Research Themes on Warnings in Information Systems Crisis Management Literature

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ABSTRACT

Early Warning Systems (EWS) are crucial to mitigating and reducing disaster impacts. Furthermore, technology and information systems (IS) are key to the success of EWSs. This systematic literature review investigates the research topics and themes from the past six years of Information Systems for Crisis Response and Management (ISCRAM) conference proceedings and seeks to identify the research developments and directions for EWSs to steer a discourse to advance the research in this field. Findings from a sample size of 60 papers show that there are technical, social, and topical considerations to using and advancing technology for EWSs. While technology has advanced EWSs to new levels, it is important to consider the influence of technology in the successful operation of EWSs. The results are based on the ISCRAM proceedings literature and may be broader or have different prioritization if a wider disciplinary body of literature was explored. This will be considered in the future.

Keywords

Early Warnings Systems, Literature Review, Ethics, Social Media.

INTRODUCTION

In the last two decades, there has been a paradigm shift in disaster risk reduction from reactive post-disaster response and recovery to proactive preparedness and mitigation. In response to this shift, both the Hyogo Framework for Action 2005-2015 and the Sendai Framework for Disaster Risk Reduction 2015-2030 prioritised the development and implementation of Early Warning Systems (EWSs) (UNISDR, 2005, 2015). EWSs are an integral element of disaster risk reduction, as they can directly prevent loss of life and reduce impacts (WMO, 2018). For example, the large death toll from the 2004 Indian Ocean tsunami is largely attribute to the lack of an EWS; a tsunami EWS could have potentially saved many lives (Chatfield & Brajawidagda, 2012).

People-centred multi-hazard EWSs have become a priority because of their consideration of individuals' and communities' needs and capacities, and their ability to warn of one or more hazards for increased efficiency and consistency (UNISDR, 2015; WMO, 2018). People-centred multi-hazard EWSs have four elements: 1) disaster risk knowledge, 2) detection, monitoring, forecasting and warning for hazards, 3) dissemination and communication of authoritative warnings, and 4) preparedness capabilities to respond to warnings (Basher, 2006; WMO, 2018). Table 1 summarises these elements. Disasters can worsen when multiple hazards cascade or interact, thus a multi-hazard approach is important to consider when designing or improving EWSs (Grace & Saunders, 2016).

Table 1. Summary of the four key elements of people-centred multi-hazard EWSs

Disaster Risk Knowledge	Detection, Monitoring, and Warning Services	Communication and Dissemination Mechanisms	Preparedness and Early Response Capacity
Building the knowledge of hazards, vulnerabilities, and risk through the systematic collection of risk-related data and carrying out risk and vulnerability assessments (Basher, 2006; Sai, Cumiskey, Weerts, & Bhattacharya, 2018)	Ensuring the technical capacity for reliable monitoring, forecasting, and warning of imminent hazards. This includes continuous and automated hazard detection and monitoring, and regular system-wide improvements (Basher, 2006; Sai et al., 2018)	Issuing clear and concise warnings and early preparedness information so that target audiences can respond and prepare appropriately. Multiple communications channels are crucial to reach as many people as possible (Basher, 2006; Sai et al., 2018).	Ensuring that response plans are in place and are operational. Running education and preparedness programmes to help people "understand their risks, respect the national warning services, and know-how to react to warning messages" (WMO, 2018, p. 6).

A multi-hazard approach introduces complexity as different stakeholders need to collaborate and coordinate to exchange information and knowledge about the various hazards that pose threats to the country or region (WMO, 2018). This introduces challenges around building partnerships and ensuring sustained inter-agency collaboration (Hemingway & Gunawan, 2018). As such, the involved agencies typically must rely on technologies and information systems (IS) to support their collaborative efforts (Hemingway & Gunawan, 2018). The success of a multi-hazard EWS depends on how well-received and acted upon it is by intended audiences.

Technological advancements and the evolution of new media continues to change how society receives and interacts with warnings. Issuing warnings to target audiences relies on rigorous and reliable dissemination and delivery tools, such as mobile alerts, social media posts, door-to-door messages, telephone alerts, etc. (Wright et al., 2014).

This paper seeks to identify past research topics and themes in EWSs and steer a discourse to advance the research in this field. This systematic literature review investigates the research topics and themes from the past six years of Information Systems for Crisis Response and Management (ISCRAM) conference proceedings; with a particular focus on warnings. We use a scoping methodology for the review process and start with a broad intention to search for past research topics and themes and future directions on warning research in the field of crisis IS. Through the process of identifying themes and directions, we raise four research questions that guide our review:

- What are the technological tools (artefacts) discussed over the past six years of warning literature in ISCRAM?
- What are the thematic topics of the past six years of warnings literature in ISCRAM?
- What are the types of hazards discussed in the papers?
- What are the future research directions presented in the papers?

Findings from the 60 articles in this review will answer these questions while providing insights that can advance the research on warnings in ISCRAM literature. The paper is structured as follows. The paper starts with providing a background for EWSs and then details the methodology. The findings section answers the research questions. The discussion provides insights to move the research discourse forward. A summary concludes the paper.

BACKGROUND ON PEOPLE-CENTRED EARLY WARNING SYSTEMS

The concept of 'people-centred' EWSs refers to developing EWSs for and with the target audiences to cater to their capabilities and needs (Basher, 2006). This involves integrating indigenous knowledge, promoting and implementing low-cost EWSs that are appropriate to the audiences' needs and capabilities, and broadening information channels (UNISDR, 2015; WMO, 2018). For example, a community-based based EWS for floods in Nepal involves community members in all elements of the system, and in Bangladesh, communities indicated that they prefer to receive alerts via mobile phone (Cumiskey, Werner, Meijer, Fakhruddin, & Hassan, 2015; Smith, Brown, & Dugar, 2017). While it is important to avoid the overreliance on technology (Basher, 2006), it continues to play an emergent role in supporting people-centred multi-hazard EWSs, such as aiding in the curation of more localised, clear and contextual warning content, and offering more diverse communication channels. As such,

much research has focused on utilising technology and IS for these purposes.

Reliable and robust communication systems are critical to the success of a people-centred multi-hazard EWS. This means maintaining and adapting technological capacity and using multiple channels for communication to minimise points of failure and to maximise coverage (Wright et al., 2014). Research has proven that Twitter hashtags increase dissemination and reach for warnings (Grasso & Crisci, 2016; Sutton, Spiro, Johnson, et al., 2014). Social media also offers a channel for hazard detection and early warning for various hazards (e.g. Chatfield & Brajawidagda, 2012; Harrison & Johnson, 2016; Slavkovikj, Verstockt, Van Hoecke, & Van de Walle, 2014).

Alternative warning and alert delivery methods have emerged with the popularity of smartphones and mobile devices. Tan et al. (2017) highlighted the role of smartphone applications (i.e. apps) in improving disaster communication. In recent years, mobile alerts (also referred to as cell-broadcasting services, wireless emergency alerts, etc.) have gained international recognition for increasing the reach of warnings. Bean et al. (2015) argued the need to understand how audiences interpret and respond to these alerts to ensure full effectiveness. In response to the growing need for people-centred EWSs that provide more contextual and location-specific information, Meissen, Hardt, and Voisard (2014) developed an architecture for mobile alerts that adapts incoming alerts to the profile and situation of the user groups.

