Twitter Early Tsunami Warning System: A Case Study in Indonesia's Natural Disaster Management

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Abstract

Twitter demonstrated its value as a viable substitute to traditional communication channels during the recent disasters. However, little is written about Twitter in government for an early disaster warning system. In this exploratory empirical research, we aim to address the question: How does the government use Twitter to inform the public about disaster hazards and vulnerability? Case study and tweets content analysis are conducted on Indonesia's Twitter early tsunami warning system to answer the question in the context of the three earthquakes occurred off the west coast of Sumatra during the period of 2010-2012. Data are collected from e-government websites of agencies involved in disaster preparedness and response. This research concludes that the Twitter-based warning system demonstrated its value as a viable complement to Indonesia's InaTEWS – a comprehensive disaster information management system for governments – by informing the public and creating public value through its communication speed, reach and information quality.

1. Introduction

With over 140 million active users worldwide as of 2012, the Twitter social media service generates more than 340 million tweets daily [1]. In 2010, Indonesia was Asia's leader with 5,616,000 Twitter users [2]. Today it ranks fifth in the world in the number of active users on Twitter [3]. With its tangible benefits such as virtual social interaction, ease of use, and financial affordance, the Twitter social media service has rapidly gained worldwide acceptance and popularity. Twitter's network externality has created new value propositions for personal, corporate, and public communication in terms of the global reach and the speed of communication. The Twitter service provides different applications for many users – both individuals and private-sector organizations, ranging from informal, personal and social interactions to formal business information exchanges, new product launch advertisements and customer reviews, and new corporate communication practices with regard to managing customer complaints and reducing corporate reputation risks. These innovative information management applications in the private-sector organizations are rapidly diffusing to the public-sector organizations in application domains of great public interest such as government use of social media for natural disaster management.

The actual use of social media for disaster response has been studied in the application domains of search and rescue [4], emergency response[5-8], evacuation [6] and recovery [8, 9]. In contrast, studies on social media use for disaster preparation have been clearly lacking. However, during the 2010 Mount Merapi Eruption [7] and the 2011 Great East Japan Earthquake and Tsunami [6], Twitter demonstrated its value as a viable substitute to traditional public communication channels under extreme natural disaster events, when demands for these communication channels such as land line and mobile telephones dramatically increased and overwhelmed existing service capacities. While issuing early warnings is not always possible for some natural disasters, effective use of Twitter as an early warning system can increase disaster preparedness of individual citizens and local communities. This improved preparedness can facilitate effective disaster response such as timely mass evacuations and contribute towards minimizing human casualties and the social, economic and environmental impacts of disasters.

Although the potential of Twitter as an early disaster warning channel for severe weather [10] and flood [11] was recognized, this paper argues that urgent need exists for empirical research on Twitter use by government agencies in issuing early disaster warnings. This exploratory empirical research, therefore, is motivated to address the research question: How does the government use Twitter to inform the public about disaster hazards and

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vulnerability? In this paper we address this research question by conducting case study research and tweets content analysis on Indonesia's Twitter early tsunami warning system in the context of the three latest earthquakes occurred off the west coast of Sumatra during the period of 2010-2012. Data are collected from e-government websites of Indonesia's lead public agencies involved in disaster preparedness and response.

The remainder of this paper is structured as follows: Section 2 presents a literature review of natural disaster management, the role of early disaster warning systems, and social media use in disaster management. Section 3 presents our research background on tsunami and disaster management in Indonesia. Section 4 describes our research methodology; the combination of case study research on Indonesia's Twitter early tsunami warning system and extant disaster information management system and content analysis of tweets generated by the Twitter early tsunami warning system. Section 5 discusses salient results of our case study and tweets content analysis. Section 6 is the conclusion of the study on the use of the Twitter early tsunami warning system towards better informing the public about the tsunami hazards and community vulnerability. In the conclusion section, we also discuss our research limitations and future research directions.

2. Literature Review

2.1. Natural disaster management

The overarching goal of natural disaster management activities is "to reduce, as much as possible, the degree to which a community's condition is worsened by a disaster relative to its pre-disaster condition" [12]. However, the recent catastrophic natural disasters, such as the 1994 Northridge Earthquake, the 1995 Great Hanshin Earthquake, the 2004 Indian Ocean Tsunami, the 2005 Hurricane Katrina, the 2009 Australian bushfires and 2011 floods, and the 2011 Japan East Earthquake and Tsunami have shown so painfully that it is very difficult to achieve this goal because of the very nature of natural disasters:

- Disasters are large, rapid-onset incidents relative to the size and resources of an affected jurisdiction;
- Disasters are uncertain with respect to both their occurrences and their outcomes;
- Risks and benefits are difficult to assess and compare;
- Disasters are dynamic events;
- Disasters are relatively rare.

