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RESEARCH AND THEORY

A content analysis of social media discourse during Hurricane María: filling a void when traditional media are silent

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Abstract

As social media is increasingly used by communities to understand and cope with environmental hazards, understanding how people use social media before, during, and after disasters can support disaster response and recovery efforts. This paper presents an empirical application of Houston et al.'s (Disasters 39:1–22, 2015) functional framework for disaster social media, using the case of Twitter use during and after Hurricane María. Our research aims to (1) identify the predominant patterns of Twitter usage and content dissemination during the Hurricane María crisis and (2) validate and refine the functional framework for disaster social media with a case study of the hurricane that hit Puerto Rico in 2017. We find that people in the US used Twitter mainly to access news of the hurricane, express emotions (both negative and positive), and to understand socio-political events shaping the response and recovery. Most tweets came from individuals rather than organizations, and most were sent as the hurricane was designated as category four and approached Puerto Rico, with far fewer posts after landfall. These findings highlight the importance of individuals sharing and accessing vital information when official outlets are absent or limited and the relatively short-lived attention to slow recovery processes.

Keywords Hurricane María · Twitter · Puerto Rico · Social Media

Introduction

As a result of climate change altering global temperatures and hydrological patterns, conditions related to existing environmental hazards will continue to exacerbate the likelihood of extreme events like floods, droughts, hurricanes, and wildfires (Sheffield and Landrigan 2011; Intergovernmental Panel on Climate Change 2018; Watts et al. 2019; Lee et al. 2023). These environmental hazards can quickly turn into disasters if they surpass pre-expected thresholds of human death, economic losses, and other costs (Smith 2013). Importantly, low-income and underrepresented communities have more difficulty recovering from disasters than higher income communities, and these communities become vulnerable when their characteristics affect their ability to avert, recover from, and cope with environmental hazards (Wisner et al. 2004; Macias et al. 2021). Anticipated changes in hazard frequency and intensity are likely to have disproportionate impacts on low-income and underrepresented communities. This underscores the "climate gap" in understanding hazard impacts, which highlights how vulnerable and marginalized communities tend to be disproportionately affected by the consequences of climate change events (Archibong and Annan 2023).

Social media plays an important role in communication during disaster response (Kim and Hastak 2018; Palen and Hughes 2018; Fan et al. 2020). As a communication tool, social media allows people to communicate and share messages and resources in real time (Kim and Hastak 2018; Lovari and Bowen 2020). Increasingly, social media plays a significant role in disseminating information about disasters

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by allowing people to share information and ask for help (Kusumasari and Prabowo 2020; Tsao et al. 2021). Social media offers a rapid and wide-reaching form of communication not only within affected areas but also between affected areas and the rest of the world (Takahashi et al. 2015, p. 392). Following a disaster event like an earthquake, the usage of social media through mobile phones and emails increases and even surpasses traditional communication methods like landlines (Velev and Zlateva 2012; Appleby-Arnold et al. 2019). For example, more than 20 million people tweeted about Hurricane Sandy during the event (Guskin 2012). This new communication trend has fostered a perceived legitimacy of social media during disasters (Murthy and Longwell 2013; Feldman et al. 2016; Zhang et al. 2019). Public expectations are changing for even emergency managers to use social media platforms in disaster response; each year more and more people are enrolling in electronic alert notification systems (Wendling et al. 2013).

Social media as a disaster communication platform allows users to both consume and distribute (re-share) disaster messages. The medium is able to rapidly adapt to real-time situations and needs (Jin and Spence 2021), which allows for communication between local residents impacted and multiple stakeholders and agencies responding (Murthy and Gross 2017). Social media also helps people to find community during disasters, including for people who have been displaced and those who are emotionally impacted, and to create resources for communities (Shklovski, Palen, & Sutton, 2008 in García-Ramírez et al. 2021).

As social media use increasingly turns mainstream (Pew Research Center 2019), especially for disaster response (Sutton, et al., 2020b; Renshaw et al. 2021), there is a need to better understand how social media communication can be harnessed to effectively engage and mobilize citizens, and to lessen public health burdens. Social media can be used in a variety of ways across different phases of disaster planning and response, from amplifying coverage of a pending disaster to sustaining coverage post-event to motivate assistance, resources, and donations, to connecting loved ones and networks (Vieweg et al. 2010). It can also be used by diverse actors, from individuals to government agencies to community organizations. At the individual level, social media enables individuals to share information, mark themselves as safe following an event, or ensure that resources are available to those who need them (Lindsay 2011). At the organizational level, emergency planning and response organizations draw on social media as an emergency management tool for disseminating emergency communication and warnings (Sutton et al. 2014).

A first step in understanding how to better harness social media is understanding how it is currently used under disaster conditions. Given the diverse users and uses of social media for disaster response, a conceptual framework can provide a basis for comparison in developing a cross-case and systematic understanding of disaster social media (Huang and Xiao 2015). To this end, Houston et al. (2015) created a functional framework for social media disaster communication that captures the various ways social media may potentially be used before, during, and after a disaster. The original framework draws on a literature review to develop categories of the ways social media is used during disasters (i.e., its functions) and when these different functions come into play. This framework provides a theoretical basis for research and can yield practical implications for disaster management, including guiding the development of social media tools and implementation processes, understanding the factors influencing social media use, and improving coordination between different users and functions.

A key next step is validating the framework against a real-world disaster situation. Understanding whether and how the framework describes an actual disaster situation will help refine the framework for particular geographies and types of hazards lending to its external validity. This paper presents an empirical application of the Houston et al. (2015) functional framework, using the case of Twitter[1] use during and after Hurricane María. We draw on a deductive content analysis of tweets shared about Hurricane María to identify the ways in which Twitter was used and by whom during and 6 weeks post-Hurricane María landfall. Our research aims are twofold: (1) to identify the predominant patterns of Twitter usage and content dissemination during the Hurricane Maria crisis and (2) to validate and refine the functional framework for disaster social media. Understanding how individuals use Twitter during disasters and in the immediate aftermath will be important as hurricanes occur more frequently, and as the public continues to turn to social media as a mainstream news source. Public health and disaster response organizations will benefit from a more detailed understanding as to who and how communication on social media can play a role in mitigating the public health burdens that result from disaster events (Sutton et al. 2020a, 2020c, 2020d).

Background

Twitter as a social media tool

Among social media platforms, Twitter (now X) has emerged as a key communication tool to respond to disasters

[1] Authors are aware that Twitter is now X. However, because the analysis of this paper was done when the platform was still Twitter, authors have decided to use the former name of the social media platform and not the current.

