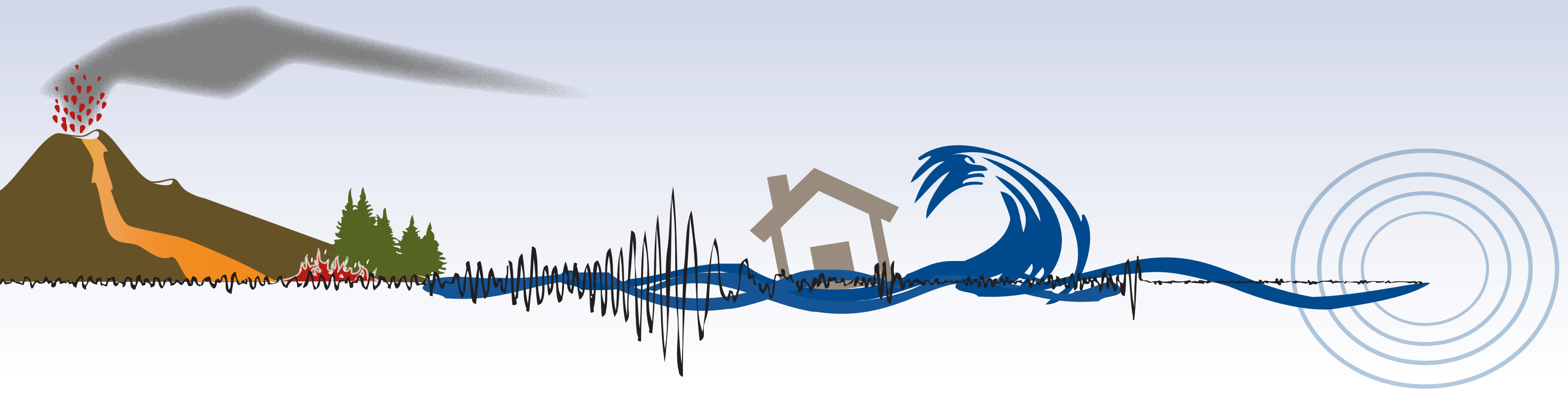
June 2020

The Australasian Journal of Disaster and Trauma Studies

VOLUME: 24, NUMBER 1



Contents: Volume 24, Number 1

Research Papers

Research Updates

ISSN: 1174-4707

Published by:
School of Psychology
Massey University
New Zealand

Volunteered Geographic Information for people-centred severe weather early warning: A literature review

Sara Harrison[1],
Sally Potter[2],
Raj Prasanna[1],
Emma E. H. Doyle[1],
David Johnston[1]

[1] Joint Centre for Disaster Research, Massey University, New Zealand.

[2] GNS Science, New Zealand.

Author correspondence:
Sara Harrison,
Joint Centre for Disaster Research,
Private Box 756,
Wellington 6140
New Zealand.
Email: S.Harrison@massey.ac.nz

URL: http://trauma.massey.ac.nz/issues/2020-1/AJDTS_24_1_Harrison.pdf

Abstract

Early warning systems (EWSs) can prevent loss of life and reduce the impacts of hazards. Yet, recent severe weather events indicate that many EWSs continue to fail at adequately communicating the risk of the hazard, resulting in significant life and property loss. Given these shortcomings, there has been a shift towards people-centred EWSs to engage with audiences of warnings to understand their needs and capabilities. One example of engaging with warning audiences is through the collection and co-creation of volunteered geographic information (VGI). Much of the research in the past has primarily focused on using VGI in disaster response, with less exploration of the role of VGI for EWSs.

This review uses a scoping methodology to identify and analyse 29 research papers on EWSs for severe weather hazards. Results show that VGI is useful in all components of an EWS, but some platforms are more useful for specific components than are others. Furthermore, the different types of VGI have implications for supporting people-centred EWSs. Future research should explore the characteristics of the VGI produced for these EWS components and determine how VGI can support a new EWS model for which the World Meteorological Organization is advocating: that of impact-based forecasting and warning systems.

Keywords: *early warning system, people-centred early warning system, volunteered geographic information, disaster risk reduction, severe weather*

Early warning systems (EWSs) can prevent loss of life and reduce the impacts of hazards by providing members of the stakeholders and the public with information about likely, imminent risks on which they can act to prepare themselves and their property. As such, they have been a focus of disaster risk reduction since the Hyogo Framework for Action 2005-2015 through to the current Sendai Framework for Disaster Risk Reduction 2015-2030 (UNISDR, 2005, 2015). EWSs are described as having four key operational components: Disaster Risk Knowledge; Detection, Monitoring, and Warning Services; Communication and Dissemination Mechanisms; and Preparedness and Response Capacity (see Figure 1; Basher, 2006; Golnaraghi, 2012).

The first component, Disaster Risk Knowledge, involves systematically collecting and analysing data related to risk, such as the exposure and vulnerability of people and infrastructure to nearby hazards (Ahmed et al., 2012; Basher, 2006; Sai, Cumiskey, Weerts, & Bhattacharya, 2018). This involves assessing risk and vulnerability, building evacuation plans, and tailoring warning systems. Detection, Monitoring, and Warning Services make up the second component and are central to EWSs. This component requires reliable technology and involves continuous, automated detection and hazard monitoring (Ahmed et al., 2012; Basher, 2006; Sai et al., 2018). Furthermore, data, forecasts, and warnings should be archived for post-event analysis and

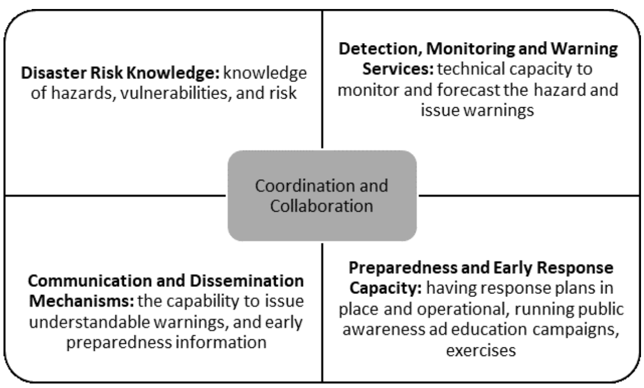


Figure 1. Four operational components of an early warning system. Adapted from Basher (2006), Golnaraghi (2012), and WMO (2018).

for continual system improvements (Ahmed et al., 2012; Basher, 2006; Sai et al., 2018). Impact data collected during and after a severe weather event would support both of these first two components (Harrison, Silver, & Doberstein, 2015).

The third component of an EWS is Communication and Dissemination, which is needed to reach those at risk. This involves using clear, concise, and understandable messages to enable proper preparedness (Ahmed et al., 2012; Basher, 2006; Sai et al., 2018). Multiple communications channels are necessary to reach as many people as possible (Ahmed et al., 2012; Basher, 2006). The fourth component of an EWS is Preparedness and Early Response Capacity. This involves 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). All four components of an EWS play a key role in crisis and risk communication.

EWSs share common characteristics with crisis and emergency risk communication theory. Like EWSs, the goal of crisis and risk communication theory is to provide sufficient and appropriate information to stakeholders that would allow them to "make the best possible decisions about their well-being" in a short period of time under uncertainty (Reynolds & Quinn, 2008, p. 14S). This involves understanding stakeholder (including the public) perceptions of risk and of the effectiveness of response, understanding the needs, capabilities, experiences, and predispositions of the stakeholders, and formulating messages based on these understandings for different audiences throughout the stages of crisis (Morgan, Fischhoff, Bostrom, Lave, & Atman, 1992; Reynolds & Seeger, 2005; Veil, Reynolds, Sellnow, & Seeger, 2008). Crisis and emergency risk communication theory is applied in risk messaging, crisis messaging, and warnings for health and emergency situations including, but not limited to, disease outbreaks, bioterrorism, hurricanes, and tornadoes (Reynolds & Seeger, 2005). The EWS framework presented in Figure 1 is thus supported by objectives of crisis and emergency risk communication theory, although the EWS framework does not include an apparent consideration for two-way communication: a key component in crisis and emergency risk communication theory for evaluating the effectiveness of communication (Garcia & Fearnley, 2012; Veil et al., 2008).

Recent severe weather events indicate that many EWSs continue to fail at adequately communicating the risk (and associated impacts) of the hazard, resulting in significant life and property loss due to limited understanding of, and response to, warnings (Ching, Carr de los Reyes, Sucaldito, & Tayag, 2015; Fleming et al., 2015; Wagenmaker et al., 2011). As such, there has been a push for "people-centred" EWSs to bring the "human factor" into consideration when designing and implementing EWSs and issuing warnings.

People-Centred Early Warning Systems

The broader EWS literature has recognised a communication gap between warning services and warning recipients, resulting in target audiences taking inadequate protective action despite receiving warnings (Anderson-Berry et al., 2018; Basher, 2006; Weyrich, Scolobig, Bresch, & Patt, 2018). In 2006, Basher introduced the concept of people-centred EWSs to address the "human factor" in EWSs, as he stated "failures in Early Warning Systems typically occur in the communication and preparedness elements" (Basher, 2006, p. 2168). Since then, there has been a shift towards people-centred EWSs which are developed for, and with, the target audiences to identify their needs and capacities and to transfer responsibility back to the audience to take protective actions (Basher, 2006; Scolobig, Prior, Schröter, Jörin, & Patt, 2015).

The United Nations Office for Disaster Risk Reduction (UNDRR; formerly known as the UNISDR) listed "investing in, developing, maintaining and strengthening people-centred multi-hazard, multi-sectoral forecasting, and Early Warning Systems" as an objective towards meeting the fourth priority of the Sendai Framework (UNISDR, 2015, p. 21). This "people-centred" aspect involves incorporating local and indigenous knowledge about hazards, promoting and applying low-cost EWSs that are appropriate to the audience based on their needs and capabilities, and broadening information channels (UNISDR, 2015; WMO, 2018). According to the Sendai Framework, people-centred EWSs can be developed through engagement with the audiences of warnings (e.g., individuals, communities, sectors: UNISDR, 2015; WMO, 2018).

One such example of engaging with warning audiences and understanding their needs and capabilities is through volunteered geographic information (VGI; WMO, 2017). VGI is information produced by or gathered from the public with associated locational attributes. The location-based information from VGI allows officials to identify high-risk areas, populations, and infrastructure

(Goodchild & Glennon, 2010; Granell & Ostermann, 2016; Haworth, 2018; Roche, Propeck-Zimmermann, & Mericskay, 2011).

Volunteered Geographic Information

VGI is valuable to disaster management because disasters are inherently location- and time-dependent and the location information from VGI allows officials to understand where the high-risk areas and populations are (Goodchild, 2007; Goodchild & Glennon, 2010; Granell & Ostermann, 2016; Haworth, 2018; Roche et al., 2011). The broader literature body around VGI, crowdsourcing, citizen science, and social media discusses and debates the relationship of these terms to each other and their associated characteristics and differences. It is argued that VGI overlaps both with citizen science and crowdsourcing (Cooper, Coetzee, & Kourie, 2018; Haklay, 2013, 2017). In Haklay's (2013) typology, crowdsourcing is classified as the lowest level of participation in citizen science. Citizen science (including crowdsourcing) is considered VGI when the information produced through the differing levels of participation includes geographic information (Haklay, 2017).

VGI can be collected in various ways, producing different types and formats of data. From reviewing the VGI and disaster risk reduction literature, we identified four types of VGI that are generally produced and/or collected for disaster risk reduction; these are summarised in Table 1. Geo-located social media refers to VGI that is posted online by social media users that has associated geographical location information. The term social media recognises online blogs, micro-blogs, online social networking, and forums, which enable sharing of text, audio, photographs, and videos (Alexander, 2014). Facebook, Twitter, Sina Weibo, WeChat, Instagram, and SnapChat are some examples of popular social media platforms. During a severe weather event, authorities can use social media to disseminate alerts and warnings and collect information from members of the public about the event and its impacts (Alexander, 2014; de Albuquerque et al., 2017; Goodchild, 2007; Harrison & Johnson, 2016; Roche et al., 2011; Simon, Goldberg, & Adini, 2015; Slavkovikj, Verstockt, Van Hoecke, & Van de Walle, 2014).

For this review, crowdsourcing refers to gathering information from active public participation, namely reports submitted via online forms or mobile applications (Harrison & Johnson, 2016). Crowdsourcing has historically been used in the response to a disaster for building situational awareness, coordinating resources, and aiding response efforts (Harrison & Johnson, 2016; Haworth & Bruce, 2015; Poblet, Garcia-Cuesta, Casanovas, 2014). Within the severe weather context,

Table 1
Summary of Volunteered Geographic Information types.

VGI Process	Spatial Data Format	Data Type	Data Sources	Disaster Risk Reduction Phase	Analysis/Outcomes
Geo-located social media harvesting	Point data	Impact data, exposure data, vulnerability data, hazard data Photos, videos, text	Facebook, Instagram, Twitter, Snapchat, Flickr, Sina Weibo, etc.	All	Cluster analysis, early detection, situational awareness, post-event damage/impact assessment, response coordination
Crowdsourcing	Point data	Impact data, exposure data, vulnerability data, hazard data Photos, videos, text	Online reporting forms, mobile application	Readiness, Risk Reduction, During, Response	Cluster analysis, early detection, situational awareness, damage/impact assessment, response coordination
Participatory mapping/ Participatory GIS	Point, line, polygon	Impact data, exposure data, vulnerability data, hazard data, expert local knowledge Shapefiles	Community members, community leaders, stakeholders	Readiness, Risk Reduction, Recovery	Hazard and risk assessments/modelling, impact forecasting, customise/personalise warnings systems for the community, identify impact thresholds, inform/improve readiness and reduction efforts based on local knowledge
Local Knowledge	Point, line, polygon, written, audio	Impact data, exposure data, vulnerability data, hazard data, expert local knowledge Shapefiles	Community members, community leaders, stakeholders, experts	Readiness, Risk Reduction, Recovery	Hazard and risk assessments/modelling, impact forecasting, customise/personalise warnings systems for the community, identify impact thresholds, inform/improve readiness and reduction efforts based on local knowledge

crowdsourcing was used in the aftermath of Hurricane Katrina to locate missing people and allocate response efforts (Roche et al., 2011). In other examples, crowdsourcing is used for people on the ground to submit reports on flood levels and weather phenomena observations (Harrison & Johnson, 2016; Horita et al., 2018).

Participatory mapping and participatory Geographic Information Systems (participatory GIS) use local spatial knowledge to create spatial data or to verify and update existing data (Peters-Guarin, Mccall, & van Westen, 2012). Participatory mapping generally evolves into participatory GIS when hand-drawn maps or features are digitised and integrated into a GIS for further analysis (Brown & Kyttä, 2014; Forrester & Cinderby, 2011). Participatory mapping is often used to map exposure and vulnerability to hazards in communities to support disaster risk planning (Gaillard & Pangilinan, 2010; Haklay, Antoniou, & Basiouka, 2014). For weather-related hazards, Haworth, Whittaker, and Bruce (2016) found that participatory mapping enabled local knowledge exchange for community preparedness to bushfire risks.

Local knowledge refers to knowledge possessed by locals about their communities, neighbourhoods, traditions, history, environment, and hazards, among others. Local knowledge has not been clearly defined in the literature. For the purposes of this paper, we consider local knowledge as information gathered in similar participatory mapping and participatory GIS processes but not translated into a map or GIS. Recently, the access to and integration of local knowledge has been recognised for its importance to disaster risk reduction (Anderson-Berry et al., 2018; Gall & Cutter, 2016; Sebastian et al., 2017; UNISDR, 2015).

Past research has focused heavily on the role of VGI in disaster response, with less exploration in understanding how VGI can inform warnings before or during a severe weather event (Harrison & Johnson, 2016; Haworth & Bruce, 2015; Horita, Degrossi, Assis, Zipf, & de Albuquerque, 2013; Klonner et al., 2016). In Klonner and colleagues' (2016) systematic literature review, the authors focused on documenting research on VGI for preparedness and mitigation but did not provide clear findings in the context of warnings for severe weather. Assumpção, Popescu, Jonoski, and Solomatine (2018) identified the role of citizen observations in providing data for flood modelling and forecasting to solve issues of data scarcity, but again with no mention of warnings.

The original conception of VGI began with identifying its value for early detection and warning of hazards, using "citizens as sensors" (Goodchild, 2007). Since then, some work has emerged exploring VGI for early warnings of various hazards, such as earthquakes, landslides, and tsunami (Carley, Malik, Landwehr, Pfeffer, & Kowalchuck, 2016; Elwood, Goodchild, & Sui, 2012; Goodchild, 2007; Granell & Ostermann, 2016; Harrison & Johnson, 2016). Horita, de Albuquerque, Marchezini, and Mendiondo (2016) argued that VGI may help address challenges of assigning proper warning thresholds by incorporating local knowledge of response capabilities. Meissen and Fuchs-Kittowski (2014) developed a conceptual framework which demonstrated how crowdsourced data can be fully integrated into an existing EWS as another dataset to augment or enhance the warnings by providing context. However, no further evidence to date indicates the adoption into practice of this framework for any type of EWS. Finally, Marchezini and colleagues (2018) conducted a literature review of research on citizen science and EWSs and found that more research is needed to identify how citizen science can be "mainstreamed" into EWSs.

Some agencies have started collecting VGI to detect, monitor, and track events and their impacts. In the United Kingdom (UK), the British Geological Survey collects landslide impact data from Twitter including text descriptions, photos, and video footage of the resulting impacts (Pennington, Freeborough, Dashwood, Dijkstra, & Lawrie, 2015). These data are integrated into the National Landslide Database, which is used to create a Hazard Impact Model (Pennington et al., 2015). In Canada, the National Meteorological Service uses hazard information posted by the public on Twitter to detect weather events such as tornadoes and to verify and update current weather watches and warnings (Harrison & Johnson, 2016). However, there is a gap in the literature for fully characterising the role of VGI for severe weather warnings. It is important to fill this gap because information and knowledge possessed by citizens have the potential to uncover "areas of importance or concern" that have yet to be identified in an official capacity (Haworth, Bruce, & Middleton, 2012, p. 40). VGI offers a way to capture local knowledge about previous severe weather events and their extent, severity, and resulting impacts, as well as information on the local exposure and vulnerability that warning services may not necessarily possess (Fleming et al., 2015; GFDRR, 2016; Krennert, Pistotnik, Kaltenberger, & Csekits, 2018; Sai et al., 2018; WMO, 2017). This paper uses a scoping review method to identify previous research into the use of VGI for severe weather EWSs, to attempt to answer the research question: *What are the current and potential uses of VGI for severe weather warnings?* The objective of this review is to determine how VGI has been, or could be, used within EWSs for severe weather hazards.

Method

This literature review uses a scoping method to explore areas of existing research and identify research gaps in VGI for severe weather early warning systems (Arksey & O'Malley, 2005; Paré, Trudel, Jaana, & Kitsiou, 2015). Scoping reviews provide a "rigorous and transparent method for mapping areas of research" in a short time (Arksey & O'Malley, 2005, p. 30). The aim is to describe the nature of the current literature on VGI for severe weather EWSs by describing the quality and quantity of the research (Grant & Booth, 2009; Paré et al., 2015). Scoping reviews are recognised for their strength in providing a broad picture of the state of research in a given topic area and are well-cited in the information systems field (Grant & Booth, 2009; Paré et al., 2015; Tan et al., 2017). This scoping review follows the five-step process defined by Arksey and O'Malley (2005): 1) identify the research question, 2) identify relevant studies, 3) select studies, 4) chart the data, and 5) report the results.

Table 2
Search string employed in EBSCO Discovery and Scopus databases.

Topics covered	Search string statement
Warnings and Disaster Risk Knowledge	("risk communication" OR "warning*" OR "impact model*" OR "risk model*" OR "impact warning*" OR "impact*based warning*" OR "impact forecast*" OR "impact*based forecast*" OR "risk*based warning*" OR "risk*based communication")
	AND
A broad definition of VGI to include social media, participatory mapping, local knowledge based on location	("participatory" OR "participatory mapping" OR "VGI" OR "volunteered geographic information" OR "participatory GIS" OR "PGIS" OR "geographic crowdsourc*" OR "citizen science" OR "crowdsourc*" OR "social media")
	AND
Severe weather hazards as defined under the WWRP HIWeather Implementation Plan (Jones & Golding, 2014)	("weather" OR "storm*" OR "snow*" OR "wind*" OR "tornado*" OR "hurricane*" OR "cyclone*" OR "typhoon*" OR "monsoon*" OR "flood*" OR "mudslide" OR "flash flood*" OR "rain*" OR "wildfire")

The initial literature search involved developing a search string to capture the broad topic area of VGI and social media for warning of severe weather hazards. The search string comprised three joined statements, shown in Table 2, to cover warnings and Disaster Risk Knowledge (as per the first component of the EWS framework: Basher, 2006; Golnaraghi, 2012), VGI, and severe weather, which were entered into two academic-focused databases, Scopus and EBSCO Discovery Service, in August 2018. Literature review papers have been published on similar topics in this space that have searched no more than two databases (e.g., Klonner et al., 2016; Tan et al., 2017). Furthermore, Scopus is recognised for indexing a larger number of journals than other databases and is the largest searchable citation and abstract source for various scientific fields (Falagas, Pitsouni, Malietzis, & Pappas, 2008; Guz & Rushchitsky, 2009). Moreover, when searching the two databases many duplicate results were found between the two databases, ensuring confidence in the coverage.

"Participatory GIS" and "participatory mapping" are different types of VGI, and thus were identified as separate search terms. During the process of developing the search string, it was found that additional VGI research was left out of the search due to the specificity of "participatory mapping" and "participatory GIS", thus the search was widened with the term "participatory" to capture more VGI studies. Similarly, "flash flood" and "flood" are likely redundant, however, they were both included to ensure full coverage. The asterisk in the search string acts as a *wildcard* to search for variations of the root term. The search covered all years from the earliest available until mid-2018 and included only peer-reviewed journals and conference proceedings in English. The search resulted in 1,015 hits from Scopus and 122 from EBSCO. After removing duplicates, 1,027 unique publications were captured.

The following inclusion-exclusion criteria were used to select publications most relevant to this study:

1) Publications that specifically focused on severe weather hazards as defined under the World Weather Research Programme's (WWRP) High Impact Weather Implementation Plan (Jones & Golding, 2014; $n = 254$);
2) Studies that explicitly discussed warnings, preparedness, mitigation, impact modeling and

forecasting, or risk mapping (reducing to *n* = 141); and,

3) Studies that focused on VGI, crowdsourcing, citizen science, participatory mapping, local knowledge gathering, or social media data (reducing to *n* = 42).
4) Finally, publications had to be original, complete research papers (*n* = 29).

After applying the inclusion-exlcusion criteria, information from the resulting papers was extracted according to different categories (see Table 3). Initially, the severe weather hazard(s) considered in the study were identified, after which the EWS framework was used to classify the papers and determine how VGI is or could be used within the EWS framework (these results are presented later in Figure 3). This classification involved identifying for which EWS component the VGI was used (see Figure 1), followed by the element within the EWS component (i.e., the specific task, tool, or process that the VGI was used for within the EWS component, such as risk mapping, detection, monitoring, forecasting, or warning dissemination). The VGI platform was identified (e.g., participatory mapping, participatory GIS, social media, crowdsourcing, citizen science, local knowledge), as well as the type of data that was collected (Haklay, 2017; Harrison & Johnson, 2016). These categories were chosen to determine the representation of VGI in severe weather EWSs.

Results

The search of the two databases led to 1,027 unique publications. After applying the inclusion-exclusion criteria, the final number of papers selected for this study was 29. The categories listed in Table 3 were used as a structure for analysis and discussion, and were chosen based upon the dominance of those themes in the papers.

Table 3
Categories for literature review.

Category	Description
Hazard	The type of severe weather hazard(s) considered in the study.
Early Warning System Component	The component from the EWS framework that each study applies to.
VGI Platform	The source of the VGI data, such as from social media, or from crowdsourcing (i.e., citizen observation), citizen science (i.e., a higher level of engagement than crowdsourcing; Haklay, 2013), participatory mapping, participatory GIS, or local knowledge.
Data Type	The type of data that was collected through the VGI process, such as local knowledge captured through interviews and/or participatory mapping, hazard data from social media or crowdsourcing, etc.

Hazard Type

The selected articles covered a range of severe weather hazards as defined in the World Weather Research Programme (WWRP) High Impact Weather (HIWeather) implementation plan (Jones & Golding, 2014). Some hazards are represented more than others; of the 29 articles, 16 focused on flood hazards, followed by seven studies that covered general severe weather hazards, two studies that examined rain-induced landslides, two for cyclones, and one each for air quality and urban heat wave.

The 16 flood studies covered a range of elements within the EWS components. These elements were identified by reviewing the selected studies and aligning them with the EWS components. Table 4 provides a summary of the selected studies which examined floods. Most studies covered flood detection, monitoring, and forecasting using VGI collected from social media and crowdsourcing. The next most common elements that were covered in the flood studies were vulnerability

Table 4
Summary of selected studies covering flood hazards.

EWS Component	Element	Purpose of the study	VGI Platform	Data Type	Reference
Disaster Risk Knowledge	Modelling	To integrate local knowledge into GIS outputs for flood risk management using participatory GIS in order to understand how people cope and adapt	Participatory GIS	Interviews with households in Barangay, Philippines	Peters-Guarin et al., 2012
	Modelling	Validating flood models using quantitative and qualitative VGI	Participatory Mapping	Local knowledge from workshop participants and interviewees	Rollason et al., 2018
	Risk mapping	To provide an example of how to engage and collaborate with local stakeholders for flood management	Participatory Mapping	Land feature layers, input from locals	Lavers et al., 2018

Table 4 *(continued)*

	Vulnerability assessment	To present a risk management framework that is based on local knowledge of the vulnerability to water hazards	Local knowledge	Meetings, workshops, interviews with people, media, and public sectors related to risk management	Arias et al., 2016
	Vulnerability assessment	To present a new methodology for incorporating stakeholder's participation, local knowledge, and locally spatial characteristics for vulnerability assessments of flood risk	Participatory GIS	Demographic data, infrastructure, hazard data (e.g., average annual rainfall), questionnaire interviews with experts and community members	Hung & Chen, 2013
	Vulnerability assessment	To present a new database for collection and assessment of flood damage using a bottom-up approach to gather and identify damage data	Social media	Personal blogs, on-site observations, public administration, social media, online media, local authorities, corporate websites	Saint-Martin et al., 2018
Detection, Monitoring, Warning Services	Detection	To develop a service-oriented architecture for flood management to capture real-time information about floods	Crowdsourcing	Rainfall, river, news, OpenStreetMap	Sharma et al., 2016
	Detection	To develop a methodology for interpreting image tags on social media for early detection of a flood and recording the impacts	Social media	Flickr posts - timestamps and location metadata	Tkachenko et al., 2017
	Detection, Forecasting	SWOT analysis of web-based access to data and model simulations, and insight on pEWMS, and conceptual framework for a Nordic pEWMS	Crowdsourcing, Social Media	Denmark: groundwater level observations Iceland: flood photos Finland: mobile phone observations	Henriksen et al., 2018
	Detection, Monitoring	To assess social media feasibility for flood detection, monitoring, and forecasting and develop a novel methodology for doing so	Social media	Twitter data	Rossi et al., 2018
	Forecasting	To develop a methodology using social media for estimating rainfall runoff estimations and flood forecasting	Social media	Twitter data	Restrepo-Estrada et al., 2018
	Forecasting	To present a real-time modelling framework to identify likely flooded areas using social media	Social Media	Twitter data, LiDAR	Smith et al., 2017
	Monitoring	To estimate flood severity in an urban coastal setting using crowdsourced data	Crowdsourcing	Crowdsourced street flooding reports	Sadler et al., 2018
	Monitoring	To present a conceptual framework for collecting and integrating heterogeneous data from sensor networks and VGI	Crowdsourcing	Flood data from in-situ sensors and volunteers	Horita et al., 2015
	Monitoring	To present a new methodology for monitoring flood hazards using remote sensing and VGI	Crowdsourcing, Social Media	Volunteered data (photos, videos, news), Landsat, DEM, meteorological data, river data	Schnebele & Cervone, 2013
Detection, Monitoring, Warning Services; Communication and Dissemination Mechanism; Preparedness and Early Response Capacity	Warning messaging, preparedness	To test if evidence exists for social media reducing flood losses by informing mitigation decisions before the flood	Social media	Surveys, in-depth interviews with households who experienced flooding in Bangkok, 2011	Allaire, 2016

assessments and risk mapping and modelling, using VGI from participatory GIS, participatory mapping, local knowledge, and social media. Just one study looked at using social media for detection, warning messaging, and for informing preparedness decisions (Allaire, 2016).

The remaining 13 studies covered other hazards, such as general severe weather, cyclones, landslides, air quality, and urban heatwaves. Table 5 provides a summary of the selected studies covering these various hazards. The general category refers to studies that did not identify a specific severe weather hazard, but referred only to "severe weather", usually in the context of severe weather warnings (Fdez-Arroyabe, Lecha Estela, & Schimt, 2018; Grasso & Crisci, 2016; Grasso, Crisci, Morabito, Nesi, Pantaleo, et al., 2017; He, Ju, Xu, Li, & Zhao, 2018; Krennert et al., 2018; Longmore et al., 2015; Lu et al., 2018).

In the general category, most of the selected studies looked at detection and forecasting using social media and crowdsourcing, followed by tracking warning dissemination across social media, and one study that used crowdsourcing for both risk and vulnerability assessment and providing warnings. The two cyclone studies each used social media and local knowledge to detect and forecast cyclone damage and to understand local responses to warnings, respectively. The two landslide studies both used VGI for landslide hazard and impact modelling, using crowdsourcing and social media. Finally, both the air quality and urban heatwave studies explored VGI from social media to forecast air quality and detect heatwaves based on individual exposure.

These studies indicate that VGI is used in the mapping, modelling, detection, monitoring, and warning of a number of severe weather hazards but that floods are the most heavily studied, with the widest range of VGI application across all of the elements. How these studies fit within the EWS framework is analysed in the following section.

Early Warning System Components

The papers were categorised by EWS component, as per Basher's (2006) framework (see Figure 1): 1) Disaster Risk Knowledge (*n* = 8); 2) Detection, Monitoring, and Warning Services (*n* = 16); 3) Communication and Dissemination Mechanisms (*n* = 2); and 4) Preparedness and Early Response Capacity (*n* =1). Two studies were found to fall into more than one EWS component. The studies were then classified by the specific elements within each component (e.g., hazard mapping, risk mapping, vulnerability assessment, modelling, hazard monitoring, detection, monitoring, warning, messaging, dissemination).

Disaster Risk Knowledge. Eight studies fall into the Disaster Risk Knowledge component of the EWS framework. Four of these studies looked at the use of VGI for hazard, risk, or impact modelling for landslides and floods (Choi, Cui, & Zhou, 2018; Pennington et al., 2015; Peters-Guarin et al., 2012; Rollason, Bracken, Hardy, & Large, 2018). Choi and colleagues (2018) presented a crowdsourcing-based smartphone application to aggregate landslide reports, which populates a landslide database for further hazard analysis. Similarly, Pennington and colleagues (2015) presented a landslide database for the UK that is partially populated by reports from Twitter to capture their impacts for further modelling. In the floods space, Peters-Guarin and colleagues (2012) utilised participatory GIS to integrate local knowledge of coping and adaptation practices into GIS-based flood risk analysis. Alternatively, Rollason and colleagues (2018) used participatory mapping to validate existing flood models.

The other four studies in the Disaster Risk Knowledge component involved risk mapping and vulnerability assessments, also for floods (Arias et al., 2016; Hung & Chen, 2013; Lavers & Charlesworth, 2018; Saint-Martin et al., 2018). Lavers and Charlesworth (2018) engaged with landowners to capture their knowledge of flood risk to inform flood management. Arias and colleagues (2016) presented a risk management framework for floods based on local knowledge of the vulnerability to water hazards. Hung and Chen (2013) incorporated stakeholders' participation and local knowledge through participatory GIS for vulnerability assessments of flood risk. Saint-Martin and colleagues (2018) developed a flood damage database (DamaGIS) to collect and assess flood damage, sourced from corporate websites, personal blogs, local authorities, on-site observations, social media, and online media. Furthermore, Saint-Martin and colleagues argued that social media can extend coverage to areas lacking regular media coverage and reveal damage that might have otherwise gone undetected.

Detection, Monitoring, and Warning. Within the Detection, Monitoring, and Warning component, 16 studies were identified. Four studies used VGI for hazard detection. Tkachenko, Jarvis, and Procter (2017) and Sharma and colleagues (2016) looked at VGI for

Table 5
Summary of selected studies covering other severe weather hazards.