Multiple studies have capitalised on social media data to understand perceptions of risk and response to hazards and warnings to improve messaging content. For example, two independent studies that analysed the content and frequency of Twitter data indicate that the social media platform offers an opportunity for officials to tune into the perceptions and emotions of those at risk, and adjust the warnings and subsequent communications to reduce fears and anxiety and provide the information they need (Brynielsson et al., 2018; Spence, Lachlan, Lin, & del Greco, 2015). Furthermore, Twitter activity can illuminate to authorities and researchers on how people decide whether or not to take appropriate or prescribed protective actions after receiving severe weather warnings (Anderson et al., 2016; Stokes & Senkbeil, 2017). Modern technology offers new channels and platforms for audiences to engage with EWSs authorities and increase their role in EWSs (Harrison et al., In Press; Henriksen et al., 2018). Research in EWSs is backed by several theories that attempt to understand or explain human behaviour in disasters and response to warnings.

Theoretical underpinning in early warning systems

When discussing EWSs, it is important to acknowledge the theoretical frameworks behind them to maximise effectiveness. For this paper, we have identified three theories or frameworks relevant to the content of this review. The first framework is the interaction processes between authorities, citizens, and media (Andersen, 2016). The second theory is crisis and emergency risk communication, which informs message creation for various audiences throughout the different stages of an event, (Morgan, Fischhoff, Bostrom, Lave, & Atman, 1992; Veil, Reynolds, Sellnow, & Seeger, 2008). The third underpinning theoretical framework commonly referred to in EWs literature is the Protective Action Decision Model (PADM); where the goal of EWSs is to instigate audiences to take appropriate protective actions. Thus decision-making plays a key role in the performance of an EWS. Each theoretical framework will be briefly described below.

Disaster communication, including EWSs, involves the interaction processes between authorities, individuals or communities, and media (i.e. mechanisms to deliver messages, such as radio, RV, sirens, internet, mobile devices, social media, email) (Andersen, 2016). Relatively recent disaster events call the need to re-conceptualise disaster communications because of the changing dynamics between authorities, media, and individuals/communities during crises, often facilitated by technology (White & Fu, 2012; Zook, Graham, Shelton, & Gorman, 2010). For example, the pervasive use of social media has become important in disaster communications by amplifying messages and changing the dynamics of communication (e.g. from top-down to bottom-up or from one-to-many to many-to-many) (Tan et al., 2017). These changes, aided by technology and the abundance of and easy access to information, must be considered when designing and implementing an EWS.

Crisis and emergency risk communication theory and EWSs share common characteristics. Both concepts share the goal of enabling stakeholders to "make the best possible decisions about their well-being" (Reynolds & Quinn, 2008, p. 145) in times of duress and uncertainty (Harrison et al., In Press). Like people-centred EWSs, this involves understanding the stakeholders' capabilities and needs, as well as perceptions of risk and response effectiveness, and predispositions (Morgan et al., 1992; Veil et al., 2008). Much research has shown that risk and threat perceptions, and comprehension of warning messages play a significant role in stakeholders' decisions to protect themselves and heed warnings. In line with this, warning services in Australia have recognized the need for communicating additional risk information along with hazards to increase understanding of warning messages (Anderson-Berry et al., 2018).

Understanding stakeholder's perceptions of risks and threats and how they process and understand warnings and

can help in the design of more effective warnings. The Protective Action Decision Model (PADM) considers a number of these factors to help build an understanding of stakeholders' responses to warnings (Lindell & Perry, 2004). The combination of critical pre-decision processes (reception, attention, and comprehension of warnings or exposure, attention, and interpretation of environmental/social cues), core perceptions (threat perceptions, protective action perceptions, and stakeholder perceptions), and situational facilitators and impediments lead to some form of behavioural response, be it seeking further information, taking protective action, or emotion-focused coping (Lindell & Perry, 2012). Thus, when designing EWSs, it is important to not only consider the technical aspects of the system, but also the responses to and perceptions of the system from all stakeholders.

This literature review attempts to identify changes in research directions over time with regards to EWSs and identify opportunities for future research.

METHODS

The literature review used Arksey and O'Malley's (2005) scoping review process to identify past research topics and themes and future directions in EWSs research within the IS field. The aim was to identify gaps and opportunities to strengthen IS for EWSs. This scoping review followed a five-step process: 1) Identify research questions (see Introduction), 2) Identify relevant studies, 3) Select studies, 4) Chart the data, 5) Report the results.

We selected the ISCRAM database as a relevant source to conduct our literature search. The ISCRAM association, as a community of researchers and practitioners, established the research area of computer-mediated communications systems for crisis management. It publishes proceedings from its international and regional conferences annually. The conferences provide platforms for knowledge exchange on emerging technologies and IS for crisis management. Given this, the ISCRAM database provides a promising start for scoping the emerging research themes and technologies for EWSs. The initial literature search included all ISCRAM papers from 2014 to 2019, which was a total of 766 manuscripts. The last six years of ISCRAM literature were chosen for the time period as the paper is focused on identifying emerging technology, which is considered to be technology that is "currently developing or will be developed over the next five to ten years, and which will substantially alter the business and social environment" according to the Business Dictionary (See emerging technologies. (n.d.)).

We used a keyword search to narrow down the selection to 161 manuscripts. We were interested in identifying emerging technologies and theories for improving both the distribution of warnings and the reception of and response towards warnings. This guided our selection of keywords for our initial filtering of the abstracts. A total of 161 manuscripts contained the following keywords: Warn* (warnings, warning), Alert, Broadcast, Notif* (notification/s, notify), Alarm, Siren, Watch* (watch, watches), Signal, Notice* (notices, notice), Distribut* (Distribution/s, distribute), Deploy, Disseminate, Notification, Perce* (Perception, perceive).

The next two stages of the paper selection were based on the abstracts, then the contents of the papers. A fundamental understanding of the four key elements of EWSs guided the selection of inclusion/exclusion criteria. The authors employed an interpretivist approach to guide the thematic analysis of the papers. This is because our interpretation of the results was based on our research interests and experience in EWSs and IS; interpretive researchers "assert their beliefs when they choose what to research, how to research, and how to interpret their data" (paraphrased from Edge & Richards, 1998; Scotland, 2012, p. 12). Our selection criteria focussed on the last two elements of EWSs: Dissemination and Communication, and Preparedness and Response Capabilities.

For the abstract selection, the primary and secondary investigators read the 161 abstracts and marked which papers to read for further analysis. Both researchers compared their decisions. Where decisions were not the same, we discussed the points for inclusion or exclusion until a decision was made. Sixty-six papers were included to be read and analysed. The last stage of selection was based on the content of the articles. The primary and secondary investigators read the 66 papers and discussed further which ones to include that matched the scope of the literature review. Six papers were deemed out of the scope of this study and excluded from the study, resulting in a total of 60 papers included in this review.

Table 2. Summary of literature search results

	2014	2015	2016	2017	2018	2019	Total
Database	116	147	110	95	159	139	766
Keywords search	23	31	29	14	39	25	161
Abstract review	16	13	9	5	13	10	66
Paper included	16	11	8	4	12	9	60

RESULTS

This section presents results from the 60 articles included in this review. It shows observations of past themes and topics, and future directions of warnings research in ISCRAM. First, we provide a summary of the articles guided by the theoretical disaster communication framework from Andersen (2016), to identify the interaction processes between authorities, citizens and the technology media of the papers. Then the research questions are answered. We discuss (1) the technological artefacts and (2) the topical themes of the past six years. We then look into (3) the hazards included in the papers. Finally, we present (4) the future research outlook raised in the articles. We note that the analysis and interpretation of the results of this study is limited to these 60 papers and cannot make claims regarding the broader literature outside of the ISCRAM conference literature.