(Sreenivasan et al. 2011; Seddighi et al. 2020). Thanks to Twitter's low-bandwidth feature, individuals can send out messages with limited internet access or when there is network congestion (Li and Rao 2010; Nguyen et al. 2013). Also, Twitter has the potential to quickly broadcast the content of a local event to a bigger audience. For example, the 2008 Mumbai bombing and the 2010 crash of US Airways Flight 1549 highlighted a reduction in the viewing of traditional media and at the same time an increase of those traditional media sources sharing news on Twitter (Murthy 2011). The social media platform has also played a key role in helping build social capital and bringing people together, for instance serving as the main line of communication between residents following an earthquake in Tskuba, Japan (Kaigo 2012).

Even though Twitter is highly utilized by people facing disaster conditions, it is not a tool widely available to all, which creates a divide between those who can access it and those who cannot. The largest age demographic of Twitter users is between 25 and 34-year-olds (Duggan et al. 2013; Duggan and Smith 2013; Blank 2017); approximately 42% of adult Twitter users have at least a bachelor's degree—11 percentage points higher than the overall share of the public with this level of education (31%) (Pew Research Center 2019). As of 2020, Twitter had more than 330 million monthly active Twitter users with 69.3 million users in the U.S. (Statista 2020), representing 25% of the US population; this fraction dropped to 23% in 2021 (Pew Research Center 2021). For Puerto Rico, this number is slightly less; as of 2021, there were 456,000 accounts (We Are Social et al. 2021), roughly 13.9% of the population. However, when Hurricane María occurred, more than 60% of Puerto Ricans had social media accounts, with 1.86 million Facebook accounts and 670,000 Twitter accounts (Statista 2022).

Social media theoretical frameworks

Disaster analysis frameworks serve as a tool for organizing social media disaster data and analyzing their use during disaster events. Several frameworks have been proposed in the literature to facilitate the use and analysis of social media in emergency, disaster, and crisis situations (Alexander 2013). The Twitter Situational Awareness framework (Karami et al. 2020) focuses on using Twitter data to measure people's awareness and understanding of the disaster to improve recovery efforts. The framework utilizes text-mining methods such as sentiment analysis and topic modeling to understand Twitter's use for disaster preparedness and response (Ptaszynski et al. 2021). The Social Amplification of Risk Framework (SARF) (Pidgeon et al. 2003) explores how hazards are portrayed in media outlets, and how institutional, cultural, social, and psychological processes amplify or downplay risk perception and as a result shape behavior (Henwood & Pidgeon, 2014). Scholarship employing SARF to analyze tweets highlights how people and organizations simultaneously can appropriate, construct, and pass on risk-relevant information, including Twitter's capacity to communicate to people of dangers and risks (Panagiotopoulos et al. 2016). Other approaches to Twitter analysis include an "infoveillance" approach using Twitter (Chew & Eysenbach, 2010). This approach involves analyzing tweets to gather information and monitor the spread of diseases and disasters as well, which is very similar to the Protective Action Decision Model (PADM) but is used for instructing how agencies should construct risk messages.

These frameworks focus on the tweets as a source of data about the disaster itself—how people understand the disaster or view the risk it poses, or how particular information is spreading. However, understanding how social media itself is used, the types of communication it enables require a distinct approach. The Houston et al. (2015) functional framework provides this focus on explaining social media uses during a disaster, as well as explaining potential factors that impacts its use. The Houston et al. (2015) framework is anchored in disaster communication theory and describes who uses social media and how they use it during disasters in real time. The framework uses a literature review to develop 15 categories describing specific functions of social media (i.e., sharing information, connecting community members). It also binds each of the categories to a specific phase of the event (pre, event, post), overcoming a key limitation of other frameworks (Imran et al., 2016). Because the management and information needs, before, during, and after a disaster are very different, understanding distinct uses of social media across these phases can provide insight on how people behave during disasters and identify phases that emergency personnel need to pay more attention to in order to build resilient pathways for people on the ground. In addition, the framework has the power to inform how social media may be leveraged by governments and public health agencies for future pending disasters.

Hurricane María

The 2017 hurricane season was one of the most active in recent U.S. history. Hurricanes María, Harvey, and Irma left swaths of the United States and Caribbean devastated (Rios et al. 2020). On September 20, 2017, Hurricane María, a category four hurricane, struck the island of Puerto Rico. The hurricane contained sustained winds of 145 mph, peaking at 155 at landfall, and around 37.9 inches (962.7 mm) of rain fell on the island (Pasch et al. 2018). Between 60,000 and 90,000 houses were destroyed and an additional 250,000 partially damaged (Meléndez and Severino 2018). At least 70,000 people were displaced from their homes and around 135,000 left the island in the hurricane's aftermath

(Meléndez and Severino 2018; Macias et al. 2021). María is the worst hurricane the island has experienced both economically and by loss of life since Hurricane San Ciriaco (category four) in 1899.

Hurricane María devastated the entire island, leaving it in a complete blackout for several months (Criss 2018; García 2021). Some sectors of the island waited a year for their power to return, and the island's power grid continues to function in a precarious state (Sanchez 2018; García 2021). Although the government of Puerto Rico states that only 64 people initially died as a consequence of Hurricane María, later assessments reported the number of deceased to be in the thousands (Robles et al. 2017; Kishore et al. 2018; Santos-Burgoa et al. 2018; Weissenstein et al. 2018). The total economic losses for the island were estimated at $90 billion (Estado Libre Asociado de Puerto Rico 2018; García 2021).

Methodology

We conducted a content analysis of Hurricane María–related tweets before, during, and 6 weeks after landfall on Puerto Rico. A total of 2315 Hurricane María–related tweets were analyzed to identify who used Twitter during this time and how it was used during and after the hurricane in response to the crisis. Our sample captures messages from September 17 (when Maria turned from a tropical storm to a hurricane) to November 7, 2017. We selected November 7 as the end point as that was the start of multiple days without any relevant tweets—it signals the end of the initial social media discourse, even though impacts from Hurricane Maria lasted years.

Data collection and processing

Tweets were retrieved from Twitter's open streaming application program interface (API), which provided a random 1% sample of tweets (Le et al. 2019). Twitter's API allowed external programs to access both the content of tweets as well as its metadata. Tweets can be identified using three parameters: keywords (i.e., words, phrases, or hashtags), geographical boundary boxes, or user ID.

