Understanding the Interrelationships between Infrastructure Resilience and Social Equity Using Social Media Data

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ABSTRACT

The 2030 Global Sustainable Development Agenda of United Nations highlighted the critical importance of understanding the integrated nature between enhancing infrastructure resilience and facilitating social equity. Social equity is defined as equal opportunities provided to different people by infrastructure. It addresses disparities and unequal distribution of goods, services, and amenities. Infrastructure resilience is defined as the ability of infrastructure to withstand, adapt, and quickly recover from disasters. Existing research shows that infrastructure resilience and social equity are closely related to each other. However, there is a lack of research that explicitly understands the complex relationships between infrastructure resilience and social equity. To address this gap, this study aims to examine such interrelationships using social media data. Social media data is increasingly being used by researchers and proven to be a reliable source of valuable information for understanding human activities and behaviors in a disaster setting. The spatiotemporal distribution of disaster-related messages helps with real-time and quick assessment of the impact of disasters on infrastructure and human society across different regions. Using social media data also offers the advantages of saving time and cost, compared to other traditional data collection methods. As a first step of this study, this paper presents our work on collecting and analyzing the Twitter activities during 2018 Hurricane Michael in disaster-affected counties of Florida Panhandle area. The collected Twitter data was organized based on the geolocations of affected counties and was compared against the infrastructure resilience and social equity data of the affected counties. The results of the analysis indicate that (1) Twitter activities can be used as an important indicator of infrastructure resilience conditions, (2) socially vulnerable populations are not as active as general populations on social media in a disaster setting, and (3) vulnerable populations require a longer time for disaster recovery.

KEYWORDS: Social media; Hurricane Michael; social equity; infrastructure resilience; disaster resilience

INTRODUCTION

Over the last several decades, disasters, both natural and man-made have accounted for huge economic losses mostly in the form of damage to infrastructure, which significantly impacts people's access to services, such as clean water, electricity, transportation, and health care, etc. (UN 2016). To eliminate disparities of access to infrastructure due to disasters, there is a growing trend of investment and improvement in the infrastructure sector to support more resilient, adaptive, and equitable human society. Given such trend, the 2030 Global Sustainable Development Agenda of United Nations has highlighted the need to understand the interactions between infrastructure improvements and the impacted society, and in particular, it emphasized that it is crucial we understand how infrastructure resilience is interrelated to social equity (UN

2016). For example, how does infrastructure resilience affect social equity? How to integrate social equity into resilience assessment or planning? Infrastructure resilience is defined as the ability of infrastructure systems to anticipate, absorb, adapt to, and/or rapidly recover from a disaster (Berkeley et al. 2010). Social equity is defined as equal opportunities provided to different people by infrastructures. It addresses disparities and unequal allocation of risks and distribution of goods, services, and amenities. Existing research (e.g., Doorn 2019, UN 2016) shows that infrastructure resilience plays an important role in supporting social equity. Infrastructure improvement leads to economic growth, which increases productivity and employment opportunities, reduces poverty, and contributes to social equity in the communities. A resilient infrastructure that better withstands and recovers from disasters, has the potential to reduce "disaster poverty" – shortage of supplies, inaccessibility to goods or services. It also has better capabilities of offering "disaster equity" by reducing vulnerabilities and disparities in different regions and communities. Despite such link between infrastructure resilience and social equity, there is a lack of research that provides an explicit understanding about the complex relationships between infrastructure resilience and social equity.

To address this gap, this paper aims to examine the interrelationships between infrastructure resilience and social equity using social media data. As one of the emerging data sources, social media data has been increasingly used by researchers to understand human activities and behaviors especially in a disaster setting (Zou et al. 2018). Comparing to traditional data sources (e.g., survey data), social media data is cost-effective, easy to access, and proved to be a reliable source of valuable information. The spatiotemporal distribution of disaster-related messages from social media allows for a quick assessment of disaster impacts in a real-time manner.

As the first step of the work, this paper aims to investigate whether twitter activities can be used as indicators of either infrastructure resilience or social equity conditions in a disaster setting. It focuses on collecting and analyzing the twitter activities during Hurricane Michael in the disaster-affected counties of Florida Panhandle area. The collected twitter data was organized based on the geolocations of the disaster-affected counties and was compared against the infrastructure resilience data and social equity data of the affected counties. This paper discusses the methodology for twitter data mining and analytics, and presents the results of statistical analysis between (1) twitter activities and infrastructure resilience data, (2) twitter activities and social equity data, and (3) infrastructure resilience data and social equity data of affected counties.

