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Text mining hurricane harvey tweet data: Lessons learned and policy recommendations

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ABSTRACT

During any crisis, relief efforts depend on the timely exchange of crisis-related information between organizations and the communities. Existing literature shows that relief efforts often fall short in terms of effective communication. One of the possible reasons for this is a misalignment between the expectations of people and the efforts of disaster respondents. Thus, understanding people's needs and expectations during disasters may help reduce the gap between the key stakeholders. In this paper, we use the Latent Dirichlet Allocation (LDA) technique to mine tweet data collected during Hurricane Harvey to better understand the needs of the people in the disaster area. Through data mining, we identify five themes of concern by Twitter users during the pre-crisis period of Harvey: disaster declaration and emergency response, concern about a specific town, event or travel cancellations, threat to oil & gas (energy) industry, and climate change. Based on these themes, we provide recommendations to help disaster management agencies and policymakers be better prepared to assist disaster victims and facilitate citizens' involvement.

1. Introduction

Hurricane Harvey that struck Texas during the period of August 25 to August 31, 2017, was a devastating humanitarian crisis characterized by heavy rainfalls, extreme winds, and storm surges. The rainfalls caused by Harvey was estimated to be 1.25×10^{11} cubic meter [1], and more than 80,000 homes were affected by flooding of at least 18 inches of rain [2]. According to Watson et al. [3]; Harvey was associated with the most rainfalls in U.S. history since records were instituted in 1880. This hurricane led to significant damages to critical infrastructures and industrial facilities and immense economic costs for the city of Houston and its surrounding areas. Specifically, it caused an estimated $125 billion in damages, which is more than any other natural disaster in U.S. history except for Hurricane Katrina [4]. Many lost their lives, primarily due to drowning in submerged vehicles and structures. According to Sebastian et al. [5]; more than 70 fatalities were reported in the greater Houston area. The mental and physical health consequences of Hurricane Harvey for affected citizens were also significant. They included injuries such as lacerations, puncture wounds, abrasions, fractures, and insect bites that commonly occur during clean-up activities [6]. The response to Harvey flooding necessitated major rescue operations from humanitarian relief organizations. It is estimated that more than 120,000 people were rescued by professional and volunteer rescuers [2].

During natural disasters like Hurricane Harvey, timely exchange of information between disaster management organizations and

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communities is critical. Social media applications play an important role in such information exchanges. According to the U.S. Department of Homeland Security [7]; "Social media and collaborative technologies have become critical components of emergency preparedness, response, and recovery." Social media tools such as Twitter and Facebook allow members of the public to quickly share information of incidents they witness irrespective of their geographic locations. Quick sharing of information about such incidents by the members of the public is critical to the planning of response strategies and deployment of resources by disaster management organizations. It also enables such organizations to disseminate information quickly to a broader audience, monitor social media networks with a view to getting a better understanding of the situation on the ground, and build community [8].

Because of social media's apparent capacity to influence people through information sharing, the use of social media such as Twitter and Facebook by disaster management organizations is on the rapid rise [8]. Data obtained through social media allows disaster management organizations to understand key themes and major players in the post-event relief efforts, which is crucial in the development of mitigation and response strategies for such future events. Data gathered from social media helps these organizations and individuals better understand the information audience, which, in turn, helps them select the right tools to disseminate the information quickly.

Prior studies show that relief efforts often fall short in terms of effective communication. One of the possible reasons for this is a misalignment between the expectations of people and the efforts of disaster respondents. Thus, understanding people's needs and expectations during disasters may help reduce the gap between the key stakeholders.

In this manuscript, we try to answer the following research question:

> *RQ:* How can government agencies and other disaster relief organizations better understand the needs of citizens in times of natural disaster through social media data and improve the effectiveness of their response plans accordingly?

In order to answer the above research question, it is important to understand the thought process that people go through during a disaster. Although surveys and interviews are one way to capture their thought processes, this happens after the disaster has occurred. During any crisis, the feelings and sentiments of the people facing the crisis are expressed through their postings on social media. Thus, analyzing the postings will provide us with a better understanding of the important needs of people during a disaster, and we will be able to formulate recommendations that can be used by government agencies to ensure that the needs of people are met. In this context, text mining is a commonly used technique to analyze a large amount of social media data.

Using text mining techniques, this paper analyzes Tweet data collected during Hurricane Harvey to extract implicit knowledge based on which policy recommendations for disaster management are formulated. Text mining is the process of extracting implicit knowledge from textual data through classification, clustering, and association of the text [9]. It is a technique used to discover significant and non-trivial patterns of information from the text [10]. Text is the unstructured data consisting of strings called words [11]. Through text mining, social media data analysis allows organizations to extract the implicit knowledge from textual (unstructured) data and make inferences about their experiences and the issues that are important to them during a crisis or disaster in order to make knowledge-based decisions.

Prior studies have shown that social media is used extensively during any disaster [12,13]. Specifically, people use Twitter to gain and provide information about the disaster, learn about the safety of their friends and families, provide emotional support, try to see how they can help, and so on. These tweets contain a lot of information, which, if mined properly, could provide government agencies and disaster management officials with the knowledge to improve disaster preparedness and response and provide relief to affected people. Therefore, a systematic approach is required to mine the tweet data for relevant insights.