Hazard	EWS Component	Element	Purpose of the study	VGI Platform	Data Type	Reference
General	Disaster Risk Knowledge; Detection, Monitoring, Warning Services	Risk mapping	To present a data infrastructure that can be used to delineate individual vulnerability to meteorological changes	Crowdsourcing	User profiles on a mobile app	Fdez-Arroyable et al., 2018
	Detection, Monitoring, Warning Services	Detection	To present an Android-based application for geohazard reduction using crowdsourcing	Crowdsourcing	Crowdsourced information (field data, photos, videos)	He et al., 2018
		Detection, Monitoring	To present a conceptual framework for collecting weather photos	Crowdsourcing	User reports, photos, videos	Longmore et al., 2015
		Detection, Monitoring	To evaluate the occurrence of crowdsourcing for severe weather within European NMHSs	Crowdsourcing, Social Media	Surveys with European National Meteorological and Hydrological Services	Krennert et al., 2018
		Forecasting	To use social media as a new way of forecasting and generating traffic alerts due to weather hazards	Social media	Temporal, spatial, traffic, and meteorological data from Weibo	Lu et al., 2018
	Communication and Dissemination Mechanism	Warning dissemination	To study the use of codified hashtags relating to weather warnings in Italy	Social media	Twitter data	Grasso & Crisci, 2016
		Warning dissemination	To evaluate the use of a list of predefined codified hashtags for weather warnings in Italy	Social media	Twitter data	Grasso et al., 2017
Cyclone	Detection, Monitoring, Warning Services	Forecasting	To determine if social media and geo-location information can contribute to a more efficient early warning system and help with disaster assessment	Social media	Twitter data, Hurricane damage loss data	Wu & Cui, 2018
	Preparedness and Early Response Capacity	Response to warnings	To integrate local and scientific meteorological knowledge and actions within coconut farming communities in the Philippines	Local knowledge	Interviews with key stakeholders	Ton et al., 2017
Landslide	Disaster Risk Knowledge	Modelling	To present a crowdsourcing smartphone app for landslide reports which populates a landslide database	Crowdsourcing	Crowdsourced landslide reports from app users	Choi et al., 2018
		Modelling	To present a national landslide database in the UK which is partially populated with social media data to capture the impacts of landslides and for early detection of landslides	Social media	Twitter data	Pennington et al., 2015
Air quality	Detection, Monitoring, Warning Services	Forecasting	To explore the use of social media as a real-time data source for forecasting smog-related health hazards	Social media	Social media data and physical sensors data	Chen et al., 2017
Urban heat wave	Detection, Monitoring, Warning Services	Detection	To investigate the relationship between heat exposure and tweet volume over time	Social media	Twitter data	Jung & Uejio, 2017

detecting floods and capturing impacts from social media and crowdsourced data respectively. Jung and Uejio (2017) tested the effectiveness of measuring heat exposure on social media and consequently detecting urban heatwaves. Similarly, He and colleagues (2018) developed a crowdsourcing application to detect various weather hazards and to capture impacts to improve the decision-making of local governments. Henriksen and colleagues (2018) indicated the role of social media and crowdsourcing for both detection and forecasting of floods, while Rossi and colleagues (2018) assessed the feasibility of social media for flood detection and monitoring. Longmore and colleagues (2015) presented a conceptual crowdsourcing framework for collecting photos of severe weather hazards in the United States to improve weather monitoring by the National Weather Service. In Europe, Krennert and colleagues (2018) assessed the occurrence of crowdsourcing (either through specialised applications or social media) by national hydrological and meteorological services to capture severe weather observations and impacts for real-time warning verification and improvement.

VGI for forecasting alone was used for floods, cyclone damage, general severe weather traffic impacts, and air quality. Restrepo-Estrada and colleagues (2018) developed a methodology using social media for estimating rainfall runoff estimations and flood forecasting, while Smith, Liang, James, Lin, and Qiuhua Liang (2017) presented a real-time modelling framework to identify likely flooded areas using social media. Alternatively, Wu and Cui (2018) found that geo-located social media can help with disaster assessment, and for future forecasting. Lu and colleagues (2018) explored how social media might be used to forecast and generate traffic alerts due to severe weather. Likewise, Chen, Chen, Wu, Hu, and Pan (2017) explored social media for real-time forecasting of smog-related hazards.

Finally, three studies used VGI to monitor floods. Schnebele and Cervone (2013) crowdsourced from social media and other online media to monitor flood hazards and to create hazard maps, finding that the VGI is useful when satellite data is unavailable. Horita, de Albuquerque, Degrossi, Mendiondo, and Ueyama (2015) developed a framework to integrate crowdsourced flood observations with official sensor data. The authors found that the VGI made it possible to capture data from areas lacking flood sensors (Horita et al., 2015). Sadler, Goodall, Morsy, and Spencer (2018) crowdsourced street flooding reports to estimate flood severity for flood prediction, but the poor temporal and spatial coverage of the crowdsourced reports hindered the performance of the prediction model (Sadler et al., 2018).

Communication and Dissemination Mechanisms. Two studies were identified for the third EWS component, Communication and Dissemination Mechanisms. Both studies used VGI to assess warning dissemination via social media (namely Twitter) for general severe weather (Grasso & Crisci, 2016; Grasso, Crisci, Morabito, Nesi, Pantaleo, et al., 2017). Grasso and Crisci (2016) analysed codified hashtags of regions in Italy impacted by rainfall and found that codified hashtags for different regions effectively enable the sharing of useful information during severe weather events. Additionally, many tweets included geo-location information along with hazard information to update and complement official data. As such, the authors argued that institutions might adopt codified hashtags to improve the performance of systems for disseminating and retrieving information. Grasso and colleagues (2017) built on this work by adding more regions to their tweet analyses and emphasised the importance of institutions and warning services to promote codified hashtags for warnings to streamline message delivery and reach.

Preparedness and Early Response Capacity. For the last component, Preparedness and Early Response Capacity, only one study applied. Ton, Gaillard, Cadag, and Naing (2017) collected VGI in the form of local knowledge using interviews and questionnaires with farmers to understand their response to cyclone warnings. In this process, the farmers identified economic, physical, social, and natural impacts of cyclone hazards. The authors found that while farmers forecast weather conditions and impacts based on their local knowledge, their confidence in the lead-time of their forecasts has declined due to changing climate conditions. As such, the authors argued for the integration of local knowledge with scientific forecasts to verify local knowledge-based forecasts and increase confidence.

Multiple components. Two studies were found to fall into more than one EWS component. Allaire (2016) used VGI for Detecting, Monitoring, and Warning, assessing Communication and Dissemination Mechanisms, and for measuring Preparedness and Early Response capacities for flood hazards. Allaire (2016) found that social media was an effective tool for flood monitoring (falling in the Detection, Monitoring, and Warning component), for receiving and spreading flood information (as a Communication and Dissemination Mechanism), and for receiving and spreading preparedness information, leading to reduced impacts (informing Preparedness and Early Response Capacity). Alternatively, Fdez-Arroyable and colleagues (2018) developed a mobile application to obtain individual vulnerabilities to meteorological changes (thus informing Disaster Risk Knowledge) and to provide personalised alerts based on the individual vulnerabilities to meteorological conditions (informing Detection, Monitoring, and Warning services).

VGI Platforms and Data Types

In this review, we broadly define VGI to include participatory mapping, participatory GIS, geo-located social media, and location-based local knowledge (de Albuquerque, Eckle, Herfort, & Zipf, 2016). Figure 2 shows the distribution of platforms discussed in each of the selected studies and to which component of the EWS framework they apply. The following section provides definitions of the platforms displayed in Figure 2 along with a description of how the VGI is used for severe weather warnings.

Geo-located social media. Geo-located social media refers to VGI that is posted online by users of Facebook, Twitter, Sina Weibo, Flickr, YouTube, Instagram, and SnapChat that has geographical location information associated to it. The heavy representation of social media (15 studies) demonstrates the growing popularity of these platforms as a data source for severe weather events (Tkachenko et al., 2017). The results indicate that social media is a valid tool for measuring the effectiveness of warning dissemination by following Twitter hashtags (Allaire, 2016; Grasso & Crisci, 2016; Grasso, Crisci, Morabito, Nesi, Pantaleo, et al., 2017; Taylor, Kox, & Johnston, 2018). The online platforms are also useful for early hazard detection and for estimating

	Disaster Risk Knowledge	Detection, Monitoring, Warning Services	Communication and Dissemination Mechanism	Preparedness and Early Response Capacity	Total
Geo-located Social Media	2	9	3	1	15
Crowdsourcing	2	6			8
Crowdsourcing and Geo-located Social Media		3			3
Local Knowledge	1			1	2
Participatory Mapping/PGIS	4				4
Total	9	18	3	2	32

Figure 2. Distibution of VGI platforms used for each early warning system (EWS) framework component. Two studies fell into multiple components and have been counted for each EWS component that they apply to, which results in a total of 32, rather than 29.

event magnitude for early warnings (Chen et al., 2017; Jung & Uejio, 2017; Restrepo-Estrada et al., 2018; Tkachenko et al., 2017). Reasons for collecting social media data were to increase coverage of the dataset(s), the ease of access and quantity of data available, real-time or near-real-time monitoring and collection, and the multi-directional communication during disaster enabled by social media (Allaire, 2016; Chen et al., 2017; Grasso & Crisci, 2016; Grasso, Crisci, Morabito, Nesi, & Pantaleo, 2017; Jung & Uejio, 2017; Pennington et al., 2015; Rossi et al., 2018; Saint-Martin et al., 2018; Smith et al., 2017; Wu & Cui, 2018).

Crowdsourcing applications and forms. Eight of the selected studies used crowdsourcing via mobile applications, reporting forms, or other active contributions (e.g., storm spotters). The crowdsourcing applications in the selected studies were used for hazard detection and monitoring and for developing personalised risk knowledge. These applications allow citizens to report the occurrence of hazards such as landslides (Choi et al., 2018; He et al., 2018) and to monitor hazards such as rainfall-induced floods (Horita et al., 2015) and storms (Krennert et al., 2018; Longmore et al., 2015). The ability to efficiently collect reports and monitor hazards in real-time, in a standardised format to ensure quality, and to increase the scale and resolution of hazard-related data were arguments made for using crowdsourcing as opposed to other VGI collection types (Choi et al., 2018; He et al., 2018; Henriksen et al., 2018; Horita et al., 2015; Longmore et al., 2015; Sadler et al., 2018; Sharma et al., 2016).

Participatory mapping and participatory GIS. In the selected studies, participatory mapping and participatory GIS were employed for severe weather risk assessments and hazard modelling. Lavers and Charlesworth (2018) engaged UK farmers in participatory mapping to identify flood impacts on their properties and subsequent opportunities for mitigation. Peters-Guarin et al. (2012) had locals in the Philippines map their historical knowledge of recurring floods and impacts for a risk assessment. In Taiwan, Hung and Chen (2013) consulted with locals and stakeholders to verify flood vulnerability maps. Participatory mapping and interviews were utilised by Rollason and colleagues (2018) to validate flood models using local knowledge and experiences. In all of these studies, the mapped information was entered into a GIS for further mapping and analysis, thus qualifying it as participatory GIS. Reasons for using participatory GIS and participatory mapping over other types of VGI were formally recognising and integrating local knowledge in a systematic way, and supporting local engagement (Hung & Chen, 2013; Lavers & Charlesworth, 2018; Peters-Guarin et al., 2012; Rollason et al., 2018).

Local knowledge. For the purposes of this paper, we consider local knowledge as information gathered in participatory processes containing knowledge of the participants' local area and geography, that may or may not be translated onto a map. Just one selected study included local knowledge. After evaluating local knowledge of cyclone hazards and response capabilities to scientific knowledge, Ton and colleagues (2017) argued that local knowledge should be integrated with scientific meteorological knowledge for verification and to increase confidence in forecasts. The choice of using local knowledge for this study was to begin a dialogue between the locals and the meteorologists towards building trust (Ton et al., 2017).

Discussion

The results show that VGI is useful in all components of the early warning system (EWS) framework, but some platforms are more useful for specific components than are others. Furthermore, the different types of VGI have implications for supporting people-centred EWSs, which is a guiding principle for EWSs under the Sendai Framework.

Volunteered Geographic Information in Severe Weather Early Warning Systems

The purpose of this study is to determine the current and potential uses of VGI for severe weather warnings. We used the EWS framework to guide the analysis of the results.

The results from this literature review show that VGI has value in all four components of an EWS for severe weather hazards (Basher, 2006), but some forms of VGI are more useful for specific EWS components than are others (see Figure 3). Figure 3 is an update of Figure 1 based on the findings from this literature review to better represent how the different types of VGI inform or support the EWS components. For example, the majority of included studies used social media and crowdsourcing for hazard detection, monitoring, and early warning, while all of the included participatory mapping and participatory GIS studies used VGI for building disaster risk knowledge.

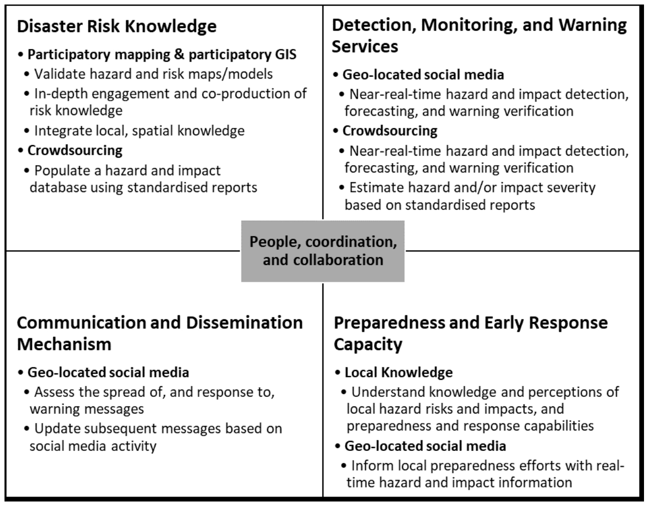


Figure 3. Volunteered Geographic Information for people-centred severe weather early warning systems.

The selected studies show that social media and crowdsourcing for severe weather are effective for early detection, monitoring, and verifying warnings (e.g., Harrison & Johnson, 2016; Henriksen et al., 2018; Krennert et al., 2018). The value of social media and crowdsourcing for EWSs lies in the real-time, or near-real-time, hazard and impact detection, forecasting, and warning verification (Henriksen et al., 2018; Kox, Kempf, Lüder, Hagedorn, & Gerhold, 2018; Krennert et al., 2018). However, the papers included in this scoping review lack forward-thinking for integrating these tools into official EWSs which is a challenge for warning services and emergency management services (Haworth, 2016; Henriksen et al., 2018; Kox et al., 2018). Despite this challenge, some national hydrological and meteorological services and emergency management agencies in Europe and North America collect information from social media for detection, monitoring, and warning verification (Harrison & Johnson, 2016; Henriksen et al., 2018; Krennert et al., 2018; Pennington et al., 2015).

Social media supports multi-directional communication, which allows for both crowdsourcing and broadcasting severe weather information. While most of the selected social media studies demonstrated the value of social media for detection and early warning, two studies also indicated its utility for disseminating warnings and assessing the spread of, and response to, warning messages (Grasso & Crisci, 2016; Grasso, Crisci, Morabito, Nesi, Pantaleo, et al., 2017). This allows warning services to gauge the reach of their message, understand the responses to their message, and update subsequent messages based on what they see on social media (Harrison & Johnson, 2016).

Before warnings are issued, knowledge of disaster risk is needed to be able to create tailored warnings. Participatory mapping and participatory GIS might be considered a long-term process for building knowledge and datasets for improving disaster risk knowledge as well as validating hazard and risk maps or models. While social media is valuable for real-time detection and communication, the participatory nature of participatory mapping enables more in-depth engagement with locals and communities in other areas of the EWS process to produce new knowledge (Haworth, 2018; Lavers & Charlesworth, 2018; Maskrey, Mount, Thorne, & Dryden, 2016; Peters-Guarin et al., 2012; Zolkafli, Brown, & Liu, 2017). Integrating local, spatial knowledge about disaster risk into an EWS through participatory mapping and participatory GIS fosters efforts towards people-centred EWSs as it translates local knowledge into usable and useful spatial data for risk analysis and for improved warnings (Basher, 2006; UNISDR, 2015).

These results support the findings from Marchezini and colleagues (2018), who presented a framework for bridging citizen science into EWSs. Like Marchezini and colleagues (2018), we found that VGI processes can bridge the gap between EWSs and audiences of warnings by incorporating local knowledge and personal experiences from stakeholders into the EWS components (see also Ton et al., 2017). This creates new data and unearths vulnerabilities at various scales (e.g., from the individual level to the community level; Haworth, 2018; Henriksen et al., 2018; Kox et al., 2018; Ton et al., 2017).

Implications for the different types of VGI. The results show that social media is a dominant platform for collecting VGI across severe weather hazards. Given the ease of access to, and the versatility of, social media (Harrison & Johnson, 2016), it is not surprising that social media is the most common platform used across hazards for collecting VGI (Granell & Ostermann, 2016). Social media is also now considered a "go-to" for collecting data because it is where the members of the public already are, thus groups or agencies looking to crowdsource do not have to do the heavy-lifting of creating a new app and attracting new users (Harrison & Johnson, 2016).

The perceived benefits of social media also come with some caveats. The data tend to be biased due to the uneven distribution of the social media user base (Granell & Ostermann, 2016; Harrison & Johnson, 2019). By relying on social media as a data source, those members of the public who are not present on social media are not represented in the data nor in the EWS process (i.e., the digital divide; Allaire, 2016; Harrison & Johnson, 2019). Additionally, tweet or post ambiguity and keyword selection for data-capture hinder data collection and analysis (Chen et al., 2017; Longmore et al., 2015; Tkachenko et al., 2017). Assimilating data of different formats into a database remains a challenge (Horita et al., 2015; Lu et al., 2018).

Capturing enough geo-located social media data is a constant challenge. It is widely known that only a small percentage of tweets contain geo-located information (Steed et al., 2019). Furthermore, the accessibility and availability of geo-located social media data are continuously limited. For example, Facebook does not offer an Application Programming Interface (API) to allow for researchers or media agencies to systematically collect Facebook posts, much less geo-located posts; it only offers an API for marketing and advertising agencies (Dubois, Zagheni, Garimella, & Weber, 2018; Thakur et al., 2018). In addition, in June 2019 Twitter announced plans to disable the geo-location feature for tweets due to its limited adoption by users and growing privacy concerns; however, the feature will still be available on photos taken within the Twitter mobile application (Benton, 2019; Khalid, 2019). While geo-located information on Instagram appears to be available for the moment (Arapostathis, 2019; Boulton, Shotton, & Williams, 2016), given the recent trends in the other major social media platforms, the continued availability and accessibility of this data in the future is uncertain.

A specialised crowdsourcing application can help to address some limitations found in social media. Crowdsourcing applications offer quality assurance, noise avoidance, application customisation, and citizen engagement (Choi et al., 2018; Longmore et al., 2015). On the other hand, crowdsourcing applications remain limited in the volume of participation due to public motivation to participate, the digital divide, and privacy concerns (Choi et al., 2018; Fdez-Arroyabe et al., 2018). Bias in reporting is also a concern, as contributors may over-exaggerate their personal experiences (Fdez-Arroyabe et al., 2018). Developing an application has the potential to streamline the integration of crowdsourced data into official processes, yet maintenance costs impede the willingness of officials to do so (Choi et al., 2018).

Capturing and representing local knowledge through participatory mapping and participatory GIS may help in bridging the digital divide, ensuring data quality, and enabling data integration. Participatory mapping and participatory GIS also enable community engagement (Haworth et al., 2016; Lavers & Charlesworth, 2018; Peters-Guarin et al., 2012). Participatory mapping and participatory GIS can be done using paper-mapping, as was done by Rollason and colleagues (2018), Lavers and colleagues (2018), and Peters-Guarin and colleagues (2012), or through digital-mapping (Haworth et al., 2016). In addition to the value of the resulting information and data itself, the process of engaging with and between locals provides another level of value in the social context by strengthening social networks, growing social capital, and increasing civic participation (Haworth et al., 2016).

Participatory GIS and participatory mapping do not come without their own limitations. For example, participatory GIS appears to be more effective with small-scale local projects. This is because most of the data collected is at a local or small scale, resulting in poor spatial distribution if scaled-up to a larger area. This could lead to underrepresentation and potential biases in the participatory GIS data (Rollason et al., 2018). Nevertheless, the rich quality and the ease of integrating this VGI into official processes may outweigh this limitation if the study is well-designed and the data is used appropriately (Brabham, 2013; Lauriault & Mooney, 2014). Within the EWS context, these perceived benefits further the movement towards people-centred EWSs by incorporating knowledge and information produced by the people into warnings that are ultimately for them (UNISDR, 2015).

Conclusion

This paper conducted a scoping literature review and explored 29 journal papers published in academic journals and conference proceedings retrieved from EBSCO Discovery and Scopus. The literature review found that VGI plays various roles for severe weather early warning systems (EWSs). The examples from the selected studies show that VGI furthers the development of people-centered EWSs; it brings people, their knowledge, and their experiences into EWSs. Still, the current research captured in this scoping review lacks forward-thinking for integrating these tools into official EWSs which is a challenge for warning services and emergency management services (Haworth, 2016; Henriksen et al., 2018; Kox et al., 2018).

In the always shifting EWSs landscape, a new type of severe weather EWS is emerging that is causing national meteorological and hydrological services and warning services to re-think their traditional warning practices. The World Meteorological Organization is advocating for the aforementioned services to adopt impact-based forecasts and warning systems (Fleming et al., 2015). Impact-based forecasts and warnings are meant to shift the focus from the physical hazard phenomena to the risk of impacts produced by the hazard, including communicating impacts in warning messages and building new warning thresholds based on risk of impact (Fleming et al., 2015; Morss, Cuite, Demuth, Hallman, & Shwom, 2018; Poolman, 2014; Potter et al., 2018; Robbins & Titley, 2018; Rogers, Kootval, & Tsirkunov, 2017; Sai et al., 2018). However, warning services have indicated a limited understanding of, and access to, the data required for developing impact-based forecasting and warning systems (Harrison et al., 2014; Kox et al., 2018; Obermeier & Anderson, 2014).

Future research would benefit from a systematic review of this topic area in the future. Additional research should investigate the data needs for impact-based forecasts and warnings and explore how VGI can help in meeting these data needs while also maintaining a people-centred focus. This would align with the goals of the World Meteorological Organization's High Impact Weather research programme (http://hiweather.net) which aims to improve the effectiveness of weather-related warnings in support of advances in weather prediction and forecasting (Zhang et al., 2019). While this literature review characterised the role of VGI within severe weather EWSs and demonstrated how it supports people-centred EWSs, future research can delve into the nature of the resulting data and how it might support impact-based forecast and warning systems. It should be noted that in spite of the popularity of collecting and using social media data, given the uncertainty of reliable access to social media data in the future (e.g., disestablishing the geolocation function on Twitter), it would be wise to minimise reliance on these platforms and consider additional VGI sources and collection processes to capture the desired information.

Acknowledgements

The authors thank the anonymous reviewers whose feedback greatly improved this manuscript. This research was supported by public research funding from the Government of New Zealand through GNS Science.

References

Alexander, D. E. (2014). Social media in disaster risk reduction and crisis management. *Science and Engineering Ethics, 20,* 717-733. doi: 10.1007/s11948-013-9502-z

Allaire, M. (2016). Disaster loss and social media: Can online information increase flood resilience? *Water Resources Research*, *52*, 7408–7423. doi: 10.1002/2014WR016618

Anderson-Berry, L., Achilles, T., Panchuk, S., Mackie, B., Canterford, S., Leck, A., & Bird, D. K. (2018). Sending a message: How significant events have influenced the warnings landscape in Australia. *International Journal of Disaster Risk Reduction*, *30*, 5–17. doi: 10.1016/j.ijdrr.2018.03.005

Arapostathis, S. G. (2019). Instagrammers report about the deadly wildfires of East Attica, 2018, Greece: An introductory analytic assessment for disaster management purposes. In *Proceedings of the 16th ISCRAM Conference* (pp. 473–481). València, Spain. Retrieved from https://github.com/h4t0n/

Arias, P. A., Villegas, J. C., Machado, J., Serna, A. M., Vidal, L. M., Vieira, C., … Mejía, Ó. A. (2016). Reducing social vulnerability to environmental change: Building trust through social collaboration on environmental monitoring. *Weather, Climate, and Society*, *8*(1), 57–66. doi: 10.1175/WCAS-D-15-0049.1

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

Assumpção, T. H., Popescu, I., Jonoski, A., & Solomatine, D. P. (2018). Citizen observations contributing to flood modelling: Opportunities and challenges. *Hydrology and Earth System Sciences Discussions*, *22*, 1473–1489. doi: 10.5194/hess-2017-456

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

Benton, J. (2019, June 19). Twitter is removing precise-location tagging on tweets — a small win for privacy but a small loss for journalists and researchers. *NiemanLab*. Retrieved from http://niemanlab.org

Boulton, C. A., Shotton, H., & Williams, H. T. P. (2016). Using social media to detect and locate wildfires. In *10th International AAAI Conference on Web and Social Media (ICWSM 16), W8: Social Web for Environmental and Ecological Monitoring*. Cologne, Germany. Retrieved from www.ushahidi.com/

Brabham, D. C. (2013). *Using crowdsourcing in government*. California, US: IBM Center for The Business of Government.

Brown, G., & Kyttä, M. (2014). Key issues and research priorities for public participation GIS (PPGIS): A synthesis based on empirical research. *Applied Geography*, *46*, 122–136. doi: 10.1016/j.apgeog.2013.11.004

Carley, K. M. K. M., Malik, M., Landwehr, P. M. P. M., Pfeffer, J., & Kowalchuck, M. (2016). Crowd sourcing disaster management: The complex nature of Twitter usage in Padang Indonesia. *Safety Science*, *90*, 48–61. doi: 10.1016/j.ssci.2016.04.002

Chen, J., Chen, H., Wu, Z., Hu, D., & Pan, J. Z. (2017). Forecasting smog-related health hazard based on social media and physical sensor. *Information Systems*, *64*, 281–291. doi: 10.1016/j.is.2016.03.011

Ching, P. K., Carr de los Reyes, V., Sucaldito, M. N., & Tayag, E. (2015). Responding to Typhoon Haiyan in the Philippines. *Western Pacific Surveillance and Response Journal*, *6*(Supplement 1), 1–4.

Choi, C. E., Cui, Y., & Zhou, G. G. D. (2018). Utilizing crowdsourcing to enhance the mitigation and management of landslides. *Landslides*, *15*, 1889-1899. doi: 10.1007/s10346-018-1034-9

Cooper, A. K., Coetzee, S., & Kourie, D. G. (2018). Volunteered geographical information, crowdsourcing, citizen science and neogeography are not the same. *Proceedings of the ICA*, *1*, 1–8. doi: 10.5194/ica-proc-1-131-2018

de Albuquerque, J. P., Eckle, M., Herfort, B., & Zipf, A. (2016). Crowdsourcing geographic information for disaster management and improving urban resilience: An overview of recent developments and lessons learned. In C. Capineri, M. Haklay, H. Huang, V. Antoniou, J. Kettunen, F. Ostermann, & R. Purves (Eds.), *European handbook of crowdsourced geographic information* (pp. 309–321). London: Ubiquity Press.

de Albuquerque, J. P., Horita, F. E. A., Degrossi, L. C., Rocha, R. dos S., Camargo de Andrade, S., Restrepo-Estrada, C., & Leyh, W. (2017). Leveraging Volunteered Geographic Information to improve disaster resilience. In A. Ballatore, B. Bennett, C. Claramount, C. J. Davis, S. Di Martino, A. Klippel, … B. Schoen-Phelan (Eds.), *Volunteered Geographic Information and the future of geospatial data* (pp. 158–184). Pennsylvania, US: IGI Global.

Dubois, A., Zagheni, E., Garimella, K., & Weber, I. (2018). Studying migrant assimilation through Facebook interests. In S. Staab, O. Koltsova, & D. Ignatov (Eds.), *Social informatics* (pp. 51–60). Switzerland: Springer, Cham.

Elwood, S., Goodchild, M. F., & Sui, D. Z. (2012). Researching Volunteered Geographic Information: Spatial data, geographic research, and new social practice. *Annals of the Association of American Geographers*, *102*(3), 571–590. doi: 10.1080/00045608.2011.595657

Falagas, M. E., Pitsouni, E. I., Malietzis, G. A., & Pappas, G. (2008). Comparison of PubMed, Scopus, Web of Science, and Google Scholar: Strengths and weaknesses. *The FASEB Journal*, *22*(2), 338–342. doi: 10.1096/fj.07-9492LSF

Fdez-Arroyabe, P., Lecha Estela, L., & Schimt, F. (2018). Digital divide, biometeorological data infrastructures and human vulnerability definition. *International Journal of Biometeorology*, *62*(5), 733–740. doi: 10.1007/s00484-017-1398-x

Fleming, G., Rogers, D., Davies, P., Jacks, E., Milton, J. A., Honore, C., … Goolaup, P. (2015). WMO Guidelines on Multi-Hazard Impact-Based Forecast and Warning Services [PDF file]. Retrieved from www.wmo.int/pages/prog/www/DPFS/Meetings/ET-OWFPS_Montreal2016/documents/WMOGuidelinesonMulti-hazardImpact-basedForecastandWarningServices.pdf

Forrester, J., & Cinderby, S. (2011). A guide to using community mapping and participatory-GIS [PDF file]. Retrieved from https://tweedforum.org/wp-content/uploads/2018/09/Borderlands-Community-Mapping-Guide.pdf

Gaillard, J. C., & Pangilinan, M. L. C. J. D. (2010). Participatory mapping for raising disaster risk awareness among the youth. *Journal of Contingencies and Crisis Management*, *18*(3), 175–179. doi: 10.1111/j.1468-5973.2010.00614.x

Gall, M., & Cutter, S. L. (2016). *Understanding disaster risk through loss data*. Washington, D.C.: International Bank for Reconstruction and Development/The World Bank. doi: 10.1016/0301-4207(78)90055-7

Garcia, C., & Fearnley, C. J. (2012). Evaluating critical links in early warning systems for natural hazards. *Environmental Hazards*, *11*(2), 123–137. doi: 10.1080/17477891.2011.609877

GFDRR. (2016). Implementing multi-hazard impact-based forecast and warning services [PDF file]. Retreived from www.gfdrr.org/sites/default/files/publication/Report%20on%20Implementing%20Multi%20Hazard%20Impact%20Based%20Forecast%20and%20Warning%20Services%2017-02-10%20Final.pdf

Golnaraghi, M. (Ed.). (2012). *Institutional partnerships in multi-hazard early warning systems*. Berlin: Springer.

Goodchild, M. F. (2007). Citizens as sensors: The world of Volunteered Geography. *GeoJournal*, *69*(4), 211–221.

Goodchild, M. F., & Glennon, J. A. (2010). Crowdsourcing geographic information for disaster response: A research frontier. *International Journal of Digital Earth*, *3*(3), 231–241. doi: 10.1080/17538941003759255

Granell, C., & Ostermann, F. O. (2016). Beyond data collection: Objectives and methods of research using VGI and geo-social media for disaster management. *Computers, Environment and Urban Systems*, *59*(2016), 231–243. doi: 10.1016/j.compenvurbsys.2016.01.006

Grant, M. J., & Booth, A. (2009). A typology of reviews: An analysis of 14 review types and associated methodologies. *Health Information and Libraries Journal*, *26*(2), 91–108. doi: 10.1111/j.1471-1842.2009.00848.x

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

Grasso, V., Crisci, A., Morabito, M., Nesi, P., & Pantaleo, G. (2017). Public crowdsensing of heat waves by social media data. *Advances in Science and Research*, *14*, 217–226. doi: 10.5194/asr-14-217-2017

Grasso, V., Crisci, A., Morabito, M., Nesi, P., Pantaleo, G., Zaza, I., & Gozzini, B. (2017). Italian codified hashtags for weather warning on Twitter - who is really using them? *Advances in Science and Research*, *14*, 63–69. doi: 10.5194/asr-14-63-2017

Guz, A. N., & Rushchitsky, J. J. (2009). Scopus: A system for the evaluation of scientific journals. *International Applied Mechanics*, *45*(4), 351–362. doi: 10.1007/s10778-009-0189-4

Haklay, M. (2013). Citizen science and Volunteered Geographic Information: Overview and typology of participation. In D. Sui, S. Elwood, & M. Goodchild (Eds.), *Crowdsourcing geographic knowledge: Volunteered Geographic Information (VGI) in theory and practice* (pp. 105–122). Dordrecht: Springer Netherlands.

