Crowdsourcing geographic information for disaster management and improving urban resilience: an overview of recent developments and lessons learned

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Abstract

In the past few years, crowdsourced geographic information (also called volunteered geographic information) has emerged as a promising information source for improving urban resilience by managing risks and coping with the consequences of disasters triggered by natural hazards. This chapter presents a typology of sources and usages of crowdsourced geographic information for disaster management, as well as summarises recent research results and present lessons learned for future research and practice in this field.

Keywords

Crowdsourced Geographic Information, Volunteered Geographic Information, Disaster Management, Social Media, OpenStreetMap

Introduction

The potential of Crowdsourced Geographic Information (CGI) as a new information source for disaster risk management has been paradigmatically shown during the earthquake that hit Haiti in 2010. Due to a lack of official data, information gathered from social media, via SMS and from OpenStreetMap became crucial for disaster response. In the past few years, CGI found their way into different disaster situations and scenarios (Horita et al. 2013). The use of geographic information for disaster risk management has attracted great interest both in research and practice, mainly because of the possibility to tap into the 'collective intelligence' or the 'wisdom of the crowds' to improve urban resilience, i.e. to improve the capacity of urban areas to better managing disaster risks and coping with the effects of extreme events.

In general, CGI in the context of disaster risk management can be categorised according to the information source into the following types:

1) *Social media*: Information produced by people about the event in usual social media platforms *(e.g. Twitter, Flickr, Instagram, Facebook)*, such as from eyewitness that exchange and disseminate information about a disaster event.
2) *Crowd sensing*: Information collected from dedicated applications and platforms (e.g. Ushahidi) that are aimed specifically at producing information for disaster risk management.
3) *Collaborative mapping*: Information about geographic features of disaster-affected or disaster-prone areas, which is produced by volunteers using mapping platforms (e.g. OpenStreetMap, Wikimapia), e.g. as derived from satellite imagery.

Although there is a growing body of research related to each of these CGI types in different phases and tasks of disaster management, existing research studies usually focus on a particular type of CGI and are not able to relate to relevant developments associated with other CGI types. The goal of this chapter is to present to a holistic view of this field by means of a typology that is able to distinguish the main features and potentials of each CGI type for disaster risk management. This typology is valuable not only to summarise recent research results, but also to identify more integrated directions for future research on CGI towards improving disaster management and urban resilience. The next sections are thus dedicated to exploring these issues for each of the aforementioned CGI types in turn, followed by a conclusion.

Social Media

The first type of geo-information produced by the 'crowd' in the context of disasters is related to the use of existing social media platforms to exchange

information. Social media has been defined as 'a group of Internet-based applications that build on the ideological and technological foundations of Web 2.0, and that allow the creation and exchange of User Generated Content' (Kaplan & Haenlein 2010). As such, these platforms allow users to easily share self-produced content within a network of contacts and/or for the general public in a variety of forms: texts via blogs (from 'web log') or short messages in 'microblogging' (e.g. Twitter), web pages and forums, photos, videos, etc. Popular social media platforms include Twitter, Facebook, Flickr, YouTube, Instagram etc.

As people are increasingly familiar with and ordinarily use social media in their day-to-day life, they naturally tend to uptake these platforms in the occurrence of a disaster for communicating their experience and/or urgent needs. Indeed, in different catastrophic events of the past few years – from the wildfires in Southern California, USA in 2007, over the Earthquake in Haiti in 2010, up to the recent super typhoon in the Philippines 2013 – social media has enabled the affected population to produce information about extreme events and their catastrophic impacts (Sakaki, Okazaki & Matsuo 2010; Crooks et al. 2013; De Longueville et al. 2010).