In this work, we borrow from and build upon the Citizen Disaster Model (see Fig. 1), a framework proposed by Evangelopoulos and

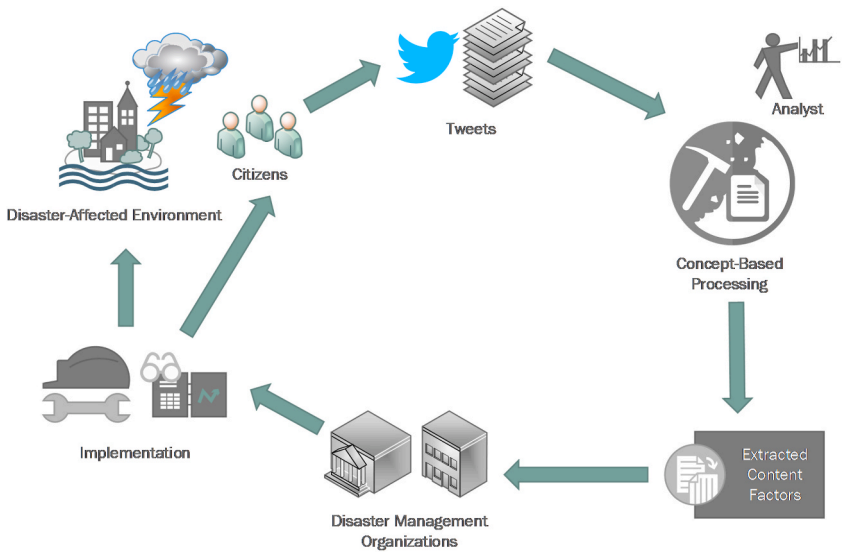

Fig. 1. The citizen disaster model.

Visinescu [14] for supporting citizens' involvement by incorporating their feedback in the administrative decision-making process.

This article seeks to contribute to diverse theoretical and practical grounds. From a theoretical perspective, we emphasize the role that social media can play during the onset of a disaster. Although social media has been used extensively for disaster management, much of the literature in this regard is related to the post-crisis period. We attempt to explicate the importance of social media use during the pre-crisis period. Although our study is based on a single disaster in Texas, United States, this methodology can be replicated, and the findings can be applied to other natural disasters around the world. Therefore, this study can be of interest to national and international research communities. From a practical perspective, we provide a framework to the government and disaster management agencies as a basis to develop and communicate policies to citizens facing an impending crisis. Several studies have examined Twitter data and carried out social media and big data analysis in the disaster management field (see Ref. [15]. However, to the best of our knowledge, this study is the first to apply the Latent Dirichlet Allocation (LDA) technique to tweet data in the disaster management area.

The rest of the paper is structured as follows: in the next section, we provide brief literature on social media & disaster management and mining social media data. After that, we introduce our research methodology, followed by our data analysis and results. Next, in the discussion section, we make policy recommendations. Finally, we provide the conclusion, limitations of the study, and suggestions for future research directions.

2. Literature review

2.1. Social media in disaster management

Over the past decade, researchers have increasingly explored the use of social media in disaster management. Prior research categorizes this scholarship into two main groups; the first group focuses on ways in which humanitarian organizations use social media to coordinate and collaborate during their relief actions, and the second group deals with the ways common citizens and disaster victims share information during disasters [16]. Within these categories, prior research has investigated several themes, including sense-making [17] and disaster situational information [18]. Researchers have also used social media-generated data to study collaborative resilience [18,19] and rumor management [20] in times of crisis. Findings from most of these studies suggest that social media can efficiently improve information dissemination and exchange during a disaster by providing additional communication options to traditional information sourcing and dissemination methods for emergency services organizations and disaster managers.

Prior research has identified some major reasons for the increasing use of social media in disaster management by the organizations involved in disaster relief and disaster respondents. Information seeking is a primary driver of social media use during disasters [21]. In times of crisis, the need for information is critical. Disaster victims, as well as disaster relief organizations, need the information to understand the unfolding event and to make decisions on how to respond. The need to receive timely information is another main driver of social media use during disasters. Social media provides real-time disaster information, which no other media can do [22]. Increasingly, people are relying on cellular and internet-based technology to fulfill this need. For instance, disaster victims use social media to share their condition with friends and family [23,24]; and information about disaster magnitude, impacts, and needed assistance with relief organizations [16,21,25]. People also use social media to stay apprised of the extent of a disaster [26], to self-mobilize [23,27], and to seek emotional support and healing [28].

The literature highlights the prevalent use of social media during disasters. For example, social media has been used for disseminating information during the 2007 Southern California Wildfire [29], the 2009 Oklahoma fires [30], the 2012 hurricane Sandy [31], the 2013 Colorado flood [32], and the 2014 Ebola fear in the U.S [33]. Although we do not have statistics regarding Twitter users in a particular city such as Houston, the number of general Twitter users in the United States alone is more than 62 million, including private citizens, government agencies, news media, for-profit companies, and non-profit organizations [13]. Further, statistics show that the average U.S. monetizable daily active users within just the first quarter of 2021 were around 38 million [34].