Summary of papers: Interaction processes

Disaster communication involves interaction processes between authorities, citizens and technology media (Andersen, 2016). Figure 1 summarises the articles' foci, whether the articles focused on the technologies, the authorities, the public, or the intersections between these three.

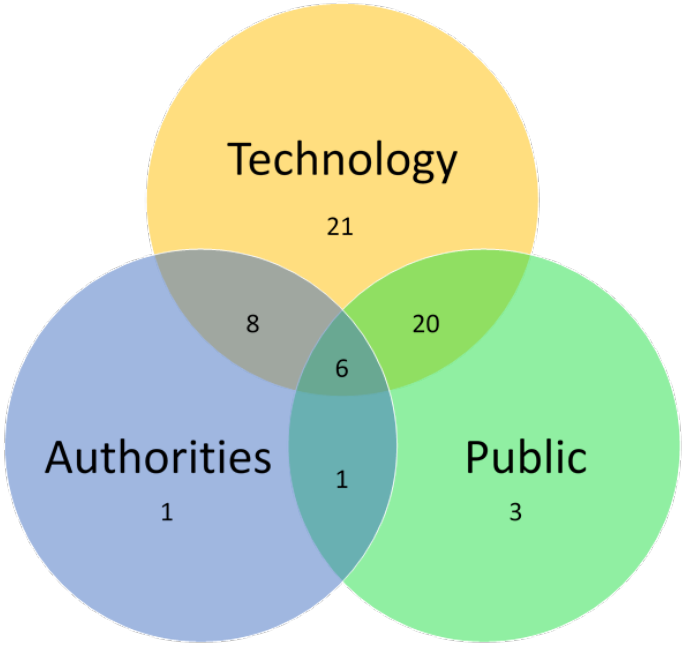

Figure 1. Summary of articles, grouped according to technology, public, authorities, and intersections

The majority of the papers (n=55) revolve around technological artefact(s) and how these interact with the public or authorities. Twenty-one papers focused on technology, looking to improve tools and systems without delving into their interaction with stakeholders. Examples of technology-centric topics include sentiment analysis algorithms to improve awareness (Sha, Yan, & Cai, 2014), big data analysis for floods (Stange, Steenhoek, Bothe, & Schnitzler, 2015), architectural principles to integrate crowdsourcing (Meissen & Fuchs-Kittowski, 2014), and others. Alternatively, twenty papers looked into how the public interacts with warning technology. Examples of technology-public focussed papers include the public's use and perceptions of different tools, such as social media and apps (Stephens, Ford, Barrett, & Mahometa, 2014; Tan et al., 2019). Eight papers investigated how authorities interact with technologies. Examples of technology-authorities papers include prototyping with authorities to capture needs (Hughes, 2014) or to get feedback on systems (Al-akkad, Raffelsberger, Boden, Ramirez, & Zimmermann, 2014). Six articles look into the interaction between the technologies, the authorities, and the public. Technology-public-authorities focussed papers often looked holistically at the multiple stakeholders involved to make effective systems (e.g. Otaka, Uchida, & Utsu, 2018; Sasaki et al., 2019).

Five articles did not focus on technology but instead investigated the public and the authorities. One authority-centric paper looked into the processes involved within an agency to make decisions (Horita, de Albuquerque, Marchezini, & Mendiondo, 2016). Three public-centric articles looked into how members of the public perceived risks (Anderson et al., 2016; Kox, 2015; Yiwei Li, Guo, & Ito, 2014). The only authority-public focussed article looked into the authorities' perception of how the public behaves during crises; showing some discrepancy between the myths that authorities believe versus reality (Schulze, Lorenz, Wenzel, & Voss, 2015). These five papers, although not technologically focussed, also provide insights into improving warning systems through

understanding the stakeholders involved. Notably, these public and authority centric papers were published in the first three years of this review and none in the latter three years. Table 3 shows the focus of the articles over the years for the 60 ISCRAM papers.

Table 3. Cross-tabulation of number of articles through the years and by article focus

	2014	2015	2016	2017	2018	2019	Total
Authorities			1				1
Public	1	1	1				3
Technology	5	5	2	1	4	4	21
Public-authorities		1					1
Technology-authorities	3	1	1	2	1		8
Technology-public	7	2	1	1	5	4	20
Technology-public-authorities		1	2		2	1	6
Total	16	11	8	4	12	9	60

All years had technology and technology-public focussed papers. Technology-authorities focussed papers also exist in most years. However, these were most prominent in 2014 and none in 2019. The 60 papers included in this review looked into various artefacts, raised different thematic topics, investigated them in varying hazard contexts, and provided suggestions for future research. We structure our interpretation of these papers on our initial research question, as follows.

Technological Artefacts

The first question: *what are the technological artefacts of the past six years of warning literature in ISCRAM?* In the past six years of warnings literature in ISCRAM, social media is the most investigated artefact (Table 4). Aside from social media, the papers from earlier years investigated different media types, such as mass media and other traditional channels (Baker, Samonas, & Artello, 2015; Stephens et al., 2014). Alternatively, papers from later years looked into alert dissemination through personal artefacts such as mobile phones and apps (e.g. Bopp, Douvinet, & Serre, 2019).

Table 4. Technological artefacts related to warnings discussed in the past 6 years of ISCRAM literature

	2014	2015	2016	2017	2018	2019	Total
Social media	5		1	2	4	1	13
Community-centred systems	3	1	1		1	1	7
Models (Forecasting/Statistical)		1	1	2	1		5
Apps					2	2	4
Different media types	3	1					4
Systems integrating multiple data sources	1	1			1	1	4
Decision support		1	1		1		3
Assessment tool for early warning systems	1	1					2
Cell broadcast					2		2
Guidelines/Protocols		1	1				2
IoT						2	2
Serious games		1				1	2
5G						1	1
Indicator for public perception on EWS			1				1
GIS-based model		1					1
Offline networks	1						1
Systems: personalised alert	1						1

Seven of the papers looked particularly into systems that support the community. Earlier literature looked at systems integrating crowdsourcing into EWSs to involve broad communities (Meissen & Fuchs-Kittowski, 2014; Tapia, LaLone, MacDonald, Priedhorsky, & Hall, 2014). In recent years, the papers look into creating multi-stakeholder systems that support local communities such as the elderly and the disabled (Otaka et al., 2018; Sasaki et al., 2019). Two papers investigated serious games as artefacts and their roles in improving communication and community resilience (van den Homberg, Cumiskey, Oprins, Suarez, & Hulst, 2015).

Five papers looked into the feasibility of technical models to improve warning systems. For example, modelling peoples' behaviour in crises (Arru & Negre, 2017) and modelling air quality index data for pre-warning systems (Adam & Andonoff, 2019; Huang, Chen, Wang, & Yuan, 2015; Zhai & Chen, 2017). Recent papers have also tapped into newer technological developments such as Internet-of-Things (IoT) (Arbib, Arcelli, Dugdale, Moghaddam, & Muccini, 2019; Moreira & Sinderen, 2019) and 5G (Lambert, Fontaine, & Monneret, 2019).