Haklay, M. (2017). Volunteered Geographic Information and citizen science. Retrieved from www.opensignal.com/

Haklay, M., Antoniou, V., & Basiouka, S. (2014). Crowdsourced geographic information use in government. Retrieved from http://discovery.ucl.ac.uk/1433169/

Harrison, J., Mccoy, C., Bunting-Howarth, K., Sorensen, H., Williams, K., & Ellis, C. (2014). Evaluation of the National Weather Service Impact-based Warning tool [PDF file]. Retrieved from https://publications.aqua.wisc.edu/product/evaluation-of-the-national-weather-service-impact-based-warning-tool/

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. doi: 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. doi: 10.1016/J.GIQ.2019.04.002

Harrison, S., Silver, A., & Doberstein, B. (2015). Post-storm damage surveys of tornado hazards in Canada: Implications for mitigation and policy. *International Journal of Disaster Risk Reduction*, *13*, 427–440. doi: 10.1016/j.ijdrr.2015.08.005

Haworth, B. (2016). Emergency management perspectives on volunteered geographic information: Opportunities, challenges and change. *Computers, Environment and Urban Systems*, *57*, 189–198. doi: 10.1016/j.compenvurbsys.2016.02.009

Haworth, B. (2018). Implications of Volunteered Geographic Information for disaster management and GIScience: A more complex world of volunteered geography. *Annals of the American Association of Geographers*, *108*(1), 226–240. doi: 10.1080/24694452.2017.1321979

Haworth, B., & Bruce, E. (2015). A review of Volunteered Geographic Information for disaster management. *Geography Compass*, *5*(9), 237–250. doi: 10.1111/gec3.12213

Haworth, B., Bruce, E., & Middleton, P. (2012). Emerging technologies for risk reduction: assessing the potential use of social media and VGI for increasing community engagement. *Australian Journal of Emergency Management*, *30*(3), 36–41.

Haworth, B., Whittaker, J., & Bruce, E. (2016). Assessing the application and value of participatory mapping for community bushfire preparation. *Applied Geography*, *76*, 115–127. doi: 10.1016/j.apgeog.2016.09.019

He, C., Ju, N., Xu, Q., Li, Y., & Zhao, J. (2018). Designing an Android-based application for geohazard reduction using citizen-based crowdsourcing data. *Mobile Information Systems*, *2018*, 1-11.

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*, *31*, 1295–1306. doi: 10.1016/j.ijdrr.2018.01.038

Horita, F. E. A., de Albuquerque, J. P., Degrossi, L. C., Mendiondo, E. M., & Ueyama, J. (2015). Development of a spatial decision support system for flood risk management in Brazil that combines volunteered geographic information with wireless sensor networks.

Computers and Geosciences, *80*, 84–94. doi: 10.1016/j.cageo.2015.04.001

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 *13th International Conference on Information Systems for Crisis Response and Management (ISCRAM 2016)*, (May 2016), 1–8.

Horita, F. E. A., Degrossi, L. C., Assis, L. F. ., Zipf, A., & de Albuquerque, J. P. (2013). The use of Volunteered Geographic Information and crowdsourcing in disaster management: A systematic literature review. In *Proceedings of the Nineteenth Americas Conference on Information Systems* (pp. 1–10).

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 *15th International Conference on Information Systems for Crisis Response and Management (ISCRAM 2018)* (May 2018), 1030–1039. Retrieved from www.scopus.com/inward/record.uri?eid=2-s2.0-85060678817&partnerID=40&md5=71160a6fc9ab22da45c84ad5116adbb9

Hung, H. C., & Chen, L. Y. (2013). Incorporating stakeholders' knowledge into assessing vulnerability to climatic hazards: Application to the river basin management in Taiwan. *Climatic Change*, *120*(1–2), 491–507. doi: 10.1007/s10584-013-0819-z

Jones, S., & Golding, B. (2014). HIWeather: A research activity on High Impact Weather within the World Weather Research Programme [PDF file]. Retrieved from www.wmo.int/pages/prog/arep/wwrp/new/documents/HIWeatherImplementationPlan.pdf

Jung, J., & Uejio, C. K. (2017). Social media responses to heat waves. *International Journal of Biometeorology*, *61*(7), 1247–1260. doi: 10.1007/s00484-016-1302-0

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

Klonner, C., Marx, S., Usón, T., Porto de Albuquerque, J., Höfle, B., Klonner, C., … Höfle, B. (2016). Volunteered Geographic Information in natural hazard analysis: A systematic literature review of current approaches with a focus on preparedness and mitigation. *ISPRS International Journal of Geo-Information*, *5*(7), 103. doi: 10.3390/ijgi5070103

Kox, T., Kempf, H., Lüder, C., Hagedorn, R., & Gerhold, L. (2018). Towards user-orientated weather warnings. *International Journal of Disaster Risk Reduction*, *30*, 74-80. doi: 10.1016/j.ijdrr.2018.02.033

Krennert, T., Pistotnik, G., Kaltenberger, R., & Csekits, C. (2018). Crowdsourcing of weather observations at national meteorological and hydrological services in Europe. *Advances in Science and Research*, *15*, 71–76. doi: 10.5194/asr-15-71-2018

Lauriault, T., & Mooney, P. (2014). Crowdsourcing: A geographic approach to public engagement. Retrieved from https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2518233.

Lavers, T., & Charlesworth, S. (2018). Opportunity mapping of natural flood management measures: A case study from the headwaters of the Warwickshire-Avon. *Environmental Science and Pollution Research*, *25*(20), 19313–19322. doi: 10.1007/s11356-017-0418-z

Longmore, S., Miller, S., Bikos, D., Lindsey, D., Szoke, E., Molenar, D., … Knaff, J. (2015). An automated mobile phone photo relay and display concept applicable to operational severe weather monitoring. *Journal of Atmospheric and Oceanic Technology*, *32*(7), 1356–1363. doi: 10.1175/JTECH-D-14-00230.1

Lu, H., Zhu, Y., Shi, K., Lv, Y., Shi, P., & Niu, Z. (2018). Using adverse weather data in social media to assist with city-level traffic situation awareness and alerting. *Applied Sciences*, *8*(7), 1193-1210. doi: 10.3390/app8071193

Marchezini, V., Horita, F. E. A., Matsuo, P. M., Trajber, R., Trejo-Rangel, M. A., & Olivato, D. (2018). A review of studies on Participatory Early Warning Systems (P-EWS): Pathways to support citizen science initiatives. *Frontiers in Earth Science*, *6*, 1–18. doi: 10.3389/feart.2018.00184

Maskrey, S. A., Mount, N. J., Thorne, C. R., & Dryden, I. (2016). Participatory modelling for stakeholder involvement in the development of flood risk management intervention options. *Environmental Modelling and Software*, *82*, 275–294. doi: 10.1016/j.envsoft.2016.04.027

Meissen, U., & Fuchs-Kittowski, F. (2014). Crowdsourcing in early warning systems. In *Proceedings - 7th International Congress on Environmental Modelling and Software: Bold Visions for Environmental Modeling, iEMSs 2014* (pp. 326–332).

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

Morss, R. E., Cuite, C. L., Demuth, J. L., Hallman, W. K., & Shwom, R. L. (2018). Is storm surge scary? The influence of hazard, impact, and fear-based messages and individual differences on responses to hurricane risks in the U.S. *International Journal of Disaster Risk Reduction*, *30*, 44-58. doi: 10.1016/j.ijdrr.2018.01.023

Obermeier, H., & Anderson, M. R. (2014). Verification and analysis of impact-based tornado warnings in the central region of the National Weather Service. *Electronic Journal of Severe Storms Meteorology*, *10*(1), 1–20.

Paré, G., Trudel, M.-C., Jaana, M., & Kitsiou, S. (2015). Synthesizing information systems knowledge: A typology of literature reviews. *Information & Management*, *52*, 183–199. doi: 10.1016/j.im.2014.08.008

Pennington, C., Freeborough, K., Dashwood, C., Dijkstra, T., & Lawrie, K. (2015). The National Landslide Database of Great Britain: Acquisition, communication and the role of social media. *Geomorphology*, *249*, 44–51. doi: 10.1016/j.geomorph.2015.03.013

Peters-Guarin, G., Mccall, M. K., & van Westen, C. (2012). Coping strategies and risk manageability: Using participatory geographical information systems to represent local knowledge. *Disasters*, *36*(1), 1–27. doi: 10.1111/j.1467-7717.2011.01247.x

Poblet, M., Garcia-Cuesta, E., & Casanovas, P. (2014). Crowdsourcing tools for disaster management: A review of platforms and methods. In *AI approaches to the complexity of legal systems* (pp. 261–274). Germany: Springer.

Poolman, E. R. (2014). *A probabilistic impact-focussed early warning system for flash floods in support of disaster management in South Africa*. South Africa: University of Pretoria.

Potter, S. H., Kreft, P. V., Milojev, P., Noble, C., Montz, B., Dhellemmes, A., … Gauden-Ing, S. (2018). The influence of impact-based severe weather warnings on risk perceptions and intended protective actions. *International*

Journal of Disaster Risk Reduction, *30*, 34–43. doi: 10.1016/j.ijdrr.2018.03.031

Restrepo-Estrada, C., de Andrade, S. C., Abe, N., Fava, M. C., Mendiondo, E. M., & de Albuquerque, J. P. (2018). Geo-social media as a proxy for hydrometeorological data for streamflow estimation and to improve flood monitoring. *Computers and Geosciences*, *111*, 148–158. doi: 10.1016/j.cageo.2017.10.010

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. doi: 10.1177/1524839908325267

Reynolds, B., & Seeger, M. W. (2005). Crisis and emergency risk communication as an integrative model. *Journal of Health Communication*, *10*(1), 43–55. doi: 10.1080/10810730590904571

Robbins, J. C., & Titley, H. A. (2018). Evaluating high-impact precipitation forecasts from the Met Office Global Hazard Map using a global impact database. *Meteorological Applications*, *25*(4), 548–560. doi: 10.1002/met.1720

Roche, S., Propeck-Zimmermann, E., & Mericskay, B. (2011). GeoWeb and crisis management: Issues and perspectives of volunteered geographic information. *GeoJournal*, *78*(1), 21–40. doi: 10.1007/s10708-011-9423-9

Rogers, D. P., Kootval, H., & Tsirkunov, V. V. (2017). Early warning, resilient infrastructure and risk transfer. In *Bridging science and policy implication for managing climate extremes* (pp. 65–79). Retrieved from www.gfdrr.org

Rollason, E., Bracken, L. J., Hardy, R. J., & Large, A. R. G. (2018). The importance of volunteered geographic information for the validation of flood inundation models. *Journal of Hydrology*, *562*, 267–280. doi: 10.1016/j.jhydrol.2018.05.002

Rossi, C., Acerbo, F. S., Ylinen, K., Juga, I., Nurmi, P., Bosca, A., … Alikadic, A. (2018). Early detection and information extraction for weather-induced floods using social media streams. *International Journal of Disaster Risk Reduction*, *30*, 145–157. doi: 10.1016/j.ijdrr.2018.03.002

Sadler, J. M., Goodall, J. L., Morsy, M. M., & Spencer, K. (2018). Modeling urban coastal flood severity from crowd-sourced flood reports using Poisson regression and Random Forest. *Journal of Hydrology*, *559*, 43–55. doi: 10.1016/j.jhydrol.2018.01.044

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. Retrieved from www.nat-hazards-earth-syst-sci-discuss.net/nhess-2018-26/

Saint-Martin, C., Javelle, P., & Vinet, F. (2018). DamaGIS: A multisource geodatabase for collection of flood-related damage data. *Earth System Science Data*, *10*(2), 1019–1029. doi: 10.5194/essd-10-1019-2018

Schnebele, E., & Cervone, G. (2013). Improving remote sensing flood assessment using volunteered geographical data. *Natural Hazards and Earth System Science*, *13*(3), 669–677. doi: 10.5194/nhess-13-669-2013

Scolobig, A., Prior, T., Schröter, D., Jörin, J., & Patt, A. (2015). Towards people-centred approaches for effective disaster risk management: Balancing rhetoric with reality. *International Journal of Disaster Risk Reduction*, *12*, 202–212. doi: 10.1016/j.ijdrr.2015.01.006

Sebastian, A., Lendering, K., Kothius, B., Brand, N., Jonkman, S. N., van Gelder, P., … Lhermitte, S. (2017). *Hurricane Harvey Report: A fact-finding effort in the direct aftermath of Hurricane Harvey in the Greater Houston Region*. Delft: Delft University Publishers.

Sharma, V. K., Rao, G. S., Amminedu, E., Nagamani, P. V., Shukla, A., Rao, K. R. M., & Bhanumurthy, V. (2016). Event-driven flood management: design and computational modules. *Geo-Spatial Information Science*, *19*(1), 39–55. doi: 10.1080/10095020.2016.1151212

Simon, T., Goldberg, A., & Adini, B. (2015). Socializing in emergencies - A review of the use of social media in emergency situations. *International Journal of Information Management, 35*(5), 609-619. doi: 10.1016/j.ijinfomgt.2015.07.001

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. doi: 10.1016/J.FIRESAF.2014.05.021

Smith, L., Liang, Q., James, P., Lin, W., & Qiuhua Liang, C. (2017). Assessing the utility of social media as a data source for flood risk management using a real-time modelling framework. *Journal of Flood Risk Management*, *10*(3), 370–380. doi: 10.1111/jfr3.12154

Steed, R. J., Fuenzalida, A., Bossu, R., Bondár, I., Heinloo, A., Dupont, A., … Strollo, A. (2019). Crowdsourcing triggers rapid, reliable earthquake locations. *Science Advances*, *5*(4), 1-6. doi: 10.1126/sciadv.aau9824

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. doi: 10.1016/j.ijdrr.2017.06.009

Taylor, A. L., Kox, T., & Johnston, D. (2018). Communicating high impact weather: Improving warnings and decision making processes. *International Journal of Disaster Risk Reduction*, *30*, 1–4. doi: 10.1016/j.ijdrr.2018.04.002

Thakur, G., Sims, K., Mao, H., Piburn, J., Sparks, K., Urban, M., … Bhaduri, B. (2018). Utilizing geo-located sensors and social media for studying population dynamics and land classification. In S.-L. Shaw & D. Sui (Eds.), *Human dynamics research in smart and connected communities* (pp. 13–40). Switzerland: Springer, Cham.

Tkachenko, N., Jarvis, S., & Procter, R. (2017). Predicting floods with Flickr tags. *PLoS ONE*, *12*(2), 1-13. doi: 10.1371/journal.pone.0172870

Ton, K. T., Gaillard, J. C., Cadag, J. R., & Naing, A. (2017). It takes two to tango: Integrating meteorological knowledge and actions for disaster risk reduction. *Climate and Development*, *9*(6), 479–492. doi: 10.1080/17565529.2016.1174658

UNISDR. (2005). Hyogo Framework for Action 2005-2015 [PDF file]. Retrieved from www.unisdr.org/files/1037_hyogoframeworkforactionenglish.pdf

UNISDR. (2015). Sendai Framework for Disaster Risk Reduction. doi: A/CONF.224/CRP.1

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), 26-34. doi: 10.1177/1524839908322113

Wagenmaker, R., Weaver, J., Garnet, G., Perry, B., Spinner, J., & Mann, G. (2011). *NWS Central Region Service*

Assessment Joplin, Missouri, Tornado – May 22, 2011. Missouri, US: National Weather Service.

Weyrich, P., Scolobig, A., Bresch, D. N., & Patt, A. (2018). Effects of impact-based warnings and behavioural recommendations for extreme weather events. *Weather, Climate, and Society*, *10*, 781–796. doi: 10.1175/WCAS-D-18-0038.1

WMO. (2017). *Joint meeting of the Commission For Basic Systems Open Programme Area Group on Public Weather Services Delivery (Opag-Pwsd) Expert Teams on Impact of Multi- Hazard Prediction and Communication (Et/Impact) and on Services and Products Innovation and Improvement*. Switzerland: WMO.

WMO. (2018). *Multi-hazard early warning systems: A checklist*. Switzerland: WMO.

Wu, D., & Cui, Y. (2018). Disaster early warning and damage assessment analysis using social media data and geo-location information. *Decision Support Systems*, *111*, 48–59. doi: 10.1016/j.dss.2018.04.005

Zhang, Q., Li, L., Ebert, B., Golding, B., Johnston, D., Mills, B., … Keller, J. (2019). Increasing the value of weather-related warnings. *Science Bulletin*, *64*(10), 647–649. doi: 10.1016/j.scib.2019.04.003

Zolkafli, A., Brown, G., & Liu, Y. (2017). An evaluation of Participatory GIS (PGIS) for land use planning in Malaysia. *The Electronic Journal of Information Systems in Developing Countries, 83*, 1–23.

This page intentionally left blank.

Citizen science as a catalyst for community resilience building: A two-phase tsunami case study

Emma E. H. Doyle[1],
Emily Lambie[1],
Caroline Orchiston[2],
Julia S. Becker[1],
Lisa McLaren[1],
David Johnston[1],
Graham Leonard[3]

[1] Joint Centre for Disaster Research, Massey University, Wellington, Aotearoa New Zealand.

[2] Centre for Sustainability, University of Otago, Dunedin, Aotearoa New Zealand.

[3] GNS Science, Avalon, Lower Hutt, Aotearoa New Zealand.

Author correspondence:
Emma E. H. Doyle,
Joint Centre for Disaster Research,
Private Box 756,
Wellington 6140
Aotearoa New Zealand.
Email: e.e.hudson-doyle@massey.ac.nz

URL: http://trauma.massey.ac.nz/issues/2020-1/AJDTS_24_1_Doyle.pdf

Abstract

The role of citizen science in natural hazard risk awareness, assessment, mitigation, and preparedness is being recognised as an important element of disaster risk reduction. Citizen science has potential as a collaborative resilience building activity that can help build the capacity of, and relationships between, individuals, communities, and institutions to prepare and respond to disaster. Specifically, citizen science can increase resilience by building the collective- and self-efficacy of individuals, organisations, and communities as well as other factors such as enhancing planning, coping mechanisms, social capital, community participation, leadership, empowerment, trust, and a sense of community. We present a case study of a two-phased citizen science initiative related to tsunami preparedness and response, undertaken between 2015 and 2016 in Orewa, Auckland, Aotearoa New Zealand. The activities of the first phase acted as a catalyst for the second phase and thus contributed directly to resilience building. Phase One was a citizen-initiated, co-developed survey on tsunami preparedness and intended response. The results from the survey, showing that participants had a low understanding of appropriate response to a potential tsunami threat, were used by community leaders to develop a community preparedness and awareness-building exercise: Phase Two. Phase Two was a joint citizen and agency-facilitated tsunami evacuation exercise "Ahead of the Wave", with science-led data collection on evacuation numbers and timing. This initiative was aimed at improving the response capacity of a coastal community at risk of tsunami and was initiated by the community itself with support from other agencies. We present an overview of the methodological approaches taken to understand community resilience to tsunami risk in Orewa. Further, we highlight the importance that researchers working in the citizen science space must recognise the time required to invest in co-production and the importance of understanding the different motivations of organisations and individuals.

Keywords: *tsunami, citizen science, community resilience, disasters, evacuation, warnings*

Citizen science is a rapidly growing area of practice and research in natural hazards and disaster risk management. Individuals and organisations recognise that citizen science has potential for collaborative resilience building and the co-production of hazard and risk knowledge and mitigation initiatives. As outlined in Aotearoa New Zealand's "A Nation of Curious Minds" government strategic plan on science and technology engagement (MBIE, 2014), such programmes seek to enhance scientific understanding and knowledge and develop community interest in science through citizen science initiatives. Developing citizen science partnership programmes to work with communities to identify and mitigate environmental risk is also highlighted in this plan as a key objective. The wide range of stakeholders and complexities in disaster risk management and citizen science can make effective collaboration challenging, particularly for resilience building and disaster risk management. Relevance, transparency, trust, partner equity, and politics are all identified as challenges for effective collaboration (e.g., Doyle, Becker, Neely, Johnston, & Pepperell, 2015). In Aotearoa New Zealand, emergency management requires collaboration, which is reflected in its Civil Defence and Emergency Management (CDEM) Act

2002 and the related National Strategy (MCDEM, 2008). Likewise, as articulated in the "Nation of Curious Minds", Aotearoa New Zealand's national science direction also explicitly calls for research to involve partnerships and collaboration (MBIE, 2014).

A wide range of research has identified related factors that help build community resilience and the capacity of individuals, communities, and institutions to respond to disasters (e.g., Lindell & Prater, 2002; Paton & Johnston, 2006; Solberg, Rossetto, & Joffe, 2010; Whitney, Lindell, & Nguyen, 2004), including in particular the importance of collective and self-efficacy (Becker, Paton & McBride, 2013; Lindell & Whitney, 2000; Paton & Johnston, 2006; Paton et al., 2010) which is the belief that a community or individual, respectively, can do something to prepare for, or respond to, an event. Other (interdependent) factors that influence resilience-building actions include outcome expectancy, action coping, planning, responsibility, social capital, community participation, leadership, individual and community empowerment, trust, sense of community, and place attachment (see also Aldrich & Meyer, 2014; Becker, Johnston, & Paton, 2015; Becker, Paton, Johnston, & Ronan, 2014; Norris, Stevens, Pfefferbaum, Wyche, & Pfefferbaum, 2008; Paton et al., 2010).

Resilience-building methods help to increase these resiliency factors in communities. For example, research shows that participating in activities focussed on solving hazard-related problems helps to develop self-efficacy and positive outcome expectancy and motivates people to undertake practical actions to prepare for events (Paton & Johnston, 2006). Various types of participatory activities could be undertaken, and such activities might be organised and facilitated by external agencies (e.g., by national or local government agencies or Non-Government Organisations) or by citizens themselves. Specific examples of such activities include door-knocking to discuss hazard and preparedness messages, hazard mapping exercises, training for emergencies, community response planning, drills and exercises, evaluation initiatives (Becker, Paton, Johnston, Ronan, & McClure, 2017; Finnis, 2007), and community-based scientific data collection, which is often framed as citizen science.

Citizen science is a broad term that encompasses a variety of different types of projects where the public work with academic researchers to undertake scientific research. It has been popular during recent years in the biological sciences field but has spread to many different scientific areas, including natural hazard research. The motivations, design, and outputs of the projects vary widely. Some projects are highly participatory, where citizens are involved in the project design, data collection, and analysis. Others are designed and coordinated solely by the scientist, and citizens only contribute limited amounts of data. Both ends of this spectrum, and all projects in between, can be effective for creating new scientific outputs (Bonney, Ballard, et al., 2009; Bonney, Cooper, et al., 2009; Haklay, 2013; Shirk et al., 2012).

Citizen science approaches have been applied by hazard and disaster researchers so that there is now a wide range of hazard-focussed citizen science projects, including on tornadoes, volcanoes, earthquakes, and flooding. Examples include the United States' National Weather Service SKYWARN program that collects reports of localised severe weather via citizen "storm spotters" (www.skywarn.org/), the "Felt Reports" of Aotearoa New Zealand's GeoNet (GNS Science's hazard monitoring initiative) where citizen scientists submit rapid reports of the level of shaking they have felt after an earthquake (www.geonet.org.nz/data/types/felt), and the British Geological Survey's "iGeology" which enables "citizen geologists" to submit photographs of areas of specific geologic interest, or indicate areas where geologic mapping needs to be revised or revisited (www.bgs.ac.uk/igeology/).

However, there exists a wide range of challenges in the space of community collaboration and knowledge transfer (e.g., Doyle et al., 2015; Orchiston et al., 2016), including: a) understanding and navigating the range of citizen science approaches available; b) the willingness of scientists and citizens to participate; c) the appropriateness of adapting citizen science initiatives across a range of different communities; d) trust, particularly for information sharing; e) available time and resources; f) transparency and accountability in the process; g) identifying what citizen science is and what it is not; and h) the need to consider the role of ethics in citizen science activities.

Citizen science is being recognised as an important tool that can be used in disaster risk management to facilitate collaboration and act as a catalyst for future resilience-building activities. It has the potential to: a) enhance citizens' "place" in disaster risk management discussions, b) enable traditional values and cultures to be considered, c) provide opportunities for citizens to ask questions and come to greater understanding, and d) provide an environment for intergenerational conversations and a sharing of collective wisdom (Orchiston et al., 2016). Further, citizen science can increase engagement resulting in more effective and meaningful policy development, develop trust, improve the public's understanding of science, and improve risk awareness and acceptance which are necessary to carry out preparedness activities (see also Doyle et al., 2015).

There are many aspects of project design and implementation that influence the citizen science process. These include the cost of the project and who funds it (Bonney, Cooper, et al., 2009; Bonney, Phillips, Ballard, & Enck, 2016; Silvertown, 2009; Tweddle, Robinson, Pocock, & Roy, 2012), the technology used within the project design (Bonney et al., 2014; Bowser & Shanley, 2013; Haklay, 2014; Peters, 2016; Silvertown, 2009), and the resources and tools made available to the participants (Bonney et al., 2016; Bonney et al., 2014; Bowser & Shanley, 2013; Peters, 2016; Silvertown, 2009). The timeframe of the project and its development also influence this process (Bowser & Shanley, 2013; Peters, 2016), as well as the ethics process (Bowser & Shanley, 2013; Eitzel et al., 2017; Orchiston et al., 2016; Riesch & Potter, 2014) and the training provided (Becker-Klein, Peterman, & Stylinski, 2016; Bowser & Shanley, 2013; Hennon et al., 2015; Straub, 2016).

Other issues to consider include how much the participants trust in the process (Lewandowski & Oberhauser, 2016; Kelman, Lewis, Gaillard, & Mercer, 2011; Soleri, Long, Ramirez-Andreotta, Eitemiller & Pandya, 2016), the quality of the data collected (Bowser & Shanley, 2013; Bonney et al., 2014; Riesch & Potter, 2014; Soleri et al., 2016), the terminology used (Eitzel et al., 2017; Johnson, 1992; Lewandowski, Caldwell, Elmquist, & Oberhauser, 2017; Riesch & Potter, 2014; Straub, 2016), maintaining the partnerships formed during the project (Bonney et al., 2016; Kearney, Wood & Zuber-Skerritt, 2013; Soleri et al., 2016), and the initial purpose or motivations behind the project design (Bonney et al., 2016; Raddick et al., 2013; Straub, 2016; Tweddle et al., 2012).

In this paper, we outline a methodological case study approach developed during a two-phased citizen science initiative focussed on tsunami preparedness and response in Orewa, Auckland, Aotearoa New Zealand. In doing so, we describe the process of developing the initiative, rather than evaluating the outcomes of the activities, to highlight issues of relevance for future hazard-related citizen science project design and implementation. The case study took place between 2015 and 2016, and involved Phase One, a citizen-initiated co-developed survey on tsunami preparedness and intended response actions by local residents, and from this Phase Two, a joint citizen and agency-facilitated tsunami evacuation exercise "Ahead of the Wave", with science-led data collection on evacuation numbers and timing. This initiative was aimed at improving the response capacity of a coastal community at risk of tsunami and was initiated by the community itself with support from other agencies as part of a community preparedness and awareness-building exercise.

Case Study Context

Orewa is a partially low-lying community with many people residing less than one kilometre from the beach and within three metres above sea level. It is at risk from local, regional, and distant source tsunami and storm surge, as well as the occurrence of king tides. Tsunami inundation modelling has identified Orewa as being the most exposed community to tsunami in the Auckland region, with a potential 6,521 people exposed as of 2015 (Horspool, Cousins, & Power, 2015; Woods & Lewis, 2017). Local and regional tsunami in particular pose the greatest risk. As illustrated in Figure 1, this modelling gives residents under an hour to undertake an evacuation response for a local source tsunami event. Effective individual and community response to natural warnings in this timeframe will be vital for life safety. Thus, to improve the tsunami response capacity of Orewa residents, they need to be actively involved in understanding their risk and identifying practicable risk management solutions and preparedness initiatives. Additionally, it is important for residents to practice evacuation procedures.

To improve citizens' awareness of their risk and evacuation zones and routes, Auckland Civil Defence Emergency Management have developed a series of tsunami evacuation maps for all of Auckland's coastline. These maps identify three different evacuation zones depending on the modelled inundation and source of the tsunami[1] as well as public messaging that encourages people to be aware of natural, official, and unofficial warnings[2]. Citizen science activities also present opportunities for a "whole of community" approach to

1 https://aucklandcouncil.maps.arcgis.com/apps/MapSeries/index.html?appid=81aa3de13b114be9b529018ee3c649c8

2 www.aucklandemergencymanagement.org.nz/hazards/tsunami

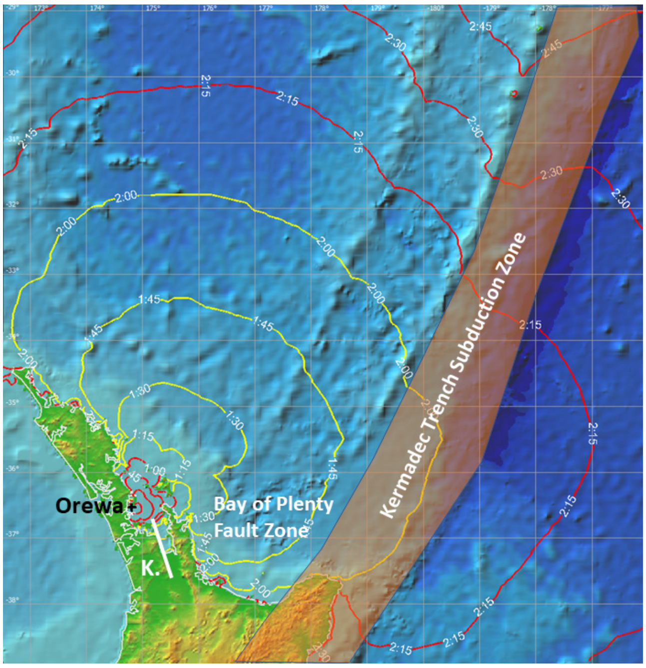


Figure 1. Tsunami travel time (t) contours for Orewa in 15-minute increments, calculated with WinITDB (Windows Integrated Tsunami Database; see http://tsun.sscc.ru/WinITDB.htm). The different coloured lines are associated with t < 1 hour, t = 1-2 hours, and t > 2 hours. Also shown on the figure are approximate locations of the Kermadec Trench Subduction Zone, the Bay of Plenty Fault Zone, and the Kerepehi Fault (labelled as K). Travel times to the west coast of North Island are not shown. Image courtesy of William Power, GNS Science, Aotearoa New Zealand, produced August 2019. We also thank David Burbidge for contributing to its production.

preparing and addressing Orewa's tsunami risk, as they increase collaboration, participation, and knowledge transfer between community members, decision makers, government agencies, scientists, and higher education institutions.

Active community participation is particularly important for schools and their families and communities (Johnston et al., 2016). For example, research by Nakahara and Ichikawa (2013) after the 2011 Tohoku earthquake and tsunami in Japan identified that school preparedness levels directly influenced child mortality rates. As discussed by Johnson, Johnston, Ronan, and Peace (2014), if parents and caregivers are unaware of a school's tsunami evacuation plans, including plans to evacuate to tsunami safe zones, there is an increased likelihood that they may put themselves at risk by going to the school to collect children during an event, thus slowing their own evacuation process (see also Johnston et al., 2016). It is thus vitally important that such communities plan, prepare, exercise, and review best practice for tsunami by incorporating schools, school children, and the wider community as part of the processes. Such plans and procedures are also required by schools under Aotearoa New Zealand's health and safety legislation (Health and Safety Act 2015). A school's Board of Trustees is legally required to ensure the school they govern has an emergency management plan, which is self-reported to the Education Review Office every three years. Accordingly, since 2015, a number of Orewa community and council-led initiatives have been developed to address this issue of tsunami preparedness in schools and their connected communities. This has included the use of citizen science methods to address critical science questions such as whether people know what to do in tsunami, how long the school children will take to evacuate to safe zones, and what challenges might arise. These methods have also helped to involve the community in the development of their understanding of these issues as part of a public education initiative.

We outline the methodology for the case study approach presented here then we discuss the results from these case studies which are relevant to the *process* of the citizen science initiative and the outcomes it created. In our discussion and conclusions we consider the impact of such an initiative on the development of effective collaborative partnerships and the community's overall resilience. We highlight aspects of this initiative that could be successfully applied to future citizen science projects, in terms of connecting and engaging with at-risk communities, and conclude that one of the main benefits of citizen science in disaster risk management is the potential to catalyse subsequent resilience building activities across individuals, agencies, communities, and regions.

Method

The method for this paper is a case study approach, which develops an analysis of a "set of related events with the specific aim of describing and explaining the phenomenon" (Berg, 2007, p. 283). The definition of what constitutes a case varies and can consider a single case, a number of cases, an individual, an organisation, a group, or an event (such as an aspect of organisational change; Burton, 2000). Such case studies investigate contemporary phenomena within their real-life context (Verschuren, 2003; Yin, 1989) and provide a pragmatic and flexible research approach that provides understanding of processes, behaviours, practices, and relationships across a diverse range of issues in context (Harrison, Birks, Franklin, & Mills, 2017).

