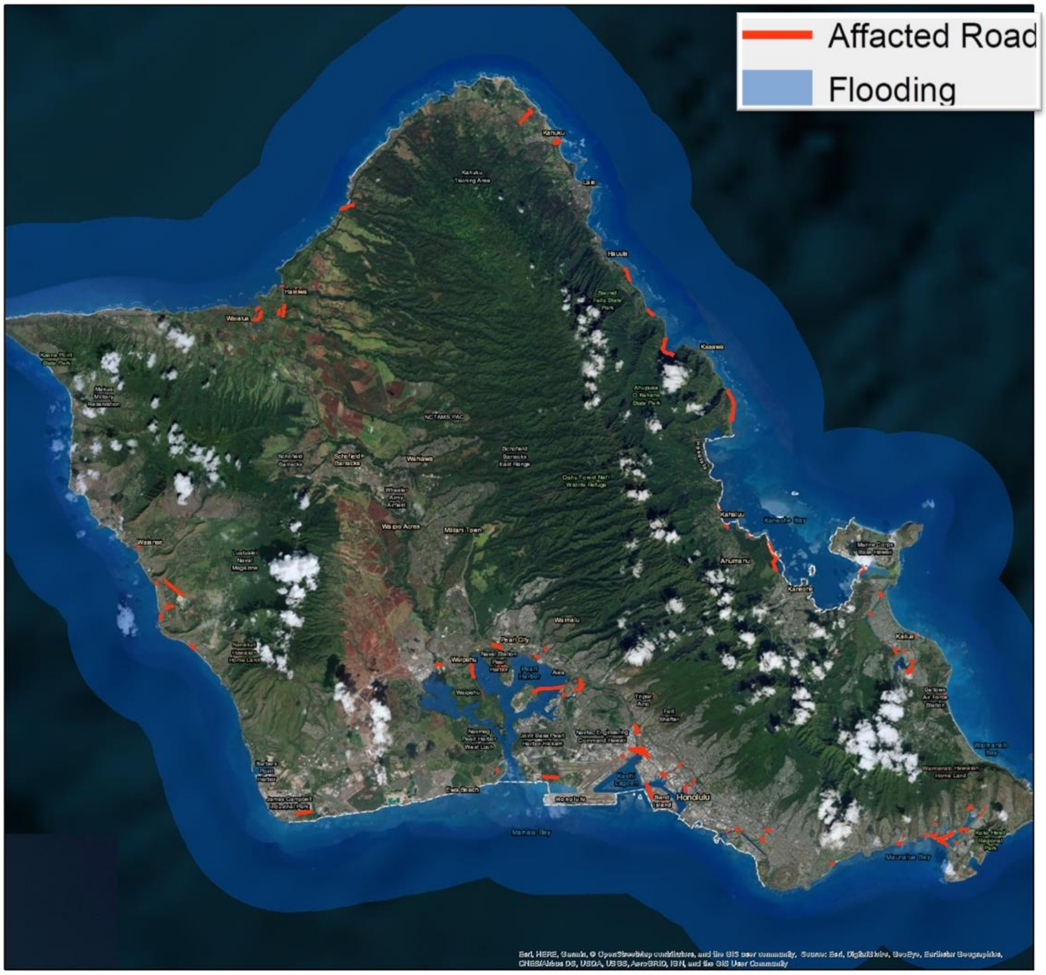
Flooding Maps and Affected Roads

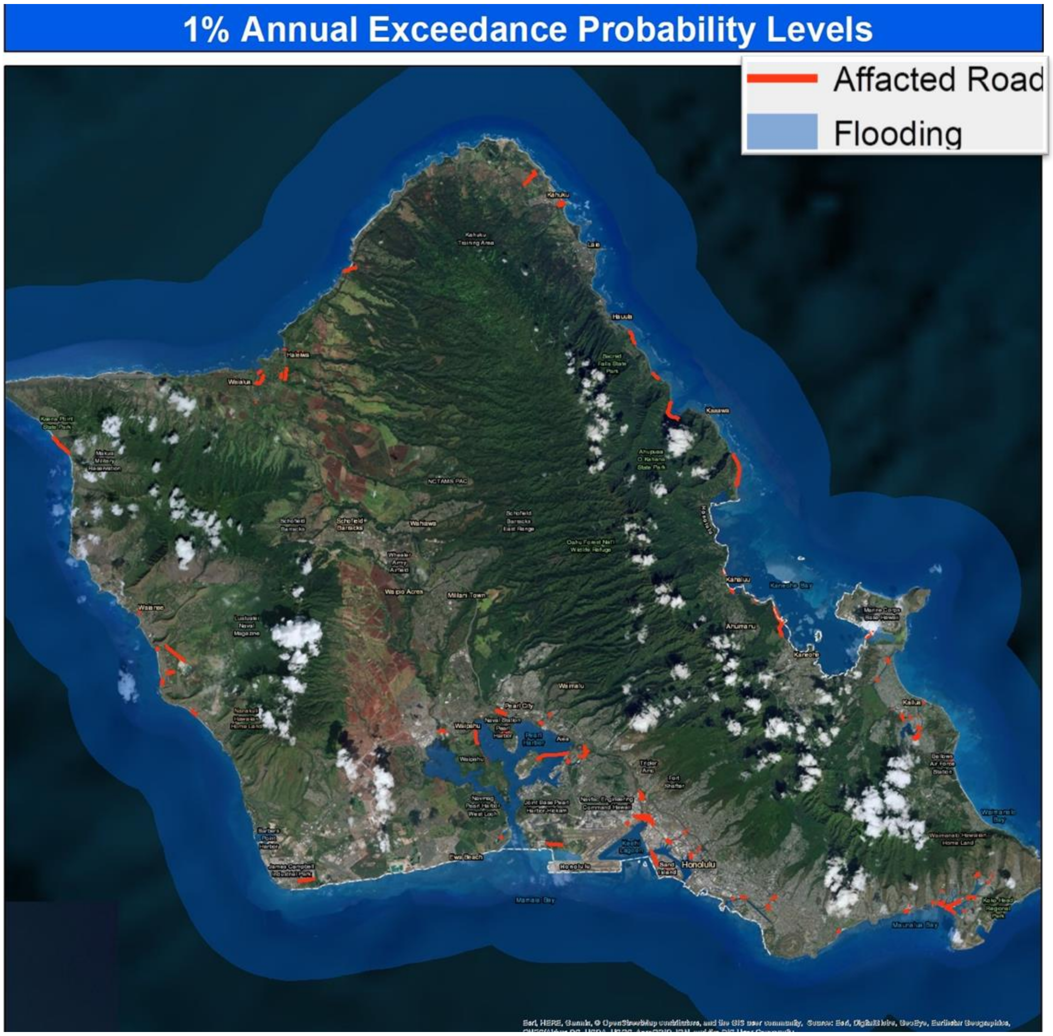


50% Annual Exceedance Probability Levels



10% Annual Exceedance Probability Levels




1% Annual Exceedance Probability Levels
Affacted Road
Flooding
Honolulu

Appendix C

Community Mapping Questions and Maps

Aloha! Researchers in Urban and Regional Planning and Geography department at the University of Hawaii Manoa are collecting community information about how travel is being affected by coastal flooding and sea level rise on the island of Oahu. Your opinion is important! You could support the project by identifying the location of the impacts and describe the type of impacts on the map. It helps us to better understand how your travel is being affected by the coastal flooding so as to develop strategies for climate adaptation in future. All inputs are anonymous.

1. By checking this box you are agreeing that, "I consent to participate and understand I can

stop at anytime without penalty."

☐ I Agree

2. Have any of the following conditions ever affected your travel? If coastal flooding affected your travel, could you tell us how and where did you experience it? (Could you show it on the map?)

Check all that apply.

☐ King tides

☐ Storm surge

☐ Inland ground water inundation (Sunny-day flooding)