To access Twitter messages, we used Texera,[2] a Python-based extraction tool that saves a daily 1% sample of all tweets posted from Twitter's API, then shares those tweets in a searchable interface (Wang et al. 2017). We then used a keyword search query to identify relevant tweets. However, this approach is no longer possible because Twitter stopped the free access to Twitter API on February 9th, 2023. Over the 8-week period of Hurricane Maria (September 16 to November 7, 2017), the 1% sample contained 5 million tweets. While a 1% sample may seem small, a study of Twitter data sampling strategies showed that use of random samples detected similar numbers of themes across multiple samples, suggesting that it was useful to qualitatively assess frequencies (Le et al. 2019). From this 1% sample of tweets, we first limited the sample to those tweets that were geolocated (allowing us to evaluate geographic patterns and restrict to US and Puerto Rico tweets) and then used keyword searches to identify tweets relevant to Hurricane Maria. Initial search terms included risk, Maria, Puerto Rico, Gobierno, and FEMA, both with and without hashtags. A sample of several hundred tweets extracted with these terms were reviewed manually to identify additional, relevant keywords and reduce the incidence of non-relevant tweets (e.g., "I liked that girl's name Maria, that is Puerto Rican.")

After refining, the final keyword query was four search strings: (1) FEMA and Puerto Rico, (2) Hurricane and Maria, (3) Gobierno and Puerto Rico, and (4) Puerto Rico and Maria; each combination was used with and without hashtags. This word search string is consistent with other social media analyses using Twitter following Hurricane Maria (Jin and Spence 2021) and is designed to identify tweets in both English and Spanish. The updated search retrieved 2315 Hurricane Maria–related tweets over the 8-week period. Duplicate and non-relevant tweets were removed (n=121, 14.5% of the sample), making the final sample 2194.

It is important to note that the only community at risk reflected in our sample was people that were in Puerto Rico, even if the messages they sent were relatively underrepresented (3%, n=64). This underrepresentation is partly due to the widespread power outages on the island at the time. Another issue that may have played a role in having a low message count from Puerto Rico is the Twitter API, and the fact that only geocoded tweets were analyzed. Puerto Rico is at the edge of the geographic region of the API, and some tweets may not have been captured. However, even the small number of messages from Puerto Rico reveals one of the advantages of Twitter: that it does not require a strong signal or connection, making sending messages under disaster conditions more accessible.

Data analysis

We used a deductive coding approach to manually assign the final sample of 2194 tweets into the categories according to the Houston et al. (2015) functional framework. Although analyses of social media content increasingly use automated coding approaches drawing on natural language processing

[2] Texera has been collecting a 1% daily sample of Twitter since 2015 and is funded by a National Science Foundation Grant at the Department of Computer Science at the University of California, Irvine.

Table 1 Function code names and definitions

Function code name	Definition from Houston et al. (2015)	Disaster phase
Provide & receive disaster information	Provide and receive disaster preparedness information	Pre-event
Provide & receive disaster warnings	Provide and receive disaster warnings	Pre-event
Signal & detect disasters	Signal and detect disasters	Pre-event, event
Send & receive help	Send and receive requests for help or assistance	Event
Inform one's condition or location	Inform others about one's own condition and location and learn about a disaster-affected individual's condition and location	Event
Document what is happening	Document and learn what is happening in the disaster	Event, post-event
Deliver & consume news	Deliver and consume news coverage of the disaster	Event, post-event
Provide & receive disaster response info	Provide and receive disaster response information; identify and list ways to assist in the disaster response	Event, post-event
Raise awareness of disaster event	Raise and develop awareness of an event; donate and receive donations; identify and list ways to help or volunteer	Event, post-event
Disaster mental health support	Provide and receive disaster mental/behavioral health support	Event, post-event
Express emotion	Express emotions, concerns, well-wishes; memorialize victims	Event, post-event
Disaster response & recovery	Provide and receive information about (and discuss) disaster response, recovery, and rebuilding; tell and hear stories about the disaster	Event, post-event
Discuss socio-political & scientific causes	Discuss socio-political and scientific causes and implications of and responsibility for events	Post-event
Reconnect community members	(Re)connect community members	Post-event
Traditional crisis communication	Implement traditional crisis communication activities	Pre-event, event, post-event

(NLP) and machine learning algorithms (Balaji et al. 2021; Camacho et al. 2021), initial screen of the dataset suggested that automated approaches would miss important nuances. In particular, the tweets contain frequent uses of sarcasm, colloquialisms, and emojis, each of which can change the underlying meaning of the tweet and are hard to detect. Additionally, most NLP tools are designed for a single language; our tweets are in English, Spanish, and Spanglish. Finally, approaches like topic modeling require either using inductively developed categories or having a pre-trained dataset on which to train the algorithm. Given that this study is applying pre-existing categories to a new dataset, a manual coding approach provides a more nuanced approach in evaluating the meaning behind word usage and assigning tweets to the functions.

The Houston et al. (2015) framework presents 15 potential social media disaster "functions," ranging from providing and receiving disaster preparedness information to expressing emotions, concerns, and well-wishes. It also assigns each function to specific phase(s) of disaster, indicating whether the functions are likely to be seen pre-event, during the event, and/or post-event. Table 1 summarizes these functions, their associated disaster phase, and the shorthand code name we used for analysis.

We assigned each tweet to the function category or categories that best reflected its content. A tweet could be assigned to one or two categories. A codebook (Table 6 in Appendix) containing coding criteria was developed to help with assigning tweets to the functions, defining the parameters of inclusion and exclusion criteria, and included examples and keywords to aid with consistently interpreting the tweets and their function in disaster discourse.

Coding was completed over two rounds, in order to enhance the consistency and reliability of our coding choices (Sweeney et al., 2013; Locke et al. 2015). In the first round of coding, the lead author categorized tweets deductively based on the coding framework and definitions by Houston et al. (2015) (see Table 1). To avoid "coding and annotation fatigue—" when all the cases start looking the same (Kleinheksel et al. 2020)—we only coded 500 messages a day. Then, a second author led the second round of coding, which focused on reviewing borderline cases and ensuring consistency in the application of codes. During the second round, codes were reviewed and discussed by the team of coders to ensure the assigned function reflected their content (O'dea et al. 2015). In this second round, we paid special attention to the use of additional tweet message properties such as use of emojis and hyperlinks in interpreting tweets. This was particularly relevant given that emojis were often used to amplify or contradict the sentiment of tweets (e.g., *my teacher just tell me if i need time off for Hurricane Maria hitting back home let her know…*😤😤😤*),* which could change the meaning of the tweet and therefore the coding category. Users likewise sometimes included hyperlinks in their tweets, the content of which could influence the tweet's underlying meaning. During the second round of coding, we also visited each hyperlink to make sure we captured the true meaning of the message.