Given the nature of natural disasters, therefore, prior research on the extreme natural disaster events has concluded on the urgent need for improved cross-agency collaboration and citizen engagement in increasing citizen awareness of disaster hazards and improving individual and community disaster preparedness [1, 13-16].

2.2. The role of early disaster warning systems

Early disaster warning systems are a type of alert systems deployed to inform the public about the emergent risk of an extreme disaster event, without delay, concurrently through multiple communication channels [17]. Early warning systems need to satisfy at least the following information system requirements:

- Speed of communication [18-20]
- Reach [20, 21]
- Information quality [18, 22]

Figure 1. Disaster management cycle

We assume that early warning systems that satisfy the requirements above will likely increase citizen awareness of disaster hazards and risks and improve individual and community disaster preparedness. Early disaster warnings are critically important for effective disaster response such as timely mass evacuations. In order to discuss the role of early disaster warning systems in disaster management practice, we describe the conceptual framework of disaster management cycle, since this empirical research is grounded in this framework. A comprehensive disaster management cycle consists of four temporal phases: preparation (or preparedness), response, recovery, and mitigation [23], which is shown in Figure 1. Here the interdependence across these four linked phases and between the adjacent phase activities should be recognized. For example, what was done or rather what was not done at the preparation phase activities – prior to an extreme natural disaster event strikes local government areas – largely influences the level of government disaster response activities at the next response phase.

Each phase involves the management and coordination of a wide array of stakeholders: government agencies, emergency response teams, community-based non-government organizations, and local residents. Prior research on network technologies such as radio frequency identification (RFID) has provided strong support for improved management and coordination of multiple stakeholders in business contexts [24]. Therefore, the management and coordination of each phase may be improved by making real-time location-aware information about people and high-value assets available through the use of network technologies.

Preparation: prior to disaster, preparedness activities such as early warnings are designed to plan the unthinkable and increase the readiness of organizations and communities to respond to a disaster timely and effectively. "Disaster plans are often developed by individual agencies, but one challenge of disasters is that they demand action from agencies and organizations that may not work closely together from day to day."[23]

Response: activities such as search-and-rescue and massive evacuation efforts are undertaken immediately following a disaster "to provide emergency assistance to victims. The response phase starts with the onset of the disaster and is devoted to reducing life-threatening conditions, providing life-sustaining aid, and stopping additional damage to property. "[23]

Recovery: short- and long-term activities undertaken after a disaster "that are designed to return the people and property in an affected community to at least their pre-disaster condition of well-being. In the immediate term, activities include the provision of temporary housing, temporary roofing, financial assistance, and initial restoration of services and infrastructure repair. Longer-term activities involve rebuilding and reconstruction of physical, economic, and social infrastructure and, ultimately, memorializing the losses from the event."

Mitigation: activities undertaken "in the long term after one disaster and before another strikes that are designed to prevent emergencies and to reduce the damage resulting from those that occur, including identifying and modifying hazards, assessing and reducing vulnerability to risks, and diffusing potential losses.

2.3. Social media use in disaster management

As we discussed in the previous section, the nature of natural disaster makes it difficult for many governments to invest in a costly large-scale, dedicated early disaster warning system when disasters are rare and uncertain with respect to both their occurrences and outcomes. Even when such an early disaster warning system can be built in-house or outsourced by governments with large financial and human resources, the system complexity and the lack of expert users may reduce its usefulness during the chaotic hours in the immediate aftermath of a large-scale extreme disaster event, as was the case during the 2011 Great East Japan Earthquake. In contrast, the existing social media channels such as Twitter, Facebook, and YouTube can provide government agencies with the tangible benefits of financial affordance and ease of use during extreme disaster events.

Although empirical research data are limited, social media have been used for disaster response since the 2007 Southern California Wildfire [8]. People were accessing blogs, photo sharing, broadcasting, and Twitter to share information about the fires. During the 2008 Wenchuan Earthquake in China, a girl used Baidu Bar (similar to Wiki) to show the appropriate helicopter landing point for disaster relief [4]. During this earthquake, web forums were also used as effective media for raising donations [25] and creating virtual communities for message distribution [9]. A Chinese version of microblogging site, Weibo, was also used during the 2010 Yushu Earthquake in China [25]. People used this microblogging site to spread the earthquake information, express their emotions, and update the disaster situations. MS Share Point, Twitter and web forums were used during the 2010 Haiti Earthquake. The MS Share Point was used by the U.S Air Force mainly to inform disaster situations and share professional knowledge of relief operations [4]. Moreover, a web forum was used by the U.S Navy for informing medical supplies and ground equipment provided the afflicted local areas [5]. A mobile based application for classifying Twitter text was also developed in order for quick message identification [26].