Although prior research highlights the importance and the increasing use of social media in disaster management, it has still not been used to its full potential [35]. Reasons for such lack of use include: (i) Privacy and Security fears - A major reason for not using social media during disasters is concern about privacy and security violations [36]; (ii) Accuracy concerns - Some members of the public have concerns about the accuracy of disaster information provided by social media [37,38]; (iii) Access issues - Discussion of social media use is predicated on the assumption that the public has access to the tools, but this is not always so [38]; and (iv) Knowledge deficiencies - Certain segments of the public do not know how to use social media prior to disasters [37]. Further, the information provided through social media, especially during the preparedness phase by different humanitarian organizations, is very critical. This enables people to take adequate precautions even before the occurrence of the disaster. Moreover, it is also important from the humanitarian organization's perspective to use social media effectively to disseminate the information that helps people prepare for the impending disaster. However, prior studies have shown that barriers such as language, culture, value, financial constraints, human resources, technology, and data pertaining to social media have become big challenges to both the organization's ability to efficiently disseminate disaster-related information and the people's ability to use this tool effectively for disaster preparedness [39].

2.2. Social media and topic modeling

The last decade has seen increasing use of topic modeling by social scientists for analyzing textual data. Topic modeling relies on statistical methods and algorithms to discover topics hidden in a large corpus [40]. This methodology has been used extensively in the social science area to answer questions such as "how critics' framings of corporate activities simultaneously affect and are affected by their audiences" [41] and "how knowledge recombination is a double-edged sword with opposite impacts to an innovation's degree of

novelty and its usefulness" [42]. Similarly, topic modeling has also been used to get new insights into specific disciplines, such as examining the diversity [43] and identity of Information Systems [44]. Further, with the emergence of social media, the amount of unstructured textual data has grown tremendously. For example, more than 500 million tweet data are generated per day by more than 300 million active Twitter users [45,46]. Such an abundance of publicly available data has created new opportunities in the area of qualitative research and topic modeling. For example, Evangelopoulos and Visinescu [14] use topic modeling to determine how technologies such as mobile telephony and the Internet are used to engage citizens in political dialog. The most frequently used techniques in Information Systems Research for unsupervised text categorization include Latent Semantic Analysis (LSA), LDA, and Leximancer [47]. In this paper, we use the LDA method described in more detail in the Methodology section.

3. Methodology

3.1. Data collection

We analyzed Tweeter data collected during Hurricane Harvey. The use of social media for disaster management and relief can be examined during pre-disaster, disaster, and post-disaster times. Examining how people behave during each of these periods helps us understand the disaster and the needs of the affected people. The focus of our paper is on the pre-crisis period. The information from this period would help the government and other disaster management organizations develop policies that can assist people in the preparation and mitigation of the impending crisis. The pre-disaster period is the time when the first information regarding the crisis or disaster is disseminated [48]. In our paper, we consider a two-day window, which includes the day before the landfall and the day Harvey made the first landfall in Texas. These two days coincide with the pre-crisis period.

To construct our sample, we started with all public tweets with a Hurricane Harvey hashtag posted during the two-day window when the hurricane made landfall – specifically, August 25–26, 2017. We filtered out all "retweets" and "quotes" and kept only original tweets and any "replies" to those tweets. This process left us with a final sample or "corpus" of 28,041 unique tweets. Then, we followed established textual analysis techniques to preprocess the tweets [44,49,50]. This process included removing punctuations, hyperlinks, stop words (such as "the" and "of"), and any terms with less than three characters or containing numbers. It also involved lemmatization, which mapped a word to its "lemma" or dictionary form. Finally, we filtered out all unique terms, i.e., terms that appeared only once in our corpus, from the tweets.

3.2. Text mining

Over the years, researchers have developed several techniques capable of summarizing high-level semantic content in unstructured text in the areas of text mining, machine learning, natural language processing, and information retrieval [51]. These information-retrieval-based techniques include methods such as LDA, LSA, Probabilistic Latent Semantic Analysis, and Non-Negative Matrix Factorization [51].

For analyzing our tweet data, we employed LDA, an extension of the classical LSA technique [47]. LDA overcomes the major disadvantage of LSA, i.e., the issue of the interpretability of factor loadings. Moreover, LDA has been widely used in academic research, in the MIS literature, and in other fields such as finance (for example, [52]. Additionally, multiple open-source software support LDA and, importantly, several empirical studies indicate that LDA is capable of identifying and categorizing meaningful topics within a corpus (e.g., Refs. [53–57]. Further, several open-source and free LDA software libraries are available for most statistical programming languages, such as R and Python. Therefore, using this method was appropriate for our study.