Table 2 Types of social media users

Social media users	Definition
Individuals	Stand-alone users
Organizations	Non-governmental organizations and private businesses
Government	Government officials, agencies, and counties
News media	News media outlets
Community	Shared interest groups (e.g., schools, colleges, and online groups)

Table 3 Twitter disaster communication functions, frequency, and examples

Function	Count	Example
Deliver & consume news	686	*Hurricane #Maria is now Cat5 strength w/ 160mph sustained winds. It's the 2nd Cat5 #Irma storm this… https://t.co/EnqKuaSua4*
Discuss socio-political & scientific causes	550	*Puerto Rico Accused of Fudging Hurricane Maria Death Toll|News|teleSUR https://t.co/zvzIzZKZeX*
Express emotion	341	*Prayers out to those people in the Caribbean Islands as Hurricane Maria heads towards them. Really is insane what's going on there*
Raise awareness of event	240	*Seriously, @realDonaldTrump @FEMA, the ppl of Puerto Rico need clean water. Send it to them!*
Send & receive help	154	*there are many groups in FB for finding people and Hurricane Maria PR updates. this one of many, coul… https://t.co/zJKw1Hs771*
Provide & receive disaster response information	77	*Taking matters into my own hands & starting a Hurricane Maria relief effort for Puerto Rico! Any donation helps & RT https://t.co/q0RzXa3Phe*
Inform about one's condition or location	67	*Drone Video Emerges From Puerto Rico Shows Flooded Streets In San Juan After Hurricane Maria https://t.co/tGRGwQY9YC*
Traditional crisis communication	*43*	*Thank you for all the great work you've been doing in Puerto Rico over the past week, @fema @USCG @USNavy @USNationalGuard @USDOT etc.*
Signal & detect disasters	31	*Three weeks after Hurricane Maria, hospitals in Puerto Rico are *still* running on a generator. https://t.co/Ycp3BTUESt*
Document what is happening	23	*Listen to the wind at before the eye of Hurricane Maria reaching San Juan, Puerto Rico at 7:50am… https://t.co/FXSne8gz7D*
Provide & receive disaster information	7	*Caribbean islands prepare for Hurricane Maria - BBC News https://t.co/NhzH4lcAec*
Provide & receive disaster warnings	7	*I saw this on the BBC and thought you should see it: Puerto Rico dam bursts in wake of Hurricane Maria - https://t.co/bys9Nwr4K7*
Disaster mental health support	7	*#Hurricane & tropical storm distress warning signs, emotional support resources via @distressline https://t.co/l8n05NGpyr #Maria*
Disaster response, rebuild, recovery	3	*How to help Puerto Rico: 10 things you can do for Hurricane Maria victims right now https://t.co/YHDuELvaAm*

After assigning the function codes, users were also categorized as one of five user types (Table 2) and one of more of the three disaster phases, drawing on categories from Houston et al. (2015).

Hurricane Maria Disaster phases were defined as pre-event, event, and post-event; for the purposes of our sample, the pre-event was September 17th (Maria upgraded to hurricane status) to September 20th (landfall on Puerto Rico), event from September 20th to September 23rd (end of direct storm impacts), and post-event after September 23rd.

Descriptive statistics of tweet content category frequencies were performed on the overall dataset to describe the frequencies of each social media function, as well as by user type, and geographic location (i.e., state or territory).

Results

Of the 15 disaster social media functions, we identified 14 in our data that were used before, during, and after Hurricane María made landfall in Puerto Rico (Table 3).

The predominant function characterizing disaster discourse during Hurricane Maria involved *Deliver and consume news coverage* (31% of tweets, n=686). Examples from this function included users tweeting and retweeting links or excerpts from news articles related to Hurricane María. Common messages from this function described the hurricane's trajectory and wind speed, as well as the hurricane's consequences and death toll. Although most tweets focused on retweeting and sharing news stories,

other tweets focused on providing vital information in a news format; most of these originated from news anchors and meteorologists.

The second most prevalent social media disaster discourse function during Hurricane Maria involved *Discuss socio-political and scientific causes* (25%, *n*=550). Within this function, most tweets focused on connections with political aspects more broadly: [e.g., *@WhitefishEnergy and FEMA are playing games with lives in Puerto Rico. This is an absolute disgrace and disaster. #MAGA*]. Users emphasized Puerto Rico's dire situation in the aftermath of Hurricane María and its connection to the political situation within the U.S. Other messages focused on Puerto Rico's socio-political condition mediating the U.S executive and federal branches' response.

The third most prevalent social media disaster discourse function was *Express emotions* (15.5%, *n*=342). Most of the messages in this function were aimed at sharing concern for the situation on the island. An example of this type of tweet was: [*To all those impacted by Hurricane Maria: our thoughts & prayers are with you. To those affected in Boston: your City is here for you.*] Tweets such as "pray for Puerto Rico" or "my prayers are with Puerto Rico" were expressed often. While most messages in the *Express emotion* function were positive, hate messages were also expressed, such as those that made fun of the situation on the island or depicted Puerto Ricans in a derogatory way [e.g., *Puerto Rico hammered by Hurricane Maria, but they are Mexicanish, so we should all have a good laugh about it. Right?*].

The fourth most prevalent disaster discourse function was *Raising awareness* (10.9%, *n*=240). These tweets raised awareness in a number of ways; some pointed out how Puerto Ricans are U.S citizens, while others called attention to the dire conditions, e.g., that people had no access to water or food for weeks. Many messages under the function *Raising awareness* highlighted the post-recovery needs of communities impacted by the disaster by encouraging people to donate, including where to donate. An example of this type of tweet was: [*There is a crisis in Puerto Rico after #Maria. I encourage you to do what you can locally: https://t.co/8LAoQgyW34*].

The fifth most prevalent function was *Send and receive help* (7%, *n*=154). For this function, users called attention to the disaster, with many using #Maria to amplify their message and bring attention to the issue. Tweets also provided assistance information for impacted groups and shared information on where to get resources.

Social media user types

Different types of users were active on Twitter in the response to Hurricane María, with all five user types proposed by Houston et al. (2015) present in our dataset (Fig. 1). The vast majority of tweets (82%, *n*=1811) came from individuals. This category included scientists, teachers, police officers, lawyers, and celebrities among others. News media outlets, which included journalists, TV anchors, and radio stations, accounted for 12% of tweets. The organization category (4% of tweets, *n*=82) included non-governmental organizations (e.g., Red Cross, Salvation Army) and private businesses, including apps such as Hurricane Pro and businesses in Puerto Rico like Dominguez Auto. Government users (1.4% of tweets, *n*=32) included U.S. government officials and institutions (e.g., FEMA, U.S Army). Finally, community users were defined as those using an account that represented a whole community (0.7% of tweets, *n*=16) which included college campuses accounts, high schools, and online groups, such as Facebook groups.