During the 2010 Mount Merapi Eruption, Twitter was used by non-profit organizations (NPO) and local communities to communicate whether or not certain villages need to be evacuated based on the latest official disaster public update. Twitter was also used by the refugee shelter for logistics support [7]. Last but not least, Twitter showed its tremendous reliability during the 2011 Great East Japan Tsunami, which motivated Japan's Prime Minister's Office to adopt and use Twitter for sharing disaster information [6]. Table

1 summarizes the salient prior research studies on a variety of social media used during disaster management cycle phases. Table 1 shows the relative lack of social media research on the earliest phase, disaster preparedness.

Table 1. Social media in disaster management

Disaster/ Year/Country/	Social Media	Disaster Management Cycle
Southern California Wildfire, 2007/USA	Blogs, forum, Flickr, Twitter	Response, Recovery [8]
Whenchuan Earthquake, 2008/China	Baidu Bar	Response, Recovery [4]
	Web Forum	Recovery [9]
	Web Forum	Recovery [25]
Yushu Earthquake, 2010/China	Microblog	Recovery [25]
Haiti Earthquake 2010/Haiti	Forum	Response, Recovery [5]
	MS SharePoint	Response, Recovery [4]
	Twitter	Response [4]
Mount Merapi Eruption, 2010/Indonesia	Facebook, Twitter	Preparedness, Response, Recovery [7]
Great East Japan Tsunami, 2011/Japan	Twitter	Preparedness, Response, Recovery [6]

3. Background: Disaster Management in Indonesia

3.1. Earthquakes and tsunamis: 2010-2012

The three latest earthquakes in the west coast of Sumatra are: the 25 October 2010 Mentawai Earthquake and Tsunami (West Sumatra), the 5 September 2011 Singkil earthquake (Aceh), and the 11 April 2012 Simeulue earthquake (Aceh). The Mentawai earthquake with a magnitude 7.7 occurred about 150 miles (240 km) west of Bengkulu and close to the Mentawai Islands. The earthquake's hypocenter was at 20.6 km depth. It caused a tsunami, which killed 530 people in the Mentawai Islands and affected 11,864 people. The Singkil earthquake was a 6.7 magnitude at a depth of 78 km, with ten casualties. The 2012 Simeulue earthquake was a 8.6 magnitude and the hypocenter was at 10 km depth. Despite its magnitude and hypocenter, this earthquake did not generate a severe tsunami.

The problem in issuing a timely early tsunami warning arose in two of the three earthquakes. In the case of the 10.25 2010 Mentawai Earthquake, the central disaster management agency failed to issue an early tsunami warning for citizens in the local areas affected by the tsunami. In the case of the 4.11 2012 Simeulue earthquake, there were several reported problems: 1) Some of early tsunami warning buoys did not work, while others were missing; 2) Some of tsunami alarms did not work properly, whereas in another case a government official responsible for the tsunami alarm left his office earlier; 3) Mass evacuations were not coordinated and operated on time, causing traffic jams everywhere; and 4) Conflicts arose between the local disaster management agency and Mayor of the city about who should issue a tsunami warning.

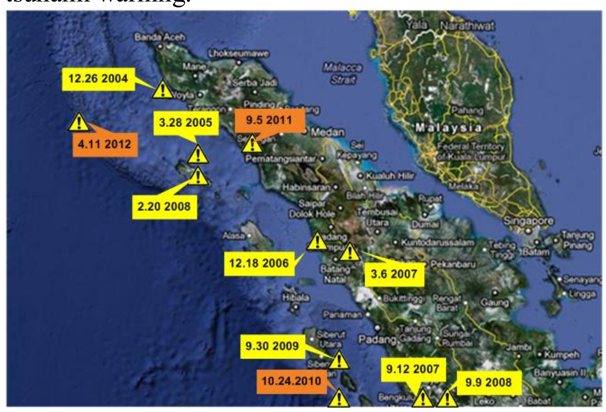

Figure 2. Earthquakes off west coast of Sumatra

Prior to the 2012 earthquake, there were ten earthquakes over the period of 7 years from January 2005 to May 2012 [27]. Figure 2 above shows a total of 11 disaster locations; the ten earlier earthquakes and the 2012 earthquake. The eleven earthquakes impacted the region with the serious economic, social, environmental damages and the enormous human casualties.