The concept of LDA as a generative probabilistic model of the corpus was first proposed by Blei et al. [58]. The idea behind the LDA is that a large body of text can be represented as a random mixture of latent topics, where each topic is defined by the distribution of words. Further, LDA assumes that the topics forming this corpus of text are in different proportions, and the proportion can range from 0%, where the corpus of text does not talk about a topic at all, to 100%, where the corpus of text talks entirely about the specific topic [47]. The LDA algorithm estimates these hidden topics and the distribution of words by examining and counting the occurrence of words in the observed corpus of text. The LDA performs such an estimation either through sampling or through an optimization process [47]. In our study, the tweets generated during the disaster Harvey comprise the corpus of text. Applying the LDA provided us with 100 topics and the words associated with each topic (20 terms in each topic), and these topics were coded by four independent researchers.

To perform LDA topic extraction, we used KNIME Analytics Platform. KNIME is an open-source platform that provides an extensive toolkit for data and textual analysis [59]. The following section gives details regarding the coding process.

3.3. Coding

The task of coding was carried out independently by four researchers. The process consisted of examining the terms and tweets related to the particular topic (from LDA analysis), interpreting the underlying theme, and determining the appropriate title. Following the extant literature, 100 topics (20 terms per topic) were extracted from Hurricane Harvey tweets. The researchers then independently coded each topic. The resulting topics were compared and tested for reliability (see Table 1, Panel A). Next, the researchers discussed the results to reconcile the disagreements and increase the reliability to 90% or better (see Table 1, Panel B). The inter-coder reliability was determined by computing the percentage of agreement regarding the titles and their underlying theme.

$$\text{Percentage agreement} = \text{agreements}/(\text{agreements} + \text{disagreements})$$ The inter-coder reliability above 90% was achieved, and, additionally, eight themes specific to Hurricane Harvey emerged, spanning multiple topics. Although it is common in text mining studies to extract 100 topics (see, for example [60], Cluster analysis (k-Means) indicated that after around 25 topics, there was no measurable gain (in terms of reduction in the SSE) of adding new topics in our sample. Fig. 2 depicts the results from cluster analysis. Therefore, the LDA analysis was performed again with 25 topics to validate the eight identified themes. These 25 topics were coded and

Table 1
Topic coding.

Inter-coder reliability (percentage agreement)				
Panel A: 100 topics, before reconciliation				
	Researcher 1	Researcher 2	Researcher 3	Researcher 4
Researcher 1				
Researcher 2	84.85%			
Researcher 3	78.79%	79.80%		
Researcher 4	75.76%	80.81%	86.87%	
Panel B: 100 topics, after reconciliation				
	Researcher 1	Researcher 2	Researcher 3	Researcher 4
Researcher 1				
Researcher 2	91.92%			91.92%
Researcher 3	92.93%	92.93%		92.93%
Researcher 4	91.92%	93.94%	92.93%	91.92%

tested for reliability, and five of the themes were validated (with a reliability of 92%, or 23 out of 25 topics).

4. Results

Table 2 demonstrates the five important themes that emerged based on the tweets that were extracted during the pre-crisis phase of Hurricane Harvey. The top two themes are associated with nearly 4700 tweets. These two themes are "Disaster declaration and emergency response" and "Concern about a specific town." The remaining three themes are associated with around 1300 tweets, which are "Event or travel cancelations," "Threat to oil & gas (energy) industry," and "Climate change." Thus, our results show that even though citizens are aware of the impending crisis, it is important that they are notified about the crisis in order for them to get into a preventive/protective mode. Moreover, citizens are very concerned about specific towns affected by the crisis and the implications for travel, specific events, or economically important industries in those towns.

The implications of our results and our recommendations based on these results are further discussed in the following section.

5. Discussion

5.1. Themes

5.1.1. Disaster declaration and emergency response

In 1974, the Disaster Relief Act was passed into law to grant the President of the United States the authority to make emergency and disaster declarations.[1] The law was further amended in 1988 through the Stafford Act[2] "… to bring an orderly and systemic means of federal natural disaster assistance for state and local governments in carrying out their responsibilities to aid citizens." All declarations are requested by the State (or Indian tribal) governments and approved by the President. Each declaration follows a Preliminary Damage Assessment (PDA) and is one of two types: an emergency declaration or a major disaster declaration.[3]

Previous literature has shown that presidential decisions regarding disaster declarations are affected by political factors, which contrasts with a solely altruistic view of disaster assistance [62]. Specifically, disaster declarations and the allocation of federal aid provided by the Federal Emergency Management Agency (FEMA) seemed to be influenced by the state's electoral importance in the presidential elections. To summarize, the purpose of disaster declarations and FEMA's mission is to help individuals and communities affected by a disaster. However, the federal disaster policies are motivated, at least partly, by political factors, which creates a "moral hazard" problem [62].

5.1.2. Concern about a specific town

During natural or man-made humanitarian disasters, a large amount of information is generated through social media by both the victims of the disaster and the disaster responders. This information may include advice, request for help, discussions, and personal experiences and thoughts, etc., specific to a town or city. Several previous studies have explored the use of social media crowdsourced data, especially tweet data, in disaster management (see Ref. [15] for a review). In recent years, Twitter has gained more popularity than other platforms (e.g., Facebook, Instagram, Flicker, and Weibo) for sharing critical disaster situational-related data [63]. However, some of the prior research has shown that one of the most important problems to be solved in reference to the use of tweet data for decision making by disaster managers is the lack of an accurate depiction of the organizational decisions made during a disaster and the information required to make them [64–66].