RESEARCH CONTEXT

Hurricane Michael, a first category five storm recorded in the northeast Gulf Coast, made landfall near Mexico Beach in Florida Panhandle on October 10, 2018. Hurricane Michael was one of the most powerful storms ever to make landfall in the contiguous U.S. With a sustained wind speed of 161 mph at landfall, it caused up to14 feet of storm surges in a few regions (NWS 2019). The high storm surges and strong wind forces caused substantive structural damage to the buildings and infrastructures. They also caused nearly 100% power outages in Florida Panhandle area, and some of these outages lasted for about a month. The physical infrastructure of power and communication networks, such as electric supply poles, transmission towers, and substations, suffered from devastating damage due to the combined effects of high wind forces, fallen trees, and flying debris. The transportation infrastructure, such as roads and bridges, were either blocked or damaged due to the fallen trees and floods.

Along with the catastrophic damage on the infrastructure, there was a tragic loss of lives (nearly 43 people) in Florida, and thousands of residents residing along the hurricane path had to be relocated (NWS 2019). The regions struck by Hurricane Michael – both the coastal counties under an evacuation order and inland counties people fled to – are among the most socially vulnerable regions in the United States (ATSDR 2016). Hurricane Michael had a huge impact on disadvantaged or vulnerable populations, such as the economically disadvantaged, the elderly, and the homeless.

DATA COLLECTION AND ANALYSIS

Twitter data collection

In our study, Twitter was selected as a source of social media data. Twitter provides an online social networking platform where people can communicate in short messages, share images, or webpages links, known as 'tweets'. With an average of generating 6,000 tweets per second, Twitter is one of the most popular social network sites that allow for the collection and analysis of the huge amount of information on human activities in a disaster setting (Zou et al. 2018). It also allows for the collection of time and location information of tweets and Twitter users, thus supporting spatiotemporal analysis (Zou et al. 2018). In our study, the following steps were conducted to extract twitter data for analysis.

First, all the twitter data was collected using a twitter scraping tool, named "Twint" (PyPI 2018). It is an advanced twitter scraping tool that utilizes twitter search operators, and it is capable of scraping the tweets related to some specific topics, users, or geographic locations (PyPI 2018). In our study, Twint was used to extract tweets based on geolocations. The coordinates and radius of coverage (calculated by assuming each of the counties as a circle) of each of the counties were firstly determined. A twitter search was then scripted to extract all the tweets that fall within the defined geolocation and radius of coverage for each of the counties. The tweets were extracted from October 7, 2018 to October 31, 2018 to cover the preparedness, response, and initial recovery phases of Hurricane Michael. Each extracted tweet contains the following information: (1) the time when the tweet was generated, (2) the tweet content, (3) the user who posted the tweet, (4) the user's profile including the name and address, and (5) the following and followers of the user. Second, after extracting all the tweets in the affected counties, the disaster-related tweets were captured by using the following keywords: Michael, hurricane, flood, and storm. The extracted tweets were then filtered by excluding those posted by users whose profile names contain the keyword "Michael". Each of the extracted tweets was then categorized based on the geolocations of disaster-affected counties of Florida Panhandle area. The total number of tweets and total number of disaster-related tweets extracted from these disaster affected counties of Florida during the disaster period were 4,376 and 716 respectively. Third, a disaster ratio index (Zou et al. 2018) that equals to the total number of disaster-related tweets to the total number of tweets was determined for each affected county. This radio index indicates the intensity of concerns and awareness in response to the impact of Hurricane Michael on social media.

Infrastructure resilience data collection

Infrastructure resilience data includes the data of infrastructure damage and infrastructure recovery. In this study, the data of five infrastructure resilience variables were collected, including the number of insurance claims per capita (I1), the damage value per capita (in the U.S. dollar) (I2), the number of damaged medical facilities per capita (I3), percentage of power outages (I4), and the time for power outage recovery (I5). These variables were selected based on the availability of the infrastructure damage data. These data were obtained from multi-sources, such as Florida Office of Insurance Regulation (FOIR 2019), Federal Emergency Management Agency (FEMA 2018 and 2019), and Florida Division of Emergency Management (FDEM 2019).

Social equity data collection

The data of seven variables that can be used to indicate social equity conditions were collected, including population (S1), percentage of population with an education level of bachelor's degree and above (S2), percentage of households with internet connection (S3), median household income (S4), percentage of population below the poverty line (S5), percentage of population of age 65 and over (S6), percentage of population with disability (S7), and average housing values (S8). These data were obtained from the US Census Bureau (US Census 2017). These social equity variables were selected based on two criteria: (1) important indicators of social equity based on a review of the literature (e.g., Schneiderbauer and Ehrlich 2006), and (2) availability of consistent and quality data from national resources (Cutter et al. 2010).