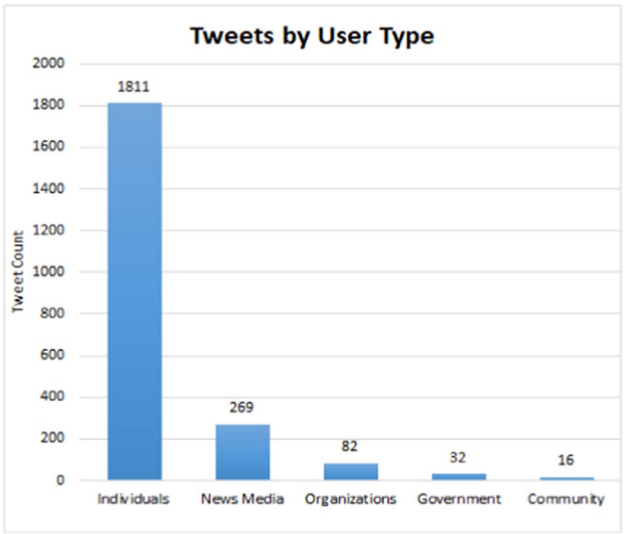

Fig. 1 Twitter use by different actors

Table 4 provides the top functions for each user type. Individuals, news media, and organizations had *Deliver and consume news* as their top tweeted function. The top function for governments was *Discuss socio-political and scientific implications*, and for Community was *Raise awareness* tied with *Deliver and consume news*. For four of the five user types, Twitter functioned to *Deliver and consume news* as carrying the most important function. For the second most frequent Twitter function, users were focused on either raising awareness about the disaster event or discussing political and scientific causes of the event. Individuals, organizations, and community had *Express emotions* as their top third function, while governments were *Deliver and consume news*.

Temporal trends

We drafted a timeline to observe how Twitter disaster discourse evolved over time (Fig. 2). Tweets increased as the Hurricane approached Puerto Rico. The highest tweet count occurred the day Hurricane María became a Category 5 and

Table 4 Top categories by user type

Ranking	Individual	News media	Organization	Government	Community
1	Deliver & consume news (30%, *n*=583)	Deliver & consume news (62%, *n*=77)	Deliver & consume news (45%, *n*=18)	Discuss socio-political & scientific causes (27%, *n*=7); Raise awareness (27%, *n*=7) (tied for 1st)	Deliver & consume news (33%, *n*=3); Raise awareness (33%, *n*=3) (tied for 1st)
2	Discuss socio-political & scientific causes (25%, *n*=493)	Discuss socio-political & scientific causes (14%, *n*=17)	Raise awareness (23%, *n*=9)		
3	Express emotions (17%, *n*=329)	Raise awareness (10%, *n*=13)	Express emotions (18%, *n*=7)	Deliver & consume news (19%, *n*=5)	Discuss socio-political & scientific causes (11%, *n*=1); Inform one's condition or location (11%, *n*=1); Express emotions (11%, *n*=1)
4	Raise awareness (10%, 202)	Inform one's condition or location (4%, *n*=5)	Provide & receive disaster response info (5%, *n*=2)	Send & receive help (8%, *n*=2); Express emotions (8%, *n*=2); Provide & receive disaster response info (8%, *n*=8)	

declined rapidly when the hurricane made landfall. Other smaller peaks occurred after the event; these included when (1) the Guajataca Dam broke, (2) former President Trump waived the Jones Act, (3) statistics on Puerto Rico's drinking water access and electricity were deleted from FEMA website, (4) EPA found that people were drinking water from a Superfund site, and (5) Trump suggested that the US government would stop relief efforts (e.g., from FEMA and the military) to Puerto Rico.

Figure 2 includes the timelines for the three most tweeted categories. The categories *Deliver and consume news coverage* and *Discuss socio-political and scientific causes* both peaked the day Hurricane María turned into Category 5, mirroring overall trends. The function *Express emotions*' highest day was the day it was announced that Hurricane María would hit Puerto Rico.

Geographic trends

In addition to temporal trends of social media disaster discourse, we assessed the geographic distribution of Tweets across the U.S. (Fig. 3). We observed tweets across all 50 states, as well as Puerto Rico and the District of Columbia; however, tweets were highly concentrated within a few states, namely, Florida (14%, *n*=315), California (13%, *n*=282), New York (12%, *n*=270), and Texas (9%, *n*=193). Only 64 tweets were geotagged from Puerto Rico. The low message count in Puerto Rico may have reflected the fact that the island's power grid was destroyed; still, they had a higher count than many other states.

In the states with higher tweet counts, the most tweeted functions varied greatly. Table 5 presents the distribution of top functions by region, including Puerto Rico. The function *Deliver and consume news* was the top function in Florida, New York, and Texas, while in California, the top function was *Discuss socio-political and scientific causes*, and in Puerto Rico, the top category was *Inform one's condition and location.* This suggests that communities in immediate risk may have a different disaster communication need from those that are far from the event.

Discussion

This paper presents an application of the Houston et al. (2015) functional framework to an empirical case study of disaster social media discourse. In this section, we first answer our research question by answering how Twitter was used during Hurricane Maria, followed by a discussion of how this case study takes a first step in validating the functional framework by applying it to real-world data and disaster response. Our empirical analysis continues to add value to the body of literature that looks at Twitter as