The two-phased citizen science initiative reported here collected qualitative researcher observations of the development and occurrence of tsunami citizen science activities through the case study of Orewa. As part of our observational process, we looked closely at the type of data collected, including the quantitative results from the Phase One surveys and the Phase Two structured tsunami evacuation exercise. Short follow up conversations occurred with people involved in the activities to confirm details about their impressions of how the events unfolded and the timeline of events, to gather their perceptions of the influences and outcomes of the process, and to identify all stakeholders involved. This information was then analysed at a high level in the context of citizen science and resilience literature, with the aim of highlighting some of the influences on the citizen science process for Orewa, and how these affected outcomes.

We discuss the case study in two phases, with Phase One representing the commencement of the citizen science project with a community-initiated quantitative survey in August 2015, and Phase Two representing the tsunami walk exercise, which occurred on 25 May 2016. Findings from the Phase One survey are presented as these were important for the rationale and development of Phase Two. We also document the interactions and co-production process that occurred between community leaders, higher education institutions, schools, and the local council before, during, and after these phases. Such documentation covers the process of undertaking the citizen science project, to identify lessons that can be applied to the development of future such activities, rather than reporting direct outcomes of these activities.

Results

Phase One: Community-initiated Quantitative Survey

Survey development. Rotary club members had identified Orewa was at risk from tsunami and wanted to understand their communities' perception and understanding of tsunami risk, as well as preparedness and intended behavioural responses to a potential future tsunami. The Director of Rotary's disaster awareness CHIP-In Project (**C**an **H**elp **I**f **P**ossible, **I**f **N**eeded) approached the Joint Centre for Disaster Research (JCDR) at Massey University in June 2015 for support to assist in the design and implementation of a tsunami awareness survey within the Orewa community. Rotary intended to use the results of the survey to understand how they could best use their limited financial resources to assist in building community preparedness.

Following an initial scoping conversation in May 2015, Rotary's questions were captured in a survey drafted by JCDR research staff. The survey was then developed and refined further with input from members of the Rotary Group, to ensure their particular areas of interest were covered in the range of questions. Auckland Council were also recognised as partners in survey development and were invited to participate, with the understanding that this survey would be community-led and the JCDR and Auckland Council were advisors to the process, maintaining an ongoing relationship. By August 2015, the Rotary clubs of Orewa, Westhaven, and Auckland, in association with the JCDR and Auckland Council, had co-developed a survey aimed at understanding the tsunami risk perception of the Orewa community, how prepared they were for a tsunami, and what they were likely to do in a tsunami event (e.g., in terms of expectations of warning time and intended evacuation behaviour), as well as their awareness of all hazards likely to affect the Orewa area. The full survey can be found in Appendix 1. Low risk ethics notifications were submitted through Massey University of New Zealand.

Data collection. Rotary members suggested that the research project could involve volunteers from the Interact Club of Auckland Grammar School[3] to increase community participation. This group of volunteers are involved with various community projects and are sponsored by Rotary Clubs. Rotary members sought the availability of volunteers and provided context about the research project and what their involvement required.

The survey data collection was carried out on Saturday 22 August (see Appendix 2 for the press release issued by Rotary). On the day of the survey, volunteers were divided into groups of three or four and were accompanied by either a Rotarian or a researcher from the JCDR. Mobile technology devices (tablets) were used for survey data collection. The survey was uploaded onto Survey Gizmo, an online survey software tool, selected because of the offline setting that enabled local storage of results when an Internet connection was not available.

3 The Interact club is an initiative developed by Rotary to build their youth membership at secondary schools (www.rotary.org/en/get-involved/interact-clubs).

A 30-minute pre-survey role play exercise was undertaken before the students interviewed participants and collected data. Rotarians and researchers observed this training so they could assist the students when undertaking the interviews. The purpose of the role play was to train the students in how to approach members of the community, how to answer common questions about tsunami, and provide information to participants regarding existing tsunami preparedness resources. Each group of students was also provided a hard copy of responses to common questions that participants might ask, such as, "What is a tsunami?" or "What is the tsunami risk in this area?". They could refer to these during the survey process to answer any questions posed by participants. The short role play exercise was an engaging way for the volunteers to understand survey dissemination and learn techniques for approaching members of the public.

Each survey team was provided with a tablet and all the devices were synced to the same Survey Gizmo account. Each group was also provided with hard copies of the survey for instances where the participant preferred to read through a hard copy or if either the technology or the survey tool was not working. Surveys were disseminated by approaching community members in public places (i.e., businesses, residents, and passers-by) and asking them to volunteer to answer a face-to-face survey.

A total of 94 surveys were collected with each survey taking approximately 10-15 minutes to complete. At the end of the survey, participants were also able to provide their contact details to the Rotary Club if they were interested in receiving further information regarding tsunami risk. The intention of Rotary members was to use the contact information to conduct a follow-up survey focused on business continuity. Additionally, the Chip-In Foundation set up a pop-up information centre for the day and provided residents and visitors with maps and reports on the tsunami risk for Orewa, a video, and assistance on planning personal, family, business, and school evacuations. These resources were available online via Auckland Council Civil Defence Emergency Management (CDEM).

Survey findings. Because the findings of the survey in Phase One informed the rationale and development of Phase Two, relevant findings are presented here. Analysis of the survey data was conducted by researchers at the JCDR. The results of the survey revealed that local residents in Orewa had a general understanding of the risk of various natural hazards in their area. Flooding and tsunami were rated as the two most likely hazards to occur (55% and 51% respectively), followed closely by storms or cyclones with high winds (49%). It is noted that the title of the survey, "Orewa tsunami survey", may have led respondents to select tsunami as a likely hazard. Coastal erosion (27%) was selected by a smaller but still considerable proportion of participants. Earthquakes (7%), forest or bush fire (2%), and ashfall from a volcanic eruption (1%) were least likely to be selected.

Sixty five percent of respondents believed that a tsunami was likely to occur within their lifetimes, with the majority (58%) believing that tsunami were not too destructive to prepare for. However, 28% believed that it was unnecessary to prepare for a tsunami as assistance would be provided by the local and regional councils or Civil Defence Emergency Management. Nearly a third (27%) of people believed that their property would never be damaged by a tsunami.

Knowledge of what to do, especially after experiencing the natural signal of a strong or prolonged earthquake, was relatively low, with only 13% of people indicating that they would evacuate immediately after shaking stopped. The majority of people indicated they would wait for official word from CDEM or other sources to be told what they should do. The majority also said they would evacuate by car rather than the recommended method of walking for all able-bodied people.

Seventeen percent of people indicated that an earthquake would be the warning for a tsunami arriving within the next 12 hours. Nearly two-thirds (63%) expected to hear radio and TV announcements, 61% expected to hear a siren, and 26% expected to hear loudspeaker announcements. Respondents also stated they expected to be warned by texting or other messaging systems (32%), word of mouth (21%), a door-to-door visit by emergency services or Civil Defence staff (19%), and flashing lights (9%). Six percent did not know how they would be warned. Currently, there are a number of alerting mechanisms across the Auckland region, including sirens[4], digital signage, and SMS and email notification to subscribed users[5], as well as other alerting systems such as broadcast radio and the Red Cross Hazards App[6]. In late 2018, Auckland

4 www.aucklandemergencymanagement.org.nz/useful-information#tsunami-warning-sirens

5 www.aucklandemergencymanagement.org.nz/auckland-emergency-management/subscribe-to-emergency-alerts

6 www.redcross.org.nz/what-we-do/in-new-zealand/disaster-management/hazard-app/

Emergency Management moved through the final stages of confirming a tsunami siren pilot for Orewa which will include both a Public Alerting (PA) siren system and electronic safe swim signs ("Orewa gets tsunami sirens pilot", 2018).

While the survey results showed that awareness of tsunami was high, people's knowledge of what to do following an earthquake was poor, making it a concern for future response to tsunami. The low understanding of what to do may stem from a range of factors including a lack of awareness of what behaviours are beneficial, the perception among some that a tsunami is too destructive to prepare for, or the expectation that agency help and guidance will be immediately available. The Orewa survey results are comparable to surveys undertaken in other areas in Aotearoa New Zealand, particularly with respect to reliance on agency support or warnings (Currie et al., 2014; Dhellemmes, Leonard & Johnston, 2016; Fraser et al., 2016; Johnston et al., 2016; Tarrant et al., 2016).

As part of the follow-up activities, members of the Rotary Club presented the lessons learned from the Orewa survey at the Auckland CDEM Group committee meeting on 25 August 2015. Feedback they received about this presentation was positive and there was an interest in the survey results, particularly regarding how the initiative could be replicated in other communities. The Interact volunteers from Auckland Grammar School were also recognised as making an excellent contribution.

Interim activities. Orewa Rotary Club continued their efforts after the survey with a variety of awareness projects, including talking to Auckland Council (mentioned above) and businesses in Orewa about developing an evacuation plan. Rotary used the results of the survey to develop, with the aid of the community, solutions to raise tsunami awareness and preparedness. For example, the concept of a co-developed dual-purpose visitor walkway that doubles as a tsunami evacuation route was explored as a potential way to increase awareness about appropriate evacuation behaviour.

Additional efforts to develop tsunami preparedness in Orewa following Phase One included the development of preparedness brochures which were distributed to businesses (approximately 400) and households (n = 3,300) in Orewa via a door-to-door "pamphlet drop". The face-to-face contact and conversations that occurred between the Rotarian volunteers and local community members during the pamphlet drop process was highlighted as being of particular benefit for community preparedness (Auckland Council, 2016), helping to also ensure the sustainability of tsunami-related activities in Orewa. The role of a trusted organisation such as Rotary visiting door-to-door cannot be underestimated since some people may not answer the door to other types of approaches.

Phase Two: Tsunami Evacuation Exercise

On 25 May 2016, a tsunami evacuation exercise was undertaken in Orewa (Rotary & Auckland CDEM, 2016). The development of the exercise built on the partnership between Rotary and Auckland Council that had been developed the previous year, discussed above, and was again supported by the JCDR. It was initiated jointly by Rotary and Auckland Council in response to the activities that had occurred in Phase One, with Auckland CDEM acting as "exercise control" on the day. The tsunami walk, called "Orewa: Ahead of the Wave" (see flyer in Appendix 3), was intended as a "tsunami public education preparedness event" to help individuals in the community identify and establish their quickest route to a safe location (Rotary & Auckland Council, 2016).

The overarching goals of the exercise were twofold. First, the exercise was designed to increase tsunami awareness and preparedness, which included raising local knowledge and understanding of evacuation zones, appropriate evacuation behaviour, tsunami evacuation signage and warnings, information boards, and blue lines (a line painted onto the road to identify safe zones from tsunami inundation; see Johnston et al., 2013 and Fraser et al., 2016 for details about "blue lines" projects) and encouraging household emergency plans and conversations with family members. It was important for the community to recognise that a felt earthquake could be the only warning which would require immediate evacuation and to understand the nature of official warnings and how to receive them. Achieving these goals required public meetings to socialise the nature of the event with the community and the involvement of the Orewa Business Association and greater Orewa community to engage local businesses and community members.

The second aim of the exercise was to support and monitor schools as they participated in the tsunami walk by collecting data on the timeframes and evaluating the success of the exercise. As such, it included two parts comprising "school participation" and self-managed "public participation". The exercise targeted three local schools (Orewa College: 1,900 students; Orewa North Primary: 280 students; and Orewa Primary: 450 students). The public were invited to join the schools on their walk or to walk their own route to tsunami safe zones[7]. Orewa College is in an orange zone, Orewa North Primary is in a yellow zone, and Orewa Primary is outside the inundation zone. Orewa Primary acted as the tsunami safe assembly area for Orewa College. All schools distributed tsunami information pamphlets to students prior to the tsunami exercise to initiate conversations with their families about tsunami preparedness.

Researchers from the JCDR offered support in a similar way to Phase One by providing assistance to Auckland Council and Rotary during the exercise plan development and as exercise observers and by supplying researchers to observe the walk and collect data. Social science involvement throughout the project also enabled an exercise evaluation methodology to be developed as a pilot for future citizen science self-evaluation that may be utilised in other community exercises. Three key elements to the pilot development included:

1) A self-completion survey for evacuation participants to evaluate their route, timing, and other aspects such as safety, accessibility, and welfare. The survey was completed during the pilot process by four key teachers at Orewa College. The blank survey form is included in Appendix 5.
2) The use of free GPS tracking applications by participating researchers walking the routes to log the route and timing along the route, and share this anonymously as a .GPX (GPS Exchange) file (example chart in Figure 2).
3) An observation questionnaire completed by researchers stationed at locations along and at the end of the evacuation route. It had the following components: location, weather conditions (open ended), a table to record the number of people passing the checkpoint each minute, observations of public behaviour (open ended), and any additional notes (open ended). The manual count of the number of people passing a given point each minute provided a cross check for the app data. The open-ended qualitative questions focussed on the behaviour of evacuees, the suitability of the route, and any issues seen in the evacuation.

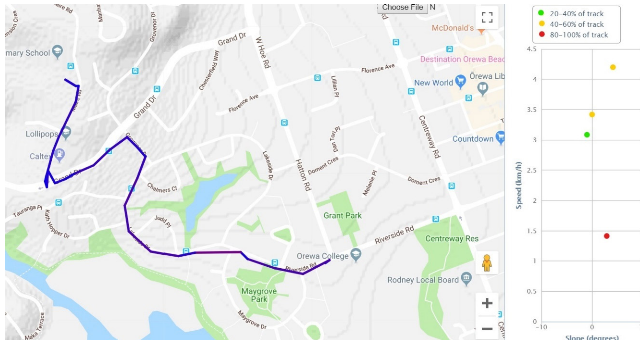


Figure 2. Anonymous file output from a free GPS application showing route and speed information for an individual following Route 2. This can also be reprocessed to show overall travel time.

On the day, exercise control resided with Auckland CDEM. A wide range of additional agencies and stakeholders were involved in a support capacity including: councillors from the Auckland CDEM Group; Hibiscus Coast Kindergarten; Early Adventures Child Care; Hibiscus and Bays Local Board; GNS Science; research staff and volunteers from Massey University, Otago University, and Auckland University; Orewa Surf Life Saving Club; More FM Rodney radio station; Hibiscus Coast Community Patrol; and East Coast Life at the Boundary (East Coast LAB[8]).

The exercise set-up, tsunami evacuation, and final debrief all occurred between 8 a.m. and 11.30 a.m., with the tsunami evacuation itself taking place between 9.30 and 10 a.m. A team of volunteers were located along the walk to ensure people could find their way and to observe and monitor the number of school participants as they passed the checkpoints. These volunteers also filled out the observer questionnaire. After practicing "Drop, Cover and Hold", participants were encouraged to walk to their nearest identified tsunami route (either Route 1 or Route 2; see Appendix 4), following the tsunami evacuation signage, and continue this route until they reached the blue line and tsunami safe zone. It is important to note that in the event of a real tsunami threat, people should "Drop, Cover and Hold' and then immediately evacuate to high ground without waiting for any official warnings.

Route 1 of the exercise, illustrated in Appendix 4, mainly involved students and staff from Orewa North Primary

7 As outlined in Appendix 4, there are three coloured zones. *Red shore exclusion zone:* Covers the beach and adjacent low-lying areas most likely to be affected by a tsunami. *Orange evacuation zone:* May need to be evacuated if there was a threat from a medium- to large-scale tsunami. *Yellow evacuation zone:* Covers the largest area that would need to be evacuated in the event of a maximum-impact tsunami.

8 East Coast Lab is a "collaborative programme that brings together scientists, emergency managers, experts and stakeholders across the East Coast to make it easy and exciting to learn more about the natural hazards that can affect [NZ's East coast]" (www.eastcoastlab.org.nz/).

school, with some members of the public (totalling 340). The school undertook a spontaneous earthquake drill at 9.25 a.m. which was based on a potential earthquake scenario where the shaking may or may not have been felt at the school but would have triggered an official warning. During this scenario the children dropped, covered, and held on in accordance with earthquake best practice. When the tsunami evacuation message from Auckland CDEM was received by the principal at 9.30 a.m., classes immediately began to evacuate onto the playing field at the back of the school. It is important to note, however, that in a real event there may not be an official tsunami evacuation warning, particularly for a near source tsunami. Local radio station More FM Rodney also broadcast a message to initiate the start of the tsunami exercise. A gate had been installed 18 months earlier at the back of the school grounds as a way to more quickly access high ground (installed after previous evacuations required students to leave via the main gate, resulting in longer evacuation times). The youngest children evacuated first, with older classes following. This was subsequently considered a slower option, and in future the principal said he would begin evacuating each class as soon as it was ready to go rather than waiting for all classes to assemble in the playing field. In total, the evacuation took 11 minutes to complete from when the first class left school grounds to the arrival of the last class at the safe zone (i.e., 9.34 to 9.45 a.m.). As the children arrived at the safe zone, they sat down to wait for instructions.

Route 2 saw 1,825 students and members of the general public evacuate during the exercise, mainly from Orewa College. The evacuation began at 9.36 a.m., six minutes after the evacuation warning was issued. Teachers wearing high visibility vests assisted during the walk. Many students reported being unsure of the evacuation route and were unable to read the map with which they were provided. The first arrivals reached the end location at 9.54 a.m., while the last arrived at 10.23 a.m., 47 minutes after the evacuation began. Exercise observers noted that older adults and those with disabilities were amongst the slowest to reach the end point.

The three datasets collected for Phase Two (self-completion survey, GPS tracking application, and observation questionnaire) were considered viable in post-event analyses and could be used by other communities in citizen science activities to help understand the components of effective tsunami evacuation. Important lessons from the Orewa exercise when using a mobile application such as the free GPS tracking application include the need to: a) access guidance on what to consider and plan before the exercise; b) provide a link to download a compatible free GPS application for some or all participants; c) provide instructions on using the application and anonymously sharing the GPX file back to the tool; d) provide a questionnaire to capture the participant and observer topics from the pilot (anonymised but linked to the GPX route); and e) incorporate a summary and reporting component to allow succinct citizen-participant self-analysis of how effective and fast the evacuation was, as well as what improvements could be made. A mobile tracking tool can also provide anonymous data to researchers which links demographics to speed and route data and can assist with refining evacuation behaviour models for both land-based and vertical building evacuation.

In the following section, we discuss the impact of the Orewa citizen science initiative, including its influence on the development of collaborative partnerships, the community's overall resilience, and the subsequent activities it inspired. We also highlight aspects of this initiative that could be successfully applied to future citizen science projects.

Discussion

Successful community-led citizen science initiatives require a number of key elements to be in place. As illustrated in this case study paper, a range of key agencies played roles in ensuring the initiation and success of the Orewa tsunami project. For example, in Phase One, higher educational institutions played an important role in responding to the approach from the Rotary Club to co-develop a survey for the community to learn about their citizens' understanding of tsunami risk. Crucial to the success of many citizen science projects is the ability for research scientists to recruit citizens. However, because this project was citizen initiated and led, citizens were already engaged and motivated to take part. The inclusion of research scientists in this way also offered the opportunity to help guide residents and resident groups through the various methods of data collection and the ethics involved in gathering data in their communities. Specifically, the JCDR: 1) listened to the needs of the Rotary Club in developing the survey and, based on this information, helped draft the initial survey; 2) ensured the data collection was done ethically; and 3) contributed resources for data collection, such as mobile technologies and the analysis of survey responses.

To empower community-led citizen science projects, higher education institutions can offer “train-the-trainer” sessions (e.g., via the role play in Phase One) on data collection methods and data analysis for community leaders of citizen science initiatives, thereby ensuring that collection of data has buy-in and is ethical, consistent, and reliable. Successful community-initiated citizen science projects also require support from trusted local leaders or groups to engage with their community, and often to take leadership of the project. These factors help to ensure that the process is personalised and relevant to the community and encourages equity between citizens and leadership in the process, factors identified as encouraging successful collaboration and knowledge transfer for building community resilience (Doyle et al., 2015).

Furthermore, involving existing local youth groups and other volunteer groups provides additional human resources for data collection. Providing volunteers with an orientation about the research and training them in data collection methods helps to increase their understanding of the “big picture” of the research and how their efforts contribute to address the wider context. For long-term data collection efforts, evaluation of volunteer experiences is essential to improving future citizen-initiated research projects and long-term engagement of volunteer support. For example, the question of how higher institutions might evolve the “train-the-trainer” immersive learning exercises to ensure core learning outcomes are achieved should be addressed.

Through the two phases of Orewa citizen science activities presented here, a number of key lessons and challenges were identified. First, collaboration and partnership between researchers and Rotary led to a co-design of Phase One via the school surveys, which then led to a much wider range of interest and participation in Phase Two from other organisations including schools, Auckland Council (particularly CDEM), local businesses, emergency service agencies, universities, and beyond. Second, the Rotary community-led citizen science project of Phase One acted as a catalyst for the much larger-scale agency-led tsunami walk in Phase Two that incorporated a more diverse group of participants. Rotary thus acted as a citizen-led hub for partnership and collaboration between researchers, communities, and CDEM.

The evolution from Phase One to Phase Two of the citizen science project demonstrates that as the scope of an activity grows, it may require a greater level of facilitation (Diaz-Puente, Galleho, Vidueira, & Fernandez, 2014; Vidal, 2009). During Phase One, the science “generated” was collected by the school students through a co-produced survey with researchers, with the findings of this survey indicating the need for more involved community tsunami awareness activities. This led to Phase Two, during which the collaborative agency-led nature of the resilience building activity (tsunami walk) meant that the “science” of the event was less co-produced and was secondary to the multiple motivations of the different stakeholder groups. Individuals from schools and the public participated in the generation and collection of tsunami travel information, yet the core motivation was providing people with an experiential tsunami awareness event. However, there was still co-production of knowledge as Auckland Council and Rotary worked alongside a range of community groups, businesses, and agencies to identify key issues and solutions regarding tsunami preparedness, evacuation, and signage (including such issues as safely crossing major highways).

The different nature of these two phases of citizen science projects fits across all three of the citizen science categorisations of Bonney, Ballard, et al. (2009), Bonney, Cooper, et al. (2009), and Shirk et al. (2012), who define: 1) “Contributory projects” that are designed by scientists, where citizens contribute data; 2) “Collaborative projects” designed by scientists and where citizens contribute data, but may also help in project design, analysis, or dissemination; and 3) “Co-created projects” designed by scientists and citizens working together and where at least some of the participants are actively involved throughout all or most of the scientific process. The first phase was a “co-created” project, while the second phase was “collaborative” with some “contributory” elements.

Additional benefits from events such as these include not just the increased collaboration, trust and relationship building, awareness, empowerment, education, and the science itself (Becker et al., 2015), but also the range of resources that were developed and the “spin-off” community resilience projects which were subsequently developed. From an Auckland Council perspective, the tsunami walk and related activities significantly increased the awareness and understanding of tsunami risk and inspired locally-driven public education about tsunami in Orewa. For example, Auckland Council ran a tsunami preparedness competition within the schools that took part in the walk, to continue to develop conversations about preparedness. The experience of the tsunami evacuation exercise was used to inform the development of Auckland's public alerting and public education strategy and supported other work programmes. In addition, lessons from this program of work informed Auckland Council's support of the development of a national guideline on vertical tsunami evacuation (MCDEM, 2018). Future work by the council will continue to explore how to incorporate citizen science into future preparedness and resilience building work.

The activities in Orewa also acted as a catalyst for activities across Aotearoa New Zealand. The planning and logistics required to develop the tsunami exercise were documented in a tsunami evacuation planning project template which can be applied to other communities in Auckland and beyond. For example, East Coast LAB utilised resources from the Orewa project to generate a set of tsunami *hīkoi* ("walk") guidelines that also included lessons from their observations of the Orewa "Ahead of the Wave" walk and similar tsunami walk activities in the United States. These guidelines have been actively used as a resource by Hawke's Bay CDEM and Bay of Plenty CDEM within their communities. The Phase Two tsunami walk also resulted in the planning of a Cape Coast tsunami hīkoi by CDEM volunteers, supported by Hastings CDEM, and in partnership with East Coast LAB. This was unfortunately cancelled due to bad weather; however, the resources were utilised in a colouring and poster competition through social media, shops, schools, and community centres. The Phase One tsunami awareness survey in Orewa also now serves as a useful resource for other communities and schools and was used as a basis for a citizen science project on tsunami awareness and preparedness run by students at Napier Girls High School as part of their geography course work, in collaboration with East Coast LAB. Finally, the GPS tracking application activity in Orewa also formed the basis for a new researcher-led agent-based modelling project entitled "Quicker Safer Tsunami" aimed at understanding effective evacuation routes in three areas of Aotearoa New Zealand: Petone, Napier, and Sumner.

These spin-off events demonstrate how the initial community and agency relationships, leadership, and facilitation of a citizen science event acted as a catalyst for a suite of community resilience and knowledge transfer processes. As stated by Doyle et al. (2015), "both leadership and facilitation are often needed to start community resilience processes" (p. 64). For effective collaboration on disaster risk management to occur, particularly when community collaboration, knowledge transfer, and citizen science approaches are involved, there exists a challenging question: who and what is the catalyst for such collaborative activities? Key challenges in community collaboration include available time and resources, relevance, and willingness or interest from scientists, citizens, and relevant agencies to participate (see earlier; Bonney et al., 2014; Doyle et al., 2015; Kearney et al., 2013; Kelman et al., 2011; Orchiston et al. 2016; Soleri et al., 2016). Effective facilitation should thus empower communities to identify and solve their own problems (Vidal, 2009) by providing guidance and facilitation at an equal level that ensures the initiative is still a community-driven project (Doyle et al., 2015). For community resilience building, it is also vital that relevant agencies and practitioners are involved to provide support and guidance to ensure expectations are met and practical initiatives that are identified can be implemented.

The different nature of the two phases presented here also highlights the importance of recognising that any project may have multiple requirements and motivations and that researchers working in the citizen science space must recognise the different motivations of organisations and individuals. The first phase of activities was motivated by a clear citizen science goal and the co-generation of "science" through community-led surveys, where a community organisation wanted to develop a greater understanding of their community's tsunami awareness and preparedness. Meanwhile, the second phase of activities was motivated primarily as a community resilience building activity, was not initially planned as an output of Phase One, and had a secondary goal of data collection by the research community. Phase Two aimed to enhance community awareness and preparedness while the citizen science element identified the speed and effectiveness of trial tsunami evacuations.

The aims and motivations varied across the phases (i.e., with the clear goal of resilience in Phase Two). However, resilience-building likely took place across the whole initiative. For example, collective efficacy, or the belief that people can work together effectively to prepare for an event, has been found to be key to motivating people to undertake preparedness actions (Paton et al., 2010). This effect tends to be stronger in countries that share cultural beliefs about the utility of collectivism (e.g., Japan, Taiwan; Paton, 2018) whereas countries which have higher levels of individualism (such as Aotearoa New Zealand) are less likely to have a collective efficacy belief (Paton, 2018). This means that more focus is required on the development of positive outcome expectancy (i.e., the belief that undertaking a certain action beforehand will be beneficial in a subsequent disaster, for example in terms of survival or safety) before collective efficacy can be built (Paton, 2018). Citizen science initiatives such as that for Orewa presented here can have multiple components that address such issues. The role-plays, surveys, and tsunami exercise used in this case study all had critical roles in raising awareness about the issue of tsunami risk through collective and experiential learning. Additionally, the process provided practical solutions for preparing for, and responding to, such an event and thus targeted outcome expectancy beliefs. The activities also provided a means for developing collective efficacy as they brought people together in a participatory fashion to discuss and solve issues, thus likely helping develop the belief that by working together they could prepare and respond to a future event. As mentioned previously, the various activities were facilitated by a number of different agencies, highlighting both the importance of leadership in the process (e.g., Doyle et al., 2015; Paton 2006; Paton & Johnston, 2006) and the interactive nature of resilience.

Engagement in communities with high risk from hazard events is challenging to initiate and to sustain. Rotary and Auckland Council acknowledged “it is the people who live in Orewa and Rotarians who are passionate about volunteering in the community who will drive the Orewa Tsunami Preparedness project – without the involvement of Rotary to coordinate this, tsunami preparedness will not be sustainable” (Rotary and Auckland Council 2016, p. 1). However, while challenging, the benefits of such events include individual and community empowerment and agency, understanding of risk and expected or ideal behaviours and actions, and the strengthening of partnerships and relationships between individuals, communities, and agencies (Bonney et al., 2016; Kearney et al., 2013; Soleri et al., 2016).

Citizen science and collaborative resilience-building activities also provide opportunities for scientists to ensure the science they (co-)develop and communicate is useful, useable, and used (Aitsi-Selmi, Blanchard, & Murray, 2016; Rovins, Doyle, & Huggins, 2014) and that research is “socially responsible” (Daedlow et al., 2016) in terms of societal goals and values, where the “transparent information and involvement of stakeholders during the research process can mitigate uncertainties and risks and is a morally responsible action” (p. 4; see also Hudson-Doyle, Paton, & Johnston, 2018).

Limitations and Future Work

This paper presents our observations and experiences of the evolution of a citizen science activity into a suite of community resilience building activities. Evaluation of the efficacy of such activities was not the focus of this study and is recognised as a limitation. Future activities that integrate citizen science and community resilience building should thus include evaluation, as advocated for by Johnson et al. (2014), Tipler, Tarrant, Johnston, and Tuffin (2016), and Johnston et al. (2016). For example, evaluation should consider how the tsunami walk increased people’s awareness of their evacuation route, the degree to which the initial survey in Phase One motivated people to identify tsunami preparedness activities, and the degree to which these activities influenced community resilience building factors (such as self and collective efficacy). Such evaluation tools can be part of the citizen science process. As researchers we also identified that future research would benefit from qualitative interviews with members from across the agencies, organisations, and schools that participated, to identify their experiences and perceptions of the process, within a time window when such views are still “fresh”. Unfortunately, due to limited resources, this was not possible for these events.

In addition, future research should consider the role of funding, leadership, and ethical standards as well as codes of practice and professional guidelines for participatory approaches to science, engagement, and citizen science (e.g., Beven, Lamb, Leedal, & Hunter, 2015; Faulkner, Parker, Green, & Beven, 2007; Janssen, Petersen, van der Slujis, Risbey, & Ravetz, 2005). This is particularly important as such values can vary significantly between agencies, individuals, and disciplines (Austin, Gray, Hilbert, & Poulson, 2015; Hudson-Doyle et al., 2018), differences which could damage future relationships and activities.

The community survey in Orewa (Phase One) was seen as the forerunner to similar community awareness projects to be undertaken throughout Aotearoa New Zealand. Rotary will use their natural hazard awareness to extend the programme into other communities throughout Aotearoa New Zealand. They will continue to work closely with university research partners to gather data and help build detailed knowledge of existing awareness within communities and, more importantly, their change over time. Such results will be used to improve their community outreach and public education efforts about tsunami risk and to help local businesses refine their pre-event planning and evacuation response procedures. Rotary also intend to share these results with other agencies, and researchers working with these communities will use these results to identify effective actions and methodologies to guide volunteer-based efforts for future community engagement initiatives and citizen science activities.

Finally, future work includes the opportunity to develop a disaster-relevant citizen science framework. Much work has been done in an environmental context to identify key components of citizen science (as discussed earlier), but how those concepts could be deliberately applied in the hazard space is still relatively unexplored. Such a framework would provide guidance on how to develop effective citizen science initiatives that reflect desired levels of participation and meet the goals of citizens and stakeholders in terms of outcomes.

Conclusion

This paper considered the case study of a two-phase citizen science project initiated by community leaders from Rotary Clubs and facilitated by a number of agencies including Massey University via the Joint Centre for Disaster Research and the Auckland CDEM Group, as well as involving students from Auckland Grammar School. Both Phase One and Phase Two aimed to understand the community's knowledge of tsunami risk and involve them in the development of appropriate and practicable responses to tsunami. The community survey in Phase One showed that the community had a low understanding of tsunami risk in terms of warning time, an unrealistic expectation of support from authorities, and low awareness of appropriate evacuation actions to take. Phase Two demonstrated that while some schools are located within easy walking distance to tsunami safe zones, others have a longer walk and require quick action to keep their students safe. Overall, these results were used by community leaders and groups to inform further community activities to build awareness of tsunami risk and address misconceptions. In our experience, Phase One was a catalyst for Phase Two and led to ongoing community initiatives within Orewa as well as across Aotearoa New Zealand. This case study highlights the importance of such catalyst events for resilience building processes. A wider outcome of this initiative will be to develop a community-based framework that provides tools such as community surveys, training, and education. These tools will increase the potential for community-led resilience building for tsunami risk, as well as for risks from other natural hazards.