For this work, we use the classification template developed by Bruns et al. [61] to map disaster-related tweet data so as to facilitate their use for decision making (see Table 3).

[1] Public Law 93–288: Disaster Relief Act of 1974. https://www.hsdl.org/?view&did=458661.
[2] Public Law 100–707: Robert T. Stafford Disaster Relief and Emergency Assistance Act. https://www.hsdl.org/?view&did=806354.
[3] https://www.fema.gov/disasters/how-declared.

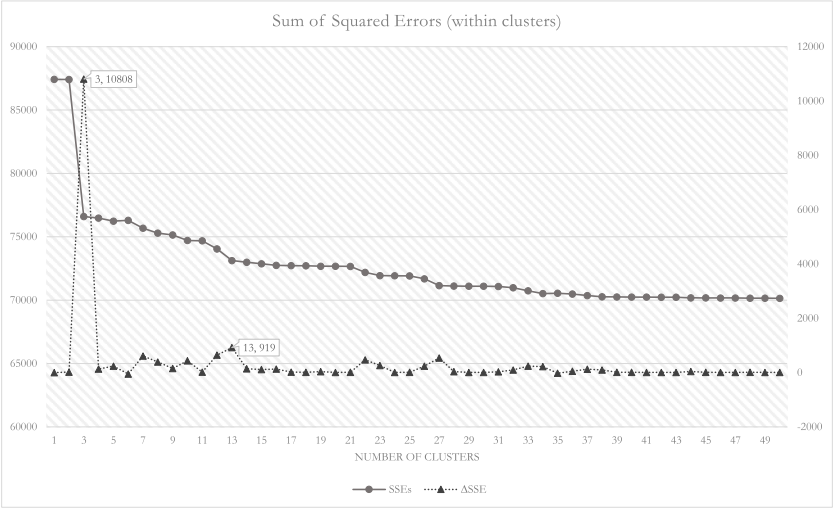

Fig. 2. Topic clustering.

Table 2
Themes and tweets.

Themes	Tweet Count
1. Disaster declaration and emergency response	3699
2. Concern about a specific town	1177
3. Event or travel cancellations	610
4. Threat to oil & gas (energy) industry	408
5. Climate change	272

5.1.3. Event or travel cancellations

Natural disasters such as hurricanes and storms have an impact on sports. The damages include cancellation of games and damages to the sports infrastructures. Such cancellations and damages further have a cascading effect on the economy of the place. For example, the cancellation of the 2012 New York Marathon in the wake of Hurricane Sandy had a huge economic impact on the city [67]. Similarly, Hurricane Katrina caused a lot of damage to New Orleans' sports infrastructure and also caused the temporary departure of the city's major league professional sports teams, the NFL (National Football League) Saints and the NBA (National Basketball Association) Hornets [68]. When a hurricane strikes a particular city, sports are not the first concern for the Government or the Disaster Management Agencies. However, the long-term impact caused due to the cancellation of sports and the damage to sporting complexes and infrastructures is staggering. For example, the city of New Orleans spent more than $500 Million to restore its sporting infrastructure [69].

Hurricane Harvey also caused a lot of game cancellations. Specifically, these cancellations were the games that were supposed to be hosted by the city of Houston, Texas. For example, the soccer match between Houston Dynamo and Sporting Kansas, which was supposed to take place at BBVA Compass Stadium, was rescheduled [69]. Similarly, College Football was also hit. SHSU (Sam Houston State University), which was supposed to host Richmond Spiders at Bowers Stadium in Huntsville, was put on hold. UTSA (The University of Texas at San Antonio) canceled their UTSA Football Fan Day due to the hurricane. Similarly, the opening game between BYU (Brigham Young University) Cougars and LSU (Louisiana State University) Tigers at the NRG Stadium in Texas was put on hold. The story was repeated for NFL and MLB (Major League Baseball) that were supposed to take place in Houston, Texas. The Dallas Cowboys, who were supposed to play Houston Texans at the NRG Stadium, changed the venue of their game to AT&T Stadium in Dallas. The Houston Astros' game with Texas Rangers was also put on hold [69].

5.1.4. Threat to oil & gas (energy) industry

Prior studies have indicated natural disasters to have an impact on the energy sector [70]. There are long-term and short-term consequences for energy consumption. Disasters have an impact on supply and demand as well as the infrastructure [70]. The energy sector is the most affected by natural disasters [71]. A natural disaster has the potential to influence cost efficiency conflicts on nuclear energy, which in turn can have an impact on the industry's risk management [72]. Although research shows that the immediate influence of natural disasters is negative, the long-term impact can be positive or negative. Natural disasters can act as economic stimuli, especially to high-income countries, and these countries see a positive impact in terms of industrial energy use, a surge in industrial production, infrastructure development, and energy consumption.

The immediate impact of Harvey was negative. This category 4 hurricane caused massive flooding taking out 11% of U.S. refining capacity and causing ports closure along the coast of Texas [73]. Further, Marathon Petroleum Corp. (MPC) had to cut back gasoline

Table 3
Tweet content classification (*Template source:* [61]).