Table 2. Earthquake/tsunami casualties

Date, Location	Type	M	Killed	Affected
4.11 2012, Aceh	Earthquake	8.6	7	107
9.5 2011, Aceh	Earthquake	6.7	10	
10.25 2010, West Sumatra	Earthquake, Tsunami	7.7	530	11,864

Date, Location	Type	M	Killed	Affected
9.30 2009, West Sumatra	Earthquake	7.5	1,195	2,501,798
9.9 2008, Bengkulu	Earthquake	5.2	2	625
2.20 2008, Aceh	Earthquake	7.3	3	25
9.12 2007, Bengkulu	Earthquake	8.5	25	459,567
3.6 2007, West Sumatra	Earthquake	6.3	67	137,660
12.18 2006, North Sumatra	Earthquake	5.5	8	1200
3.28 2005, North Sumatra	Earthquake	8.6	915	105,313
12.26 2004, Aceh	Earthquake, Tsunami	9.1	165,708	532,898
Total			168,470	3,751,057

Source: EM-DAT, 2012

Table 2 above provides information about the eleven disasters with regard to the date and location, types of disaster, magnitude, the number of people killed and the number of people affected. In terms of the human casualties, 168,470 people were killed and more than 3.75 million people were affected by the earthquakes and tsunamis. On the one hand, Table 2 shows that the earthquakes with greater magnitude do not always cause a tsunami. On the other hand, the occurrence of a tsunami is influenced by the earthquakes hypocenter, which is spread across the west coast of Sumatra, from Bengkulu in the southern part to Aceh in the northern part of Sumatra. While some of the earthquake hypocenters were located directly below the land mass, others were located just off the sea that might cause a tsunami.

3.2. Indonesia’s disaster management agencies

As we discussed earlier, the eleven disasters had staggeringly high economic, social and environmental costs and affected the most vulnerable. Especially after the 2004 Indian Ocean Tsunami, therefore, Indonesia established the National Disaster Management Agency (BNPB) in 2008 to reduce disaster risks and minimize their impacts on human casualties [28]. BNPB is charged to lead and collaborate with other disaster management agencies to maximize Indonesia’s overall disaster response capacities. While the National Disaster Management Agency serves as the lead agency in national disaster management, it works closely with the Meteorological, Climatological and Geophysical Agency of Indonesia (BMKG). The latter is charged as the lead agency for tsunami detection and early disaster warnings [29]. The National Disaster Management Agency also works with National Mapping Agency (Bakosurtanal) responsible for developing maps of the hazardous areas. Finally, the National Disaster Management Agency works with the National Armed Forces (TNI), the National Police (Polri) and with the Search and Rescue Agency (Basarnas) to search and rescue disaster victims.

The Meteorological, Climatological and Geophysical Agency of Indonesia (BMKG) is also responsible for operating the Indonesia Tsunami Early Warning System (Ina TEWS) to detect, analyze, simulate, and disseminate disaster information on earthquake, tsunami, and severe weather. It was officially launched on November 11, 2008. Figure 3 below shows the information flows within the InaTEWS [30].

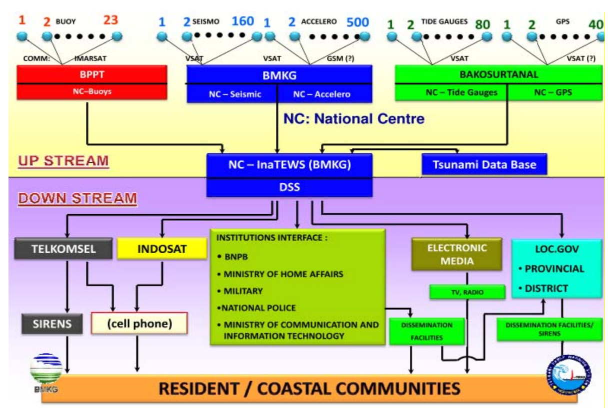

Figure 3. The tsunami warning information flows. Adopted from [31]

The InaTEWS receives seismic data from BMKG, the crustal deformation from Bakosurtanal, and sea wave level monitoring information both from Bakosurtanal and from the Agency for The Assessment and Application of Technology (BPPT). The Decision Support System (DSS) functions of the InaTEWS support decision-making processes of the following four sub-systems: 1) situation assessment system for creating earthquake maps and running simulations; 2) real-time monitoring system which employs GPS, buoys, and tide gauges; 3) decision system for suggesting the appropriate types of warnings; and 4) product system for disseminating warnings to other GSM broadcast, national government agencies (BNPB, Ministry of Home Affairs, TNI, Polri, Ministry of Communication and Information Technology or Kominfo), electronic media, and local governments.

Leveraging on information from the four sub-systems, BMKG can issue 3 different warnings. The first early tsunami warning can be issued during the first 5-7 minutes after the occurrence of an earthquake. The second early tsunami warning contains either confirmation or cancellation of the first early tsunami warning and can be issued within 10-30 minutes. The third early tsunami warning is issued after the coastal observation of a tsunami and can be issued between 30-60 minutes. While all these early tsunami warnings are intended to inform government agencies, they are not issued directly to the public.