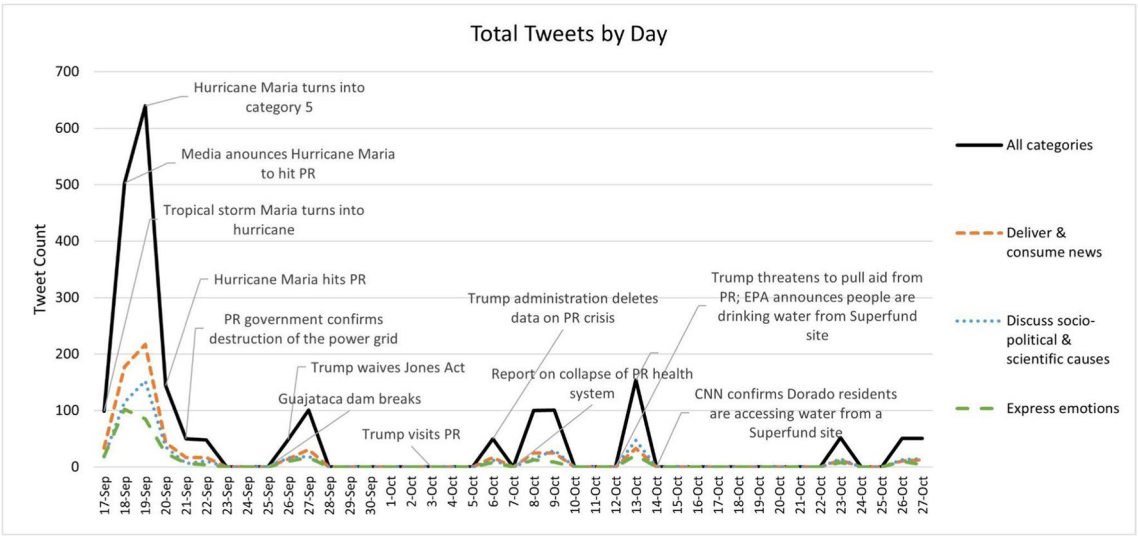

Fig. 2 Timeline of Hurricane Maria tweets

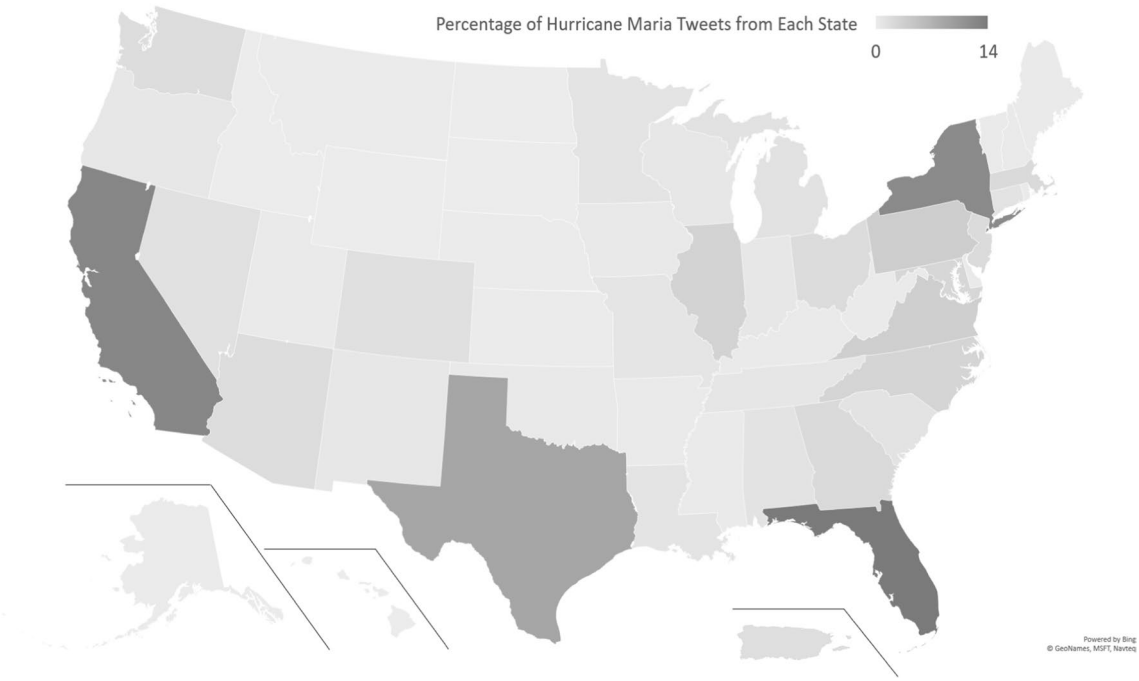

Fig. 3 Percentage of Hurricane Maria by state (including Puerto Rico)

social media tool to analyze people's understandings of real-world disaster events. Guided by the framework, the content analysis of social media disaster discourse shows the various ways in which social media users responded to the Hurricane disaster and for what purpose. Although others have examined Hurricane María social media discourse (Alam et al. 2018; Martín et al. 2020; García-Ramírez et al. 2021), our analysis provides a roadmap to compare user behavior during Hurricane Maria to that of future disasters. Our approach is different on two aspects. First, we used a hand coding approach to analyze tweets to better capture message's main theme. Second, we analyze Twitter use under Hurricane María using Houston et al.'s (2015) framework to validate its applicability.

Table 5 Top tweet functions by state (including Puerto Rico)

Ranking	Florida	California	New York	Texas	Puerto Rico
1	Deliver & consume news (32%, *n*=108)	Discuss socio-political & scientific causes (35%, *n*=92)	Deliver & consume news (20%, *n*=66)	Deliver & consume news (18%, *n*=61)	Inform one's condition & location (27%, *n*=17)
2	Express emotions (36%, *n*=68)	Deliver & consume news (27%, *n*=91)	Discuss socio-political & scientific causes (23%, *n*=58)	Discuss socio-political & scientific causes (18%, *n*=46	Express emotions (16%, *n*=10)
3	Discuss socio-political & scientific causes (22%, *n*=54)	Raise awareness (11%, *n*=32)	Raise awareness (19%, *n*=52)	Express emotions (16%, *n*=30)	Send & receive help (12%, *n*=9); Deliver & consume news (12%, *n*=9) (tied for 3rd)
4	Raise awareness (20%, *n*=27)	Express emotions (16%, *n*=30)	Express emotions (26%, *n*=49)	Raise Awareness (15%, *n*=19)	
5	Send & receive help (33%, *n*=25)	Send & receive help (20%, *n*=15)	Send & receive help (19%, *n*=14)	Send & receive help (20%, *n*=15)	Document disaster (53%, *n*=7)

How social media was used during Hurricane María

In asking what the predominant patterns of Twitter usage and content dissemination during the Hurricane Maria crisis were, this article reveals diverse users and uses of Twitter. Our results highlight that social media was used primarily to understand what was happening on the ground in Puerto Rico, as our top function was *Deliver & consume news*. This finding is aligned with other research that highlights Twitter's role as a microblog for consuming and sharing news, and how it is increasingly a platform where people go to get information during disasters (Gaol et al. 2020). Delivering and consuming news was also the top function for four of the five user types. Users both shared news posts containing vital information as well as copied and pasted news media quotes in separate messages.

Our second most prevalent function, *Discuss socio-political & scientific causes,* revealed that users were interested in understanding the conditions that turned the hurricane into a disaster. This function was the top social media function for governments, and the second most frequent for individuals and news media. Understanding the scientific causes allows for better prediction and preparedness for future hazards. It enables communities and governments to take proactive measures to mitigate risks and minimize potential damages. In addition, recognizing the social and political factors that contribute to disasters can lead to the development of policies that address vulnerabilities and promote resilience. This can include zoning regulations, building codes, and land use planning. Furthermore, this category reflected the outcry of people on the ground and on main media outlets regarding the slow and inefficient response both from the local and federal government. This category underscores that people are paying attention to the socio-political implication of an event and the ways management failures can cause disaster within disasters.

People also used the platform as a way to voice what they were feeling, as our third most prevalent function was *Express emotions and show appreciation*. This social media function has also been observed in flooding events like in South Carolina (Brandt et al. 2019). This category underscored the role social media plays in solidarity efforts, especially in states with high concentration of Puerto Ricans. This is particularly relevant given the many philanthropic organization and even private donations came from continental U.S. Lack of trust of the local government and Congress' refusal to lift the Merchant Marines Act fueled the Puerto Rican diaspora's engagement in grassroots recovery efforts through social media (González 2020).