Thematic Observations

The second question: *what are thematic topics of the past six years of warning literature in ISCRAM?* Table 5 details the topics the literature has tackled over the past six years. Risk perception and credibility of information were topics of interest during the earlier years. For example, Kox's (2015) research on the public's risk perception showed that the public's fear of the hazard, coupled with their confidence in the information leads the public to take protective action. Endsley et al. (2014) investigated social ties and sources of information as factors affecting the credibility perception of crisis information. In more recent years, studies investigated how individual citizens use technologies, such as social media and apps during crises (Spielhofer, Hahne, Reuter, Kaufhold, & Schmid, 2019). Research from Kremer (2018) and Tan et al. (2019) investigated interface design of personal systems to improve the delivery of critical information to the public.

Table 5. Thematic topics discussed in the past 6 years

Topics through the years

	Topics	2014	2015	2016	2017	2018	2019
1	Understanding population behaviour and risk perceptions	■	■	■			■
2	Technology, misinformation and credibility of information	■	■			■	
3	Economic modelling of warning systems	■	■				
4	Integrating human factors and perception indicators into systems		■	■	■		
5	Inclusiveness and addressing digital divide in warnings systems			■		■	■
6	Frameworks and recommendations on social media crisis communications				■	■	
7	Understanding practitioners' perceptions on technology	■			■	■	
8	Understanding the publics' perceptions on technology						■
9	Design, user interface, user experience of apps					■	■

Hazard Types

The third question: *what are the types of hazards discussed in the papers?* Forty percent (24 out of 60) of the papers had a multi-hazard or generic context (See Figure 2). The discussions of these 24 papers are not limited to a particular hazard, and the artefact or concept of the article can apply in different or multiple hazard contexts. For example, Moreira and Sinderen (2019), without focussing on a particular hazard context, offered a conceptual architecture for the development of interoperable IoT-supported EWSs. For hazards-specific related papers, high-impact weather (n=25) are the most commonly discussed. Twelve papers were in the context of meteorological hazards (e.g. cyclones/typhoons, tornado), nine papers for hydrological hazards (e.g. floods), and four papers on climatological hazards (e.g. extreme heat, bushfire). Eleven percent of the papers are on human-driven events (e.g. bombings, gun violence). Three papers looked specifically into geophysical hazards (e.g.

earthquakes/landslides), and only one paper investigated biological hazards (e.g. Ebola).

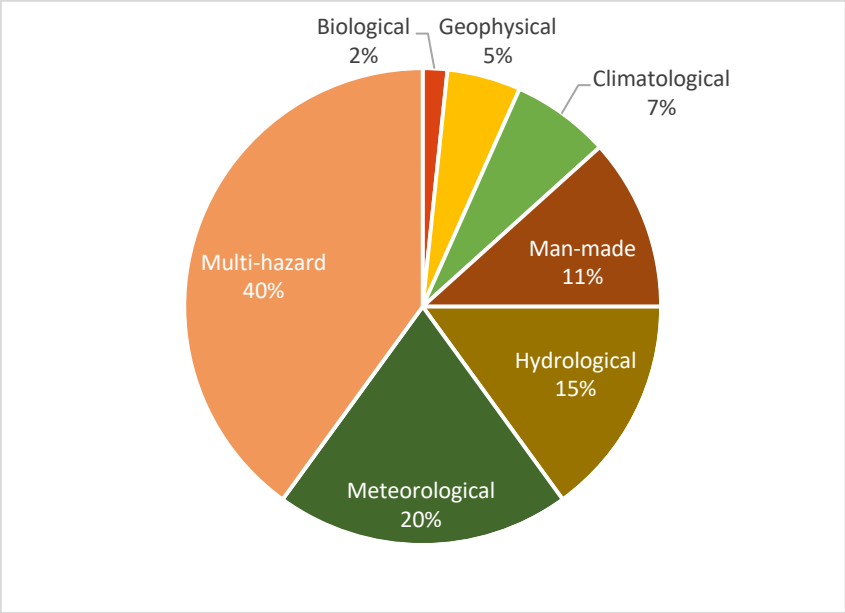

Figure 2. Pie-chart on hazard contexts of the articles

The proportions of the type of hazard contexts discussed in the papers differ per year. Figure 3 indicates a potential increase from single-hazard to multi-hazard approaches, acknowledging that due to the small sample size we would need to confirm this with reanalysis in the future (e.g. 2021).

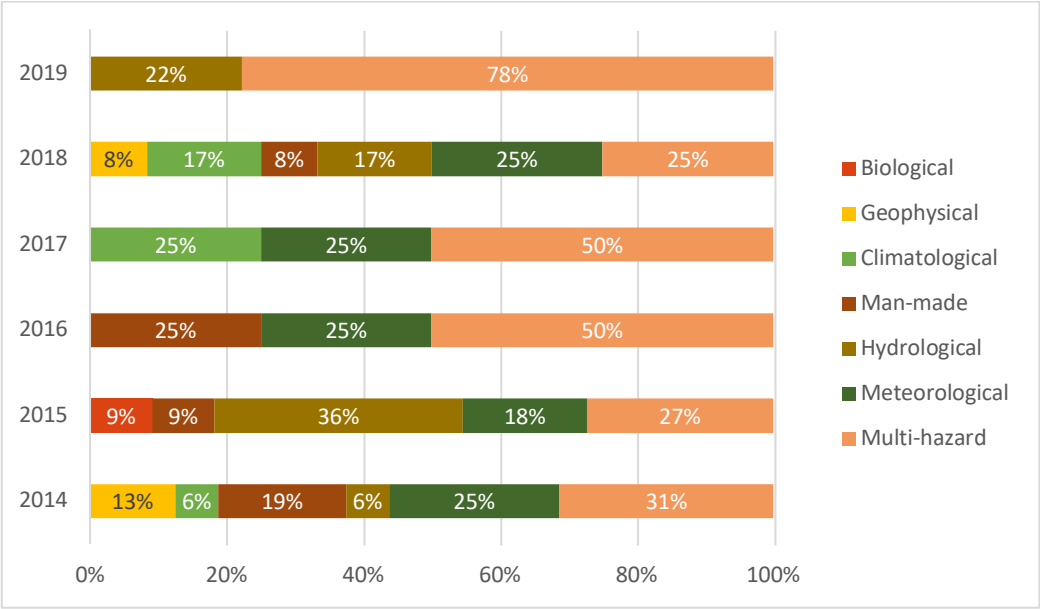

Figure 3. Stacked bar on articles and hazards contexts through the years

Future Research Directions

The final question: *what are the future research directions presented in the papers?* The future directions can be categorised into three main themes: technical research, social research, and strategic practice.

Technical research directions

The literature calls for awareness and adaptability to new technologies and industry trends. Thirty-five of the 60 articles provided suggestions for future technical research. Thirteen papers particularly mentioned new technologies that may affect warning systems. In 2019, the papers highlighted the potential benefits and challenges with IoT, 5G, artificial intelligence, and cloud-based digital systems (Lambert et al., 2019; Lorini et al., 2019).

Technological artefacts worth investigating include wearable technology (Vaghela & Shih, 2018) and apps with calm technology (See Kremer, 2018).