In the field of disaster risk management, a large part of the existing research focused on the analysis of short messages of the Twitter platform, the so-called Tweets (Steiger et al. 2015). For instance, Sakaki et al. (2010) and Crooks et al. (2013) investigated the use of Twitter for detecting and estimating the trajectory of earthquakes in real time. De Longueville et al. (2010) proposed the use of VGI as a sensor for detecting forest fire hot spots, based on previous work that analysed the application of Twitter as a source of spatiotemporal information for wildfire events in France. In contrast, Fuchs et al. (2013) showed that event detection based on peaks of Twitter activity did not work for the 2013 floods in Germany and presented an analysis of spatiotemporal clusters. Bakillah et al. (2014) applied graph clustering to support the detection of geolocated communities in Twitter after the typhoon Haiyan in the Philippines. Furthermore, a number of studies are concerned about developing tools for visualising social media data in order to enable make-sensing and location- based knowledge discovery (MacEachren et al. 2011; Terpstra & de Vries 2012; Croitoru et al. 2013; Spinsanti & Ostermann 2013).

Another group of studies seek to identify useful information from social media that could be valuable for improving situation awareness (Yin et al. 2012). For instance, Vieweg et al. (2010) and Starbird et al. (2010) analysed Twitter messages during the flooding of the Red River Valley in the United States and Canada in 2009, seeking to discern activity patterns and extract useful information.

Most of the existing work in the area has sought to make sense of social media data as a stand-alone source by analysing aggregated patterns, e.g. by defining thresholds for the size of spatiotemporal clusters of messages that would serve as signals for crisis events of earthquakes (Sakaki et al. 2010, Crooks et al. 2013),

wildfires (De Longueville et al. 2010, Slavkovikj et al. 2014) or disease sur-
veillance (Gomide et al. 2011, Bernardo et al. 2013). However, with such an
approach the actual content of social media messages is largely ignored, and
with this, much of their potential to improve the current knowledge about the
unfolding situation is lost. Furthermore, although event detection is useful for
sudden-onset crises for which there do not exist any other related data, in many
concrete cases, there are additional information sources available. As pointed
out by Lazer et al. (2014), one should not see 'big data' as a substitute for all
existing data, but rather take the challenge of doing innovative analytics by
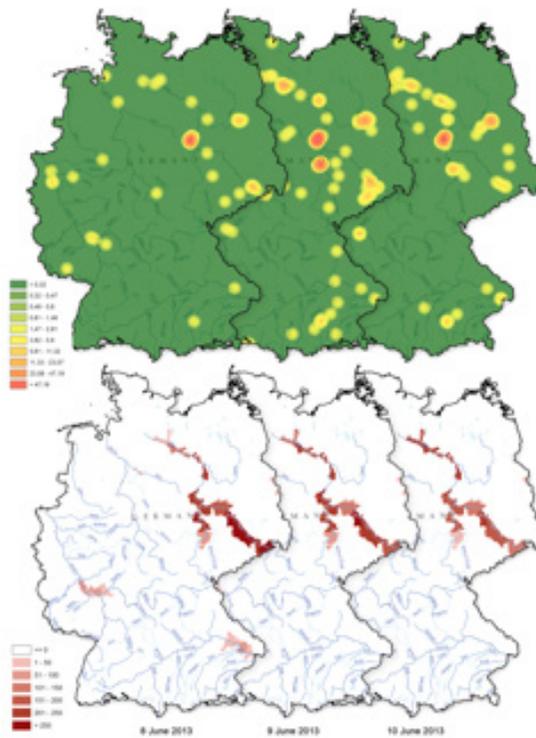using data from all traditional and new sources.

This is in line with a nascent research stream that uses VGI in combination
with other geodata sources in the field of disaster management (Albuquerque
et al. 2015; Schnebele, Cervone & Waters 2014; Triglav-Čekada & Radovan
2013; Spinsanti & Ostermann 2013). For instance, Albuquerque et al. (2015)
leveraged authoritative sensor data of water gauges to show that Tweets close
to flooded areas are more probable to contain useful information for disaster
management (see Figure 1).

Building upon these initial results, an important direction for future research
endeavours is the development of improved analytical methods that are able
leverage several different data sources in order to provide event detection, visu-
alisation and information extraction from crowdsourced geo-information of
social media that are better matched to the needs of decision makers in the field
of disaster management.