Category	Meaning
Information	
A – Advice:	*Tweets that provide information about what to do (e.g. during evacuations), safety tips, and how best to act to streamline the relief and recovery process.* Make sure you pack & double check your #emergency kits! #Hurricane #Harvey #Texas #CorpusChristi #Houston #Louisiana https://t.co/GalxjS2VD4
S – Situational Information:	*Tweets that provide information about the location of the event, road closures, areas to avoid, and other risks.* We are closed due to Hurricane Harvey. We will reopen on Tuesday. Be smart and be safe. #hurricaneharvey #houston https://t.co/wHMLtsy9Lr Everyone: Hurricane Harvey is now a category 4 please be safe! Houston: https://t.co/rOiWUsiVdp Hurricane Harvey: 60,000 Without Power in Houston Area https://t.co/DwAbJMalSE https://t.co/MLht0tUAzX Reports of price gouging in Houston area over #HurricaneHarvey Man paid almost $72.00 for four cases of water. https://t.co/PYNbE8a7Lx Unusual fare surprises Houston taxi driver during Hurricane Harvey – https://t.co/yATzia2x8W https://t.co/89J9w42fMy https://t.co/hBzZOzpGa5
RI – Requests for Information:	*Where individuals ask questions about the current situation or about specifics, such as looking for particular individuals.*
Media Sharing	
NM – News Media:	*Media updates, news reports, press releases and press conferences. Includes both links to other sources and headline-like tweets from official and media sources that contain statistics and provide news information independently of links.* Houston Mayor warning Houstonians to be prepared for a major flood event as Hurricane Harvey heads up the TX Coast https://t.co/cK1QWfJNaS Due to the anticipated flooding impact of Hurricane Harvey, Houston Premium Outlets will be closing at 1pm today. https://t.co/LSrNfDyJJ9
MM – Multimedia:	*Links to photo galleries, videos, and images of the event.*
Help and Fundraising	
H – Help:	*Tips for how to help as well as requests for help, volunteers, etc. Both from official sources or individuals.* Local Red Cross Volunteers Head to Houston to Assist with Hurricane Harvey Relief Effort … https://t.co/VOFsKJQIlN https://t.co/zqtJMJhOhT Take it to Akin volunteers are ready to take your Hurricane-related calls. 713-469-2926 #Harvey @Fox26Houston https://t.co/YTUywkmgEw
FR – Fundraising:	*Requests for donations, invitations to fundraising events, announcements of donations.*
Direct Experience	
PNE – Personal Narrative and Eyewitness Reports:	*Includes tweets about direct, personal experience of the events and eyewitness reports on the ground of events as they happen.* Houston stores racing to restock water ahead of Hurricane Harvey https://t.co/wdTPNXZbL0 https://t.co/NQnfvlcBaF Gas in Houston is in short supply tonight. Many pumps are closed #HurricaneHarvey https://t.co/XgbjKG1fRk Bottled water, bread, pasta shelves nearly bare at some #Houston supermarkets as residents prep for #HurricaneHarvey https://t.co/PoCR7gMeUS Water shelves completely cleared out in #houston except for a few sparkling waters … #hurricaneharvey @ABC https://t.co/6hPNxTXnzV Long lines at grocery store as Houston prepares for #HurricaneHarvey https://t.co/WW1nIbbnko Houston stores racing to restock water ahead of Hurricane Harvey https://t.co/HqWlxzztKa by @KHOU via @retailwire https://t.co/hSCNZkOMmP
Reactions and Discussion	
AD – Adjunctive Discussion:	*Use of the event in question to spark off other discussions about, e.g., environmental politics or the performance of the federal government.*
PR – Personal Reaction:	*Expression of reaction to the events as they unfold. Pertains to people who are responding to information about the event.* People in #Houston still driving despite the TURN AROUND DONT DROWN signs. #HurricaneHarvey https://t.co/dHM8j5tXmG We have decided to cancel all of tonight's events. Stay safe, Houston friends! #HurricaneHarvey https://t.co/iqZcrIybOQ We have closed our doors early today. Please stay safe! #houston #katytexas #HurricaneHarvey https://t.co/gjznPiUCwm
T – Thanks:	*Expressions of thanks and appreciation to particular actors for their role during the crisis.*
SP – Support:	*Expressions of support toward those affected by the event.* Hope all my Houston and other folks out in the path of Hurricane Harvey stay safe. Prayers and good vibes your way https://t.co/mAQ7va64XP I hope they get to shelter. #HomelessInHouston #HurricaneHarvey #Harvey https://t.co/zn9UsG4UX2 We need #Houstonians to check on our seniors and the disabled during #HurricaneHarvey. Stay calm and watch the news. https://t.co/XZ6Os1AMr1 So the rain begins. To our followers in Houston: please stay safe this weekend. | #HurricaneHarvey https://t.co/oXYkBOBdZR
META – Meta-Discussion:	*Discussions on Twitter and in the media about the significance of social media and its role in crisis response.*

production due to heavy floods on the highways between Texas City and Houston. Similarly, due to heavy floods, Royall Dutch halted their operations in Deer Park, Texas, refinery, and Exxon closed their second-largest US refinery in Baytown, Texas [73].