User types actively tweeting during Hurricane Maria

Regarding user type, our data revealed that most messages about Hurricane María came from the public, i.e., individuals. Twitter use predominantly by citizens during flooding and hurricanes has been increasingly observed such as during historical flooding in Colorado floods in 2013, Louisiana flooding in 2016, and Hurricane Harvey flooding in 2017 to name a few (Brandt et al. 2019; Chu and Yang 2020). When an event like Hurricane María occurs, individuals can trigger the coverage of an event in addition to media (Olteanu et al. 2015). This brings to light individuals' capacity to create their own narrative about an event. We observed messages claiming that the news media were not covering the event, even when literature points out that mainstream media is 20% more likely of covering disaster events (Olteanu et al. 2015).

Relatively little communication came from organizations, despite a growing literature that highlights that first responders and relief organizations are increasing their presence on social media (Landwehr and Carley 2014; Murthy and Gross 2017). Their limited participation during Hurricane Maria may reflect the fact that organizational response to disasters can be slow at times, as they require logistics and security-based practices with legal authority (Tapia and Moore 2014). Moreover, the

accounts managers for public organizations do not always have the liberty of communicating internal information that may be important for the public under disaster conditions (Gunawong et al. 2019). However, organizations could use teams of individuals to monitor social media to identify critical pieces of information that they can later use in planning disaster responses (Landwehr and Carley 2014).

Social media discourse trends over the course of a disaster

In examining temporal trends, the majority of tweets occurred prior to landfall. Far fewer tweets were issued after landfall, with the event more or less disappearing over the following weeks with the exception of a few minor peaks. This pattern, in which there is an initial peak of messages, follow by smaller peaks, and eventually social media discourse dies out, has been observed for other extreme weather events (Jongman et al., 2015; Thackaberry et al. 2020) including wildfires (Ko et al. 2024). Interestingly, we observed no Twitter discussion during a few important events, for instance the signing of the Whitefish contract on October 17 (a $300 million contract to repair the electrical grid) or an outbreak of leptospirosis that started in September 2017 and continued to grow past November of that same year. Most surprisingly, we expected that President Trump's visit to the island would have triggered a peak in messages traffic. Trump's visit to the island caused great turmoil: he tossed paper towels like it was a basketball game to a crowd full of people that lost everything, and also praised local government efforts to address the crisis while local leaders and entities revealed the high death toll as a cause of government inaction (Weissenstein et al. 2018).

At the same time, additional minor events triggered more widespread responses. For example, on September 22, 2017, a day after reports came confirming the destruction of the island power grid, former President Trump tweeted about NFL players kneeling during the national anthem. That sparked a wave of messages that critiqued the president by focusing more on players from the National Football League (NFL) than what was happening in Puerto Rico with Hurricane María (e.g., *Since Maria made landfall in Puerto Rico, @realDonaldTrump has mentioned Luther Strange 6 times, NFL/kneeling 8 times- P.R. twice. F'n sad!*). Another event that triggered a wave of messages occurred a week after the hurricane when FEMA deleted Puerto Rico's disaster statistics from their website.

Social media trends by geography

The four states with the highest percentage of tweets were Florida (14%), California (13%), New York (12%), and Texas (9%). These states have the highest Twitter usage and also the highest population in the U.S., so it makes sense that they have the highest percentage of tweets about Hurricane María. We also found that the topics people tweeted about when they were located at the disaster site were quite distinct from those located on the mainland. While users observing the event from afar were interested in the functions *Deliver and consume news*, *Express emotion*, and *Discuss socio-political & scientific causes*, Twitter users in Puerto Rico were using social media to *Inform one's condition and location*, *Express emotions*, *Send & receive help*, and *Document disaster.* This highlights the importance of focusing on communities at risk when evaluating social media's function. The literature highlights the importance of social media as it provides crisis information in real time and improve stakeholder understanding of community experiences (Velev and Zlateva 2012; Houston et al. 2015).

Validating the functional framework

All functions from the Houston et al. (2015) framework were present in our empirical data except for *Reconnect community members,* which may only emerge post disaster. The absence of this function may respond to the fact that reconnecting community members occurred outside of the timeframe in which we collected data. For the first months after the hurricane, transportation in and out of the island was extremely limited and difficult. Thus, by the time people could return and reconnect with family members this may likely have occurred after the months we collected data.

Another challenge when applying this framework relates to the distribution of tweets when categories include more than one theme. For example, tweets categorized as *Discuss socio-political & scientific causes* suggest an equal representation of both subjects. Nevertheless, when zooming in on the data, we observed that the content distribution is disproportionate (i.e., more socio-political content than scientific ones). Splitting this function into two categories would capture this nuance and more accurately reflect the social media discourse.

Likewise, the original conceptualization of the function *Raise awareness* included three types of messages: raise and develop awareness of an event, donate and receive donations, and identify ways to help or volunteer. When we look closely at this data, most tweets for this function had to do with donating and receiving donations. We also suggest a split for this function.

This research extends the functional framework by noting which users engage in which functions, which is not covered by the original framework. Within the top user categories, a few findings were striking. From all the actors, the government top function was *Discuss socio-political & scientific cause* tied with *Raise awareness*. This was surprising since most of the

tweets coming from *Discuss socio-political and scientific causes* blamed different government branches as being responsible for the lack of relief and efforts to aid in the disaster. Community users' top concern was *Deliver and consume news* tied with *Raise Awareness*. Tweets raising awareness informed communities where to donate and denounced the inefficient government response. Social media provides a space that users can use in real time to signal their location with respect to their condition, including warning from possible perils. It can also be used as a tool to pressure a prompt government response. In addition, soliciting resources and donations during post-hurricane phases is certainly a critical time to communicate the needs to minimize loss of life and adverse health outcomes.

Finally, the original framework proposes that each function occurs during specific disaster phases: pre-event, event, and/or post-event (Table 1). In our data, some of the categories expanded beyond their hypothesized phases into neighboring ones. For example, the function *Discuss socio-political & scientific causes* was active and had minor peaks through all three phases of the Hurricane event. This differentiates significantly from the original framework, which restricted this function to the post-event phase. Another function that was present in a different stage was *Provide and receive disaster warnings*. In the framework, this function is hypothesized to occur pre-event. However, we observed empirically that this function of tweets occurred post-event as well. For instance, 2 days after the hurricane, one of the island's dams collapsed, creating a ripple effect of people sending messages through social media about the potential of disasters for such an event. These examples bring to light the idea that categories can occur through different phases depending on the disaster; their boundaries are not static but rather evolving.