Acknowledgments

We acknowledge funding from the National Science Challenge: Resilience to Nature's Challenges Kia manawaroa – Ngā Ākina o Te Ao Tūroa 2016-2019. In addition, we would like to acknowledge the valuable partnership and support of Kate Boersen, Tom Morton, Chris Horrocks, Cr Sharon Stewart, Denise Lee MP, John Dragicevich, Emma Hunt, Donna Murray, Hamish Keith, and Kiri Maxwell. We also thank JC Gaillard, Alan Kwok, Miles Crawford, Raj Prasanna, Amandine Dhellemmes, Mary Anne Thompson, Steve Ronoh, Emma Ryan, Jack Lindsay, and Richard Woods for being on the ground volunteers on survey and exercise days. We also acknowledge the following agencies, organisations, and individuals for their involvement in the citizen science initiatives: Orewa College: Kate Shevland (Principal), Chris Clark (Deputy Principal), Janet Delaney (Business Manager), Orewa North Primary: Bruce Tilby (Principal), Daryl Mogg (Caretaker), Orewa Primary: Diane Lambert (Principal), Barry Smith (Caretaker), Hibiscus Coast Kindergarten: Viv Wilcock, Early Adventures Child Care: Bridget Ross, NZ Police: Jason Homan, Fire & Emergency NZ: Vaughan Mackereth, Greater Orewa Community Response Group and Hibiscus Coast Community Patrol: Frank Rands, Orewa Surf Life Saving: Brenda Larsen, More FM Rodney: Anna McGovern, Auckland Council: Hibiscus and Bays Local Board, Communications and Engagement team, Auckland Emergency Management. Finally, we gratefully acknowledge William Power (GNS Science) for the provision of the tsunami travel time figure (Figure 1) and thank David Burbidge (GNS Science) for contribution to its production.

References

Aitsi-Selmi, A., Blanchard, K., & Murray, V. (2016). Ensuring science is useful, usable and used in global disaster risk reduction and sustainable development: a view through the Sendai framework lens. *Palgrave Communications, 2*, 1-9. doi: 10.1057/palcomms.2016.16

Aldrich, D. P., & Meyer, A. M. (2014). Social capital and community resilience. A*merican Behavioral Scientist, 59,* 254-269. doi: 10.1177%2F0002764214550299

Austin, J., Gray, G., Hilbert, J., & Poulson, D. (2015). The ethics of communicating scientific uncertainty. *Environmental Law Reporter: News & Analysis*, *45*(2), p. 10105.

Becker, J.S., Johnston, D.M., & Paton, D. (2015). Communication of risk: A community resilience perspective. *GNS Science Report*, *2015*(55), 30 p.

Becker, J. S., Paton, D., Johnston, D. M., & Ronan, K. (2014). Societal influences on earthquake information meaning making and household preparedness. *International Journal of Mass Emergencies and Disasters, 32*, 317-352.

Becker, J. S., Paton, D., Johnston, D. M., Ronan, K. R., & McClure, J. (2017). The role of prior experience in informing and motivating earthquake preparedness. *International Journal of Disaster Risk Reduction, 22*, 179-193. doi: 10.1016/j.idrr.2107.03.006

Becker, J., Paton, D., & McBride, S. (2013). Improving community resilience in the Hawke's Bay: A review of resilience research, and current public education, communication and resilience strategies. *GNS Science Report, 2012*(38), 72 p.

Becker-Klein, R., Peterman, K., & Stylinski, C. (2016). Embedded assessment as an essential method for understanding public engagement in citizen science. *Citizen Science: Theory and Practice*, *1*(1), 1-8. doi: 10.5334/cstp.15

Berg, B. L. (2007). *Qualitative research methods for the social sciences* (6th ed.). Boston, MA: Pearson Education Inc.

Beven, K., Lamb, R., Leedal, D., & Hunter, N. (2015). Communicating uncertainty in flood inundation mapping: A case study. *International Journal of River Basin Management*, *13*(3), 285-295.

Bonney, R., Ballard, H., Jordan, R., McCallie, E., Phillips, T., Shirk, J., & Wilderman, C. C. (2009). Public participation in scientific research: Defining the field and assessing its potential for informal science education [PDF file]. Retrieved from www.informalscience.org/sites/default/files/PublicParticipationinScientificResearch.pdf

Bonney, R., Cooper, C. B., Dickinson, J., Kelling, S., Phillips, T., Rosenberg, K. V., & Shirk, J. (2009). Citizen science: A developing tool for expanding science knowledge and scientific literacy. *BioScience*, *59*, 977-984. doi: 10.1525/bio.2009.59.11.9

Bonney, R., Phillips, T. B., Ballard, H. L., & Enck, J. W. (2016). Can citizen science enhance public understanding of science? *Public Understanding of Science*, *25*(1), 2-16. doi: 10.1177%2F0963662515607406

Bonney, R., Shirk, J. L., Phillips, T. B., Wiggins, A., Ballard, H. L., Miller-Rushing, A. J., & Parrish, J. K. (2014). Next steps for citizen science. *Science*, *343*(6178), 1436-1437. doi: 10.1126/science.1251554

Bowser, A., & Shanley, L. (2013). *New visions in citizen science*. Washington, D.C.: Woodrow Wilson International Center for Scholars.

Burton, D. (2000) The use of case studies in social science research. In D. Burton (Ed.), *Research training for social scientists* (pp. 215-225). London: SAGE Publications Ltd.

Civil Defence Emergency Management Act 2002. Retrieved from www.legislation.govt.nz/act/public/2002/0033/25.0/DLM149789.html

Currie, C-S., Enjamio, J., Girardo, D. O., Hensel, C., Leonard, G. S., & Johnston, D. M. (2014). Tsunami awareness and preparedness in the Greater Wellington Region. *GNS Science Report, 2014*(10), 83 p.

Daedlow, K., Podhora. A., Winkelmann. M., Kopfmüller, J., Walz, R., & Helming, K. (2016). Socially responsible research processes for sustainability transformation: an integrated assessment framework. *Current Opinion in Environmental Sustainability*, *23*, 1–11. doi: 10.1016/j.cosust.2016.09.004.

Dhellemmes, A., Leonard, G. S., & Johnston, D. M. (2016). Tsunami awareness and preparedness on the East Coast of New Zealand's North Island. *GNS Science Report, 2016*(20), 81 p.

Diaz-Puente, J. M., Gallego, F. J., Vidueira, P., & Fernandez, M. J. (2014). Facilitation in community development. Twenty-five years of experience in rural territories in Cuenca, Spain. *European Planning Studies, 22*, 2231-2247. doi: 10.1080/09654313.2013.830695

Doyle, E. H., Becker, J. S., Neely, D. P., Johnston, D. M., & Pepperell, B. (2015). Knowledge transfer between communities, practitioners, and researchers: A case study for community resilience in Wellington, New Zealand. *Australasian Journal of Disaster and Trauma Studies, 19*(2), 55-66.

Eitzel, M. V., Cappadonna, J. L., Santos-Lang, C., Duerr, R. E., Virapongse, A., West, S. E., ... Metcalfe, A. N. (2017). Citizen science terminology matters: Exploring key terms. *Citizen Science: Theory and Practice*, *2*(1), 1-20. doi: 10.5334/cstp.96

Faulkner, H., Parker, D., Green, C., & Beven, K. (2007). Developing a translational discourse to communicate uncertainty in flood risk between science and the practitioner. *AMBIO: a Journal of the Human Environment*, *36*(8), 692-705.

Finnis, K. K. (2007). From science to practice: Community-based public education initiatives. *Joint Centre for Disaster Research, Massey University/GNS Science Research Report, 2007*(1), 39 p.

Fraser, S. A., Doyle, E. E. H., Wright, K. C., Potter, S. H., McClure, J., Johnston, D. M., … Johal, S. (2016). Tsunami response behaviour during and following two local-source earthquakes in Wellington, New Zealand. *International Journal of Disaster Risk Reduction, 16*, 123-133. doi: 10.1016/j.ijdrr.2016.02.008

Haklay, M. (2013). Citizen science and volunteered geographic information: Overview and typology of participation. In D. Sui, S. Elwood, & M. Goodchild (Eds.), *Crowdsourcing geographic knowledge* (pp. 105-122). Dordrecht: Springer.

Haklay, M. (2014). *Citizen science: an overview* [Powerpoint presentation]. Retrieved from www.slideshare.net/mukih/overview-of-citizen-science-zurich-november-2015?qid=268edd50-5fd9-4bf6-b86a-9993b1f3d01f&v=&b=&from_search=5

Harrison, H., Birks, M., Franklin, R., & Mills, J. (2017). Case study research: Foundations and methodological orientations. *Forum: Qualitative Social Research*, *18*(1), 1-17. doi: 10.17169/fqs-18.1.2655

Health and Safety at Work Act 2015. Retrieved from www.legislation.govt.nz/act/public/2015/0070/latest/DLM5976660.html

Hennon, C. C., Knapp, K. R., Schreck III, C. J., Stevens, S. E., Kossin, J. P., Thorne, P. W., ... Striegl, M. (2015). Cyclone center: Can citizen scientists improve tropical cyclone intensity records? *Bulletin of the American Meteorological Society*, *96*(4), 591-607.

Horspool, N., Cousins, W. J., & Power, W. L. (2015) Review of tsunami risk facing New Zealand: A 2015 update. *GNS Science Consultancy Report 2015*(38), 38 p.

Hudson-Doyle, E. E., Paton, D., & Johnston, D. (2018) Reflections on the communication of uncertainty: Developing decision-relevant information. In *Proceedings of the ISCRAM Asia Pacific Conference* (November, 2018). Wellington, NZ: Massey University. Retrieved from www.confer.co.nz/iscramasiapacific2018/programme/

Janssen, P. H. M., Petersen, A. C., van der Sluijs, J. P., Risbey, J. S., & Ravetz, J. R. (2005). A guidance for assessing and communicating uncertainties. *Water Science and Technology*, *52*(6), 125–131.

Johnson, M. (1992). Research on traditional environmental knowledge: its development and its role. In M. Johnson (Ed.), *Lore: Capturing traditional environmental knowledge* (pp. 3-20). Canada: IDRC.

Johnson, V. A., Johnston, D. M., Ronan, K. R., & Peace, R. (2014). Evaluating children's learning of adaptive response capacities from ShakeOut, an earthquake and tsunami drill in two Washington State school districts. *Journal of Homeland Security and Emergency Management*, *11,* 347-373. doi: 10.1515/ jhsem-2014-0012

Johnston, D. M., Becker, J. S., McClure, J., Paton, D., McBride, S. K., Wright, K. C., … Hughes, M. (2013) Community understanding of, and preparedness for, earthquake and tsunami risk in Wellington, New Zealand. In H. Joffe, T. Rossetto, & J. Adams (Eds.), *Cities at risk: Living with perils in the 21st century* (pp. 131-148). Dordrecht: Springer.

Johnston, D., Tarrant, R., Tipler, K., Lambie, E., Crawford, M., Johnston, V., … Ronan, K. R. (2016) Towards tsunami-safer schools in the Wellington region of New Zealand: evaluating drills and awareness programs. *Australian Journal of Emergency Management, 31*(3), 59-66.

Kearney, J., Wood, L., & Zuber-Skerritt, O. (2013). Community–university partnerships: Using participatory action learning and action research (PALAR). *Gateways: International Journal of Community Research and Engagement, 6*(1), 113-130. doi: 10.5130/ijcre.v6i1.3105

Kelman, I., Lewis, J., Gaillard, J. C., & Mercer, J. (2011). Participatory action research for dealing with disasters on islands. *Island Studies Journal*, *6*(1), 59-86.

Lewandowski, E., Caldwell, W., Elmquist, D., & Oberhauser, K. (2017). Public perceptions of citizen science. *Citizen Science: Theory and Practice, 2*, 1-9. doi: 10.5334/cstp.77

Lewandowski, E., & Oberhauser, K. (2016). Butterfly citizen science projects support conservation activities among their volunteers. *Citizen Science: Theory and Practice*, *1*(1), 1-8. doi: 10.5334/cstp.10

Lindell, M. K., & Prater, C. S. (2002). Risk area residents' perceptions and adoption of seismic hazard adjustments. *Journal of Applied Social Psychology, 32,* 2377–2392. doi: 10.1111/j.1559-1816.2002.tb01868.x

Lindell, M. K., & Whitney, D. J. (2000). Correlates of household seismic hazard adjustment adoption. *Risk Analysis, 20*, 13-25. doi: 10.1111/0272-4332.00002

MBIE. (2014). A nation of curious minds / He whenua Hihiri I Te Mahara: A national strategic plan for science in society [PDF file]. Retrieved from www.curiousminds.nz/assets/Uploads/science-in-society-plan-PDF.pdf

MCDEM. (2008). National Civil Defence Emergency Management strategy [PDF file]. Retrieved from http://civildefence.govt.nz/assets/Uploads/publications/national-CDEM-strategy-2008.pdf

MCDEM. (2018). Assessment and Planning for Tsunami Vertical Evacuation: Director's Guideline for Civil Defence Emergency Management Groups [DGL 21/18]. Wellington, NZ: Ministry of Civil Defence & Emergency Management.

Nakahara, S., & Ichikawa, M. (2013). Mortality in the 2011 tsunami in Japan. *Journal of Epidemiology*, *23*, 70-73. doi: 10.2188/jea. JE20120114.

Norris, F. H., Stevens, S. P., Pfefferbaum, B., Wyche, K. F., & Pfefferbaum, R. L. (2008). Community resilience as a metaphor, theory, set of capacities, and strategy for disaster readiness. *American Journal of Community Psychology, 41*, 127-150.

Orchiston, C., Hudson-Doyle, E., Johnston, D.M., Becker, J.S., Crowley, K., Beatson, A., … Pepperell, B. (2016). Citizen Science in Disaster Risk Management Workshop: Summary report. *GNS Science Miscellaneous Series, 90,* 35 p.

Orewa to get tsunami sirens pilot. (2018, October 2). *Local Matters.* Retrieved from www.localmatters.co.nz/news/

Paton, D. (2006). Disaster resilience: Integrating individual, community, institutional and environmental perspectives. In D. Paton & D. Johnston (Eds.), *Disaster resilience: An integrated approach* (pp. 306-319). Springfield, Illinois: Charles C Thomas.

Paton, D. (2018). Disaster risk reduction: Psychological perspectives on preparedness. *Australian Journal of Psychology*, *71,* 327-341. doi: 10.1111/ajpy.12237

Paton, D., & Johnston, D. (2006) Identifying the characteristics of a disaster resilient society. In D. Paton, & D. Johnston. (Eds.), *Disaster resilience: An integrated approach* (pp. 11-18). Springfield, Illinois: Charles C. Thomas.

Paton, D., Sagala, S., Okada, N., Jang, L.-J., Burgelt, P., & Gregg, C. E. (2010). Making sense of natural hazard mitigation: Personal, social and cultural influences. *Environmental Hazards, 9,* 183-196. doi: 10.3763/ehaz.2010.0039

Peters, M. (2016). *An inventory of citizen science initiatives, resources and learning opportunities in New Zealand.* Hamilton, NZ: NZ Landcare Trust.

Raddick, M. J., Bracey, G., Gay, P. L., Lintott, C. J., Cardamone, C., Murray, P., ... Vandenberg, J. (2013). Galaxy Zoo: Motivations of citizen scientists. *Astronomy Education Review, 12*(1), 1-41. doi: 10.3847/AER2011021

Riesch, H., & Potter, C. (2014). Citizen science as seen by scientists: Methodological, epistemological and ethical dimensions. *Public Understanding of Science*, *23*(1), 107-120.

Rotary, & Auckland Civil Defence and Emergency Management. (2016). *General instruction: Orewa Tsunami Walk*. Auckland, NZ: Auckland Council.

Rotary, & Auckland Council. (2016). Strategic Orewa Tsunami Preparedness project overview. Internal document outlining the process and aims and objectives for the tsunami evacuation exercise, May 26th 2016.

Rovins, J. E., Doyle, E. E. H., & Huggins, T. J. (2014). Integrated disaster risk science: A tool for sustainability. In the proceedings of *2nd Integrated Research on Disaster Risk Conference. Beijing, China, June 7-9* (pp. 332–336). Retrieved from https://planet-risk.org/index.php/pr/article/view/127/254

Shirk, J. L., Ballard, H. L., Wilderman, C. C., Phillips, T., Wiggins, A., Jordan, R., ... Bonney, R. (2012). Public participation in scientific research: A framework for deliberate design. *Ecology and Society*, *17*(2), 29-48. doi: 10.5751/ES-04705-170229

Silvertown, J. (2009). A new dawn for citizen science. *Trends in Ecology & Evolution*, *24*(9), 467-471.

Solberg, C., Rossetto, T., & Joffe, H. (2010). The social psychology of seismic hazard adjustment: Re-evaluating the international literature. *Natural Hazards and Earth System Science, 10*(8), 1663–1677. doi: 10.5194/nhess-10-1663-2010.

Soleri, D., Long, J., Ramirez-Andreotta, M., Eitemiller, R., & Pandya, R. (2016). Finding pathways to more equitable and meaningful public-scientist partnerships. *Citizen Science: Theory and Practice*, *1*(1).

Straub, M. (2016). Giving citizen scientists a chance: A study of volunteer-led scientific discovery. *Citizen Science: Theory and Practice*, *1*(1), 1-11. doi: 10.5334/cstp.46

Tarrant, R. A., Johnston, D., Tipler, K., Lambie, E., Crawford, M., Johnson, V., … Ronan, K. (2016). Towards tsunami-safer schools in the Wellington region of New Zealand: Evaluating drills and awareness programs. *Australian Journal of Emergency Management, 31*(3), 59-68.

Tipler, K. S, Tarrant, R. A., Johnston, D. M., & Tuffin, K.F. (2016). New Zealand Shakeout exercise: Lessons learned by schools. *Disaster Prevention and Management: An International Journal, 25*(4), 550-563. doi: 10/1108/DPM-01-2016-0018

Tweddle, J. C., Robinson, L. D., Pocock, M. J. O., & Roy, H. E. (2012). *Guide to citizen science: developing, implementing and evaluating citizen science to study biodiversity and the environment in the UK*. UK: NERC/Centre for Ecology & Hydrology.

Verschuren, P. (2003). Case study as a research strategy: Some ambiguities and opportunities. *International Journal of Social Research Methodology, 6*(2), 121-139. doi: 10.1080/13645570110106154

Vidal, R. V. V. (2009). Community facilitation of problem structuring and decision-making processes: Experiences from EU LEADER + programme. *European Journal of Operational Research, 199*, 803-810.

Whitney, D. J., Lindell, M. K., & Nguyen, H. D. (2004). Earthquake beliefs and adoption of seismic hazard adjustments. *Risk Analysis, 24*(1), 87–102. doi: 10.1111/j.0272-4332.2004.00414.x

Woods, R. J., & Lewis, A. E. (2017). Auckland tsunami community exposure analysis. *GNS Science consultancy report 2017*(74), 48 p.

Yin, R.K. (1989). *Case study research, design and methods*. London: Sage Publications.

Appendix 1: Orewa tsunami awareness survey

TSUNAMI AWARENESS SURVEY –

1. **Which are the two natural hazards that you think are most likely to affect Orewa? (Tick only two)**

☐ 1 Flooding (river or sea)
☐ 2 Storm or cyclone with high winds
☐ 3 Forest or bush fire
☐ 4 Earthquake
☐ 5 Ashfall from a volcanic eruption
☐ 6 Tsunami
☐ 7 Coastal erosion
☐ 8 Landslide

2. **To what extent do you agree that?** Please use the scale below to show much each statements matches your views**:**

	Strongly disagree	Disagree	Neither Agree nor disagree	Agree	Strongly agree
Tsunami are too destructive to bother preparing for	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
A serious tsunami is unlikely to occur during your lifetime	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
It is unnecessary to prepare for tsunami as assistance will be provided by local/regional councils or Civil Defence	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
Your property will never be damaged by a tsunami	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
Preparing for tsunami will improve my everyday living conditions	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
Preparing for tsunami will help save lives	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
I do not know how I can prepare for tsunami	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

3. When do you expect the next damaging tsunami to hit Orewa? (Tick only one)

- ☐ 1 Never
- ☐ 2 In the next 10 years
- ☐ 3 In the next 100 years
- ☐ 4 In the next 1000 years
- ☐ 5 In the next 10 000 years
- ☐ 6 Don't know

4. Have you <u>heard or received</u> any information about preparing for tsunami hazards from any of the following? (Tick all that apply)

- ☐ 1 I haven't heard or received any information
- ☐ 2 Friends
- ☐ 3 Neighbours
- ☐ 4 Relatives
- ☐ 5 Central Government agencies
- ☐ 6 Regional Council
- ☐ 7 Local Council
- ☐ 8 Local Civil Defence group
- ☐ 9 Business establishments
- ☐ 10 Research organisations e.g. GNS Sciences
- ☐ 11 My workplace
- ☐ 12 My child's school
- ☐ 13 Other, please specify__________

5. Do you **have** a **'getaway kit' or** items ready to evacuate your home quickly?

- ☐ 1 Yes
- ☐ 2 No

6. What is in that kit/ what are those items? (Tick all that apply)

- ☐ 1 First aid kit / supply of any medicines needed
- ☐ 2 Food
- ☐ 3 Water
- ☐ 4 Torch
- ☐ 5 Portable radio
- ☐ 6 Spare batteries
- ☐ 7 Warm clothes
- ☐ 8 Important documents
- ☐ 9 A household plan
- ☐ 10 Other (please specify)_________

7. How do you expect to be warned that a tsunami is coming within the next 12 hours? (Tick all that apply)

- ☐ 1 Earthquake
- ☐ 2 Sirens
- ☐ 3 Loud speaker announcements
- ☐ 4 Flashing lights
- ☐ 5 Door-to-door visit by emergency services or Civil Defence staff
- ☐ 6 Radio and TV announcements
- ☐ 7 Word of mouth
- ☐ 8 Don't know
- ☐ 9 Other (please specify)______ __

8. How do you expect to be warned that a tsunami is coming within an hour?

- ☐ 1 Earthquake
- ☐ 2 Sirens
- ☐ 3 Loud speaker announcements
- ☐ 4 Flashing lights
- ☐ 5 Door-to-door visit by emergency services or Civil Defence staff
- ☐ 6 Radio and TV announcements
- ☐ 7 Word of mouth
- ☐ 8 Don't know
- ☐ 9 Other (please specify)_______ ___

9. If you feel a strong earthquake while at the beach (or anywhere on the coast),

a. Would you evacuate?

- ☐ 1 Yes
- ☐ 2 No

b. How much time do you think will you have to move to safety from any approaching tsunami it may cause? (Tick only one)

- ☐ 1 A few minutes
- ☐ 2 10 minutes to 30 minutes
- ☐ 3 30 minutes to 1 hour
- ☐ 4 1 – 3 hours
- ☐ 5 More than 3 hours
- ☐ 6 Don't know

10. Do you have a specific evacuation destination in mind if you had to evacuate after a tsunami warning?

☐ 1 Yes, within Orewa

☐ 2 Yes, outside of Orewa

☐ 3 No

11. If yes, how do you plan to evacuate?

☐ 1 Walk

☐ 2 Drive

☐ 3 Cycle

☐ 4 Use a mobility scooter

☐ 5 Taxi

☐ 6 Other (please specify)_____ ____

12. What would you do before evacuating? (Tick all that apply)

☐ 1 Nothing

☐ 2 Assist others in evacuation

☐ 3 Get life essentials (Food, water, medicine, etc.)

☐ 4 Valuables (jewelry, money, etc.)

☐ 5 Call family or friends

☐ 6 Gather family

☐ 7 Seek further information (from radio, TV…)

☐ 8 Other (please specify)______ ___

13. Are there any factors that would impair your ability to evacuate?

☐ 1 I am mobility impaired but I can self-evacuate

☐ 2 I am heavily mobility impaired and require assistance to evacuate

☐ 3 I have health issues and require assistance to evacuate

☐ 4 Other (please specify) _____________

☐ 5 None of the above

Why are you in Orewa today?

☐ 1 I live in Orewa

☐ 2 I live and work in Orewa

☐ 3 I work in Orewa but live elsewhere on high ground

☐ 4 I am a visitor and live beside the coast on ground less than 5 meters above sea level

☐ 5 I am a visitor and live inland higher than 5 meters above sea level

14. What is your gender?

☐ 1 Male

☐ 2 Female

15. Please indicate your age

☐ 1 > 18 years

☐ 2 18- 30 years

☐ 3 31-40 years

☐ 4 41- 50 years

☐ 4 51- 60 years

☐ 5 61- 70 years

☐ 6 < 71 years

16. Would you like follow up assistance from Rotary as community coordinators in terms of assisting you plan your evacuation?

☐ 1 Yes

☐ 2 No

Appendix 2: Rotary Clubs media release

22 August 2015

MEDIA RELEASE

CHIP IN
Your Neighbourhood Your Need

Orewa community research into tsunami awareness

Research into disaster awareness in the seaside community at Orewa was conducted by Massey University today (Saturday 22 August).

The research is sponsored by the Chip-In Foundation, which is the disaster awareness section of the Rotary Clubs of Orewa, Auckland and Westhaven, and was carried out by the Massey University Joint Centre for Disaster Research, with assistance from Auckland Council.

“We have identified the Orewa centre as a high-risk spot for a tsunami disaster event,” says Tom Morton, Director of the Chip-In Foundation.

“Orewa is one of the east coast areas that would be in a direct line of a tsunami caused by an earthquake in the Kermadec Trench, which runs almost parallel to the coastline.

“We are keen to find out just how aware people in the Orewa community are about what they should do if a tsunami struck their area, and that is the reason we are partnering with Massey to carry out today’s research.”

The survey was carried out by Rotary volunteers and and post-graduate scholars from Massey University. It can also be completed on-line.

Chip-In set up a pop-up information centre for the day, and provided residents and visitors with maps and reports on the tsunami risk for Orewa, a video and assistance on planning home, business and school evacuation.

Chip-In will report back to the community with its findings from today’s research.

For further information please contact
Tom Morton, Chip In Director
Phone 0274 751 800
CHIP-In Foundation, chip-in.org.nz
Sponsored by the Rotary Clubs of Orewa, Auckland and Westhaven and Auckland Council

Appendix 3: "Orewa: Ahead of the Wave", Auckland CDEM Flyer

OREWA:

AHEAD OF THE WAVE

Orewa tsunami preparedness and evacuation project

The only warning you may get from a tsunami caused by an earthquake is the earthquake itself.
If you feel a long or strong earthquake, one that is hard to stand up in or that continues for a minute or more, walk past the blue lines!
If you see any strange sea behaviour, such as a sudden rise or fall in sea level, or hear unusual noises such as roaring like a jet plane, evacuate immediately.

Auckland Council, Civil Defence and Emergency Management has been working with the Orewa community and Rotary to make Orewa tsunami ready.

A large earthquake could cause a tsunami in Orewa, similar to the one that hit Japan in 2011. Because the first tsunami wave could arrive within an hour, it is important that you have an evacuation plan and know your nearest safe zone location.

We have identified safe zones and evacuation routes for you to take in the event of a tsunami.

Evacuation signs will be installed to indicate the quickest routes to the safe zones. Painted blue lines show where the largest tsunami could reach and indicate the safest zone.

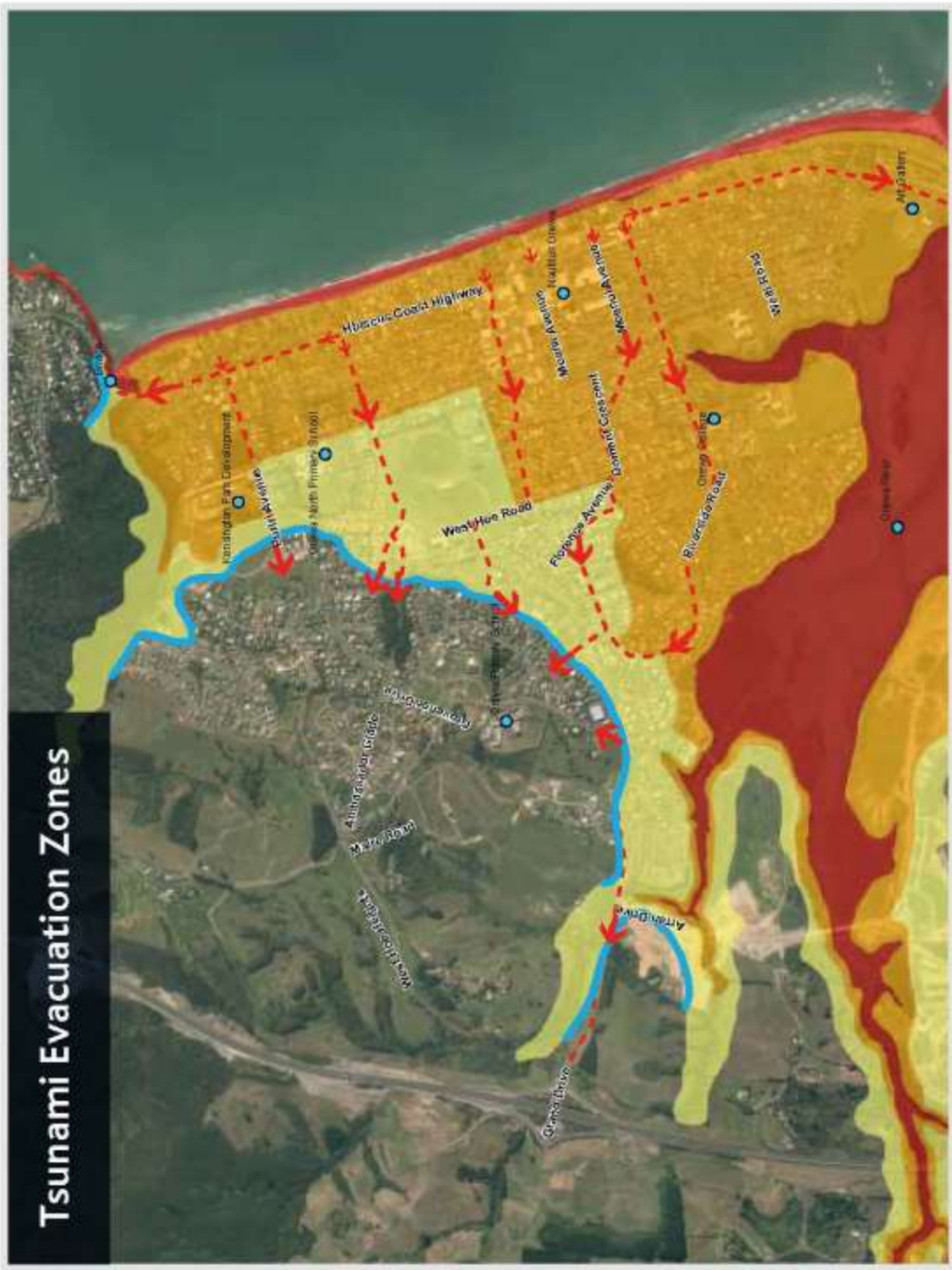
Once you have walked or cycled past the blue line, keep going and stay away until the official all-clear has been given.

Others may need help to evacuate – remember those who might need extra assistance.

For more information:
download the Civil Defence app for real-time alerts or call Auckland Council on 09 301 0101.

Civil Defence and Emergency Management

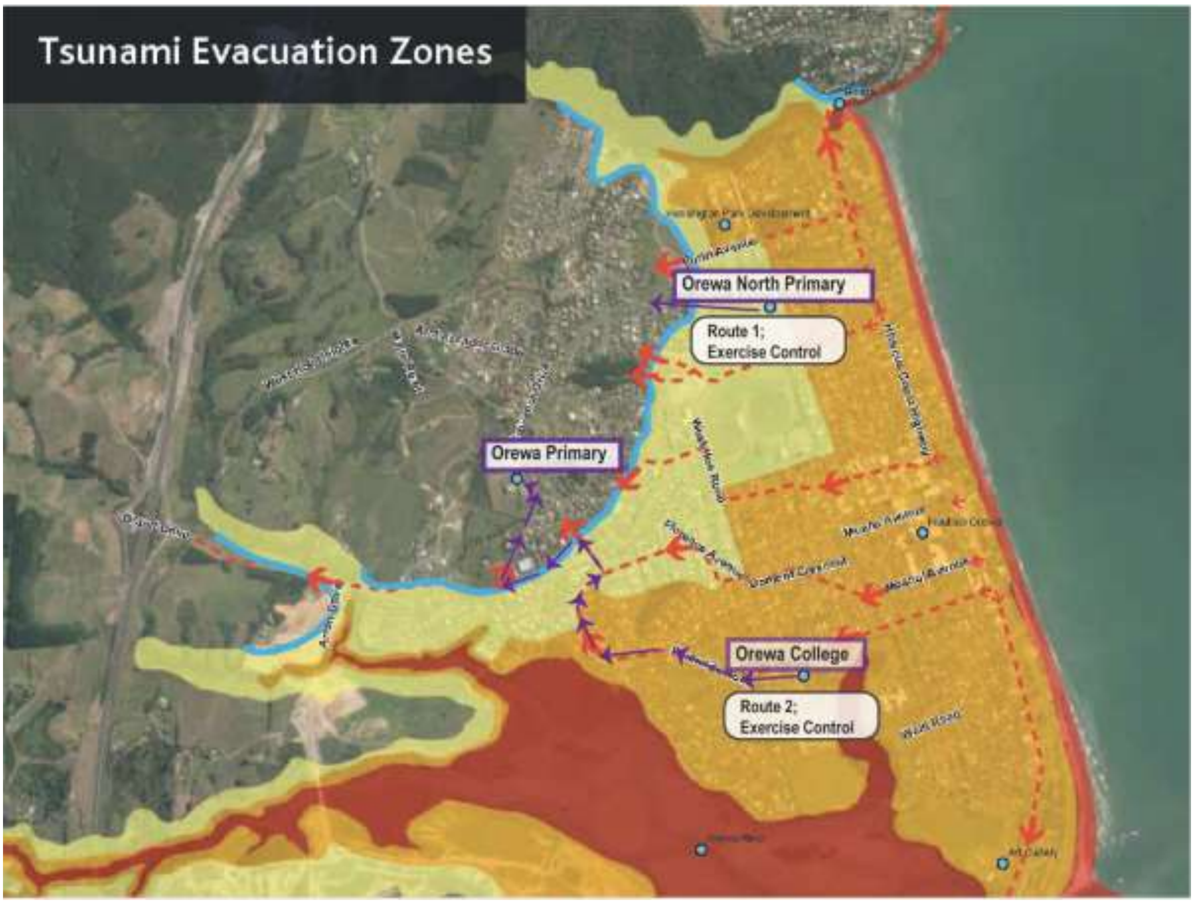
Auckland Council


Tsunami Evacuation Zones

Appendix 4: Orewa Tsunami Walk locations

Final map for the tsunami walk and school locations, adapted from the Orewa tsunami walk general instruction (Rotary & Auckland Council, 2016).