The low production of energy and the news regarding closures of the refinery had an impact on Texas residents as well. These might also have created some panic as people started tweeting about the closure of oil and gas operations. This is evident from the tweets such as "Hurricane Harvey closes key oil gas operations texas bigoli," and "hurricane harvey knocked percent gulf gas production." Similarly, Harvey also caused a lot of power outages, which led to tweets like "power outages reported wake hurricane harvey,"

"hurricane harvey knock power," and "hurricane harvey scaring people." These tweets indicate that, during Harvey, people were keeping track of oil and gas refineries that were closed and the power outages that were reported.

5.1.5. Climate change

Researchers have devoted a considerable amount of time exploring the connections between the frequency and/or intensity of natural disasters such as storms, hurricanes, wildfire, and climate change [74–80]. Findings from these previous studies tend to suggest that storms and hurricanes have become stronger worldwide during the past couple of decades. Moreover, some studies that have investigated the global warming effect on hurricanes have detected an increase in the frequency and/or intensity of these events [74, 78,79]. For instance, the results of a study by Appendini et al. [79] suggest that the future climate would result in more frequent intense hurricanes and more frequent rapidly intensifying storms due to global warming. Similarly, Holland and Bruyère [74] find that there has been a rise in the propensity for intense hurricanes and conclude that the result is strongly related to an Anthropogenic Climate Change Index (ACCI). This index, defined as the difference between the means of ensembles of climate simulations with and without anthropogenic gases and aerosols, indicates that the bulk of the current anthropogenic warming has occurred in the past four decades [74]. Furthermore, examining the hurricane record in the Atlantic basin from 1986 to 2015, Balaguru et al. [78] found that rapid intensification increased 4.4 mph per decade. They defined rapid intensification as an increase of wind speed of at least 35 mph in 24 h. The authors attributed most of the gains to a shift into the warmer phase of the Atlantic Multidecadal Oscillation.

With regards to the specific case of Hurricane Harvey, previous research shows that substantial changes in the likelihood and magnitude of measured precipitation totals in the Houston, Texas region are likely attributable to anthropogenic climate change [81]. Table 4 shows a few examples of climate change-related tweets.

5.2. Recommendations

Based on our discussions above, of the five important themes extracted from the social media data, we make the following recommendations for policymakers and relief organizations.

5.2.1. Recommendation 1: train the general public to formulate simple and actionable disaster-related posts

Simple and actionable posts systematically seek to answer *Where, Why, When, Who,* and *What* questions [82]. Common citizens serve as the true "First responders," with a visible, active, and extensive involvement. Nowadays, with the use of social media, their role offers additional ways to participate and communicate in disaster relief operations [16]. Further, as seen from our emerging themes, timely disaster declarations are very important. More than three thousand tweets in our sample were related to *disaster declaration and emergency responses.* Simple messages can be disseminated quickly and are easy enough so that people with high anxiety are able to comprehend and comply appropriately [16]. These messages should also take into consideration the infrastructure of the town that is bearing the brunt of the disaster. Additionally, people who are not residents of the town that is facing disasters are worried about their near and dear ones living in the town. As seen from much of the tweets (more than 1000) that focus on specific towns, people pay close attention to the towns that face natural disasters and the management plans that are in place in these towns to take care of these disasters. Thus, having good evacuation plans and good public training on the actions and the channel to provide information will help curb panic and lead to safer management of the disaster. Training on how to write simple and actionable disaster-related posts would greatly improve people's participation in responding to disasters.

5.2.2. Recommendation 2: establish channels to properly communicate procedures and guidelines as life returns to post-disaster normalcy

Another major concern during disasters is the disruption in the daily life of people impacted by the disaster. For example, disasters can lead to a shortage of essentials, such as gas, food, and water. It may also lead to loss of power. In our sample, a significant number of tweets were related to the concern that the oil and gas industry would be critically disrupted. Such concerns could additionally lead to public panic and unnecessary stockpiling of essentials. Another example of a disruption caused by the disaster is the cancellation of pre-planned sports and entertainment events. Such events could be much anticipated, and people would have invested in these events well in advance. As is apparent from the tweets in our sample, the uncertainty regarding whether these events would take place at a later time or the money paid for tickets would be refunded poses a concern. Therefore, we recommend that the agencies establish a channel through which they can post information related to procedures and guidelines on how these events will be dealt with as the town returns to normalcy.

Table 4
Sample of climate change-related tweets from the dataset.