4. Research Methodology

In order to address the research question on how the government uses Twitter to inform the public about disaster hazards and vulnerability, we conducted case study research and tweets content analysis on Indonesia's Twitter early tsunami warning system in the context of the three latest earthquakes occurred off the west coast of Sumatra during the period of 2010-2012. Case study research is best suited to answer the 'how' research question [32]. In the case study we needed the expert knowledge of the Indonesian language and governments to examine e-government website information and documents and identify a network of the lead government agency and other salient disaster management agencies which are responsible for issuing early disaster warnings and other disaster management cycle activities which are relevant to the first two phases.

Table 3. Agencies related to tsunami warning's number of tweet

Agency	Tweets Accessed	Total Tweets	%	Data Period
BMKG	1,898	6,203	30	Sept 1-May 1 2012
BNPB	428	493	86	Aug 1 2010-1 May 2012
Polri	827	1,304	63	Aug 1 2010-1 May 2012
Kominfo	505	552	91	Aug 13 2010-1 May 2012

We also conducted a content analysis of tweets issued by Indonesia's disaster management agencies to further address the research question. The data were gathered from Twitter with the help of Tweepy, a Twitter Application Programming Interface (API) library for python programming language. As long as users set their tweets to public mode, the tweets are transparent and visible to anyone whether or not he/she has a given Twitter account. Table 3 shows the tweet data we accessed and analyzed in this research. Out of all the tweets issued by the four lead disaster agencies, we accessed and analyzed the sample of 3,658 (42.8%) out of the total of 8,552 tweets issued.

The Military and Ministry of Home Affair was excluded from this study, because it had no Twitter account. Once data were collected, we analyzed the contents of tweets using the Meteorological, Climatological and Geophysical Agency (BMKG), the lead agency's basic keywords to find whether or not Twitter was utilized as a means for informing the public about early tsunami warnings.

One of the research problems with tweets as archival data is how open they are and how far along they are accessible for our research need. In order to ensure data access, we have selected the three latest earthquakes occurred off the west coast of Sumatra. Furthermore, the earthquakes occurred after the lead disaster response agencies in Indonesia had experienced using Twitter as one of their disaster communication channels. The strategic selection of data collection sites enabled us to examine how the lead agency, BMKG, responsible for issuing early tsunami warnings responded to the actual three disasters using Twitter, and observe how the disaster information diffused among the network of the government agencies.

5. Results

5.1. Twitter use by BMKG

The Meteorological, Climatological and Geophysical Agency's official website has direct links to its official Twitter and Facebook channels. As the central agency responsible for issuing early warnings about meteorological hazards, the BMKG actively uses its Twitter and Facebook channels to inform the public about the emergent disasters events. The BMKG started using Twitter on January 26, 2010 and now has 303,540 followers with 6,182 tweets issued as of May 24, 2012. On the one hand, in the immediate aftermath of the April 11, 2012 earthquake, the number of tweets issued only marginally increased by 76 tweets (or 1.2%). On the other hand, over the short period of one month, the number of the central agency's followers radically increased from 255,139 on April 11 to 303,540 on May 24, registering a sharp increase of 48,401 followers (nearly 19%). The earthquakes seemed to have significantly stimulated the public interest in the agency's Twitter early tsunami warnings. Similarly, the content of the BMKG Facebook channel received an increase from 70,405 friends/likes as of April 13 2012 to 72,486 as of May 24 2012 with an increase of 2,081 (or nearly 3%).

We performed a content analysis of all BMKG tweets from September 1, 2010 to May 10, 2012, using the BMKG's own keywords such as weather, earthquake, high sea, and other basic terms. The total number of Tweets analyzed was 1,898 (30% of total tweets), covering the three earthquakes prior to, during and after the issuance of the earthquake warnings. There are a small number of tweets that did not fit with any keywords, such as tweets about solar storms, and therefore we classify them as "others". Figure 4 shows the results of the content analysis. It show the high frequency occurrence of earthquake warnings (58%), which is followed by weather forecast (37%).