Conclusion and implications

As we address future disasters, strengthening our understanding of the ways social media is used during disasters can help promote more effective planning and recovery as well as highlight the ways that individuals understand and cope with disasters. Validating this framework empirically supported key arguments on how to improve the framework and at the same time identified practical implications for those experiencing an event on the ground. Our work suggests several extensions to Houston et al.'s (2015) functional framework for disaster social media. First, individual functions extend across multiple stages of the event (pre, during, and post), suggesting the need for more flexible boundaries between these phases. Second, most tweets occurred before landfall, not during the event itself or during the recovery surprisingly, suggesting that social media could be deployed more actively to help with recovery. Third, individuals predominantly rather than relief response agencies or government agencies were the major user type engaging with Hurricane María–related content. Further disaggregating the "individual" category may add more nuanced understanding of the roles social media plays for different user types, as does linking functions to specific user types. Fourth, adding a geographic dimension can highlight how people experience the event differently depending on region and city. Understanding how people with no direct connection to a disaster (geographically and perhaps socially) perceive the event can help inform how broader support networks form to encourage or discourage particular types of volunteers and/or government responses. By continuing to refine the disaster functional framework through its application to new hazard and disaster events, researchers can help promote more resilient and equitable disaster management.

Our research findings signal various directions for future research. Based on individual's leverage of Twitter (X), new research should continue to study how traditional media outlets can influence discourse on X or other social media platforms for disaster response and recovery, and or where media narratives differ from social media narratives. Even when our paper highlights Twitter capacity for influencing emergency management and policy decisions, it remains unclear if after Hurricane Maria, emergency responders or policymaker pay attention to discourses on the platform—research in this area remains vital to analyze the influence of X to improve disaster response. Additionally, future research should explore how different groups (e.g., individuals from different socioeconomic levels) use social media during disasters. This could reveal if there are populations that rely more on social media and why. By knowing this government and organization can do a more targeted approach when investing in tools to increase societal resilience.

Implications for Praxis

Implications for practice are twofold. First, even though we had a smaller sample from Puerto Rico, the data captured how locals tweeted about when the Guajataca damn failure, as it occurred. Being able to access critical data during and after a disaster can provide the difference between life and death, especially for those on the ground. Recognizing the increasing use of social media for disaster response and aid can increase communities' disaster resilience, especially when the communities hardest hit have limited communication and are remote, like the case of Puerto Rico. Secondly, our data brings to light the geographical implications of disasters. Even when Hurricane Maria was a very local event, we could see by looking at the geographical distribution of messages the ripple effect in terms of people funneling resources (e.g., where to donate) or the effect of the event (e.g., express emption). These lessons serve as a foundation for improving future response efforts in the face of natural disasters like Hurricane Maria. It is important to continuously learn, adapt, and refine strategies to enhance overall resilience and preparedness.

Appendix

Table 6 Codebook

Code	Definition	Keywords	Example
Deliver & consume news	Tweets sharing an external news source	"reporting from", "according to XXX", "check the following post" "wind strength"	*Hurricane #Maria is now Cat5 strength w/ 160mph sustained winds. It's the 2nd Cat5 #Irma storm this… https://t.co/EnqKuaSua4*
Discuss socio-political & scientific causes	Tweets highlighting social, economic, political, scientific, etc. causes of the hurricane or its impact	"Hurricane Maria death", "PR-US relations", "Climate change", 'accused"	*Puerto Rico Accused of Fudging Hurricane Maria Death Toll|News|teleSUR https://t.co/zvzJzZKZeX*
Express emotion	Tweets that contain emotions (positive + negative) related to the event	"prayer", "thoughts", "solidarity", "happy", "sad"	*Prayers out to those people in the Caribbean Islands as Hurricane Maria heads towards them. Really is insane what's going on there*
Raise awareness of event	Tweets urging coverage of the event	"where is FEMA", "not paying attention", "people are dying", "humanitarian crisis"	*Seriously, @realDonaldTrump @FEMA, the ppl of Puerto Rico need clean water. Send it to them!*
Send & receive help	Tweets requesting or sharing information about a lost person—including where to donate and provide essential goods	"Finding people", "family", "where is", "help", "updates", "fundraising"	*there are many groups in FB for finding people and Hurricane Maria PR updates. this one of many, coul… https://t.co/zJKw1Hs771*
Provide & receive disaster response information	Tweets documenting disaster response vital information about one safety	"relief efforts", "FEMA is reporting", "safety"	*Taking matters into my own hands & starting a Hurricane Maria relief effort for Puerto Rico! Any donation helps & RT https://t.co/q0RzXa3Phe*
Inform about one's condition or location	Tweets sharing personal experience and location	"I am here at XXX these are the conditions", "in my house"	*Drone Video Emerges From Puerto Rico Shows Flooded Streets In San Juan After Hurricane Maria https://t.co/tGRGwQY9YC*
Traditional crisis communication	Tweets about methods and strategies used by organizations, governments, and authorities to manage and disseminate information during emergencies,	"Thanks FEMA", "the government sending aid", "they're doing enough", "We sent army reserve personnel to support the event"	*Thank you for all the great work you've been doing in Puerto Rico over the past week, @fema @USCG @USNavy @USNationalGuard @USDOT etc.*
Signal & detect disasters	Tweets containing information about significant and potentially harmful events during the event	"hospital", "bridges", "winds", "power outages"	*Three weeks after Hurricane Maria, hospitals in Puerto Rico are *still* running on a generator. https://t.co/Ycp3BTUESt*
Document what is happening	Tweets that provide real-time accounts, updates, and firsthand information about events	"I am seeing XXX", "I saw",	*Listen to the wind at before the eye of Hurricane Maria reaching San Juan, Puerto Rico at 7:50am… https://t.co/FXSne8gz7D*
Provide & receive disaster information	Tweets focus on providing news about the event	"prepared", "hurricane Maria", "Caribbean", "news"	*Caribbean islands prepare for Hurricane Maria - BBC News https://t.co/NhzH4lcAec*
Provide & receive disaster warnings	Tweets focus on providing warnings from the event	"Caution", "Imminent", "brace yourself", "war zone"	*I saw this on the BBC and thought you should see it: Puerto Rico dam bursts in wake of Hurricane Maria - https://t.co/bys9Nwr4K7*

Table 6 (continued)

Code	Definition	Keywords	Example
Disaster mental health support	Tweets about where to seek help or support regarding mental health	"hotline", "seek help", "where to go", "support"	*#Hurricane & tropical storm distress warning signs, emotional support resources via @ distressline https://t.co/l8n05NGpyr #Maria*
Disaster response, rebuild, recovery	Tweets about people engaging in actions leading to recovery and rebuilding	"resilience", "recovered", "community"	*How to help Puerto Rico: 10 things you can do for Hurricane Maria victims right now https://t.co/YHDuELvaAm*
Not relevant	Tweets that are not about Hurricane Maria		*I love a girl named maria who is Puerto Rican*

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Declarations

Competing interests The authors declare no competing interests.

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