Key: **Red** shore exclusion zone: Covers the beach and adjacent low-lying areas most likely to be affected by a tsunami. **Orange** evacuation zone: May need to be evacuated if there was a threat from a medium- to large-scale tsunami. **Yellow** evacuation zone: Covers the largest area that would need to be evacuated in the event of a maximum-impact tsunami[1]. The **blue line** indicates the safe zone, the **red lines the** potential evacuation routes, and the **purple lines** illustrate the two official routes taken by the schools on the day: Route 1, from Orewa North Primary School, and Route 2 from Orewa College.



[1] See also Auckland's Hazard Viewer for latest tsunami evacuation zone maps https://aucklandcouncil.maps.arcgis.com/apps/MapSeries/index.html?appid=81aa3de13b114be9b529018ee3c649c8 (last accessed 28/8/2019)

Appendix 5: Orewa tsunami evacuation exercise: Participant survey form

Orewa Tsunami Evacuation Exercise: Participant Survey Form

25th May 2016

Q1a. Where did you start the walk from?
☐1 Orewa North Primary School ☐2 Orewa College ☐3 Other (Please specify the street address) ____________

Q1b. What was your final evacuation destination?
☐1 Kensington Park Hill ☐2 Orewa Primary school ☐3 Other (Please specify the street address) ____________

Q2a. Time of departure: ______

Q2b. Time of arrival at blue line: ______

Q2c. Time you reached your final destination: ______

Q2d. Were you aware that you needed to walk past the blue line?
☐1 Yes ☐2 No

Q3. Did you know about the initiative 'Orewa: Ahead of the wave' ahead of time?
☐1 Yes ☐2 No

Q4. If yes to Q3, how had you heard/read about it?
____

Q5. Have you already practiced a tsunami evacuation route in Orewa before the 'Orewa: Ahead of the wave' project?
☐1 Yes ☐2 No

Q6. If yes to Q5, when was the last time you practiced? (Approximate date): ____________

Q7. If yes to Q5, did you follow the same route as today?
☐1 Yes ☐2 No

Q8. If no to Q7, what was the route you followed last time?
____

Q9. Was the terrain easy for mobile people?
☐1 Yes ☐2 No ☐3 None in our party
Q9a. If no, please describe the issue: ____________

Q10. Was the terrain easy for mobility impaired people?
☐1 Yes ☐2 No ☐3 None in our party
Q10a. If no, please describe the issue: ____________

Q11. Did you (or someone in your group) travel with a pushchair/stroller or wheelchair?
☐1 Yes (which) ____________ ☐2 No

Q12. What item(s) did you take with you during the evacuation drill?
____

Q13. What item(s) would you want to take with you in the event of a real tsunami evacuation?
____

Q14a. How easy were the tsunami evacuation signs to follow?
☐1 Very easy ☐2 Easy enough
☐3 Not easy ☐4 Didn't see any signs

Q14b. Was it useful having the blue lines on the footpath?
☐1 Yes ☐2 No ☐3 None in our party

Q15. Would you be able to use the evacuation route in all weather conditions?
☐1 Yes ☐2 No

Q16. Would you be able to use the evacuation route in the dark?
☐1 Yes ☐2 No ☐3 Yes, if carrying a torch

Q17. What would you like to have at your final destination if staying there?

____

Q18. What additional information do you need to evacuate safely?

____

____

Q19. Any suggestions for improving the evacuation arrangements in a real event?

____

____

Q20. Do you think you are more prepared now than before the 'Orewa: Ahead of the wave' project? (Please explain)

____

____

Q21. How many people in total in your party/group? (including you) ______
How many are:

- **Q21a**. Less than 10 years old ____
- **Q21b**. Over 65 years old ____
- **Q21c**. Disabled ____

Q22. Would anybody in your household need special assistance in case of real tsunami evacuation?
☐1 Yes ☐2 No

Q23. Are you: ☐1 A resident ☐2 A visitor

Q23a. **Residents:** How long have you lived in this community? (even with gaps)
☐1 First year ☐2 2-10 years ☐3 11-20 years ☐4 21+ years

Q23b. **Visitors**: How many days do you expect to visit this community this year?
☐1 1 day ☐2 2-5 days ☐3 6-10 days ☐4 11+

Q23c. All: Where do you normally live?: Town/Country: ______________________________

Q23. Are you:
☐1 Male ☐2 Female ☐3 Gender diverse ☐4 Prefer not to disclose

Q24. In what year were you born? ________________

This page intentionally left blank.

Post-disaster health status of train derailment victims with posttraumatic growth

Danielle Maltais[1],
Anne-Lise Lansard[1],
Mathieu Roy[2],
Mélissa Généreux[2],
Geneviève Fortin[1],
Jacques Cherblanc[1],
Christiane Bergeron-Leclerc[1],
Eve Pouliot[1]

[1] Université du Québec à Chicoutimi

[2] Université de Sherbrooke

Author correspondence:
Danielle Maltais
Department of Human and Social science, UQAC,
555 Boulevard de l'Université, Saguenay,
QC, Canada, G7H2B1
Email: danielle_maltais@uqac.ca

URL: http://trauma.massey.ac.nz/issues/2020-1/AJDTS_24_1_Maltais.pdf

Abstract

In July 2013, a train derailment causing explosions and a fire in downtown Lac-Mégantic (Municipalité Régionale de Comté du Granit, Quebec, Canada) resulted in the death of 47 people and the destruction of many homes and other buildings. This article compares the physical and psychological health of 624 adults from the Granit area exposed to this disaster three years after the tragedy, comparing based on the presence or absence of posttraumatic growth. Women, people with high levels of social support, lower levels of education, and with lower incomes were more likely to show posttraumatic growth. For psychological health, the presence of post-traumatic stress symptoms and the use of antidepressants were positively related to posttraumatic growth. Our study demonstrates that, over time, many people managed to initiate a recovery process and to see benefits from this disaster.

Keywords: *technological disaster, train derailment, posttraumatic growth, post-traumatic stress disorder, post-disaster psychological health, positive effects of disaster*

On July 6, 2013, a train carrying crude oil exploded in downtown Lac-Mégantic (Québec, Canada). In a community of 6,000 inhabitants, this disaster caused the death of 47 people and the destruction of 44 buildings as well as a spill of over five million litres of crude oil into the environment. More than 2,000 individuals were relocated for a few days or weeks. Of these, 169 were never able to return to their homes (Petit & Gosselin, 2016). Three years after this disaster, physical and psychological health consequences were still felt not only by those who were exposed to the train derailment (i.e., were directly impacted), but also throughout the Lac-Mégantic community. This article focuses on the socio-demographic and health characteristics associated with posttraumatic growth only among those directly exposed to the train derailment.

The concept of posttraumatic growth, as measured with the Posttraumatic Growth Inventory (PTGI), is used to reflect the positive changes that may result from a disaster (Tedeschi & Calhoun, 1996, 2004). This article aims to: 1) document the characteristics of adults who show posttraumatic growth three years after being exposed to the derailment disaster and 2) examine the contribution of different elements (e.g., marital, family, personal, and social) to their posttraumatic growth.

Literature Review

According to Tedeschi and Calhoun (2004), posttraumatic growth, unlike recovery, is not a simple return to normal life; it is rather an enrichment of various aspects of one's life elements, referring to real transformations rather than ones that are illusory and transitory. According to these authors, this phenomenon stems from a potentially traumatic event associated with the destruction of fundamental patterns. In such a situation, people begin a cognitive process that can lead to the emergence of posttraumatic growth (Tedeschi & Calhoun, 2004). The presence of posttraumatic growth, as measured by Calhoun and Tedeschi (1999; see also Tedeschi & Calhoun, 2004), can be observed in five main areas: a) relationships with others, b) perception of new possibilities, c) personal strengths, d) appreciation of life, and e) spiritual changes. More specifically, relationships with others refers to closeness with members of one's social group and a greater ability to demonstrate a compassionate attitude. Perceiving new opportunities can be the emergence of new interests or new career choices. Personal strengths reflect the (re)discovery of (un)suspected resources. Appreciation of life is characterized by higher levels of gratitude for life or changes in prioritising important aspects of life. Posttraumatic growth can also indicate a deeper spirituality and changes in the philosophical principles on which behaviours are based. As stated in Tedeschi and Calhoun (2004), posttraumatic growth occurs relatively late in the adaptation process and is stable over time (Marshall, Frazier, Frankfurt, & Kuijer, 2015). However, positive impacts may also occur soon after exposure to a disaster (Carra & Curtin, 2017; Fergusson, Boden, Horwood, & Mulder, 2015).

Several sociodemographic factors are linked to the presence of posttraumatic growth in victims of disasters with natural or technological causes. For example, women usually have higher posttraumatic growth after such events than men (Achterhof et al., 2017; Marshall et al., 2015; Smith et al., 2016). However, other researchers have found that gender is not predictive of posttraumatic growth (Mordeno, Nalipay, Alfonso, & Cue, 2016). Those who are 50 years old or younger also more often demonstrate posttraumatic growth than those who are older (Achterhof et al., 2017; Guo, Fu, Xing, Qu, & Wang, 2017). Higher education is also linked to the presence of more post-disaster benefits (Kaijun, Yuqing, Zhengkui, Peiling, & Chuguang, 2015) although no correlations with post-disaster benefits were found among economic levels (Jin, Xu, Liu, & Liu, 2014). However, other researchers have shown that the lower the income, the higher the posttraumatic growth (Achterhof et al., 2017). As for family characteristics, marital status has been shown to not relate to posttraumatic growth (Helgeson, Reynolds, & Tomich, 2006).

The level of disaster exposure and associated traumatic experiences is also important when examining post-disaster benefits (Jin et al., 2014; Tang, 2007; Xu & Liao, 2011), while relocation is associated with the perception of benefits (Wu, Xu, & Sui, 2016), especially concerning personal safety (Maltais & Gauthier, 2009). In addition, individuals who have experienced other traumatic events prior to their exposure to a disaster are more likely to experience posttraumatic growth than those who have never experienced such events (Bonanno, Brewin, Kaniasty, & La Greca, 2010). With regard to social support, the higher the level of satisfaction with social support among those exposed to a disaster, the more those people are able to experience posttraumatic growth (Bonanno et al., 2010; Lowe, Rhodes, & Waters, 2015) and the less likely they are to present post-disaster psychological health problems (Maltais & Côté, 2007; Maltais, Lachance, Brassard, & Dubois, 2005).

Finally, several studies have shown that people with post-traumatic stress disorder experience higher levels of posttraumatic growth (Achterhof et al., 2017; Dursun, Steger, Bentele, & Schulenberg, 2016). However, a similar connection is not apparent between depression or anxiety and posttraumatic growth (Chan & Rhodes, 2013). Depression is more likely to be a barrier to the development of posttraumatic growth (Guo et al., 2017). In fact, individuals with fewer depressive symptoms demonstrate more posttraumatic growth, discovery of post-disaster benefits, and overall well-being (Helgeson et al., 2006).

Despite the growing interest of researchers in identifying the positive impacts of disaster exposure, this field of research is less developed compared to studies of the dysfunctional responses that victims of such events may experience (Bonanno et al., 2010). In addition, previous studies lack information about variables that may contribute to posttraumatic growth (Linley & Joseph, 2004). This study therefore had the following two objectives: 1) to identify socio-demographic characteristics (gender, age, education, income, etc.), contextual factors (loss and damage suffered, fears for one's own life and that of a loved one, relocation), and personal factors (perception of one's physical and psychological health) that are associated with posttraumatic growth among adults who have been exposed to a rail disaster; and 2) document the changes observed by respondents in different areas of their lives as a result of this event.

Method

Recruitment Procedure

During October and November 2016, 800 adults living in the Granit area, nearly half of which lived in the city of Lac-Mégantic, were recruited from a randomly generated telephone number list. Selected individuals were invited to answer a questionnaire, either by telephone or online. The duration of the telephone interviews was 30 minutes.

Participant Characteristics

The questions to identify exposed individuals from those not exposed to the train derailment related to various events and losses experienced during the disaster. Participants were asked whether they had experienced the following situations during the train derailment: fear for their own lives or that of a loved one (immediate or extended family member or friend), have no news of a loved one for a few hours or days, suffer personal injury or find that a relative has been injured, experience the loss of a loved one, and suffer damage or the total loss of one's home and be temporarily or permanently relocated. Participants who answered yes to any of these questions were classified as exposed to the train derailment, while others were considered unexposed. Based on the participants' responses on stress and the various losses, it was possible to classify them in two categories: those exposed (n = 624) and unexposed to the tragedy (n = 176). Given that, according to Tedeschi and Calhoun (2004), posttraumatic growth can only emerge as a result of a potentially traumatic experience in which individuals have struggled to rebuild their basic patterns, it was decided that, for this study, only those exposed directly to the train derailment would be analysed. In addition, given that three years elapsed between the tragedy and the data collection, excluding those not exposed allowed us to limit the risk that the presence of posttraumatic growth is related to other potentially traumatic events such as an accident or a health problem. For this study, therefore, only the 624 exposed respondents were selected to identify the characteristics of the train derailment victims who show posttraumatic growth three years after the tragedy.

Data Collection Tools and Variables Under Study

For the survey, a questionnaire was developed based on tests with good psychometric qualities and questions related to consequences of technological disasters previously validated in various studies.

The Posttraumatic Growth Inventory (PTGI; Tedeschi & Calhoun, 1996) was selected as the measure of posttraumatic growth. This test contains 21 questions aimed at defining the positive impacts of exposure to traumatic events in five areas: a) relationships with others (7 items; Cronbach's alpha α = .91); b) new possibilities (5 items; α = .88); c) personal strengths (4 items; α = .86); d) appreciation of life (3 items; α = .83); and e) spiritual changes (2 items; α = .66). This tool offers six answer choices ranging from 0 ("I never experienced this change") to 5 ("I experienced this change very strongly"). Individuals showing positive effects of their exposure to a potentially traumatic event typically receive 23 points or more for the sub-scale relationship with others (out of a possible 35 points), 18 for new opportunities (out of a possible 25 points), 15 for personal strengths (out of a possible 20 points), five for spiritual changes (out of a possible 10 points), and 11 for appreciation of life (out of a possible 15 points). A score greater or equal to 57 (out of a possible 105 points) indicates the presence of posttraumatic growth (Bianchini et al., 2017). The PTGI remains one of the most used tools among the seven existing measuring instruments for measuring the presence or absence of posttraumatic growth (Linley & Joseph, 2004). In addition, this measuring scale was considered a relevant model to best represent the long-term experiences of survivors of a disaster (Mordeno, Nalipay, & Cue, 2015). In this study, the Cronbach's alpha coefficient was .95 for the overall score indicating very good internal reliability.

To identify positive or negative impacts on various aspects of their lives, respondents also had to consider if there had been any changes in their personal, professional, and social life over the past three years prior to the data collection but after the train derailment. Depending on the items investigated, respondents could answer that their situation had improved, deteriorated, or remained stable, as well as whether the number and frequency of their contacts increased, decreased, or remained stable over time.

To measure respondents' level of resilience in coping with day-to-day difficulties, this study used the 10-item Connor-Davidson Resilience Scale (CD-RISC: Connor & Davidson, 2003). Resilience is the individual's or community's capacity to adapt positively when faced with stressful or traumatic events (Luthar, Ciccetti, & Becker, 2000). This scale contains 10 questions used to assess the extent to which a respondent has felt able to handle various aspects of life during the last month (Campbell-Sills & Stein, 2007; Connor & Davidson, 2003). Items refer to being able to adapt to change, dealing with whatever comes, seeing the humorous side of problems, coping with stress and strengthening oneself, tendency to bounce back after illness or hardship, achieving goals despite obstacles, staying focused under pressure, not being easily discouraged by failure, thinking of self as a strong person, and being able to handle unpleasant feelings. Every question provides five possible answers (i.e., "not true at all", "rarely true", "sometimes true", "often true", "true nearly all the time") which correspond to values of 0 to 4. The scale provides a composite score of 0 to 40 (the sum of the score of the 10 questions). A higher score indicates higher resilience. This measure has been used in large studies elsewhere (Antunez, Navarro, Adam, 2015; Jeste et al., 2013) and had good internal consistency (Cronbach's α = .88) in this study.

The Inventory of Complicated Grief (Prigerson et al., 1995) was used to assess the presence or absence of complicated grief among respondents who reported the loss of a loved one. Only the bereaved, who lost a member of their immediate family (child, spouse, brother, sister, parent or grandparents), a member of their extended family (cousin, brother-in-law, sister, uncle or aunt), or someone significant (friend, neighbour, or work colleague) completed this scale. This tool focuses on two elements: symptoms of separation distress (e.g., nostalgia) and traumatic distress (e.g., bitterness, avoidance). It includes 19 items and respondents must indicate how often each of the 19 feelings has been experienced since the death of a loved one. The answer choices range from 0 ("never") to 4 ("always"). A score of 26 or higher corresponds to complicated or pathological grief (Prigerson et al., 1995). Of the 624 respondents who were exposed to the train derailment, 268 people were bereaved (42.9%), of whom 71 had complicated grief (26.5%). The Cronbach's alpha coefficient was .90 for the overall score, indicating good internal reliability.

The original version of Horowitz, Wilner, and Alvarez's (1979) Impact of Event Scale (IES) was used to measure the presence of post-traumatic stress disorder. This tool includes 15 items for which respondents are asked to indicate the frequency of occurrence of the symptoms during the last week (Alexander & Klein, 2001) from 0 to 5, to give a total scale score between 0 and 75 points. The higher the score, the more post-traumatic stress symptoms respondents show. A score greater than 25 indicates the presence of a post-traumatic stress disorder (Ticehurst, Webster, Carr, & Lewin, 1996). The alpha coefficient was .93 for the overall score.

The six-item Kessler Psychological Distress Scale (K6) was used to assess the psychological distress of respondents (Kessler et al., 2002). This scale, validated in many American, Australian, and Canadian population surveys, deals with feelings of nervousness, hopelessness, agitation, depression, discouragement, and uselessness experienced during the last month. Each of the six items is evaluated on a 4-point scale, for a total score ranging from 0 to 24. The higher the score, the greater the psychological distress. People who score seven or higher are classed as suffering from psychological distress (Camirand, Traoré, Baulne, & Courtemanche, 2016). The alpha coefficient was .85 for the overall score.

The presence of depressive symptoms was assessed with two questions determining whether, for a consecutive period of two weeks or more in the past 12 months, respondents felt sad, melancholic, or depressed and had experienced a loss of interest in the things they usually liked. Respondents also had to answer two questions asking them if they had been diagnosed by a doctor regarding: a) the presence of a mood disorder, such as depression, bipolar disorder, mania, or dysthymia; and b) the presence of an anxiety disorder, such as a phobia, obsessive-compulsive disorder, or panic disorder. These questions were previously used in two population surveys conducted in 2014 and 2015 (Généreux, Perreault, & Petit, 2016).

Positive mental health was captured with the 14-item Mental Health Continuum-Short Form questionnaire (MHC-SF) which provides a mental health assessment based on hedonic (three items) and eudemonic (11 items) approaches to well-being (Keyes, 2002, 2005). This measure acknowledges that mental health is more than the absence of mental disorders; people with such disorders are able to experience well-being and quality of life while people without such disorders can experience low levels of mental health (Keyes, 2007). Participants indicated how often during the last month they had experienced each item (e.g., happy, interested in life) using a 6-point Likert-type scale (i.e., "never", "rarely", "a few times", "often", "most of the time", "always"). In this study, the alpha coefficient was .89, again indicating good internal reliability.

The Multidimensional Scale of Perceived Social Support (MSPSS; Zimet, Dahlem, Zimet, & Farley, 1988; Zimet, Powell, Farley, Werkman, & Berkoff, 1990) was used to assess respondents' social support. This tool uses 12 questions to measure three dimensions of social support: 1) support received from family members (four questions); 2) support received from friends (four questions); and 3) support received from other people, those who are present when needed, people with whom they can share their joys or sorrows, who care about their feelings, or who are sources of comfort (four questions). Responses used a 7-point Likert scale ranging from 1 ("strongly disagree") to 7 ("strongly agree"). The lower the score, the weaker the social support network. A score of 69 points or more shows that respondents have a high level of social support, while a score of 49 to 68 points represents an average level of social support.

Respondents scoring 12 to 48 points have access to low social support (Bergeron & Hébert, 2004). In this study, the alpha coefficient was .92 for the overall score.

Finally, the use of prescribed medication was identified based on two questions about the use or not of tranquillizers, sedatives, or antidepressants prescribed by a physician in the last 12 months preceding the survey. The respondents had to answer the following questions with "yes", "no", or "do not know": "In the past 12 months, did you use doctor-prescribed sedatives or tranquillizers?" and "In the past 12 months, did you use doctor-prescribed antidepressants?"

Data Analysis

This study aimed to compare respondents split by the presence of posttraumatic growth on all variables under study. Chi-square tests were used for nominal or ordinal data. When significant differences were identified through these analyses, post hoc comparative tests were conducted using the Bonferroni correction. For the presence of post-traumatic stress, psychological distress, complicated grief, resilience, and positive mental health, the Student's *t*-test or the Mann-Whitney U test was used to compare the averages of these five variables between respondents with and without posttraumatic growth. The significance threshold was established at $p < .05$ for all analyses. Due to an over-representation of women and people aged 65 or over who agreed to participate in this study according to their actual distribution in the population, all data were weighted for age and gender according to the method of Weighting Factors (NIST, 2019). Analyses were carried out using IBM SPSS version 24 software.

Results

Sociodemographic characteristics, social support, and posttraumatic growth of respondents.

Significant differences exist between respondents exposed to adversity showing signs of posttraumatic growth ($n = 269$) and those who are not in this situation ($n = 355$) in terms of their gender, level of education, income, and level of social support (Table 1). There was a significantly higher proportion of women than men who scored above 57 on the PTGI. There were also more people with lower income who showed posttraumatic growth three years after the train tragedy than among those who did not show posttraumatic growth. People with posttraumatic growth were also more likely to have a high level of social support than those who did not have such growth.

Table 1
Sociodemographic characteristics of respondents split by the presence or not of posttraumatic growth (%).

Variables	Posttraumatic Growth Yes ($n = 269$)	No ($n = 355$)	χ^2	*p*
Gender			6.24	.014*
Man	29.0	38.6		
Woman	71.0	61.4		
Age			4.07	.130
18-49 years old	29.5	30.9		
50-64 years old	34.5	40.5		
65 years +	36.0	28.6		
Live alone			0.079	.853
Yes	25.3	26.3		
No	74.7	73.7		
Marital status			1.83	.608
Married / Free union	65.4	65.6		
Single	13.0	14.6		
Separated / divorced	14.1	11.0		
Widowed	7.4	8.7		
Children of 18 years old and under			0.64	.449
Yes	22.3	25.1		
No	77.7	74.9		
Source of income			1.02	.796
Full-time worker	38.4	41.5		
Part-time worker	10.1	10.7		
Retired	39.6	37.6		
Others	11.9	0.2		
Last level of education completed			4.07	.130
High school or less	64.3	51.6		
College or more	35.7	48.4		
Family annual income			10.45	.005**
Under 30 000$	37.1	25.8		
Between 30 000 and 79 999$	49.6	54.2		
Over 80 000$	13.3	20.0		
Social support			10.50	.005**
Low	3.3	6.5		
Average	27.5	36.6		
High	69.1	56.9		

$*p < .05$, $**p < .01$

Women were more likely than men to show posttraumatic growth in the areas of relation with others (Women = 80.7%, Men = 67.4%) and spiritual changes (Women = 75.5%, Men = 69.8%). However, there were no significant differences between genders among those who showed posttraumatic growth in the areas of discovering new opportunities (Women = 36.3%, Men = 39.5%), personal strengths (Women = 29.7%, Men = 31.4%), or appreciation of life (Women = 64.2%, Men = 65.1%).

Posttraumatic growth and loss during the train derailment.

Survivors with posttraumatic growth were significantly more likely to have suffered the death of one of their relatives and to have been forced to relocate temporarily or permanently (see Table 2). However, those with and without posttraumatic growth did not differ on any of the other exposure factors (fear for their own or a close other's life, damage to property, loss of employment, or exposure to the damaged city centre).

Table 2
Exposure to and effect of the disaster split by the presence or not of posttraumatic growth (%).

Variables	Posttraumatic Growth		χ^2	*p*
	Yes (*n* = 269)	No (*n* = 355)		
Fear for the life for oneself			2.43	.121
Yes	41.8	34.7		
No	58.2	65.3		
Fear for the life of a loved one			3.42	.068
Yes	78.6	70.9		
No	21.4	29.1		
Death of a loved one			5.07	.027*
Yes	48.5	39.4		
No	51.5	60.6		
Loss of or damages to one's home			3.03	.090
Yes	13.3	8.9		
No	86.7	91.1		
Loss of employment			0.66	.436
Yes	17.2	14.8		
No	82.8	85.2		
Relocation			4.64	.036*
Yes	42.0	33.6		
No	58.0	66.4		
Exposure to the destroyed city centre			1.11	.324
Yes	60.6	56.4		
No	39.4	43.6		

*$p < .05$

Post-disaster physical and psychological health status and posttraumatic growth.

Three years after the tragedy, most respondents with or without posttraumatic growth rated their physical health as excellent or very good (see Table 3). However, more people with posttraumatic growth than people without

Table 3
Physical and psychological health categorical variables of persons exposed to train derailment split by the presence or absence of posttraumatic growth (%).

Variables	Posttraumatic Growth		χ^2	*p*
	Yes (*n* = 269)	No (*n* = 355)		
Physical health status				
Perception of health status			3.67	.057
Excellent and very good	85.6	79.7		
Fair to poor	14.4	20.3		
Health level			31.47	.000***
Has improved	18.2	4.5		
Remained stable	55.3	62.1		
Has deteriorated	26.5	33.4		
Psychological health status				
Presence of mood disorder			0.089	.805
Yes	11.7	12.5		
No	88.3	87.5		
Presence of anxiety disorder			0.73	.399
Yes	19.3	16.7		
No	80.7	83.3		
Depressive episode			2.12	.148
Yes	31.1	36.7		
No	68.9	63.3		
Use of anxiolytics			2.86	.093
Yes	24.6	19.0		
No	75.4	81.0		
Use of antidepressants			4.64	.040*
Yes	18.6	12.3		
No	81.4	87.7		

*$p < .05$, *** $p < .001$

it felt that their health status had improved over the last three years. Regarding the psychological health status of respondents (Tables 3 and 4), the presence of post-traumatic stress symptoms, complicated grief, positive mental health, and antidepressant use were positively associated with posttraumatic growth. However, presence of mood disorder, anxiety disorder, depressive episodes, high psychological distress, level of resilience, and the use of anxiolytics were not associated with posttraumatic growth.

Table 4
Averages, median, and standard deviation of psychological health continuous variables exposed to train derailment according to the presence or absence of posttraumatic growth.

Variables	Posttraumatic Growth		$\chi 2$	*p*
	Yes (*n* = 269)	No (*n* = 355)		
Posttraumatic stress status				
Average	32.42	24.72	8.20	.000***
Median	31.00	21.20		
Standard Deviation	19.50	19.58		
High psychological distress				
Average	5.30	5.48	1.09	.276
Median	5.00	4.00		
Standard Deviation	3.93	4.65		
Complicated grief				
Average	20.69	17.46	2.28	.023*
Median	20.00	15.07		
Standard Deviation	11.58	11.63		
Resilience				
Average	28.86	28.84	-0.58	.564
Median	30.00	30.00		
Standard Deviation	6.16	7.20		
Positive mental health				
Average	47.58	44.08	-3.13	.002**
Median	47.00	45.00		
Standard Deviation	9.59	11.70		

Note. The test values for resilience and positive mental health are z-scores from Mann-Whitney U tests, conducted due to significant Levene's tests.

*$p < .05$, ** $p < .01$, *** $p < .001$

Positive changes in various aspects of respondents' lives based on the presence or absence of posttraumatic growth.

Reports of changes since the train derailment in various aspects of personal, marital, family, social, and professional aspects of life identified several significant differences between the two groups of respondents. Table 5 shows, for example, that people with posttraumatic growth were more likely than survivors without it to have noticed improvements since the derailment in their relationships with their spouses, relationships with their children, and in the quality of life in their neighbourhood. These respondents also had a more positive perception of the future and of life in general than those who did not demonstrate posttraumatic growth. Those who demonstrated growth were also significantly more likely to report an improvement in their work performance as well as an increase in work motivation. In terms of their social life, people with posttraumatic growth were significantly more likely to have noticed an increase in the quality of their relationships with members of their entourage and an increase in the frequency of their leisure activities and of their outings. These respondents with posttraumatic growth also had a stronger sense of belonging to their community but were more likely to have noticed that their stress level at work had increased since the train derailment.

Discussion

This study found that women demonstrated more posttraumatic growth than men, which is consistent with most of the scientific literature. Several studies demonstrated gender differences in the specific areas of the posttraumatic growth index (PTGI); women are more likely to perceive positive changes in some areas, whereas men are more likely to do so in others (Anderson et al., 2016). However, in this study, men did not demonstrate significantly higher scores than women for any of the five areas of the PTGI. The fact that more women than men experienced posttraumatic growth after the train derailment may be due to their greater sensitivity and greater attentiveness to the feelings of the different members of their social groups. In addition, to cope with stressful events, women tend to use social support and express their feelings more often than men do (Simard, 2000), which promotes the emergence of posttraumatic growth (Tedechi & Calhoun, 2004). Further, the research conducted with men indicates that many of them are often not very attentive to their own needs and feelings, whether they are positive or negative, and that they have difficulties in sharing them (Mahalik et al., 2003). Men typically also show little self-compassion (Reilly, Rochlen, & Awad, 2014), which may be detrimental to identifying changes in themselves, including benefits after exposure to a disaster.

The results for differences based on income are consistent with what is stated in the literature. In this study and in the literature, low income fosters the development of posttraumatic growth (Achterhof et al., 2017; Wu et al., 2016). This result could be explained by the fact that less economically vulnerable people seem to attach more importance to lost properties and goods than people who are more economically vulnerable (Saccinto, Prati, Pietrantoni, & Pérez-Testor, 2012). In addition, Platt, Lowe, Galea, Norris, and Koenen (2016) emphasized that disaster relief is primarily available to the poor and those with precarious health status. The fact that emergency assistance is available may have made it possible for the victims of the derailment to take a more positive look at different PTGI aspects, including relationships with others, appreciation for life, and the discovery of new opportunities. The current study also highlights that a high level of social support is positively associated with posttraumatic growth, which has already been observed in other studies (Lowe et al., 2015), as well as the fact that a high level

Table 5
Personal, family, social, and professional life of people exposed split by the presence or absence of posttraumatic growth (%).