Changes in technology have brought about numerous data sources and increasing data availability. Research efforts need to investigate how these can be managed (Hughes, 2014; Stange et al., 2015). Machine learning was suggested as a method worth exploring that can reduce manual data management (Stange et al., 2015). Research should also further investigate the topic of data integration (Gray, Weal, & Martin, 2017; Musaev, Wang, & Pu, 2014). Decision models, ontologies, and decision rules can also be developed in future research to improve decision making (Arbib et al., 2019; Arru & Negre, 2017; Horita et al., 2016). Other technical topics to explore include the use of transportation modelling for evacuation decisions (van den Homberg et al., 2015) and crowd-sensing to improve decision making (Horita et al., 2018),

Social research directions

Twenty-seven of the 60 papers highlighted future research directions related to social or behavioural aspects of EWSs. The ISCRAM literature calls for more research on engagement and participation of communities to improve effectiveness of warning systems. For example, Chang and Chen (2018) demonstrated the success of a cell broadcast system in Taiwan and suggested next steps to look into how the public responds to those messages. Further studies are also needed on persuasive messaging to prompt the public to take protective action (Comes, Mayag, & Negre, 2015; Yajie Li, Hughes, & Howe, 2018). Future research should also look into the role of the public as end-users to aid in improving credibility and trust (Endsley et al., 2014; Hughes, 2014) and in the design of technologies (Kremer, 2018; Sasaki et al., 2019).

Furthermore, Schulze et al. (2015) argued moving away from a general approach to warnings towards a more differentiated approach. Future research on EWSs should acknowledge the diversity of cultures and languages in populations (Lorini et al., 2019; Schulze et al., 2015). Moreover, the research body should recognise that as technology advances so does the digital divide (Stephens et al., 2014). Inclusivity is a direction for future research. Studies should look into the needs and constraints of digitally disadvantaged groups such as the elderly and disabled (Anderson et al., 2016; Otaka et al., 2018). Further research could investigate how decision systems can account for the capabilities of their constituent communities (Horita et al., 2016). Although much of the literature highlights the positive benefits of technology, negative considerations should also be recognised. Technology can be used to detect social crisis but misuse of technology can lead to unfair control of the public (Sha et al., 2014). Future research on EWSs should look into ethical, legal, and social issues.

Research directions for strategic practice

Aside from technical and social research directions, some papers (19 of 60) encouraged further research on strategic and organisational aspects of EWSs. For example, organisational research can aid resource management (Comunello & Mulargia, 2017). More studies on pre-planning strategies could also provide insights for decision-makers (Hughes, 2014; Sutton, Spiro, Fitzhugh, et al., 2014). Research and application of systems should not approach warnings as a binary problem of issuing or not issuing an alert, rather context and mitigation measures should be considered (Comes et al., 2015). Suggested areas for future research include developing a lexicon of appropriate words and phrases for warnings and advisory messages (Blanford et al., 2014), engaging the public before events, and understanding the potentiality of utilising serious games to establish trust between stakeholders (Adam & Andonoff, 2019).

DISCUSSION AND CONCLUSION

The findings from the review of the 60 documents address the research questions, and provide insights into past research themes and topics, and suggestions for future research. We next consolidate some of the key points from the findings to identify further questions for EWS research in ISCRAM.

The results and subsequent analysis and interpretation have several limitations that must be acknowledged. Due to the small sample size of 60 papers and limited time scale of 6 years, the interpretation of results is limited to thematic and topical analysis and discussion; no statistical conclusions in terms of trends and significance can be drawn from these results. Future research may expand the time period for wider coverage and more in-depth analysis. Furthermore, the research gaps identified are based on the ISCRAM proceedings literature and may be broader or have different prioritization if a wider disciplinary body of literature was explored. This will be considered in the future. A focal point of this paper is to determine to what extent research around interactions with and between the groups and their use of technology is present in ISCRAM conference proceedings to highlight potential gaps in socio-technical perspectives for effective and fair use of technology.

Ethical and Privacy Implications when using Social Media or Crowdsourcing Data

Much of the past research has focused on new IS technologies for EWSs, such as developing new systems infrastructure or testing the performance or validity of a new system or data source. In comparison, less consideration has been given to risks of implementing the new technologies, which are gaining attention from users and audiences. For example, while the benefits of social media data have been proven in countless studies for disaster communication, using social media in this way introduces concerns around the ethics of such use, and raises questions about protecting users' privacy (Fulton & Kibby, 2017; Harrison & Johnson, 2019). In response, governing bodies and social media platforms have introduced measures to protect users' privacy that may impede how social media data can be used. In 2018, the European Union implemented the General Data Protection Regulation, which has potential to reduce publicly available user data (Reuter, Backfried, Kaufhold, & Spahr, 2018). In 2019, Twitter announced plans to disable the geolocation feature for Tweets (except for photos taken from within the app), to protect users' privacy (Khalid, 2019). These changes in social media data access indicate growing uncertainty in the reliability of this data source (Harrison et al., In Press). When using crowdsourcing, crowd monitoring, data mining or any other techniques and technologies to capture publicly-produced data it is critical to consider the ethical and privacy implications (e.g. Chan, Liang, & Vasconcelos, 2008; Yang, Zhang, Ren, & Shen, 2015) and evaluate whether the data, technique, or technology appropriately suits the mission of the organisation or project.

Adaption to Technological Developments

The ISCRAM literature for the past six years has focussed heavily on social media as the artefact of interest. This is expected given the increasing presence of social media in our networked world. The ISCRAM body has produced research that has kept pace with the progression of social media. However, the research may not be fast or thorough enough to respond to developing trends. For example, in 2014, Sutton, Spiro, Fitzhugh, et al. suggested investigating Twitter Alerts, a new feature at the time, to help users get accurate, official information (Peña, 2013; Twitter, n.d.). Since then, however, no further research on Twitter Alerts has been published in ISCRAM. In September 2019, Twitter discontinued this service with no specified reasons (See Twitter, 2019). The lack of research on this feature, its successes, and failures, may have been a missed opportunity to advance the use of social media as a credible platform for warnings. Research in this space could have guided future developments of alerting services for other platforms, as Facebook plans to launch a similar service in 2019 (Samenow, 2019). Aside from social media trends, research should also keep pace with other technological developments (e.g. IoT, 5G, etc.). Simultaneously, research should also be aware of the risk of overlooking non-technical populations.

Early Warning Systems for everyone

Moving from broad research on understanding the general public as a homogenous whole, recent research has emphasised that the public consists of diverse groups. Different demographics can respond to warnings variedly. Spielhofer et al. (2019) highlighted that social media is used the least by older and socio-economically disadvantaged citizens. The digital divide, a product of demographics, socioeconomic status, and physical location (e.g. urban vs rural internet access), has introduced problems for online engagement and information dissemination (Harrison & Johnson, 2019). It is of particular concern for EWSs as technology advances and systems moving online. Authorities and researchers must continue to innovate and ensure that those under-represented in the digital world are given a voice and do not miss critical, life-saving information (Anderson et al., 2016), as two recent papers from this review have done (e.g. Otaka et al., 2018; Sasaki et al., 2019). Furthermore, the multicultural values of modern societies introduce unique challenges of language barriers for official communications (Harrison & Johnson, 2019). It is imperative to ensure that communications reach all diverse groups within society in ways they can understand and engage (Chen, 2018). Existing guidance on communicating for diversity should be explored (e.g. Community Comms Collective, 2019).