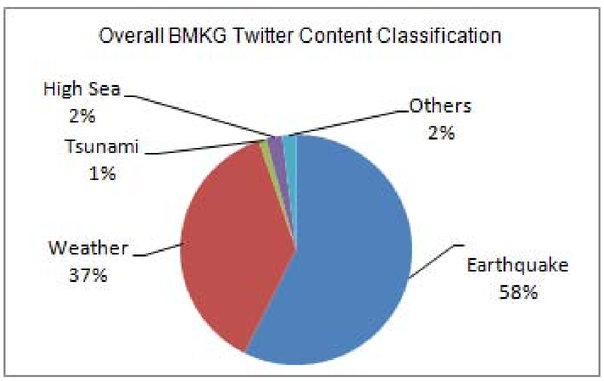

Figure 4. Content analysis results of BMKG tweets from September 1 2010 to May 10 2012

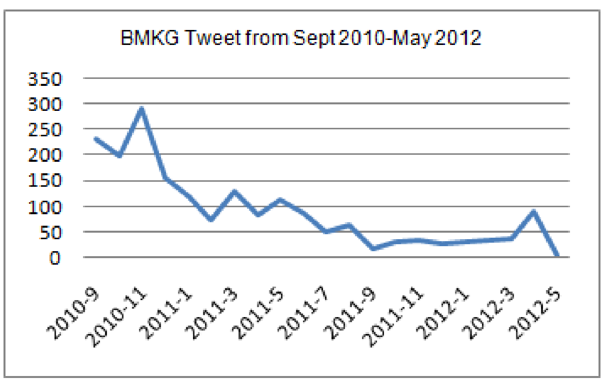

Figure 5. BMKG monthly tweets

Figure 5 above shows a timeline of the BMKG Twitter contents monthly distribution. The three down arrows show the three earthquakes. The number of tweets related to earthquakes continues to dominate over the other tweet contents during the period studied. There are two sudden surges in October 2010 and April 2012, when the two earthquakes occurred during the period. While tweets containing severe weather information dominated at the beginning, they decreased sharply after December 2010 and never regained its dominance afterwards. In contrast, tweets regarding high sea, tsunami warnings, and other information did not fluctuate significantly in comparison to the earthquake and weather tweets.

Recently, BMKG has used specific information structures for composing its tweets, regardless of the tweet content. With regard to tsunami information, BMKG uses the following information structure:

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Tsunami Early Warning in-Area Affected-The Cause-Link
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The first tsunami warning issued for the 4.11 2012 earthquake and tsunami is a prime example. It stated: "Tsunami Early Warning in Bengkulu, Lampung, Aceh, West Sumatra, North Sumatra, Earthquake Mag: 8.9 SR, April 11 2012 15:38:29 West Indonesian Time, Location 2.31 LU,9", which is shown in Figure 6 below.

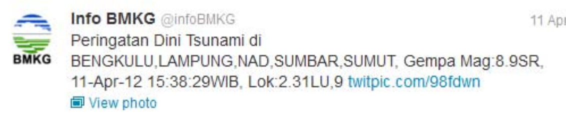

Figure 6. BMKG tweet tsunami warning

Prior to using this new information structures, BMKG used a single tweet to convey a complex mix of different information contents. For example, BMKG published an earthquake warning and a tsunami warning in one tweet. Later, it was found that this mixed information structure was confusing and misleading those who followed the BMKG tweets.

5.2. BMKG tweet response time to earthquake

In order for social media such as Twitter to function as an effective early disaster warning system, the speed of communication is critically important; they need to provide disaster information in a timely manner. On June 26, 1917, the 8.3 magnitude Samoan earthquake triggered a 3 m tsunami reached the nearest coast within 10 minutes [33]. The speed at which early disaster warnings are diffused across the lead disaster management agencies is critically important. Therefore, in this section, we discuss BMKG tweet response time. Table 4 shows the availability of Twitter early tsunami warnings for the three earthquakes.

The 10.25 2010 Mentawai earthquake occurred at 14:42:22 UTC and the BMKG's first tweet was issued at 14:50:08 UTC; 7 minutes 46 seconds after the earthquake. It was followed by the second early tsunami warning tweet released at 14:50:32 UTC (24 seconds after the first tweet). Later it was found that the earthquake had really generated a tsunami. Although there was no official report of the exact time at which the 10.25 2010 Mentawai tsunami inundated the nearest coast, a study estimated that the tsunami arrived in 15 minutes after the earthquake (or at 14:57:22 UTC), with 530 people killed [24]. However, there were a series of earthquakes that followed the first one. In consequence, the BMKG continued to inform these earthquakes using its Twitter channel. This is why the number of tweets increased sharply in October 2010 (see Figure 5).

Table 4. Twitter tsunami warning availability

Date	Tsunami Earthquake	Tsunami Warning Tweet	Tsunami Occurred
4.11 2012	No	Yes	No Tsunami
9.5 2011	No	No	No Tsunami
10.25 2010	Yes	Yes	Yes Tsunami

The second earthquake with magnitude 5.5 occurred at 15:21:09 UTC but it did not cause a tsunami. BMKG then issued a tweet informing this earthquake and the additional information: no tsunami caused by this earthquake. However, since the information was similar to the previous tweet, the public misunderstood this as the cancellation of the first tsunami warning. This tweet content was also posted on the BMKG Facebook, and many people inquired why the previous tsunami warning was cancelled.