RESEARCH QUESTIONS

This study aims to understand the relationships between social equity and infrastructure resilience in a disaster setting. This paper focuses on addressing the following research questions:

1. How do the twitter activities represent the infrastructure resilience conditions of the affected counties in the context of Hurricane Michael?
2. How do the twitter activities relate to social equity conditions of the affected counties in the context of Hurricane Michael?
3. What are the infrastructure resilience conditions of the affected counties with different social equity conditions?

RESULTS AND DISCUSSIONS

To answer the above research questions, three sets of Spearman's rank order correlation analysis were conducted between (1) the twitter activities and infrastructure resilience variables, (2) the twitter activities and social equity variables, and (3) social equity variables and infrastructure resilience variables. The following sections discuss about these results in detail.

Relationships between infrastructure resilience and twitter activities

The results of the Spearman's rank order correlation between infrastructure resilience variables and twitter activity variables are shown in Table 1. As per Table 1, all the infrastructure resilience variables are generally positively correlated with the disaster ratio indexes. Among them, significant correlations were observed between the disaster ratio indexes and (1) the number of claims per capita, (2) percentage of power outages, and (3) time of power outage recovery. This result is consistent with a number of studies that show the increase in twitter activities is commonly corresponded to the significant disaster damage and recovery efforts (Kryvasheyeu et al 2016). During a disaster, the community residents are more concerned about the destructions and damage that happen near their surroundings, and they turn to social media platforms for disaster-related communication and information exchange about these destructions.

This leads to a time-sensitive increase of the number of disaster-related tweets in those regions (Zou et al. 2018). Therefore, twitter activities can be used as an important indicator for assessing the infrastructure damage as well as recovery efforts for a specific region in real-time (Kryvasheyeu et al. 2016).

However, in our study, the data of Franklin County were found to be an outlier, as the relatively high damage value per capita was not aligned with the relatively low twitter activities in that county. A further investigation on the data of Hurricane Michael damage value showed that Franklin County has a significantly higher damage value compared to the other eleven affected counties of Florida. This is mainly due to the tremendous amount of road/highway damage on the U.S. Coastal Highway 98 in Franklin County, where the gulf side of the two-lane roadway was completely washed out, and the damage value was estimated to be approximately $10 billion (FDEM 2019). Strong wind forces, storm surges, and rapid floodwater are the major reasons for the tremendous damage in this coastal highway. As a scenic highway along the shoreline, there were few coastal barrier protections installed to resist the potential high tides and storm surges due to storms. Without adequate and robust barrier protections that serve as the mainland's first line of defense against the impacts of severe storms and erosions, the roadway infrastructure along the gulf coast of the county was especially vulnerable during a disaster.

Based on our results, twitter activities can be useful as a rapid and easy way of assessing the intensity of damage due to disasters. However, attention needs to be paid to the outliers in the data, and more detailed virtual and field investigations are needed to understand the actual damage conditions in certain regions.

Relationships between social equity and twitter activities

The results of the Spearman's rank order correlation between social equity variables and twitter activity variables are shown in Table 2. As per Table 2, the population (S1), the percentage of population with an educational level of bachelor's degree and above (S2), the percentage of households with internet connection (S3), and the average housing values (S8) show significantly positive correlations with the number of disaster-related tweets. In contrast, the percentage of population below the poverty line (S5) and the percentage of population with disability (S7) have significantly negative correlations with the number of disaster-related tweets. In general, these results indicate that the communities that have relatively high socioeconomic status (e.g., income, housing value, education level) are more active on social media in the context of Hurricane Michael. This result is supported by a number of research studies (e.g., Duplaga 2017) that show vulnerable people lack access to internet and online social activities. In general, populations with higher education level or higher household income have better access to internet, cellphones, and social media. These populations are more inclined to express their concerns or share and exchange information on social media regarding the disasters. They are also more aware of the online communication channels with public agencies (e.g., emergency management department, transportation department) or non-government organizations (e.g., disaster relief organizations, volunteer groups). Thus, they may turn to these agencies for aid and support through social media. In contrast, vulnerable populations (e.g., the economically disadvantaged, the disabled) are relatively "quiet" on social media. Although social media has become more ubiquitous in 2018, the disparities on social media usage during disasters still exist across communities with different socioeconomic status.