Challenges for the Multi-Hazard Early Warning System

Disasters can worsen when multiple hazards cascade or interact. The Sendai Framework and other sources argue for a multi-hazard approach to improve warning efficiency (UNISDR, 2015). The results of this review show indications of a potential trend that aligns with this objective, however confirmation from future research is required. It is worth highlighting the WMO's Multi-Hazard EWS checklist (see WMO, 2018) as an international benchmark for agencies and counties on designing and implementing multi-hazard EWS. Implementing multi-hazard EWSs, however, may be easier said than done; as this substantial undertaking requires cooperation and coordination across various stakeholders (Hemingway & Gunawan, 2018; WMO, 2018). Before countries choose to transition their existing systems, it may be worth assessing their existing single-hazard EWSs, determining if

there is a viable need for a multi-hazard EWS, identifying all potential risks and barriers to this undertaking, and ensuring that a plan is in place for the sustainability of the program (Hemingway & Gunawan, 2018). After the transition, authorities should continue to evaluate and improve the system based on audience needs and capabilities, and technological advancements (Basher, 2006; WMO, 2018).

The paper has highlighted that there are socio-technical considerations to using and advancing EWSs. While technology has advanced EWSs to new levels, it is important to consider the influence of technology on people's perceptions of and response to EWSs. This systematic literature review investigated the research themes and topics from the past six years of ISCRAM conference proceedings to identify the research developments and directions for EWSs from an IS perspective and to steer a discourse advancing this field of research.

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REFERENCES

Adam, C., & Andonoff, E. (2019). VigiFlood: a serious game for understanding the challenges of risk communication. In *Proceedings of the 16th ISCRAM Conference* (pp. 338–351). Valencia.

Al-akkad, A., Raffelsberger, C., Boden, A., Ramirez, L., & Zimmermann, A. (2014). Tweeting 'When Online is Off'? Opportunistically Creating Mobile Ad-hoc Networks in Response to Disrupted Infrastructure. In *Proceedings of the 11th ISCRAM Conference* (pp. 662–671). Kristiansand.

Andersen, N. B. (2016). Analysing communication processes in the disaster cycle: Theoretical complementarities and tensions. In M. T. Vendelø, O. Rubin, & R. Dahlberg (Eds.), *Disaster research: Multidisciplinary and international perspectives* (pp. 126–139). London: Routledge.

Anderson, J., Kogan, M., Bica, M., Palen, L., Anderson, K. M., Stowe, K., … Henderson, J. (2016). Far Far Away in Far Rockaway: Responses to Risks and Impacts during Hurricane Sandy through First-Person Social Media Narratives. In *Proceedings of the 13th ISCRAM Conference*. Rio de Janeiro.

Arbib, C., Arcelli, D., Dugdale, J., Moghaddam, M. T., & Muccini, H. (2019). Real-time Emergency Response through Performant IoT Architectures. In *Proceedings of the 16th ISCRAM Conference* (pp. 388–401). Valencia.

Arksey, H., & O'Malley, L. (2005). Scoping studies: towards a methodological framework. *International Journal of Social Research Methodology*, *8*(1), 19–32. https://doi.org/10.1080/1364557032000119616

Arru, M., & Negre, E. (2017). People behaviors in crisis situations: Three modeling propositions. In *Proceedings of the 14th ISCRAM Conference* (pp. 139–149). Albi.

Baker, N. D., Samonas, S., & Artello, K. (2015). (Not) Welcome to the US: Hyper-ebola and the crisis of misinformation. In *Proceedings of the 12th ISCRAM Conference*. Kristiansand.

Basher, R. (2006). Global early warning systems for natural hazards: systematic and people-centred. *Philosophical Transactions of the Royal Society*, *364*, 2167–2182. https://doi.org/10.1098/rsta.2006.1819

Bean, H., Sutton, J., Liu, B. F., Madden, S., Wood, M. M., & Mileti, D. S. (2015). The study of mobile public warning messages: A research review and agenda. *Review of Communication*, *15*(1), 60–80. https://doi.org/10.1080/15358593.2015.1014402

Blanford, J. I., Bernhardt, J., Savelyev, A., Wong-Parodi, G., Carleton, A. M., Titley, D. W., & MacEachren, A. M. (2014). Tweeting and Tornadoes. In *Proceedings of the 11th ISCRAM Conference* (pp. 319–323). Pennsylvania.

Bopp, E., Douvinet, J., & Serre, D. (2019). Sorting the good from the bad smartphone applications to alert residents facing disasters – Experiments in France. In *Proceedings of the 16th ISCRAM Conference* (pp. 435–449). Valencia.

Brynielsson, J., Granåsen, M., Lindquist, S., Narganes Quijano, M., Nilsson, S., & Trnka, J. (2018). Informing crisis alerts using social media: Best practices and proof of concept. *Journal of Contingencies and Crisis Management*, *26*, 28–40. https://doi.org/10.1111/1468-5973.12195

Chan, A. B., Liang, Z. S. J., & Vasconcelos, N. (2008). Privacy preserving crowd monitoring: Counting people

without people models or tracking. *26th IEEE Conference on Computer Vision and Pattern Recognition, CVPR*, (June). https://doi.org/10.1109/CVPR.2008.4587569

Chang, T.-Y., Wu, S.-Y., & Chen, J.-Y. (2018). Mobile communication technology and cell broadcast service for emergency alerts in Taiwan. In *Proceedings of ISCRAM Asia Pacific 2018*. Wellington.

Chatfield, A. T., & Brajawidagda, U. (2012). Twitter tsunami early warning network: a social network analysis of Twitter information flows. In *23rd Australasian Conference on Information Systems* (pp. 1–10). Geelong.

Comes, T., Mayag, B., & Negre, E. (2015). Beyond early: Decision support for improved typhoon warning systems. In *Proceedings of the 12th ISCRAM Conference*. Kristiansand.

Community Comms Collective. (2019). Communicating for diversity.

Comunello, F., & Mulargia, S. (2017). A #cultural_change is needed. Social media use in emergency communication by Italian local level institutions. In *Proceedings of the 14th ISCRAM Conference* (pp. 512–521). Albi.

Cumiskey, L., Werner, M., Meijer, K., Fakhruddin, S. H. M., & Hassan, A. (2015). Improving the social performance of flash flood early warnings using mobile services. *International Journal of Disaster Resilience in the Built Environment*, *6*(1), 57–72. Retrieved from https://doi.org/10.1108/IJDRBE-08-2014-0062

Edge, J., & Richards, K. (1998). May I see your warrant, please?: Justifying outcomes in qualitative research. *Applied Linguistics*, *19*(3), 334–356. https://doi.org/10.1093/applin/19.3.334

emerging technologies. (n.d.). Retrieved January 31, 2020, from BusinessDictionary website: http://www.businessdictionary.com/definition/emerging-technologies.html

Endsley, T., Wu, Y., & Reep, J. (2014). The source of the story: Evaluating the credibility of crisis information sources. In *Proceedings of the 11th ISCRAM Conference* (pp. 158–162). Pennsylvania.

Fulton, J. M., & Kibby, M. D. (2017). Millennials and the normalization of surveillance on Facebook. *Continuum*, *31*(2), 189–199. https://doi.org/10.1080/10304312.2016.1265094

Grace, E. S., & Saunders, W. S. A. (2016). *Good practice case studies of regional policy statements, district plans, and proposed plans* (No. 2015/03). Lower Hutt.