Variables	Posttraumatic Growth		χ^2	Variables	Posttraumatic Growth		χ^2
	Yes (*n* = 269)	No (*n* = 355)			Yes (*n* = 269)	No (*n* = 355)	
Personal life				Family life			
Perception of the future			31.25***	Relationship with partner/spouse			14.21**
Is more positive	43.2	22.2		Has improved	20.1	8.7	
Remains the same	39.0	53.9		Remained stable	68.5	76.5	
Is more negative	17.8	23.9		Has deteriorated	11.4	14.9	
Outlook on life			41.80***	Relationship with children			23.56***
Is more positive	47.1	22.8		Have improved	30.3	13.1	
Remains the same	41.8	57.5		Remained stable	67.8	81.7	
Is more negative	11.0	19.7		Have deteriorated	1.9	5.2	
Professional life							
Quality of relationships			13.70**	Performance			18.56***
Has increased	27.3	17.0		Has improved	25.3	9.9	
Remained stable	65.2	68.8		Remained stable	64.4	74.6	
Has decreased	7.6	14.2		Has decreased	10.3	15.5	
Frequency of leisure activities			19.44**	Motivation			12.89**
Has increased	29.9	15.8		Has increased	26.2	14.5	
Remained stable	55.3	61.9		Remained stable	55.2	55.7	
Has decreased	14.8	22.2		Has decreased	18.6	29.8	
Number of outings			18.99***	Level of stress at work			5.78*ns*
Has increased	31.2	16.4		Has increased	26.2	21.7	
Remained stable	48.7	59.2		Remained stable	61.2	70.0	
Has decreased	20.2	24.4		Has decreased	12.5	8.3	
Quality of life in the neighbourhood			19.75***	Sense of belonging			3.81ns
Has improved	31.9	18.0		Strong	81.3	74.6	
Remained stable	7.6	14.6		Poor	18.7	25.4	
Has deteriorated	60.5	67.3					

ns $p > .05$, ** $p < .01$, *** $p < .001$

of perceived social support is beneficial to physical and mental health (Bruchon-Schweitzer, 2002). In addition, the fact that Lac-Mégantic is a small community may encourage access to support from informal and formal resources and may play a role in the development of posttraumatic growth of citizens, although this study did not produce firm evidence to support this idea. Future research could explore more closely the role of community connectedness and access to support in the development of posttraumatic growth.

In addition, the fact that people who lost a loved one, their home, or were relocated were more likely to experience posttraumatic growth can be explained by the fact that a high level of disaster exposure is positively related to posttraumatic growth (Jin et al., 2014). These situations, therefore, remain opportunities to experience a psychological process that leads individuals to give meaning to disruptive events as well as life in general (Park, 2016). Establishing the relationship between exposure to a disaster and posttraumatic growth can inform how such victims are supported after the event to increase the benefits they experience.

However, this study did not show that psychological distress is related to posttraumatic growth. This can possibly be explained by the fact that the measuring tool used (Kessler et al., 2002) specifically addresses feelings of depression rather than distress more broadly. In fact, depression is recognized as having no positive link with posttraumatic growth and is considered a potential constraint to it (Guo et al., 2017; Helgeson et al., 2006). Moreover, in this study, as the use of antidepressants is associated with posttraumatic growth, this may suggest that taking these medications can reverse any negative effects that depression may have on posttraumatic growth (Guo et al., 2017; Helgeson et al., 2006). In addition, the results also confirm the existence of a positive association between posttraumatic growth and post-traumatic stress manifestations (Achterhof et al., 2017; Dursun et al, 2016; Gibbs et al., 2016) such as: repetitive, involuntary, and pervasive memories of the traumatic event causing a feeling of distress; repetitive dreams related to the event also causing a feeling of distress; and dissociative reactions (e.g., flashbacks) in which the subject feels or acts as if the traumatic event(s) were to recur (American Psychiatry Association, 2015).

This study also found an association between posttraumatic growth and complicated grief as well as positive mental health, but no association with resilience. This result supports the suggestion that posttraumatic growth can coexist with resilience (Smith et al., 2016). However, further studies are needed to clarify the relationship between resilience and posttraumatic growth. The positive association between complicated grief and posttraumatic growth can be explained by the fact that people suffering complicated grief following a tragic event, such as natural or technological disaster, often also suffer from post-traumatic stress symptoms (Suar et al., 2015; Sveen et al., 2016) and that these reactions are themselves positively related to the presence of posttraumatic growth (Achterhof et al., 2017; Chan & Rhodes, 2013; Dursun et al., 2016; Gibbs et al., 2016; Guo et al., 2017; Jin et al., 2014; Linley & Joseph, 2004; Saccinto et al., 2012; Tang, 2007; Xu & Liao, 2011). It is not uncommon for people with complicated grief to ruminate and have intrusive thoughts (Shear, 2015). This rumination, related to the disruption of fundamental beliefs of life, can facilitate the posttraumatic growth process (Kaijun, Yuqing, Zhengkui, Peiling, & Chuguang, 2015; Tedeschi & Calhoun, 2004). Future research could test whether there is a mediating effect of rumination and post-traumatic stress disorder on the relationship between complicated grief and posttraumatic growth.

This study also shows that people with posttraumatic growth are more likely to notice various positive effects that are not measured by the PTGI in their lives. In this regard, people with posttraumatic growth were significantly more likely than those not in this situation to consider that their family and social relationships have improved in the three years following the derailment of the train. The studies of Shakespeare-Finch and Barrington (2012) and Bonanno et al. (2010) also highlighted these same findings. Indeed, they noted that many survivors of a traumatic event report spending more time with family members and friends and that this type of event brings them emotionally closer to those connections. In addition, Carra and Curtin (2017) recently demonstrated in their qualitative study that some flood victims in Australia reported having developed more links with their local community, which is also consistent with our finding that a large percentage of people with or without posttraumatic growth feel they have a high sense of belonging to their community. Without minimizing the negative impact that a disaster may have on survivors' lives, psychologists and social workers could not only focus on the reduction of post-traumatic symptoms but also take into account the potential for personal and social growth following such an event (Joseph, 2009;

Shakespeare-Finch & Lurie-Beck, 2014; Zoellner & Maercker, 2006). This would likely facilitate the recovery process of victims and their loved ones.

In addition to measuring the presence or absence of posttraumatic growth with a proven standardized tool, victims of disasters ought to be questioned on various other benefits that may result from their exposure to this type of event. Getting survivors to maintain hope, to seek the meaning of events, and to identify positive changes in other areas of their lives can guide them in their adaptation and recovery process. Again, since perceived social support is linked to posttraumatic growth, it is essential that before, during, and after a disaster, victims receive tangible and emotional support from various individuals and organizations to cope with their various stresses. It would be relevant to conduct longitudinal studies with the same respondents to determine whether posttraumatic growth and other positive effects of the train derailment are sustained over time. This type of study could also be beneficial for different subgroups of the population, such as young people attending secondary and post-secondary schools, as there have been few studies to date with this age group to identify the positive consequences of disasters.

Limitations

Although the results support the importance of integrating diverse variables to identify those that are associated with the presence of posttraumatic growth, these results cannot be generalized to all individuals exposed to other types of disasters. It is possible that people who refused to complete the telephone survey had different socio-demographic characteristics and more or less precarious state of health than those who elected to respond. It is also possible that those exposed to the train derailment and agreed to participate in this study were better able to cope with the different stresses experienced, and therefore would be more likely to show posttraumatic growth, than those who refused to complete the questionnaire administered by telephone. Further, some respondents may not have been completely honest when answering questions about their mental health status, especially the questions on the presence of mood, anxiety, or depression issues. The use of validated tests would have been preferable, but as the data was primarily collected through a telephone survey, it was necessary to focus on certain issues to the detriment of others. The findings from the variables which were focused on, such as different types of exposure and effects on various life domains, offer valuable contributions to the existing literature.

In addition, the lack of pre-disaster data with respect to respondents' health status and the fact that the data collection was performed more than three years after the train derailment are limitations that do not allow us to conclude that exposure to this disaster is the only traumatic event causing posttraumatic growth. People were able to experience various other personal, marital, family, professional, or social events that forced them to question their values, beliefs, and lifestyle and that could have contributed to the effects we founds. In order to avoid this limitation, multiple traumatic experiences should be controlled for in future studies of long-term impacts after a disaster. In the same vein, the cross-sectional nature of this study does not allow us to collect information on the stability of posttraumatic growth over time. Longitudinal studies are therefore preferred after a disaster to try to overcome this difficulty. The high number of respondents in the two groups of participants is, however, a positive factor in the internal validity of the results. Finally, other measures for post-traumatic stress and for resilience might be more appropriate in some situations; however, the measures used here have been used repeatedly in previous work, were validated in these studies, and showed high internal reliability in the current study.

Conclusion

Studies have widely documented the negative impacts that a disaster may have on the health of individuals. However, few have demonstrated that these negative impacts can coexist with the presence of posttraumatic growth. The present study suggests that posttraumatic growth can occur in a significant number of victims (43.1%) after exposure to a train derailment, a percentage higher than a study conducted one year after earthquakes in Italy (18.6%, Bianchini et al., 2017). Conducting of this study three years after the traumatic event left more time for respondents to develop effective coping strategies, in turn allowing them to develop posttraumatic growth.

This study also demonstrates that certain factors are associated with posttraumatic growth. Among the pre-traumatic factors, gender and income were associated with the presence of posttraumatic growth. Some stressful events such as the loss of a loved one and relocation were also positively associated with posttraumatic growth. The presence of post-traumatic stress disorder, complicated grief, and positive mental health, as well as having access to a high level of social support, were also factors contributing to the presence of this growth. Thus, this study encourages us to consider differently the preventive and curative interventions to be implemented before, during, and after a disaster. It is essential then to develop various types of interventions, both individually and collectively, allowing individuals, particularly men and those with post-traumatic stress disorder, to normalize both negative and positive feelings when exposed to a traumatic event.

Authors' Note

This research was supported by a grant from Social Sciences and Humanities Research Council of Canada (CRSH). This study was validated by two ethics committees: CER-UQAC and CER-Université de Sherbrooke.

References

Achterhof, R., Dorahy, M. J., Rowlands, A., Renouf, C., Britt, E., & Carter, J. D. (2017). Predictors of posttraumatic growth 10–11 months after a fatal earthquake. *Psychological Trauma: Theory, Research, Practice, and Policy, 10*(2), 208-215. doi: 10.1037/tra0000286

Alexander, D. A., & Klein, S. (2001). Ambulance personnel and critical incidents: Impact of accident and emergency work on mental health and emotional well-being. *The British Journal of Psychiatry*, *178*(1), 76–81. doi: 10.1192/bjp.178.1.76

American Psychiatric Association. (2015). *Diagnostic and statistical manual of mental disorders* (5th ed., French translation edited by P. Boyer, J-D. Guelfi, J-F. Henry, A. Lisoprawski, C-B. Pull, M-C. Pull, & G. Welsh). Washington, DC: Author.

Anderson, D., Prioleau, P., Taku, K., Naruse, Y., Sekine, H., Maeda, M., … Yanagisawa, R. (2016). Post-traumatic stress and growth among medical student volunteers after the March 2011 disaster in Fukushima, Japan: Implications for student involvement with future disasters. *Psychiatric Quarterly, 87*(2), 241–251. doi: 10.1007/s11126-015-9381-3

Antunez, J.M., Navarro, J.F., & Adan, A. (2015). Circadian typology is related to resilience and optimism in healthy adults. *Chronobiology International, 32*(4), 524-530.

Bergeron, M., & Hébert, M. (2004). *Mesure de la qualité du soutien perçu de l'entourage lors du dévoilement de l'agression sexuelle et face à la démarche d'aide entreprise*. Document inédit. Canada: Université du Québec à Montréal.

Bianchini, V., Giusti, L., Salza, A., Cofini, V., Cifone, M., Casacchia, ... Roncone, R. (2017). Moderate depression promotes posttraumatic growth (Ptg): A young population survey 2 years after the 2009 L'Aquila earthquake. *Clinical Practice and Epidemiology in Mental Health, 13*, 10-19.

Bonanno, G. A., Brewin, C. R., Kaniasty, K., & La Greca, A. M. (2010). Weighing the costs of disaster: Consequences, risks, and resilience in individuals, families, and communities. *Psychological Science in the Public Interest, 11*(1), 1–49. doi: 10.1177/1529100610387086

Bruchon-Schweitzer, M. (2002). *Psychologie de la santé: modèles, concepts et méthodes*. Paris: Dunod.

Calhoun, L. G., & Tedeschi, R. G. (1999). *Facilitating posttraumatic growth: A clinician's guide*. Mahwah, NJ: Erlbaum.

Camirand, H., Traoré, I., Baulne, J., & Courtemanche, R. (2016). *L'enquête québécoise sur la santé de la population 2014-2015 : pour en savoir plus sur la santé des Québécois : résultats de la deuxième édition*. Canada: Institut de la statistique du Québec.

Campbell-Sills L., & Stein, M.B. (2007). Psychometric analysis and refinement of the Connor-Davidson resilience scale (CD-RISC): Validation of a 10-item measure of resilience. *Journal of Traumatic Stress, 20*(6), 1019-1028.

Carra, K. A., & Curtin, M. (2017). Posttraumatic growth among Australian farming women after a flood. *Journal of Loss and Trauma, 22*(5), 453–463. doi: 10.1080/15325024.2017.1310506

Chan, C. S., & Rhodes, J. E. (2013). Religious coping, posttraumatic stress, psychological distress, and posttraumatic growth among female survivors four years after hurricane Katrina. *Journal of Traumatic Stress, 26*(2), 257–265. doi: 10.1002/jts.21801

Connor, K. M., & Davidson, J. R. T. (2003). Development of a new resilience scale: the Connor-Davidson Resilience Scale (CD-RISC). *Depression and Anxiety*, *18*(2), 76–82.

Dursun, P., Steger, M. F., Bentele, C., & Schulenberg, S. E. (2016). Meaning and posttraumatic growth among survivors of the September 2013 Colorado floods. *Journal of Clinical Psychology, 72*, 1247–1263. doi: 10.1002/jclp.22344

Fergusson, D. M., Boden, J. M., Horwood, L. J., & Mulder, R. T. (2015). Perceptions of distress and positive consequences following exposure to a major disaster amongst a well-studied cohort. *Australian & New Zealand Journal of Psychiatry, 49*(4), 351–359. doi: 10.1177/0004867414560652

Généreux, M., Perreault, G.,& Petit, G. (2016). Portrait de la santé psychologique de la population du Granit en 2015. *Vision santé publique, 51*, 1-8.

Gibbs, L., Bryant, R., Harms, L., Forbes, D., Block, K., Gallagher, H. C., …Waters, E. (2016). *Beyond bushfires: Community resilience and recovery final report*. Australia: University of Melbourne.

Guo, J., Fu, M., Xing, J., Qu, Z., & Wang, X. (2017). Coping style and posttraumatic growth among adult survivors 8 years after the 2008 Wenchuan earthquake in China. *Personality and Individual Differences, 111*, 31–36. doi: 10.1016/j.paid.2017.01.046

Helgeson, V. S., Reynolds, K. A., & Tomich, P. L. (2006). A meta-analytic review of benefit finding and growth. *Journal of Consulting and Clinical Psychology, 74*(5), 797–816. doi: 10.1037/0022-006X.74.5.797

Horowitz, M., Wilner, N., & Alvarez, W. (1979). Impact of event scale: a measure of subjective stress. *Psychosomatic Medicine*, *41*(3), 209–218.

Jeste, D. V., Savia, G. N., Thompson, W. K., Vahia, I. V., Glorioso, D. K., Martin, A. S., … Depp, C. A. (2013). Association between older age and more successful aging:

critical role of resilience and depression. *American Journal of Psychiatry, 170*(2), 188-196.

Jin, Y., Xu, J., Liu, H., & Liu, D. (2014). Posttraumatic stress disorder and posttraumatic growth among adult survivors of Wenchuan earthquake after 1 year: Prevalence and correlates. *Archives of Psychiatric Nursing, 28*(1), 67–73. doi: 10/1016/j.apnu.2013.10.010

Joseph, S. (2009). Growth following adversity: Positive psychological perspectives on posttraumatic stress. *Psihologijske teme, 18*(2), 335–344.

Kaijun, E., Yuqing, E., Zhengkui, E., Peiling, E., & Chuguang, E. (2015). Coexistence and different determinants of Post-traumatic Stress Disorder and Post-traumatic Growth among Chinese survivors after earthquake: Role of resilience and rumination. *Frontiers in Psychology, 6,* 1-9. doi: 10.3389/fpsyg.2015.01043

Kessler, R. C., Andrews, G., Colpe, L. J., Hiripi, E., Mroczek, D. K., Normand, S. L., … Zaslavsky, A. M. (2002). Short screening scales to monitor population prevalence and trends in nonspecific psychological distress. *Psychological Medicine*, *32*(6), 959–976. doi: 10.1017/S0033291702006074

Keyes, C. L. M. (2002). The mental health continuum: From languishing to flourishing in life. *Journal of Health and Social Behavior*, *43*(2), 207–222.

Keyes, C. L. M. (2005). Mental illness and/or mental health? Investigating axioms of the complete state model of health. *Journal of Consulting and Clinical Psychology*, *73*(3), 539–548.

Keyes, C. L. M. (2007). Promoting and protecting mental health as flourishing: A complementary strategy for improving national mental health. *American Psychology*, *62*(2), 95–108.

Linley, P. A., & Joseph, S. (2004). Positive change following trauma and adversity: A review. *Journal of Traumatic Stress, 17*(1), 11–21. doi: 10.1023/B:JOTS.0000014671.27856.7e

Lowe, S., Rhodes, J., & Waters, M. (2015). Understanding resilience and other trajectories of psychological distress: A mixed-methods study of low-income mothers who survived hurricane Katrina. *Current Psychology, 34*(3), 537–550. doi: 10.1007/s12144-015-9362-6

Luthar, S. S., Cicchetti, D., & Becker, B. (2000). The construct of resilience: A critical evaluation and guidelines for future work. *Child Development*, *71*(3), 543-562.

Mahalik, J. R., Locke, B., Ludlow, L., Diemer, M., Scott, R. P. J., Gottfried, M., & Freitas, G. (2003). Development of the conformity to masculine norms inventory. *Psychology of Men & Masculinity*, *4*(1), 3–25. doi: 10.1037/1524-9220.4.1.3

Maltais, D., & Côté, N. (2007). Soutien social et personnes âgées en cas de désastre: Points saillants des recherches existantes**.** *Vie et vieillissement, 6*(2), 39-42.

Maltais, D., & Gauthier, S. (2010). Long term impacts on personal and spiritual values for French Canadian elderly victims of a flood in Quebec: a question of resilience. In A. Kalayjian and D. Eugene (Eds.), *Mass trauma and emotional healing around the world: rituals and practices for resilience and meaning-making*, (vol. 1, p. 193–211). US: ABC-CLIO.

Maltais, D., Lachance, L., Brassard, A., & Dubois, M. (2005). Soutien social et santé psychologique de victimes d'inondations. *Sciences Sociales et Santé*, *23*(2), 5-38.

Marshall, E. M., Frazier, P., Frankfurt, S., & Kuijer, R. G. (2015). Trajectories of posttraumatic growth and depreciation after two major earthquakes. *Psychological Trauma: Theory, Research, Practice, and Policy, 7*(2), 112-121. doi: 10.1037/tra0000005.

Mordeno, I., Nalipay, M., Alfonso, M., & Cue, M. (2016). Examining the latent structure of posttraumatic growth between male and female survivors in the immediate aftermath of a flash flood disaster. *Current Psychology, 35*(4), 587–594. doi:10,1007/s12144-015-9325-y

Mordeno, I. G., Nalipay, M. J. N., & Cue, M. P. (2015). The role of functionality in the latent structure of posttraumatic growth among survivors of a flash flood disaster. *Psychological Studies*, *60*(2), 138–145.

NIST. (2019). Engineering Statistics Handbook section 4.4.5.2.: Accounting for non-constant variation across the data. Retrieved from www.itl.nist.gov/div898/handbook/pmd/section4/pmd452.htm.

Park, C-L (2016). Meaning making in the context of disaster. *Journal of Clinical Psychology*, *72*(12),1234-1246.

Petit, G., & Gosselin, J. (2016). La ville de Lac-Mégantic et la catastrophe de juillet 2013. In D. Maltais & C. Larin (Eds.), *Lac-Mégantic: De la tragédie à la résilience (*pp. 93-107). Québec: Les Presses de l'Université du Québec.

Platt, J. M., Lowe, S. R., Galea, S., Norris, F. H., & Koenen, K. C. (2016). A longitudinal study of the bidirectional relationship between social support and posttraumatic stress following a natural disaster. *Journal of Traumatic Stress, 29*(3), 205–213.

Prigerson, H. G., Maciejewski, P. K., Reynolds, C. F., Bierhals, A. J., Newsom, J. T., Fasiczka, A., ... Miller, M. (1995). Inventory of complicated grief: A scale to measure maladaptive symptoms of loss. *Psychiatry Research*, *59*(1), 65–79.

Reilly, E. D., Rochlen, A. B., & Awad, G. H. (2014). Men's self-compassion and self-esteem: The moderating roles of shame and masculine norm adherence. *Psychology of Men & Masculinity*, *15*(1), 22-28. doi: 10.1037/a0031028.

Saccinto, E., Prati, G., Pietrantoni, L., & Pérez-Testor, C. (2012). Posttraumatic stress symptoms and posttraumatic growth among Italian survivors of emergency situations. *Journal of Loss and Trauma, 18*(3). 210-226. doi: 10.1080/15325024.2012.687321

Shakespeare-Finch, J., & Barrington, A. J. (2012). Behavioural changes add validity to the construct of posttraumatic growth. *Journal of Traumatic Stress, 25*(4), 433–439. doi: 10.1002/jts.21730

Shakespeare-Finch, J., & Lurie-Beck, J. (2014). A meta-analytic clarification of the relationship between posttraumatic growth and symptoms of posttraumatic distress disorder. *Journal of Anxiety Disorders, 28*(2), 223–229. doi:10.1016/j.janxdis.2013.10.005

Shear, M.K. (2015). Complicated grief. *The New England Journal of Medecine*, *372*, 153-160. doi: 10.1056/NEJMcp1315618

Simard, N. (200). *Relations entre les stratégies d'adaptation et les manifestations post-traumatiques et dépressives des sinistrés des inondations de juillet 1996 au Saguenay*. Canada: Université du Québec à Chicoutimi.

Smith, R., McIntosh, V., Carter, J., Colhoun, H., Jordan, J., Carter, F., & Bell, C. (2016). Thriving after trauma: Posttraumatic growth following the Canterbury earthquake sequence. *Australasian Journal of Disaster and Trauma Studies, 20*(2), 125–134.

Suar, D., Sekar Das, S., & Alat, P. (2015). Bereavement, postdisaster trauma and behavioral changes in tsunami survivors. *Death Studies*, *39*(4), 226-233. doi: 10.1080/07481187.2014.979957

Sveen, J., Pohlkamp, L., Ohlén, J., Sandberg, J., Brandange, K., & Gustavsson, P. (2016). Posttraumatic stress among not-exposed traumatically bereaved relatives after the MS Estonia disaster. *Plos One, 11*(11), 1-10. doi: 10.1371/journal.pone.0166441

Tang, C. S. K. (2007). Posttraumatic growth of Southeast Asian survivors with physical injuries: Six months after the 2004 Southeast Asian earthquake-tsunami. *Australasian Journal of Disaster and Trauma Studies 2007*(1). Retrieved from http://trauma.massey.ac.nz/issues/2007-1/tang.htm

Tedeschi, R. G., & Calhoun, L. G. (1996). The posttraumatic growth inventory: Measuring the positive legacy of trauma. *Journal of Traumatic Stress, 9*(3), 455–471. doi: 10.1002/jts.2490090305

Tedeschi, R. G., & Calhoun, L. G. (2004). Posttraumatic growth: Conceptual foundations and empirical evidence. *Psychological Inquiry, 15*(1), 1–18. doi: 10.1207/s15327965pli1501_01

Ticehurst, S., Webster, R.A., Carr, V.J., & Lewin, T.J. (1996). The psychosocial impact of an earthquake on the elderly. *Journal of Geriatric Psychiatry*, *11*(11), 943–951. doi: 10.1002/(SICI)1099-1166(199611)11:11%3C943::AID-GPS412%3E3.0.CO;2-B

Wu, Z., Xu, J., & Sui, Y. (2016). Posttraumatic stress disorder and posttraumatic growth coexistence and the risk factors in Wenchuan earthquake survivors. *Psychiatry Research, 237*, 49–54. doi: 10.1016/j.psychres.2016.01.041

Xu, J., & Liao, Q. (2011). Prevalence and predictors of posttraumatic growth among adult survivors one year following 2008 Sichuan earthquake. *Journal of Affective Disorders, 133*(1–2), 274–280. doi: 10.1016/j.jad.2011.03.034

Zimet, G.D., Dahlem, N.W., Zimet, S.G., & Farley, G.K. (1988). The Multidimensional Scale of Perceived Social Support. *Journal of Personality Assessment*, *52*(1), 30-41.

Zimet, G.D., Powell, S.S., Farley, G.K., Werkman, S., & Berkoff, K.A. (1990). Psychometric characteristics of the Multidimensional Scale of Perceived Social Support. *Journal of Personality Assessment*, *55*(3-4), 610-617.

Zoellner, T., & Maercker, A. (2006). Posttraumatic growth in clinical psychology: A critical review and introduction of a two component model. *Clinical Psychology Review, 26*(5), 626–653. doi: 10.1016/j.cpr.2006.01.008

This page intentionally left blank.

A research update on the demography and injury burden of victims of New Zealand earthquakes between 2010 and 2014

Shewa Basharati[1],
Michael Ardagh[1,2],
Joanne Deely[1,3],
Nicholas Horspool[4],
David Johnston[5],
Shirley Feldmann-Jensen[6],
Alieke Dierckx[7],
Martin Than[1]

[1] Canterbury District Health Board, Christchurch, New Zealand
[2] University of Otago, Christchurch, New Zealand
[3] Lincoln University, Lincoln, New Zealand
[4] GNS Science, Wellington, New Zealand
[5] Joint Centre for Disaster Research, Massey University, Wellington, New Zealand
[6] California State University, Long Beach, California, USA
[7] Emergency Care Foundation, Christchurch, New Zealand

Author correspondence:
Joanne Deely,
Canterbury District Health Board,
Christchurch,
New Zealand.
Email: joanne.deely@cdhb.health.nz

URL: http://trauma.massey.ac.nz/issues/2020-1/AJDTS_24_1_Basharati.pdf

Abstract

This study compared the populations exposed to different shaking intensities of recent New Zealand earthquakes with injury burden, demography, and scene of injury. The population exposed to each earthquake was approximated by overlaying estimates of ground shaking with models of day and night population distributions. Injury data from all earthquakes and their aftershock periods were analysed for patient age and sex, location, scene of injury, and date of injury. An association was found between population exposed to shaking intensity and injury burden. The total injury burdens for each earthquake were: 2,815 (Darfield, 2010); 9,048 (Christchurch, February 2011); 2,057 (Christchurch, June 2011); 1,385 (Christchurch, December 2011); 106 (Cook Strait, 2013); 166 (Grassmere, 2013); and 49 (Eketahuna, 2014). All earthquakes injured approximately twice as many females as males. Most people who were injured were in the age range of 40-59 years. Two-thirds of injuries occurred at home, followed by 14% in commercial locations and 6.5% on roads and streets. This pattern was repeated within the data for each sex. The results suggest that the total injury burden was positively associated with both the intensity of shaking and size and density of the exposed population. The localities where most injuries occurred suggest that where people were at the time of shaking influenced their risk of injury. Potential explanations for the sex disparity in number of injuries are discussed.

Keywords: *earthquakes, sex and age, scene of injury, population exposed to shaking intensity, injury burden*

Identifying the causes of injury and understanding who is most at risk during an earthquake will help to inform interventions that reduce injury risk and improve rescue and medical strategies. New Zealand is a country of 5 million people, located in the south-western Pacific Ocean, consisting of two main islands which lie along a tectonic plate boundary that forms part of the "Pacific ring of fire". Both islands suffered some major earthquakes and aftershocks between 2010 and 2014 (see Figure 1).

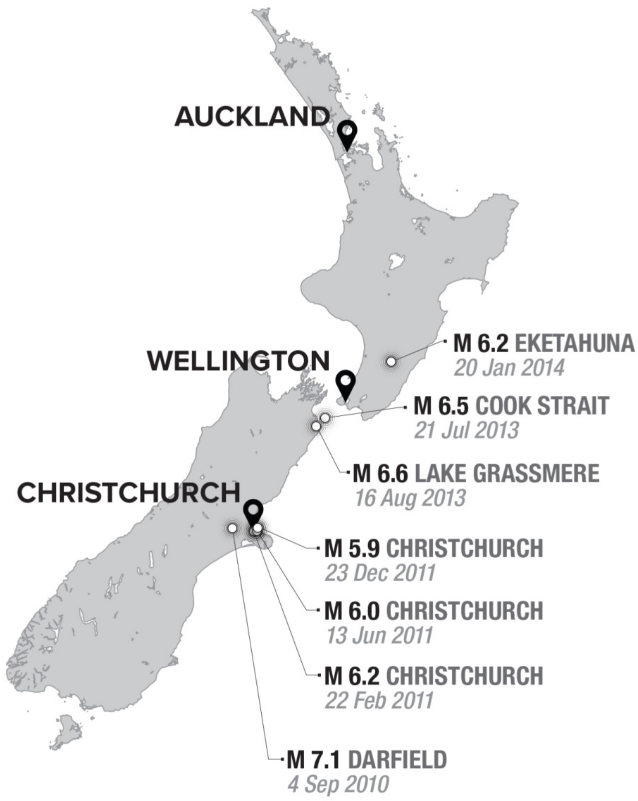


Figure 1. Epicentres of New Zealand earthquakes from 2010 to 2014. M = Magnitude.

Table 1.
Summary of New Zealand earthquakes from 2010 to 2014.

	Earthquakes						
Details	Darfield	Chch-Feb-11	Chch-Jun-11	Chch-Dec-11	Cook Strait	Grassmere	Eketahuna
Locality	Darfield	Christchurch	Christchurch	Christchurch	Seddon	Seddon	Eketahuna
Date	4/9/10	22/2/11	13/6/11	23/12/11	12/07/13	16/8/13	20/1/14
Time	4:35	12:51	14:20	15:18	17:09	14:31	15:52
Day	Sat	Tues	Mon	Fri	Fri	Fri	Mon
Magnitude	7.1	6.2	6.0	5.9	6.5	6.6	6.2
PGA	1.26g	2.2g	2.13g	1.0g	0.2g	0.75g	0.26g
Depth	10.8km	5.9 km	7km	7km	13km	8km	34km
Aftershock Period	4/9/10 – 21/2/11	22/2/11 – 12/6/11	13/6/11 – 22/12/11	23/12/11 – 12/2015	21/07/13 – 15/08/13	16/07/13 – 12/2015	20/01/14 – 12/2016

Note. PGA = Peak ground acceleration; Dates are in day/month/year format.

In this paper, we present an overview of the seven most significant New Zealand earthquakes between September 2010 and February 2014 (see Table 1). The major Darfield earthquake (2010) caused extensive damage to many older brick and masonry buildings in the Canterbury region, including Christchurch City. There was a significant number of injuries associated with this event (Gledhill, Ristau, Reyners, Fry, & Holden, 2011; Johnston et al., 2014). The Darfield earthquake initiated a period of continuous local seismic activity, which included three other major earthquakes (aftershocks) close to Christchurch City. The most significant occurred on the 22nd of February 2011. This earthquake led to 185 deaths and thousands of injuries (Ardagh et al., 2012; Johnston et al., 2014). Destruction, including property damage and liquefaction, was widespread (Kaiser et al., 2012). The Christchurch central business district (CBD) was significantly damaged with two multi-storey buildings collapsing (Ardagh et al., 2012). The other two significant Christchurch-based earthquakes that caused injury in Canterbury occurred on the 13th of June 2011 and the 23rd of December 2011 (Table 1).

Later, on the 21st of July 2013, the Cook Strait earthquake (also known as the Seddon earthquake) struck 20 kilometres east of the town of Seddon in the Marlborough region of the South Island (Table 1; USGS, 2016a). This earthquake caused moderate damage in the wider Marlborough area and Wellington (the capital city, 55 kilometres north of the epicentre; see Figure 1). Six weeks later, the Lake Grassmere area was struck by an earthquake 10 kilometres south-east of Seddon (Table 1; USGS, 2016b).

On Monday the 20th of January 2014, an earthquake struck the Eketahuna area in the south-east of New Zealand's North Island (GeoNet, 2014) in the middle of the afternoon. This earthquake caused minor to moderate damage in Palmerston North, Eketahuna, and the wider Wellington region (EQC, 2018).