Information exchange and sharing play a vital role in disaster management. Vulnerable populations, which lack access to internet or new technologies, are confronted with difficulties in effectively communicating, sharing and exchanging information during a disaster. Thus, the needs of vulnerable populations are usually not sufficiently considered in disaster management (Taeby and Zhang 2018). Although social media has become a new channel for the government agencies to acquire public situational information for emergency response, it is also crucial that the government officials are aware of the invisibility of vulnerable populations on social media; more efforts should be spent on addressing the concerns and needs of vulnerable populations.

Relationships between social equity and infrastructure resilience

Counties that are close to the hurricane path have more severe damage. Therefore, to eliminate the effect of disaster threat levels on the infrastructure damage, a set of normalized infrastructure resilience variables were developed so that we can examine how the infrastructure damage or recovery conditions are affected by the social equity status of these counties. The normalized infrastructure resilience variables were calculated by dividing the original variables by the sustained average windspeed during the hurricane period in each county. The Spearman's correlation was then conducted between these variables and the social equity variables. The results of this analysis are summarized in Table 3. Based on the results, two main findings are presented.

First, social equity variables such as the percentage of population with an education level of bachelor's degree and above(S2), the percentage of households with internet connections (S3), and the median household income (S4), have significantly negative correlations with the time for power outage recovery. This generally indicates that the counties that have lower socioeconomic status spend longer time on recovery in Hurricane Michael. For example, Calhoun County, which has a lower percentage of population with higher education and the lowest median household income, spent the longest time (i.e., 27 days) to completely recover from the power outages. While natural disasters may strike without prejudice, the path to recovery is much less equal. In a disaster, communities with better socioeconomic status are more likely to have access to disaster information and knowledge, they can thus receive rescue responses and recovery efforts in a quicker manner (Zou et al. 2018). On the other hand, people in the socioeconomically disadvantaged communities typically perceive more risks and have higher concerns towards disasters. Most of them are less educated about the disaster-related knowledge, and they are less aware of the resources that are available to them. These people may experience more barriers to receiving aid, getting resources, and recovery form the disasters. Many organizations (e.g., American Red Cross) have thus been calling for a voluntary registration program for the disabled, frail, or economically-disadvantaged to provide those citizens with increased assistance during disasters. In recent years, multiple counties in the state of Florida have initiated some vulnerable-population registry programs (e.g., the Emergency and Evacuation Assistance Program of Miami-Dade County and the Broward County Vulnerable Population Registry) (Taeby and Zhang 2019).

Second, under the same threat level, there is a positive correlation between average housing values (S4) and hurricane damage value per capita (I2). For example, Bay County and Leon County, which have higher average housing values (higher than $200,000), also experienced higher damage value due to Hurricane Michael. Typically, higher housing values indicate stronger structures and more resilient components or features (e.g., high impact windows, hurricane doors) of the buildings, which would yield less damage value. However, in the event of Hurricane Michael, the design wind speeds (115mph to 130mph) of structures in the impacted communities at Florida Panhandle region are lower than the sustained wind speed (i.e.,161mph) of the hurricane at landfall. In addition, a high percentage of structures in this area were constructed before 1990s, and they were not reinforced or retrofitted to be compliant with the most updated building code. After Hurricane Michael, there is a growing consensus that the building codes at Florida Panhandle area need to be upgraded to support the development of resilient communities (Allen 2018).

Table 1. Correlations between Twitter Activities and Infrastructure Resilience Variables

Infrastructure resilience variable	Disaster ratio index		Disaster-related tweets		Total tweets	
	ρ-value	P value	ρ-value	P value	ρ-value	P value
I1	0.839	0.010[a]	0.503	0.095	0.333	0.291
I2	0.476	0.118	0.503	0.095	0.399	0.198
I3	0.328	0.299	0.522	0.081	0.484	0.111
I4	0.657	0.020[a]	0.329	0.297	0.130	0.688
I5	0.863	0.010[a]	0.570	0.053[a]	0.444	0.148

a = significant correlation with p value less than 0.05
ρ = Spearman's ρ coefficient

Table 2. Correlations between Twitter Activities and Social Equity Variables.