In comparison to the 10.25 Mentawai Earthquake, the 9.5 2011 Singkil earthquake with a 6.7 magnitude was less powerful and less damaging. The hypocenter was not in the seabed, and therefore it did not cause a tsunami. The first early tsunami information was issued in 7 minutes 27 second after the earthquake.

With regard to the 4.11 2012 Simeulue earthquake, the BMKG issued its first early tsunami warning tweet 7 minutes and 46 seconds after the earthquake. Three minutes 17 seconds later, the BMKG issued the second tweet informing the public that the tsunami warning was still in effect. While the tsunami warning was still in effect, another earthquake occurred 2 hours 3 minutes and 7 seconds later. After two more earthquakes occurred, BMKG revoked all the tsunami warnings 4 hours 28 minutes and 49 seconds later. This time, there was no confusion about the tsunami status.

Table 5. BMKG tweet response time to earthquakes

Earthquake Date/Time*	First Tweet Date/Time	Time Gap
April 11, 2012 at 08:38:37 UTC	April 11, 2012 at 8:46:17 UTC	7 min 40 seconds
September 05, 2011 at 17:55:11 UTC	September 05, 2011 at 18:02:38 UTC	7 min 27 seconds
October 25, 2010 at 14:42:22 UTC	October 25, 2010 at 14:50:08 UTC	7 min 46 seconds

*Source: USGS (http://earthquake.usgs.gov)

Table 5 above shows that it took the BMKG the average 7 minute and 37 seconds after the earthquake before it issued the first early tsunami warning tweet. However, the Head of BMKG Decree [34] stated that the standard time for issuing the first early tsunami warning must be within 5 minutes after the earthquake. However, both the speed of disaster communication and the significant improvement in the way which the tsunami warning information was structured and presented contributed to reduce the level of citizen confusion and misinterpretation of tsunami hazards and community vulnerability. Our content analysis of the Twitter early tsunami warnings suggests the importance of information quality to help the public develop an accurate understanding of the disaster hazards and vulnerability during the disaster preparedness and disaster response phases of the disaster management cycle.

5.3. Cross-agency tweet propagation

On the one hand, Indonesia's InaTEWS, a comprehensive disaster information management system, does not inform the public about disaster hazards. On the other hand, the InaTEWS tsunami warning information flows (Figure 3) show that tsunami warnings can be issued directly to other disaster management agencies, the electronic media and local governments in the forecasted vulnerable region. For the three earthquakes, the number of tweets released by the BMKG was 47, 2 and 14 for Mentawai, Singkil and Simeulue earthquake respectively, as shown in Table 6 below.

Table 6. Re-tweeting disaster information

Date of Event	Number of BMKG Tweet	Average Retweet per Tweet	Maximum Retweet
4.11 2012	14	2132	8291
9.5 2011	2	1130	2080
10.25 2010	47	19	121

The average re-tweets for the warning dramatically increased since 2011; it almost increased 50 times. The maximum re-tweet of a BMKG tweet was 8,291, which occurred with the 4.11 2012 Simeulue earthquake. According to topsy.com [35], there were 21,273 re-tweet of this tweet. However, an analysis of the data shows that the tweet exchanges across the government agencies did not represent the intended cross-agency collaboration. The data analysis shows that the Naval Armed Forces, BNPB, the National Police, the Ministry of Welfare and Social Affairs and the Indonesia Red Cross merely followed the BMKG Twitter early warnings. BMKG itself only followed the tweets issued by its 5 regional offices.

6. Discussion

Research on social media use in disaster management is very new, with the 2007 Southern California Wildfires [8] as one of the earliest empirical research studies in the literature. While prior research focused largely on the recovery phase or the interdependent response and recovery phases of the disaster management cycle, very insufficient research attention has been paid to social media use in the earlier preparedness and response phases. From an e-government research perspective, very little is written about social media use by government disaster agencies for an early disaster warning system. This exploratory empirical research, therefore, addressed the research question: How does the government use Twitter to inform the public about tsunami hazards and vulnerability? We conducted case study research and tweets content analysis on Indonesia's Twitter early tsunami warning system to answer the question in the context of the three earthquakes occurred off the west coast of Sumatra during the period of 2010-2012.

Our case study research found that the Indonesian Government attempted to transform its disaster management practice at the national government level, if not at the local government level, after having suffered the catastrophic human casualties and the enormous economic, social and environmental damages from the 2004 Indian Ocean Tsunami. Organizationally, Indonesia established the National Disaster Management Agency (BNPB) in 2008 as the lead disaster management agency responsible for the overall disaster management policy and practice to minimize human casualties through better disaster risk management and IT-enabled disaster preparedness and response. With the BNPB as the hub, Indonesia created a network of disaster management agencies which perform different disaster risk reduction functions in cooperation with the BNPB.