☐ Coastal erosion

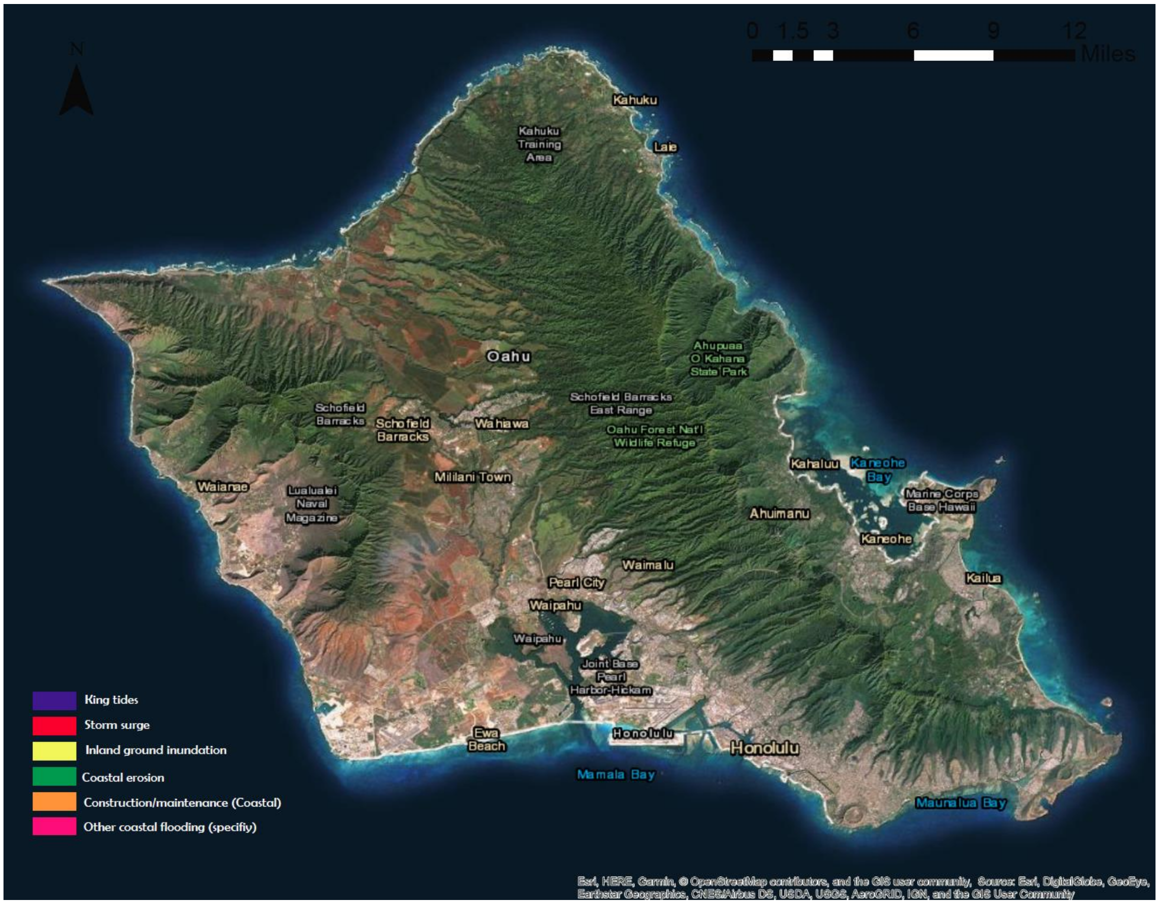
☐ Construction/maintenance on coastal roads

☐ Other coastal flooding (Specify)

3. These conditions have affected my travel by

Check all that apply.

☐ Bike ☐ Walk ☐ Car ☐ Motorcycle ☐ Transit ☐ None



4. What was the original purpose of the affected trips?

Check all that apply.

☐ Work

☐ Recreation/leisure

☐ Groceries

☐ Shopping

☐ Returning home

☐ School

☐ Family/social

☐ Other (Specify)

5. Please give an explanation for what you think is causing the most damage to roadways and/or causing degradation, repair, and construction to transportation infrastructure (e.g. Sea Level Rise, Storm Surge, Sunny Day Flooding, Erosion, Rain, Heavy Vehicles, or Excessive Use).

6. Do you think Sea Level Rise (SLR) will increase the frequency of coastal flooding?

Mark only one oval.

☐ Yes

☐ No

☐ Maybe

7. Are you concerned that frequent coastal flooding could affect your travel in the future?

Mark only one oval.

☐ Yes

☐ No

☐ Maybe

8. Do you think the impacts of coastal flooding and SLR would be self-manageable?

Mark only one oval.

☐ Yes

☐ No

☐ Maybe

9. What would be your strategy or suggestions to manage frequent coastal flooding impacts?