Social equity variable	Disaster ratio index		Disaster-related tweets		Total tweets	
	ρ-value	P value	ρ-value	P value	ρ-value	P value
S1	0.014	0.966	0.812	0.001[a]	0.990	0.033[a]
S2	0.091	0.779	0.629	0.028[a]	0.992	0.010[a]
S3	0.168	0.602	0.743	0.006[a]	0.764	0.004[a]
S4	0.002	0.995	0.514	0.087	0.523	0.080
S5	-0.204	0.526	-0.596	0.041[a]	-0.583	0.046[a]
S6	0.215	0.501	-0.445	0.147	-0.562	0.061
S7	-0.379	0.224	-0.793	0.002[a]	-0.808	0.001[a]
S8	-0.056	0.863	0.663	0.019[a]	0.715	0.009[a]

a = significant correlation with p value less than 0.05
ρ = Spearman's ρ coefficient

RESEARCH LIMITATIONS

Several limitations are acknowledged in this study, which indicates the necessity of future research. First, Twint was used to extract twitter data in the affected counties of Florida Panhandle area. This data collection method was selected to avoid the need of geocoding the twitter data. However, only twitter data that contains geolocation information was extracted through this process, which limits the number of extracted twitter data. Also, the extracted twitter data cannot be regarded as a random sample and therefore the results cannot be generalized to the entire twitter activities of the affected counties. Second, only eight social equity and five infrastructure resilience variables were considered in this paper, and they cannot fully represent social equity and infrastructure resilience conditions of the affected counties. Other variables, such as employment rate, percentage of young populations, or miles of roads that are damaged, can be integrated into this study to allow for a wider scope of analysis. Third, some correlation results between infrastructure resilience variables and social equity variables were not statistically significant. Although existing study (e.g., Doorn 2019) indicates that infrastructure resilience has an impact on social equity, more research is needed to explore such relationships in a quantitative manner.

Table 3. Correlations between Social Equity Variables and Infrastructure Resilience Variables.

Resilience Variable	I1*		I2*		I3*		I4*		I5*	
Social equity variable	ρ-value	P-value	ρ-value	P-value	ρ-value	P-value	ρ-value	P-value	ρ-value	P-value
S1	0.105	0.746	0.140	0.665	0.101	0.754	0.112	0.729	-0.580	0.048[a]
S2	0.273	0.391	0.524	0.080	0.710	0.010[a]	-0.007	0.983	-0.573	0.050[a]
S3	0.070	0.829	0.021	0.948	0.569	0.053	-0.350	0.265	-0.608	0.036[a]
S4	-0.070	0.829	0.084	0.795	0.413	0.182	-0.147	0.649	-0.776	0.030[a]
S5	-0.098	0.761	-0.056	0.86	0.192	0.551	-0.074	0.820	0.242	0.448
S6	0.263	0.409	0.182	0.571	0.359	0.251	0.049	0.880	0.133	0.680
S7	-0.326	0.301	-0.309	0.329	-0.489	0.107	-0.070	0.828	0.168	0.601
S8	0.119	0.713	0.469	0.124	0.600	0.039[a]	-0.126	0.697	-0.510	0.090

* = normalized by the disaster threat levels
a = significant correlation with p value less than 0.05
ρ = Spearman's ρ coefficient

CONCLUSIONS AND FUTURE WORK

This paper presents a preliminary study of using social media data to understand the relationships between the infrastructure resilience and social equity conditions of communities in the context of Hurricane Michael. Three sets of correlation analysis were conducted between (1) infrastructure resilience and twitter activity variables, (2) social equity and twitter activity variables, and (3) infrastructure resilience and social equity variables. The results indicate that (1) twitter activities can be used as an important indicator of infrastructure resilience conditions, (2) socially vulnerable populations are not as active as general populations on social media in a disaster setting, and (3) vulnerable populations require a longer time for disaster recovery. The study contributes to the body of knowledge by quantitively examining the possible relationships between infrastructure resilience and social equity in a disaster setting using social media data. This knowledge would facilitate the design and development of resilient infrastructures while addressing social equity across different communities and populations, thus accounting for the needs and rights of all citizens.

In the future/ongoing work, the authors will further explore how communities with different social equity conditions react to the infrastructure conditions in the context of disasters. The authors will continue with data collection to extend the current work to a national scale of study. In addition, the authors will further analyze the data by categorizing them based on the different phases of the disaster, including mitigation, preparedness, response, and recovery phases. Other types of analysis will also be conducted, such as using natural language processing techniques to understand the trending topics throughout different phases of disasters and to understand local communities' attitudes towards disasters.

ACKNOWLEDGEMENTS

This material is based upon work supported by the National Science Foundation under Grant No. 1933345 and the Quick Response Program of Natural Hazards Center. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation or Natural Hazards Center.

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