Grasso, V., & Crisci, A. (2016). Codified hashtags for weather warning on twitter: An Italian case study. *PLoS Currents*, *8*(Disasters), 1–30. https://doi.org/10.1371/currents.dis.967e71514ecb92402eca3bdc9b789529

Gray, B., Weal, M. J., & Martin, D. (2017). Social Media during a Sustained Period of Crisis: The Case of the UK Storms. In *Proceedings of the 14th ISCRAM Conference* (pp. 633–644). Albi.

Harrison, S., & Johnson, P. A. (2016). Crowdsourcing the Disaster Management Cycle. *International Journal of Information Systems for Crisis Response and Management*, *8*(4), 17–40. https://doi.org/10.4018/IJISCRAM.2016100102

Harrison, S., & Johnson, P. A. (2019). Challenges in the adoption of crisis crowdsourcing and social media in Canadian emergency management. *Government Information Quarterly*, *36*, 501–509. https://doi.org/10.1016/J.GIQ.2019.04.002

Harrison, S., Potter, S., Prasanna, R., Doyle, E.E.H. (In Press). Volunteered Geographic Information for People-Centred Severe Weather Early Warning: A Systematic Review. *Australasian Journal of Disaster and Trauma Studies*.

Hemingway, R., & Gunawan, O. (2018). The Natural Hazards Partnership: A public-sector collaboration across the UK for natural hazard disaster risk reduction. *International Journal of Disaster Risk Reduction*, 499–511. https://doi.org/10.1016/j.ijdrr.2017.11.014

Henriksen, H. J., Roberts, M. J., van der Keur, P., Harjanne, A., Egilson, D., & Alfonso, L. (2018). Participatory early warning and monitoring systems: A Nordic framework for web-based flood risk management. *International Journal of Disaster Risk Reduction*, (March 2017), 1–12. https://doi.org/10.1016/j.ijdrr.2018.01.038

Horita, F. E. A., de Albuquerque, J. P., Marchezini, V., & Mendiondo, E. M. (2016). A qualitative analysis of the early warning decision-making process in disaster management. In *Proceedings of the 13th ISCRAM Conference* (pp. 1–8). Rio de Janeiro.

Horita, F. E. A., Vilela, R. B., Martins, R. G., Bressiani, D. A., Palma, G., & de Albuquerque, J. P. (2018). Determining flooded areas using crowd sensing data and weather radar precipitation: A case study in Brazil.

In *Proceedings of the 15th ISCRAM Conference* (pp. 1030–1039). Rochester.

Huang, L., Chen, T., Wang, Y., & Yuan, H. (2015). Forecasting daily pedestrian flows in the Tiananmen Square based on historical data and weather conditions. In *Proceedings of the 12th ISCRAM Conference*. Kristiansand.

Hughes, A. L. (2014). Participatory Design for the Social Media Needs of Emergency Public Information Officers. In *Proceedings of the 11th ISCRAM Concerence*. Pennsylvania.

Khalid, A. (2019, June 19). Twitter removes precise geo-tagging option from tweets. *Engadget*.

Kox, T. (2015). Criteria affecting people's decision to take protective measures during winter storm XAVER on 5 December 2013. In *Proceedings of the 12th ISCRAM Conference*. Kristiansand.

Kremer, K. (2018). Critical human factors in UI design : How calm technology can inform anticipatory interfaces for limited situational awareness . In *Proceedings of ISCRAM Asia Pacific 2018*. Wellington.

Lambert, G., Fontaine, B., & Monneret, M. (2019). How to build an innovative C2 system supporting individual-centric emergency needs? In *Proceedings of the 16th ISCRAM Conference* (pp. 327–337). Valencia.

Li, Yajie, Hughes, A. L., & Howe, P. D. (2018). Communicating crisis with persuasion: Examining official Twitter messages on heat hazards. In *Proceedings of the 15th ISCRAM Conference* (pp. 469–479).

Li, Yiwei, Guo, Y., & Ito, N. (2014). An exploration of a social-cognitive framework for improving the human-centric risk communication. In *Proceedings of the 11th ISCRAM Conference* (pp. 394–398). Pennsylvania.

Lindell, M. K., & Perry, R. W. (2004). *Communicating Environmental Risk in Multiethnic Communities*. 2455 Teller Road, Thousand Oaks California 91320 United States : SAGE Publications, Inc. https://doi.org/10.4135/9781452229188

Lindell, M. K., & Perry, R. W. (2012). The Protective Action Decision Model: Theoretical Modifications and Additional Evidence. *Risk Analysis*, *32*(4), 616–632. https://doi.org/10.1111/j.1539-6924.2011.01647.x

Lorini, V., Castillo, C., Dottori, F., Kalas, M., Nappo, D., & Salamon, P. (2019). Integrating Social Media into a Pan-European Flood Awareness System: A Multilingual Approach. In *Proceedings of the 16th ISCRAM Conference* (pp. 646–659). Valencia.

Meissen, U., & Fuchs-Kittowski, F. (2014). Towards a reference architecture of crowdsourcing integration in early warning systems. In *Proceedings of the 11th ISCRAM Concerence* (pp. 339–343). Pennsylvania.

Meissen, U., Hardt, M., & Voisard, A. (2014). Towards a general system design for community-centered crisis and emergency warning systems. In *Proceedings of the 11th ISCRAM Conference* (pp. 155–159). Pennsylvania.

Moreira, J., & Sinderen, M. Van. (2019). SEMIoTICS : Semantic model-driven development for IoT interoperability of emergency services. In *Proceedings of the 16th ISCRAM Conference* (pp. 961–973). Valencia.

Morgan, G., Fischhoff, B., Bostrom, A., Lave, L., & Atman, C. J. (1992). Communicating Risk to the Public. *Environmental Science & Technology*, *26*(11), 2048–2056.

Musaev, A., Wang, D., & Pu, C. (2014). LITMUS: Landslide detection by integrating multiple sources. In *Proceedings of the 11th ISCRAM Conference* (pp. 677–686). Pennsylvania.

Otaka, R., Uchida, O., & Utsu, K. (2018). Prototype of notification and status monitoring system using LINE smartphone application to support local communities. In *Proceedings of ISCRAM Asia Pacific 2018*. Wellington.

Peña, G. (2013). Twitter Alerts: Critical information when you need it most. Retrieved November 14, 2019, from https://blog.twitter.com/en_us/a/2013/twitter-alerts-critical-information-when-you-need-it-most.html

Reuter, C., Backfried, G., Kaufhold, M.-A., & Spahr, F. (2018). ISCRAM turns 15: A Trend Analysis of Social Media Papers 2004-2017. In *Proceedings of the 15th ISCRAM Conference*. Rochester.

Reynolds, B., & Quinn, S. C. (2008). Effective communication during an influenza pandemic: The value of using a crisis and emergency risk communication framework. *Health Promotion Practice*, *9*(4), 13S-17S. https://doi.org/10.1177/1524839908325267

Sai, F., Cumiskey, L., Weerts, A., & Bhattacharya, B. (2018). Towards impact-based flood forecasting and warning in Bangladesh: a case study at the local level in Sirajganj district. *Natural Hazards and Earth System*

Sciences Discussions, (February), 1–22. https://doi.org/10.5194/nhess-2016-122

Samenow, J. (2019). Facebook launching local alerts to keep you safe during emergencies, including severe weather. Retrieved November 14, 2019, from https://www.washingtonpost.com/weather/2019/08/27/facebook-launching-local-alerts-keep-you-safe-during-emergencies-including-severe-weather/

Sasaki, J., Maejima, T., Li, S., Sato, Y., Hiyama, M., & Herrera-Viedma, E. (2019). Life-Area Broadcasting System (LABS) for Normal and Emergency Cases by Using Easy Contents Management System and New Speaker Devices. In *Proceedings of the 16th ISCRAM Conference* (pp. 933–939). Valencia.