1	Is Hurricane Harvey Related to Climate Change? Scientists Have a Better Answer https://t.co/JYk11geGRN https://t.co/8BkA3Wp8Ss
2	Will Hurricane Harvey show Trump that climate change exists? https://t.co/gyi9o2fyi0 https://t.co/f3juXOT82o
3	When we talk about #HurricaneHarvey, we need to talk about climate change. https://t.co/khOftTzQRS
4	Hurricane #Harvey through the eyes of #climate science deniers | HotWhopper https://t.co/qpEflKnVd7 via @SouBundanga https://t.co/qON0CnxzwG
5	Climate change is real y'all. This warning for hurricane harvey has me nauseous https://t.co/QwTSs5pqZb
6	Unsurprisingly, Warmists Are Bringing 'Climate Change' Into Discussion Of Hurricane Harvey https://t.co/moMplVe7V4 https://t.co/SSvXStURpN
7	#HurricaneHarvey Trump on his way to comfort victims of hurricane harvey with his ignorance of climate change https://t.co/x4UOm9tVvX
8	#Liberal #ClimateChange How Hurricane Harvey Could Cause Long-Term Devastation https://t.co/aK6VQ6qvz7 https://t.co/lPQbLaTPQ7
9	After #HurricaneHarvey will #Trump voters in #Texas finally accept climate change? Nope it's all Obama's fault. #WTF https://t.co/EvHohm1nEr
10	New post (Did climate change make Hurricane Harvey worse?) has been published on all new - https://t.co/yJHRpmwwSQ https://t.co/9gwgk8FGsp

5.2.3. Recommendation 3: provide specific and detailed information regarding transportations

One of the themes that emerged from our sample of tweets is regarding travel and event cancellations. During disasters, there is a possibility that some people have recently left an impacted town for a short vacation. Consequently, they may not have made proper arrangements to ensure there is minimum damage to their property during the disaster and will naturally be inclined to come home as soon as possible to take care of their personal belongings. Similarly, some people may be visiting a town and want to leave the town as soon as possible to be safe from impending disasters. Thus, a constant feed of news and information regarding transportation options, schedules, and ports of entry and exit will help people travel in a disciplined manner.

5.2.4. Recommendation 4: promote the use of specific hashtags to simplify tweet classification

Researchers have been working for over two decades to identify information relevant to crises posted on social media by the public and use them for decision-making in relief operations (examples: [15,65]. The public can assist disaster management organizations in the classification and sorting of the large amount of information generated through social media posts, facilitating their processing and analysis. From our analysis, the adoption, promotion, and encouragement of two broad categories of posts would greatly improve social media data filtering and analysis. The two categories include personal (relevant to family and friends) and informative (relevant to the public) posts. For example, in our sample, posts related to climate change and the media's reaction to the presidential pardoning are informative and may not have a direct impact on the people affected by the disaster. Accordingly, disaster management agencies can ignore such informative tweets, which are not relevant to emergency or relief operations. Therefore, the agencies can promote the use of specific hashtags that can simplify the identification and classification of tweets.

6. Conclusion

In this study, we examine the tweet data to understand the needs of the general public during the onset of a disaster. We use text mining techniques to analyze Tweet data collected during Hurricane Harvey and extract implicit knowledge based on which we make policy recommendations to governmental and non-governmental organizations involved in disaster management and relief operations. The results show that climate change, concerns regarding specific disaster locations, impact on travel and entertainment events, impact on the oil and gas industry, and timeline of disaster declaration and emergency responses are the major issues for the citizens. We provide an in-depth discussion of the themes with the purpose of demonstrating their importance to the general public with regard to disaster management and response. Further, we offer additional validation illustrating that these themes are still very much in people's minds whenever they encounter a disaster such as Hurricane Harvey. With regards to policy recommendations, we make the following four recommendations based on the findings of our study: 1) train the general public to formulate simple and actionable disaster-related posts; 2) establish channels to properly communicate procedures and guidelines as life returns to post-disaster normalcy; 3) provide specific and detailed information regarding transportations; and 4) promote the use of specific hashtags to simplify tweet classification.

7. Implications for academics and practitioners

Our study has implications for both academics and practitioners. From the academics' perspective, the study extends the literature on social media use in disaster management. Specifically, we validate the importance of social media as a tool to assist in disaster management and relief operations, as shown in the previous literature [15]. Moreover, we examine the specific case of Hurricane Harvey and the related tweets to identify different themes that are of concern to people during the pre-crisis period of disasters. Additionally, we showcase the LDA methodology as a useful technique for textual analysis and mining in the context of disaster management. With regards to implications for practitioners, our study provides relief organizations, disaster management agencies, and policymakers with a framework to understand the citizens' concerns during disasters and formulate effective disaster management policies. Furthermore, our specific recommendations, formulated in relation to Hurricane Harvey, can be applied to other disasters.

8. Limitations and future directions

Despite our attention to methodological rigor, our results should be interpreted with certain limitations in mind. First, the focus of our paper, as mentioned in the previous sections, is on the pre-crisis period with a two-day window. Thus, further research is required to examine the tweets in the crisis and post-crisis periods. Second, this study is limited to a single disaster, namely, Hurricane Harvey. Further research is required to examine other disasters in the same light and see if the findings are comparable to the ones seen during the pre-crisis period of Harvey. Third, the locations or coordinates of individuals or organizations that send a tweet are not available in our data set. This prevents us from conducting any spatial analysis. Finally, the data is limited to Twitter's public domain, i.e., it does not include private communications.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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