Johnston et al. (2014) and Ardagh et al. (2012; 2016) reported injuries from the Darfield 2010 and Christchurch (22nd February 2011) earthquakes. These three studies noted a disproportionate number of females injured compared with males, and that most people injured were in the age range 40-59 years. Although most injuries occurred at home (Ardagh et al., 2016), Johnston et al. (2014) also reported that most people were injured while moving during the Darfield earthquake, but most were injured while stationary during the Christchurch earthquake. These studies concluded that where people were, what they were doing, and their actions during earthquake shaking influenced their risk of injury. To build on this previous research, our study had two objectives. Firstly, we compared the Darfield and Christchurch (22nd February 2011) earthquake data over their total aftershock periods with similar data from the five more recent earthquakes presented in Table 1 to determine if the distributions found in the earlier studies are common phenomena. The other important objective of this study was to compare the populations exposed to different shaking intensities with injury rates, demography, and scene of injury. Such a comparison was not made in previous research but will contribute important information for understanding earthquake injury burden.

Methods

The population exposed to each earthquake was approximated by overlaying estimates of ground shaking from ShakeMap (Horspool, Chadwick, Ristau, Salichon, & Gerstenberger, 2015) with a model of population distribution for day and night populations within the RiskScape Multi-hazard Impact Modelling software (Schmidt et al., 2011). The injury data from all earthquakes and their aftershock periods were obtained from the “Researching the Health Impacts of Seismic Events” (RHISE) database (housed at the Canterbury District Health Board, Christchurch, New Zealand). The database was established after the 22nd of February, 2011, Christchurch earthquake with patient data from the Canterbury District Health Board (CDHB) live warehouses of patient data and the New Zealand Accident Compensation Corporation (ACC) client datasets (Ardagh et al., 2016). The CDHB provides free health care to the region while the ACC scheme provides free health care for people injured in accidents in New Zealand. Each episode of care requires the completion of details to progress funding for the claim. The RHISE database combines and links patient data from both sources and has continued to be updated following each new earthquake event. Consequently, a comprehensive database has been developed.

The RHISE database contained data from 15,697 patients injured on the day of each earthquake and during the aftershock periods presented in Table 1. Of the total patients, 71 were excluded from the study because they were not earthquake-related, leaving 15,626 people injured in the seven earthquakes. Each patient’s data contain demographic information and a description of injuries. The following data were analysed: patient age and sex, scene of injury, and date of injury.

Results

Populations Exposed to Different Intensities of Shaking

The estimated populations exposed to different intensities of shaking are presented in Table 3 with definitions for the Modified Mercalli Intensity (MMI) scale given in Table 2. The results for populations exposed to shaking reflect severity of shaking and proximity of epicentres to large urban areas. The highest magnitude Darfield earthquake, with a rurally located epicentre 40 kilometres from Christchurch City, was felt over a wide area. More than 400,000 people experienced extreme and severe intensity shaking and about 50,000 people experienced moderate to strong intensity shaking.

During the Christchurch, February 2011, earthquake, more than 300,000 individuals suffered extreme intensity shaking and more than 200,000 experienced moderate to severe intensity shaking. During each of the latter two Christchurch 2011 earthquakes, 500,000 people experienced moderate to severe shaking intensities, though none experienced the extreme shaking intensities felt during the earlier 2011 earthquake. In the case of the June earthquake, more than 300,000 individuals experienced severe shaking and more than 170,000 experienced strong shaking whereas the populations were more evenly spread over the moderate to severe shaking intensities during the December event.

During each of the three other earthquakes examined in this study (Cook Strait, Grassmere, and Eketahuna) with rurally-located epicentres, more than 2,000

Table 2.
Modified Mercalli Intensity (MMI) scale for New Zealand context.

MMI	Intensity	Description
1	unnoticeable	Barely sensed only by a very few people.
2	unnoticeable	Felt only by a few people at rest in houses or on upper floors.
3	weak	Felt indoors as a light vibration. Hanging objects may swing slightly.
4	light	Generally noticed indoors, but not outside, as a moderate vibration or jolt. Light sleepers may be awakened. Walls may creak, and glassware, crockery, doors, or windows rattle.
5	moderate	Generally felt outside and by almost everyone indoors. Most sleepers are awakened, and a few people alarmed. Small objects are shifted or overturned, and pictures knock against the wall. Some glassware and crockery may break, and loosely secured doors may swing open and shut.
6	strong	Felt by all. People and animals are alarmed, and many run outside. Walking steadily is difficult. Furniture and appliances may move on smooth surfaces, and objects fall from walls and shelves. Glassware and crockery break. Slight non-structural damage to buildings may occur.
7	severe	General alarm. People experience difficulty standing. Furniture and appliances are shifted. Substantial damage to fragile or unsecured objects. A few weak buildings are damaged.
8	extreme	Alarm may approach panic. A few buildings are damaged, and some weak buildings are destroyed.

Note. This table is adapted from Dowrick and Rhoades (2011).

Table 3.
Estimated population exposed (in thousands) to different levels of shaking.

	Shaking Intensity Level				
Event	MMI5 (Moderate)	MMI6 (Strong)	MMI7 (Severe)	MMI8+ (Extreme)	Total
Darfield-Sep-10	31	24	202	210	467
Chch-Feb-11	98	54	68	310	530
Chch-Jun-11	41	178	305	0	524
Chch-Dec-11	145	231	178	0	554
C. Strait-Jul-13	456	35	1	0	492
Grassmere-Aug-13	237	2	2	0	241
Eketahuna-Jan-14	98	157	1	0	256

Note. The MMI scale is defined in Table 2. Chch = Christchurch; C. Strait = Cook Strait.

individuals experienced severe intensity shaking, but none experienced extreme levels of shaking. In the case of the Cook Strait event, 35,000 people in rural towns of the Marlborough region experienced strong intensity shaking and more than 450,000 people in Wellington City (further from the epicentre) likely experienced moderate intensity shaking (Table 3). The pattern was similar for the Lake Grassmere earthquake except that approximately half the population size was affected by shaking. In the case of the deeper seated Eketahuna earthquake, more than 150,000 people felt strong shaking and more than 100,000 experienced moderate shaking.

Injury Burden

Figure 2 relates the maximum MMI intensity of earthquakes affecting populations of more than 150,000 to total injury burden. This figure suggests a relationship between the size of the population exposed to different shaking intensities and injury burden. The high intensity February Christchurch and Darfield earthquakes (MMI 8+) had the highest injury burdens, followed by the June

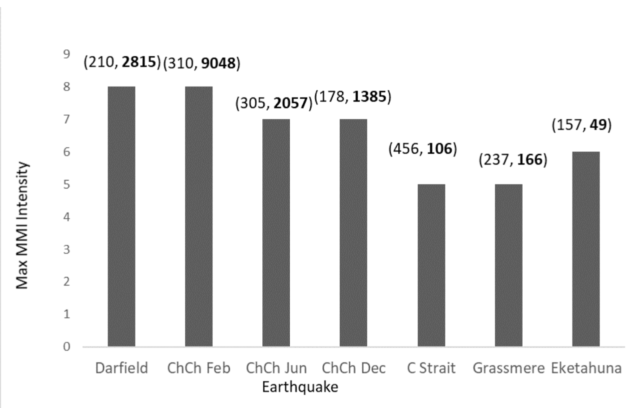


Figure 2. Comparison of the maximum MMI intensity (bars) that affected populations >150,000, and total injury burden; (population (thousands), **total injury burden**).

and December Christchurch events which had maximum MMI intensities of 7. The populations which experienced MMI intensities of less than 6 had injury burdens an order of magnitude less than the Canterbury (Christchurch and Darfield) events.

The earthquakes where more than 300,000 people experienced severe (MMI7) or extreme (MMI8+) shaking intensities had the highest injury burden rate proportional to the estimated population exposed to shaking (Table 4). These included the Darfield and February Christchurch events. The February Christchurch extreme earthquake shaking occurred during the middle of the day, affecting 310,000 people and injuring approximately 9,000. Although severe and extreme shaking affected more than 400,000 people in the Darfield event, this earthquake happened in the early hours of the morning and fewer than 3,000 were injured in total. In line with the February event, the injury rate for the June and December Christchurch earthquakes reflects the high numbers of people affected by strong and severe shaking intensities during the daytime.

The much lower total injury burden from the lower intensity Cook Strait and Grassmere events compared to the higher intensity Darfield and Christchurch earthquakes (see Figure 2) suggests a relationship between population size/shaking intensity and total numbers injured. This relationship did not hold for the deep epicentre Eketahuna earthquake, which had a similar total affected population size to that of Grassmere (256,000 vs 241,000), but had the smallest injury burden (N = 49) of the earthquakes considered here.

Demographic Distribution

Gender. The data suggest that most earthquakes injured approximately twice as many females as males. In the case of the Cook Strait and Eketahuna earthquakes, which had the lowest injury burdens of 106 and 49 respectively, the disparity between females and males was largest. The total injury burdens were: Darfield, 1,863 females versus 952 males; Christchurch (February), 5,960 females versus 3,088 males; Christchurch (June), 1,417 females versus 640 males; Christchurch (December), 978 females versus 407 males; Cook Strait, 82 females versus 24 males; Grassmere, 112 females versus 54 males; and Eketahuna, 39 females versus 10 males.

Age. Table 4 also presents the injury rate in the estimated population exposed to shaking stratified by age. Where the total injury rate for an earthquake was lower than 250 people per 100,000 exposed to shaking (i.e., the Darfield and three Christchurch events), most people who were injured were in the age ranges 40-49 years and 50-59 years. Older people had the next highest percentage of injuries (60-69 years and 70+ years). Children between the ages of 0-9 years were the least injured, followed by teenagers, young adults, and finally adults 30-39 years (Table 2). These trends held for the Grassmere earthquake, but the lower injury burdens in the Cook Strait and Eketuna earthquakes means that trends were not clear. In the Darfield, Christchurch, Grassmere, and Eketahuna earthquakes, the sex disparity held for all age groups except children. However, more female than male adults over the age of 40 were injured during the Cook Strait event.

Scene of Injury

The scenes of injury for all the earthquakes under study combined are presented in Table 5. Approximately two-thirds of injuries occurred at home, followed by 14% in commercial locations and 6.5% on roads and streets. This pattern was repeated within the data for each sex. Twice as many females as males were injured in all locations, except industrial places, farms, and data with no scene of injury.

Table 4.
Injury rate per hundred thousand of the total estimated population exposed to shaking.

		Age range							
	Total	0–9	10–19	20–29	30–39	40–49	50–59	60–69	70+
Darfield-Sep-10									
Male	204	3	8	15	31	51	45	28	23
Female	399	3	15	25	65	95	85	60	52
Total	603	6	23	39	96	146	129	88	75
Chch-Feb-11									
Male	583	12	27	57	88	123	125	80	71
Female	1125	11	45	114	165	233	233	158	166
Total	1707	23	72	171	253	356	357	238	236
Chch- Jun-11									
Male	122	2	5	10	17	28	25	19	16
Female	270	3	10	22	37	54	58	45	42
Total	393	5	15	32	54	82	83	64	57
Chch-Dec-11									
Male	73	1	3	5	7	14	17	13	13
Female	177	2	4	11	18	37	38	34	34
Total	250	3	7	16	25	50	55	47	47
C. Strait-Jul-13									
Male	5	0	0	1	0	1	1	1	1
Female	17	0	1	3	3	3	3	2	2
Total	22	0	1	3	3	4	4	3	3
Grassmere-Aug-13									
Male	22	1	2	2	3	4	5	2	3
Female	46	0	4	2	5	12	12	6	5
Total	69	2	6	4	8	16	17	8	8

Note. Data for Eketahuna not included as the low injury burden means injury rates per 100,000 are typically below 1.

Table 5.
Scene of injury for all patients across all earthquakes.

	Total	Female	Male
Claim Scene	n (%)	n (%)	n (%)
Home	10,076 (64.5)	6,846 (65.5)	3,230 (62.3)
Commercial Location	2,229 (14.3)	1,542 (14.8)	687 (13.3)
Road/Street	1,012 (6.50)	648 (6.20)	364 (7.06)
Industrial Place	358 (2.30)	159 (1.52)	199 (3.86)
School	235 (1.50)	175 (1.67)	60 (1.16)
Place of Recreation and Sport	196 (1.30)	139 (1.33)	57 (1.11)
Place of Medical Treatment	64 (0.40)	51 (0.49)	13 (0.25)
Farm	15 (0.10)	8 (0.08)	7 (0.14)
Other	1,394 (8.90)	857 (8.20)	537 (10.4)
Not Obtained	245 (0.30)	26 (0.25)	219 (4.25)
Total	15,824 (100)	10,451 (66.1)	5,373 (34.0)

Discussion

This study found a positive association between population exposed to shaking intensity and the total injury burden of each of the seven earthquakes. Although most of the earthquakes considered in this study had shallow epicentres, the size of the populations affected by different intensities of shaking varied depending on proximity of the epicentres to major cities or towns.

The high injury burdens of all Christchurch earthquakes largely reflect daytime shaking. The February Christchurch event exposed the largest population to extreme shaking and led to the highest number of injuries, consistent with the findings of the ShakeMap Atlas which demonstrated a strong link between population exposed to extreme shaking and injury and mortality rates (Allen et al., 2009). However, although it was the highest magnitude earthquake with the second largest population exposed to extreme shaking, the night-time Darfield event caused approximately one-third the number of injuries as the February Christchurch event and no deaths. The data in this study therefore suggest that the time of day at which an earthquake occurs also impacts injury burden, supporting some existing evidence (Johnston et al., 2014). Considering this, the Darfield earthquake would likely have resulted in many more injuries if it had occurred during day-light hours when more people were active. However, some of the credit for the low injury burden from the Darfield earthquake can also be attributed to the Canterbury region's high proportion of flexible timber-framed houses (Quigley et al., 2010). Research demonstrates a positive association between shaking-induced building damage, which tends to be less in flexible-framed houses, and injuries (So & Spence, 2013).

The similar injury rates within the age groups of each sex suggests that males and females of the same age had the same risk of injury during all the events. Nonetheless, the injury disparity between the sexes and absence of it in children aged under 10 years need further consideration. Ardagh et al. (2016) reported similar age distributions of injuries during the first 24-hours of response to the February Christchurch earthquake as that of our study which considered all reported injuries following the event. In Ardagh et al.'s paper, the largest proportions of casualties were in the 40-49 years age group (21%) and 50-59 years age group (20%). While Johnston et al. (2014) reported similar age distributions for casualties of the Darfield earthquake (40-49 years, 24%; 50-59 years, 21%), they reported that injury burden of the February Christchurch earthquakes was relatively evenly spread across the 10-year age groups (0-59 years; 12.3%-14.7%). This discrepancy may be due to differences in the periods over which the data were assessed in each study. Ardagh et al. (2016) assessed the injury burden during the first 24 hours of response and Johnston et al. (2014) assessed burden (including casualties who incurred injuries during clean-up) in the following five months.

The most likely place to be injured during the earthquakes and aftershocks was at home. Ardagh et al. (2016) reported that about 50% of total casualties during the first 24 hours after the Christchurch earthquake were injured at home. In the current study, this increased to more than 60% when looking at all seven earthquakes and their aftershocks periods together. Two-thirds (6,659) of the total injury burden from the February Christchurch earthquake occurred in the first 24 hours (Ardagh et al., 2012). Ardagh et al. (2012) found slightly more people injured in the commercial and services industries during this one specific event compared with our study looking across multiple earthquakes; this difference is likely due to differences in proximity of earthquake epicentres to cities.

Ardagh et al. (2016) reported that in the first 24 hours of the February 2011 earthquake approximately twice as many females as males were injured at home (2,390 versus 1,002) and close to three times as many females as males injured in the commercial/service industries (1,105 versus 444) and schools (106 vs 34). International reports of earthquakes causing high mortality and injury numbers have found that the most important risk factors are the degree of damage to buildings and the location of individuals within buildings at the time of shaking (Ellidokuz, Ucku, Aydin, & Ellidokuz, 2005; Ramirez & Peek-Asa, 2005). While our findings support Ardagh et al.'s conclusion that where people were and what they were doing influenced their risk of injury during earthquake shaking, as well as an apparent sex disparity in reported injuries, Canterbury's high proportion of flexible timber-framed houses likely contributed to the low number of serious injuries and fatalities incurred during the Darfield and Christchurch events (excluding the February event) compared to similar international earthquakes (Ardagh et al., 2016; Ardagh et al., 2012; Johnston et al., 2014; Quigley et al., 2010).

The high proportion of injuries that occurred at home and in commercial localities may also relate to what happened during shaking (Johnston et al., 2014). Close to half of the total injuries in the Darfield earthquake occurred when people rushed about in darkness in their homes during shaking in the early hours of the morning. In contrast, during the February Christchurch midday earthquake, less than 20% of people were injured this way. Johnston et al. (2014) found that approximately 25% of both sexes tripped or fell during shaking and approximately 10% were hit by projectiles. Most of the hospitalised patients who were injured during the February Christchurch earthquake came from the central business district (Ardagh et al., 2016).

If more adult females than males were at home, working in commercial areas, and teaching at schools, this may partly explain the sex disparity. Many reports on earthquake injury and mortality data evaluate samples of patients treated in hospitals, including field hospitals, without including the multitude of minorly injured patients (Amundson et al., 2010; Bozkurt, Ocguder, Turktas, & Erdem, 2007; Kreiss et al., 2010; Sami et al., 2009). Many reports also focus on subsets of injury types or disease processes (Etienne, Powell, & Faux, 2010; He et al., 2011; Hu et al., 2012; Mahue-Giangreco, Mack, Seligson, & Bourque, 2001; Rathore et al., 2007). Consequently, some studies report higher injury and mortality rates for females than males (Armenian, Melkonian, Noji, & Hovanesian, 1997; Chan et al., 2003; Etienne et al., 2010; Liang et al., 2001; Peek-Asa, Kraus, Bourque, & Vimalachandra, 1998; Peek-Asa, Ramirez, Seligson, & Shoaf, 2003; Tanaka et al., 1998) and some report the rate as equal for both sexes (Bozkurt et al., 2007; Ellidokuz et al., 2005; He et al., 2011; Hu et al., 2012; Mahue-Giangreco et al., 2001; Mulvey, Awan, Qadri, & Maqsood, 2008; Rathore et al., 2007; Sami et al., 2009; Xie et al., 2008; Zhang, Li, Carlton, & Ursano, 2009), while males tend to suffer more non-disaster related injuries than females (Udry, 1998).

It is possible that the lower rates of injuries for males could be due to under-reporting of injuries among this demographic, an aligned tendency for females to seek treatment more often than males (e.g., general practice visits in New Zealand: Jatrana & Crampton, 2009), or that a general, well-established difference in average physical size and strength could mean that the same impacts which injured females sufficiently that reporting was necessary would not injure males to the same extent (Blue, 1993). Finally, the disparity in our study could also have been influenced by differences in behaviour between the sexes during earthquake shaking. For example, it might be that males are more likely to undertake protective actions during shaking. Future research could explore this idea to support more education regarding securing objects to walls and other surfaces, and self-protective actions such as drop, cover, and hold (see e.g., getthru.govt.nz). In particular, if there is a sex difference in use of self-protective actions then tailoring education campaigns to be more effective for females may help to lower the injury rate for this demographic in future earthquakes.

Conclusion

This study found a positive association between population exposed to shaking intensity and the total injury burden from each of the seven earthquakes. Across the seven earthquakes, the size of the total injury burdens appeared associated with the severity of shaking experienced, which in turn could relate to the proximity of epicentres to major cities or towns as well as the time of day at which the earthquake occurred. As an extension of this study, current work led by author NH aims to develop a model that will predict the total injury burden and short- and long-term social impacts of future major earthquakes. The model is being developed by combining data from Statistics New Zealand on baseline populations with social and health data from the RHISE database. Our findings also align with those of Ardagh et al. (2016) and Johnston et al. (2014) whereby more females than males were injured in all events, most people were injured in the age range 40-59 years, and the most likely place to be injured during the earthquakes and aftershocks was at home. Future work specifically educating females on protective action during shaking could reduce the proportion of females injured in future events and therefore also meaningfully reduce the overall injury burden of earthquakes.

Acknowledgements

This project was partially supported by QuakeCoRE, a New Zealand Tertiary Education Commission-funded Centre. This is QuakeCoRE publication number 0431.

References

Allen, T. I., Wald, D. J., Earle, P. S., Marano, K. D., Hotovec, A. J., Lin, K., & Hearne, M. G. (2009). An Atlas of ShakeMaps and population exposure catalog for earthquake loss modeling. *Bulletin of Earthquake Engineering*, *7*, 701–718.

Amundson, D., Dadekian, G., Etienne, M., Gleeson, T., Hicks, T., Killian, D., . . . Miller, E. J. (2010). Practicing internal medicine onboard the USNS COMFORT in the aftermath of the Haitian earthquake. *Annals of Internal Medicine*, *152*, 733-737. doi: 10.7326/0003-4819-152-11-201006010-00215

Ardagh, M., Richardson, S., Robinson, V., Than, M., Gee, P., Henderson, S., … Deely, J. (2012). The initial health-system response to the earthquake in Christchurch, New Zealand, in February, 2011. *The Lancet, 379*, 2109-2115. doi: 10.1016/S0140-6736(12)60313-4

Ardagh, M., Standring, S., Deely, J., Johnston, D., Robinson, V., Gulliver, P., … Than, M. (2016). A sex disparity among earthquake victims. *Disaster Medicine and Public Health Preparedness*, *10*, 1-7. doi: 10.1017/dmp.2015.81

Armenian, H. K., Melkonian, A., Noji, E. K., & Hovanesian, A. P. (1997). Deaths and injuries due to the earthquake in Armenia: A cohort approach. *International Journal of Epidemiology*, *26*, 806-813. doi: 10.1093/ije/26.4.806

Bozkurt, M., Ocguder, A., Turktas, U., & Erdem, M. (2007). The evaluation of trauma patients in Turkish Red Crescent Field Hospital following the Pakistan earthquake in 2005. *Injury*, *38*, 290-297. doi: 10.1016/j.injury.2006.10.013

Chan, C. C., Lin, Y. P., Chen, H. H., Chang, T. Y., Cheng, T. J., & Chen, L. S. (2003). A population-based study on the immediate and prolonged effects of the 1999 Taiwan earthquake on mortality. *Annals of Epidemiology*, *13*, 502-508. doi: 10.1016/S1047-2797(03)00040-1

Dowrick, D. J., & Rhoades, D. A. (2011). Spatial distribution of ground shaking in characteristic earthquakes on the Wellington and Alpine Faults, New Zealand, estimated from a distributed source model. *Bulletin of the New Zealand Society for Earthquake Engineering*, *44*, 1-18. doi: 10.5459/bnzsee.44.1.1-18

Ellidokuz, H., Ucku, R., Aydin, U. Y., & Ellidokuz, E. (2005). Risk factors for death and injuries in earthquake: Cross-sectional study from Afyon, Turkey. *Croatian Medical Journal*, *46*, 613-618.

EQC. (2018). Eketahuna claims update. Retrieved from www.eqc.govt.nz/news/eketahuna-claims-update

Etienne, M., Powell, C., & Faux, B. (2010). Disaster relief in Haiti: A perspective from the neurologists on the USNS COMFORT. *Lancet Neurology*, *9*, 461-463. doi: 10.1016/S1474-4422(10)70091-0

GeoNet. (2014). M 6.2 Eketahuna Mon, Jan 20 2014. Retrieved from www.geonet.org.nz/quakes/region/wellington/2014p051675

Gledhill, K., Ristau, J., Reyners, M., Fry, B., & Holden, C. (2011). The Darfield (Canterbury, New Zealand) Mw 7.1 earthquake of September 2010: A preliminary seismological report. *Seismological Research Letters*, *82,* 378-386.

He, Q., Wang, F., Li, G., Chen, X., Liao, C., Zou, Y., . . . Wang, L. (2011). Crush syndrome and acute kidney injury in the Wenchuan Earthquake. *The Journal of Trauma and Acute Care Surgery*, *70*, 1213-1217. doi: 10.1097/TA.0b013e3182117b57

Horspool, N. A., Chadwick, M., Ristau, J., Salichon, J., & Gerstenberger, M. C. (2015). ShakeMapNZ: Informing post-event decision making. In *Proceedings of the New Zealand Society for Earthquake Engineering Conference,* 369-376. Retrieved from www.nzsee.org.nz/db/2015/Presentations/O-40.pdf

Hu, Z., Zeng, X., Fu, P., Luo, Z., Tu, Y., Liang, J., … Qin, W. (2012). Predictive factors for acute renal failure in crush injuries in the Sichuan earthquake. *Injury*, *43*, 613-618. doi: 10.1016/j.injury.2010.08.025

Johnston, D., Standring, S., Ronan, K., Lindell, M., Wilson, T., Cousins, J., … Bissell, R. (2014). The 2010/2011 Canterbury earthquakes: Context and cause of injury. *Natural Hazards, 73,* 627-637. doi: 10.1007/s11069-014-1094-7

Kaiser, A., Holden, C., Beavan, J., Beetham, D., Benites, R., Celentano, A., … Zhao, J. (2012). The Mw 6.2 Christchurch earthquake of February 2011: Preliminary report. *New Zealand Journal of Geology and Geophysics, 55*, 67-90. doi: 10.1080/00288306.2011.641182

Kreiss, Y., Merin, O., Peleg, K., Levy, G., Vinker, S., Sagi, R., … Ash, N. (2010). Early disaster response in Haiti: The Israeli field hospital experience. *Annals of Internal Medicine*, *153*, 45-48. doi: 10.7326/0003-4819-153-1-201007060-00253

Liang, N. J., Shih, Y. T., Shih, F. Y., Wu, H. M., Wang, H. J., Shi, S. F., … Wang, B. B. (2001). Disaster epidemiology and medical response in the Chi-Chi earthquake in Taiwan. *Annals of Emergency Medicine*, *38*, 549-555. doi: 10.1067/mem.2001.118999

Mahue-Giangreco, M., Mack, W., Seligson, H., & Bourque, L. B. (2001). Risk factors associated with moderate and serious injuries attributable to the 1994 Northridge Earthquake, Los Angeles, California. *Annals of Epidemiology*, *11*, 347-357. doi: 10.1016/S1047-2797(01)00220-4

Mulvey, J. M., Awan, S. U., Qadri, A. A., & Maqsood, M. A. (2008). Profile of injuries arising from the 2005 Kashmir earthquake: The first 72 h. *Injury*, *39*, 554-560. doi: 10.1016/j.injury.2007.07.025

Peek-Asa, C., Kraus, J. F., Bourque, L. B., Vimalachandra, D., Yu, J., & Abrams, J. (1998). Fatal and hospitalized injuries resulting from the 1994 Northridge earthquake. *International Journal of Epidemiology*, *27*, 459-465. doi: 10.1093/ije/27.3.459

Peek-Asa, C., Ramirez, M., Seligson, H., & Shoaf, K. (2003). Seismic, structural, and individual factors associated with earthquake related injury. *Injury Prevention*, *9*, 62-66.

Quigley, M., Van Dissen, R., Villamor, P., Litchfield, N., Barrell, D., Furlong, K., . . . Pedley, K. (2010). Surface rupture of the Greendale fault during the Mw 7.1 Darfield (Canterbury) earthquake, New Zealand: Initial findings. *Bulletin of The New Zealand Society for Earthquake Engineering*, *43*, 1-7.

Ramirez, M., & Peek-Asa, C. (2005). Epidemiology of traumatic injuries from earthquakes. *Epidemiologic Reviews*, *27*, 47-55. doi: 10.1093/epirev/mxi005

Rathore, M. F., Rashid, P., Butt, A. W., Malik, A. A., Gill, Z. A., & Haig, A. J. (2007). Epidemiology of spinal cord injuries in the 2005 Pakistan earthquake. *Spinal Cord*, *45*, 658-663. doi: 10.1038/sj.sc.3102023

Sami, F., Ali, F., Zaidi, S. H., Rehman, H., Ahmad, T., & Siddiqui, M. I. (2009). The October 2005 earthquake in Northern Pakistan: Patterns of injuries in victims brought to the Emergency Relief Hospital, Doraha, Mansehra. *Prehospital and Disaster Medicine*, *24*, 535-539. doi: 10.1017/S1049023X00007470

Schmidt, J., Matcham, I., Reese, S., King, A., Bell, R., Henderson, R., … Heron, D. (2011). Quantitative multi-risk analysis for natural hazards: A framework for multi-risk modelling. *Natural Hazards*, *58*, 1169-1192. doi: 10.1007/s11069-011-9721-z

So, E., & Spence, R. (2013). Estimating shaking-induced casualties and building damage for global earthquake events: A proposed modelling approach. *Bulletin of Earthquake Engineering*, *11*, 347–363.

Tanaka, H., Iwai, A., Oda, J., Kuwagata, Y., Matsuoka, T., Shimazu, T., & Yoshioka, T. (1998). Overview of evacuation and transport of patients following the 1995 Hanshin-Awaji earthquake. *Journal of Emergency Medicine*, *16*, 439-444. doi: 10.1016/S0736-4679(98)00014-6

USGS. (2016a). M 6.5 - 46km ESE of Blenheim, New Zealand. Retrieved from http://earthquake.usgs.gov/earthquakes/eventpage/usb000iivv#general_summary

USGS. (2016b). M6.5 - 29km SE of Blenheim, New Zealand. Retrieved from http://earthquake.usgs.gov/earthquakes/eventpage/usb000j4iz#general_summary

Xie, J., Du, L., Xia, T., Wang, M., Diao, X., & Li, Y. (2008). Analysis of 1856 inpatients and 33 deaths in the West China Hospital of Sichuan University from the Wenchuan earthquake. *Journal of Evidence-Based Medicine*, *1*, 20-26. doi: 10.1111/j.1756-5391.2008.00010.x

Zhang, L., Li, H., Carlton, J. R., & Ursano, R. (2009). The injury profile after the 2008 earthquakes in China. *Injury*, *40*, 84-86. doi: 10.1016/j.injury.2008.08.045

This page intentionally left blank.

Instructions for Authors

This journal has been established to provide a resource for the Australasian region (New Zealand, Australia and the Pacific), and as such we prioritise and seek contributions from Australasia. We will occasionally consider contributions from other parts of the globe but only if the articles cover issues directly relevant to an Australasian readership.

MANUSCRIPT FORMAT:

Well written English manuscripts of NOT MORE THAN 10,000 words will be considered for publication.

The format and style of the article, including referencing, must follow current American Psychological Association (APA style) conventions.

Authors are requested to supply an abstract of no more than 300 words when submitting an article. The abstract should be a condensed, accurate representation of the rationale, methodology, significant results, conclusions and recommendations contained within the article.

Authors should also provide 4 - 5 keywords that clearly describe the subject matter of the article. Other options for manuscript formats are provided at http://trauma.massey.ac.nz/info/submissions.html.

TABLES, FIGURES AND GRAPHICS:

Each table and figure should possess a brief title and a concise description of its content and should be included in full at the end of a manuscript.

Care should be taken to ensure that tables and figures will be viewable within the limitations of web browsers. Tables and figure numbers and titles should also be inserted into the manuscript text at an appropriate position.

Other pictures or other graphics required for the article should be attached as separate files.

Web compatible GIF, PNG or JPG image formats are preferred.

OTHER DETAILS:

Contributions should be original and not published or submitted for publication in any other journal, electronic or otherwise.

One corresponding author should be designated. Their email address should appear on the manuscript cover page.

As an electronic journal, article reprints will not be provided in the traditional sense. Authors wishing to distribute published copies of their article may do so with the proviso that they clearly acknowledge the source of the publication.

Papers should be submitted, in Microsoft Word format, to the editor via email: **ajdts@massey.ac.nz.**

Peer Review Process

On receipt of an article, the editor will assess its appropriateness for inclusion in the Journal. If the content of the article is appropriate and in an acceptable format, the editor will send the article for review. A final decision on acceptance will be made after the submission has been reviewed.

Acceptance or rejection of a contribution will be based on the "blind" peer review of a submission by at least two members of either the Editorial Board or by others invited to review the article due to their particular expertise. The editors will make a decision to accept, seek revision, or reject a contribution based on the reviewers' comments and recommendations. Contributors will receive a copy of the reviewers' comments at the same time as they receive a response from the editor. Copies of reviews and the editors' decision will also be sent to each reviewer. It is anticipated that the review process should take from 4 to 6 weeks.

The Editor will assume that the paper is an original contribution. Papers appearing in the journal should not be published elsewhere without the written consent of the Publisher of the journal. A copyright declaration will be required of all papers accepted for publication.

Contact Details

WORLD WIDE WEB SITE

Australasian Journal of Disaster and Trauma Studies

http://trauma.massey.ac.nz/

EDITOR

Professor David Johnston

Email: D.M.Johnston@massey.ac.nz

Telephone: +64 (04) 801 5799 ext. 63672

MANAGING EDITOR

Lauren Vinnell

Email: ajdts@massey.ac.nz

POSTAL ADDRESS

Joint Centre for Disaster Research

Massey University

P.O. Box 756

Wellington 6140

New Zealand

PUBLISHED BY: SCHOOL OF PSYCHOLOGY, MASSEY UNIVERSITY, NEW ZEALAND

JOINT CENTRE FOR DISASTER RESEARCH

MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA
UNIVERSITY OF NEW ZEALAND