Schulze, K., Lorenz, D., Wenzel, B., & Voss, M. (2015). Disaster myths and their relevance for warning systems. In *Proceedings of the 12th International ISCRAM Conference*. Kristiansand.

Scotland, J. (2012). Exploring the philosophical underpinnings of research: Relating ontology and epistemology to the methodology and methods of the scientific, interpretive, and critical research paradigms. *English Language Teaching*, *5*(9), 9–16. https://doi.org/10.5539/elt.v5n9p9

Sha, Y., Yan, J., & Cai, G. (2014). Detecting public sentiment over PM2.5 pollution hazards through analysis of Chinese microblog. In *Proceedings of the 11th ISCRAM Conference* (pp. 720–724).

Slavkovikj, V., Verstockt, S., Van Hoecke, S., & Van de Walle, R. (2014). Review of wildfire detection using social media. *Fire Safety Journal*, *68*, 109–118. https://doi.org/10.1016/J.FIRESAF.2014.05.021

Smith, P. J., Brown, S., & Dugar, S. (2017). Community-based early warning systems for flood risk mitigation in Nepal. *Nat. Hazards Earth Syst. Sci*, *17*, 423–437. https://doi.org/10.5194/nhess-17-423-2017

Spence, P. R., Lachlan, K. A., Lin, X., & del Greco, M. (2015). Variability in Twitter Content Across the Stages of a Natural Disaster: Implications for Crisis Communication. *Communication Quarterly*, *63*(2), 171–186. https://doi.org/10.1080/01463373.2015.1012219

Spielhofer, T., Hahne, A. S., Reuter, C., Kaufhold, M.-A., & Schmid, S. (2019). Social media use in emergencies of citizens in the United Kingdom. In *Proceedings of the 16th ISCRAM Conference* (pp. 620–632). Valencia.

Stange, H., Steenhoek, S., Bothe, S., & Schnitzler, F. (2015). Insight-driven crisis information – Preparing for the unexpected using big data. In *Proceedings of the 12th ISCRAM Conference*. Kristiansand.

Stephens, K. K., Ford, J., Barrett, A., & Mahometa, M. J. (2014). Alert networks of ICTs and sources in campus emergencies. In *Proceedings of the 11th ISCRAM Conference* (pp. 652–661). Pennsylvania.

Stokes, C., & Senkbeil, J. C. (2017). Facebook and Twitter, communication and shelter, and the 2011 Tuscaloosa tornado. *Disasters*, *41*(1), 194–208. https://doi.org/10.1111/disa.12192

Sutton, J., Spiro, E. S., Fitzhugh, S., Johnson, B., Gibson, B., & Butts, C. T. (2014). Terse message amplification in the Boston bombing response. In *Proceedings of the 11th ISCRAM Conference* (pp. 612–621). Pennsylvania.

Sutton, J., Spiro, E. S., Johnson, B., Fitzhugh, S., Gibson, B., & Butts, C. T. (2014). Warning tweets: serial transmission of messages during the warning phase of a disaster event. *Information, Communication & Society*, *17*(6), 765–787. https://doi.org/10.1080/1369118X.2013.862561

Tan, M. L., Prasanna, R., Stock, K., Hudson-Doyle, E., Leonard, G., & Johnston, D. (2017). Mobile applications in crisis informatics literature: A systematic review. *International Journal of Disaster Risk Reduction*, *24*, 297–311. https://doi.org/10.1016/j.ijdrr.2017.06.009

Tan, M. L., Prasanna, R., Stock, K., Hudson-Doyle, E., Leonard, G., & Johnston, D. (2019). Enhancing the usability of a disaster app : exploring the perspectives of the public as users. In *Proceedings of the 16th ISCRAM Conference* (pp. 876–886). Valencia.

Tapia, A. H., LaLone, N., MacDonald, E., Priedhorsky, R., & Hall, M. (2014). Crowdsourcing rare events: Using curiosity to draw participants into science and early warning systems. In *Proceedings of the 11th ISCRAM Conference* (pp. 135–144). Pennsylvania.

Twitter. (2019). How to use Twitter Alerts. Retrieved January 31, 2020, from https://help.twitter.com/en/managing-your-account/how-to-use-twitter-alerts

UNISDR. (2005). *Hyogo Framework for Action 2005-2015*. Kobe, Hyogo, Japan. Retrieved from https://www.unisdr.org/files/1037_hyogoframeworkforactionenglish.pdf

UNISDR. (2015). *Sendai Framework for Disaster Risk Reduction 2015-2030*. *Third World Conference on*

Disaster Risk Reduction, Sendai, Japan, 14-18 March 2015. https://doi.org/A/CONF.224/CRP.1

Vaghela, S. J. D., & Shih, P. C. (2018). WalkSafe: College campus safety app. In *Proceedings of the 15th International ISCRAM Conference* (pp. 983–993). Rochester.

van den Homberg, M., Cumiskey, L., Oprins, E., Suarez, P., & Hulst, A. van der. (2015). Are you Ready! to take early action? Embedding serious gaming into community managed DRR in Bangladesh. In *Proceedings of the 12th ISCRAM Conference*. Kristiansand.

Veil, S., Reynolds, B., Sellnow, T. L., & Seeger, M. W. (2008). CERC as a Theoretical Framework for Research and Practice. *Health Promotion Practice*, *9*(4), 26S-34S. https://doi.org/10.1177/1524839908322113

White, J. D., & Fu, K.-W. (2012). Who do you trust? Comparing people-centered communications in disaster situations in the United States and China. *Journal of Comparative Policy Analysis: Research and Practice*, *14*(2), 126–142. https://doi.org/10.1080/13876988.2012.664688

WMO. (2018). Multi-hazard Early Warning Systems: A Checklist Foreword. In *Outcome of the first Multi-hazard Early Warning Conference*. Cancun, Mexico.

Wright, K. C., Leonard, G. S., Beatson, A., O'Sullivan, R., Coomer, M. A., Morris, B., & Freire, D. (2014). *Public Alerting Options Assessment: 2014 update* (No. 2014/66). Lower Hutt.

Yang, K., Zhang, K., Ren, J., & Shen, X. S. (2015). Security and privacy in mobile crowdsourcing networks: Challenges and opportunities. *IEEE Communications Magazine*, *53*(8), 75–81. https://doi.org/10.1109/MCOM.2015.7180511

Zhai, B., & Chen, J. (2017). Research on the forecasting of air quality index (AQI) based on FS-GABPNN: A case study of Beijing, China. In *Proceedings of the 14th ISCRAM Conference* (Vol. 2017-May, pp. 307–321). Albi.

Zook, M., Graham, M., Shelton, T., & Gorman, S. (2010). Volunteered geographic information and crowdsourcing disaster relief: A case study of the Haitian earthquake. *World Medical and Health Policy*, *2*(2), 7–33. https://doi.org/10.2202/1948-4682.1069