Crowd Sensing

A second type of activity related to the use of new collaborative technologies
for disasters is the emergence of the so-called 'crowd sensing' (Ma et al. 2014).
This activity involves citizens on the Web that can act as sensors and share their
observations. Differently from crowdsourced information derived from social
media covered in the previous section, here the term 'crowd sensing' is used to
describe approaches that rely upon dedicated software platforms for gathering
specific and structured data, as well as for exploiting the interpretive and ana-
lytic skills and local knowledge of citizens.

These approaches are also related to the concept of citizen science, which is
described by Haklay (2013) as 'scientific activities in which non-professional
scientists voluntarily participate in data collection, analysis and dissemination
of a scientific project'. As such, people using platforms for 'citizens as sensors' or
'citizen scientists' get engaged for accomplishing a set of tasks in a coordinated
and purposeful manner. These tasks mostly involve some kind of data collec-
tion for different types of scientific investigations, the most famous examples
being bird watching and other types of environmental observations.

Figure 1: Distribution of Twitter messages that were sent during the 2013 Elbe Floods in Germany (top) in contrast with flooded catchments as indicated by river gauges (bottom) (adapted from de Albuquerque et al. 2015).

In the context of disasters, several 'crowd sensing' platforms were created including dedicated mobile applications for disaster management and earth observation (Ferster & Coops 2013). Using volunteers to perform a specific task, such as environmental monitoring, collectively make a Citizen Observatory (CO), where data can be collected, collated and published (Degrossi, et al. 2014; Liu et al. 2015). Thus, the term Citizen Observatory can be understood as a software platform used by citizens to produce volunteered information about a specific topic through different devices (e.g. web, mobile app and SMS), and allow their visualisation.

An important software platform for implementing Citizen Observatories is called Ushahidi[1] (which means 'testimony' in Swahili). This platform was first developed in the context of election monitoring in Kenya and later developed

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[1] Available at: http://www.ushahidi.com [Accessed February 12th 2014].

Figure 2: Flood Citizen Observatory prototype (adapted from Degrossi et al. 2014).

as an open-source toolbox that can be deployed in several situations to collect data from on-the-ground volunteers via web site and mobile application, but also for remote volunteers to collaborative categorise information collated from many sources, including social media (discussed in the previous section). One application example that is built upon the Ushahidi platform is the prototype Flood Citizen Observatory implemented in Brazil (Figure 2) for allowing citizens to report about the local conditions of river levels, flooded areas, as well as consequences of flooding (Degrossi et al. 2014; Horita et al. 2015).

While crowd sensing and citizen observatories can be potentially used to provide useful information about the impacts caused by extreme events and their victims, one important issue is to be addressed is how to motivate people to contribute with valuable information. Another important point to be addressed is how to validate and integrate information from volunteers with other sources of data for effectively improving decision-making related to disaster risk management.

Collaborative Mapping

The third type of crowdsourced geo-information comprises a specific type of information and collaboration platform: the collaborative edition of geographic

features to fulfil internet-based interactive maps. The well-known platforms Wikimapia[2] and OpenStreetMap (OSM)[3] fall into this category, as well as the 'crowdsourcing' component of the popular GoogleMaps platform, so-called GoogleMapMaker[4] (which, unlike the previous ones, does not have an open data policy and thus does not provide users with full access to the collected data).

A distinctive feature of this type of activity is the collaborative collection of a very specific type of data – namely, georeferenced data about features like streets and roads, buildings etc. – and the structuring of this information in form of a map. In doing so, the volunteer community seeks to produce a map that is as complete and detailed as possible, leveraging the local knowledge of a wide base of users to collaboratively fill the gaps. Recent research works have shown that, at least for the regions with the most active communities in OSM, the results achieved a quality level that is comparable to official and commercial maps (Neis, Zielstra & Zipf 2011; Haklay 2010).