Technologically, Indonesia developed the national Tsunami Early Warning System (Ina TEWS); a comprehensive disaster information management system, which has been operated by the Meteorological, Climatological and Geophysical Agency of Indonesia (BMKG) since 2008. The Ina TEWS does not issue early tsunami warnings directly to the public or to the vulnerable high-risk local communities. However, it can issue early tsunami warnings to national-level and local-level government agencies and electronic media.

The BMKG also adopted the use of social media channels, especially Twitter and Facebook since 2010 to inform the public directly with early earthquake warnings, early tsunamis warnings, and severe weather warnings.

While Indonesia's Twitter early tsunami warning system is adopted and used by the disaster management agencies, our content analysis of tweets and re-tweets exchanged across these agencies does not find evidence for increased inter-agency collaboration at the early preparedness and response phases of the disaster management cycle. E-government interoperability research shows that cross-agency collaboration has accumulated a long history of friction, conflict, and failure [36]. Prior research identified nine barriers to e-government interoperability: 1) constitutional/legal constraints; 2) jurisdictional constraints; 3) collaborative constraints; 4) organizational constraints; 5) informational constraints; 6) managerial constraints; 7) cost constraints; 8) technological constraints; and 9) performance constraints [36]. Of the nine barriers above, some constraints might be relevant to this case study. While the Twitter early tsunami warning system provides technological interoperability among the agencies which hold Twitter and Facebook accounts, constitutional, jurisdictional and organizational barriers need to be fully addressed to improve inter-agency collaboration through social media channels. More specifically, new social media governance structure and processes will be required to develop a better understanding of the different levels of organizational readiness to collaborate and share disaster information. In the case of Indonesia's disaster management agencies, transforming their disaster management practice and creating non-technological interoperability and integration will remain a complex endeavor.

However, with regard to informing the public, this research found evidence that Twitter use by the Meteorological, Climatological and Geophysical Agency of Indonesia (BMKG) for an early tsunami warning system demonstrated its public value as a viable complement, not a substitute, to Indonesia's Ina TEWS in terms of disaster communication speed and information quality. First, we evaluated the BMKG's disaster communication speed by measuring the average tweet response time; the tweet response time taken by the BMKG before it issued the first tweet early tsunami warning to the public, after each of the three earthquakes occurred on October 25, 2010, September 05, 2011, and April 11, 2012. The average tweet response was 7 minute and 37 seconds after the earthquake struck Indonesia. Of the three earthquakes, only the 10.25 2010 Mentawai earthquake triggered a tsunami. A study estimated that the tsunami arrived in 15 minutes after the earthquake [37]. This means that the BMKG's Twitter early tsunami warning system can provide the public with the lead time of more than 7 minutes for their timely evacuations.

Second, the BMKG derives its tweet content from the Ina TEWS, a comprehensive disaster information management system. Furthermore, the BMKG radically changed the information structure of its tweet early tsunami warning to improve information quality. The new information structure for tweets aimed to reduce the public's misinterpretation of the earlier unstructured, complex, and often confusing tweets. Our content analysis of the Twitter early warnings suggests the importance of information quality to help the public develop an accurate understanding of the disaster hazards and vulnerability during the disaster preparedness and disaster response phases of the disaster management cycle.

7. Conclusion

Our empirical research finds that Twitter use by the BMKG for informing the public directly through its Twitter early tsunami warning system demonstrated public value as a viable complement, not a substitute, to Indonesia's Ina TEWS. This is in contrast to the conclusions of prior research that Twitter demonstrated its value as a viable substitute to traditional public communication channels during the recent extreme natural disaster events. However, prior research did not focus on Twitter use for the interdependent disaster preparedness and response phase activities and functions such as early disaster warnings. Further research is needed to explain the different findings.

Future research directions include theory development to better explain the effect of social media use on improving disaster preparedness, disaster response, and overall inter-agency disaster coordination and management performance. Toward this future goal, we draw on the concept of a comprehensive disaster management cycle to argue for the critical role of Twitter use for an early tsunami warning system in increasing citizen awareness of disaster hazards and risks and improving individual and community disaster preparedness. With the lead time of over 7 minutes the Twitter early tsunami warning system provides, the residents of the vulnerable communities can assess the situation and decide whether or not they should evacuate. Without the early warning, effective mass evacuations of citizens will be difficult. Finally, future research directions should also investigate user experience through a survey of the citizens who follow the tweets through the lead agency's Twitter tsunami warning system.

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