The maps produced by volunteers in this way are clearly of great relevance in the context of disasters. High quality and precise maps are an important resource for a number of tasks in disaster management, being used from emergency planning up to the coordination of relief efforts. In several disaster events of the past few years, the volunteer community has been very actively engaged in producing collaborative maps to assist disaster management, especially the community of OpenStreetMap. By digitising the infrastructure, and especially important, also the level of damage (where it can be detected), they create a situation map that can be used by the emergency responders directly in the field.
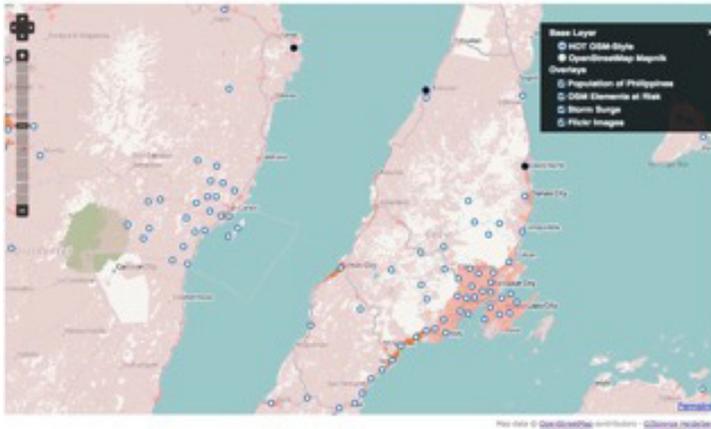
After the devastating earthquake that struck Haiti in January 2010, for instance, there was a very significant response of the international OSM community (Neis et al. 2010; Zook et al. 2010). In the aftermath of that severe quake, good-quality maps were not available to guide the relief efforts, and the standard map services in the web (e.g. GoogleMaps) lacked adequate coverage and had to be updated to reflect the current status of the many blocked roads and streets. A few hours after the quake, the volunteers of the OpenStreetMap (OSM) community around the world started mapping remotely the affected regions based on satellite imagery, seeking to trace the outlines of streets, buildings and places of interest. Later, high-resolution and very up-to-date post-disaster satellite images were made freely available and the OSM community could then resort to those in order to also record the damage of buildings and blockages in streets and roads. Such imagery is a very crucial source of information for the mappers to be used, because it allows also volunteers to contribute from all over the world, not only people that are directly at the affected areas. For large-scale disaster events with many international contributors this can

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[2] Available at: http://wikimapia.org [Accessed February 12th 2014].
[3] Available at: http://openstreetmap.org [Accessed February 12th 2014].
[4] Available at: https://www.google.com/mapmaker [Accessed February 12th 2014].

Figure 3: Elements of the critical infrastructure from OpenStreetMap in the
Phillipines, which was affected by Typhoon Haiyan 2013 (adapted from
Reimer et al. 2014).

generate highly-detailed maps extremely quickly. The information produced
was then available for guiding relief efforts, not only allowing better visual
orientation through the interactive maps, but also for importing the data into
GPS devices for local orientation, as well as using the database behind OSM
for providing more sophisticated services. For instance, an emergency rout-
ing service was developed to allow quick identification of the best routes for
relief efforts based on the up-to-date situation mapped by the OSM community
(Neis, Singler & Zipf 2010).

Ever since 2010, numerous OSM contributors provided their support in
mapping events in the aftermath of a disaster, producing the so-called Crisis
Maps. As a result, within the OSM community a initiative called Humanitar-
ian OpenStreetMap Team (H.O.T.)[5] was launched to organise the many crisis
mapping actions of the OSM community and is also in contact with other rel-
evant humanitarian organisations. This engagement attracted serious interest
in academic circles as well as on the side of humanitarian-aid organisations
(Harvard Humanitarian Initiative 2011; United Nations Office for the Coor-
dination of Humanitarian Affairs 2013). One significant example of the use of
such information could be attested in a more recent major catastrophic event:
the typhoon Haiyan that hit the Philippines in 2013 (Reimer et al. 2014). In this
case, the international OSM community was also very active and collaborated
in a coordinated way with humanitarian organisations such as the American

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[5]   Available at: http://hot.openstreetmap.org/ [Accessed February 12th 2014].

Red Cross and UN-OCHA (Office for Coordination Affairs of the United Nations), for example, for extracting information about elements at risk of the so-called Critical Infrastructure (see Figure 3), i.e. critical elements that must particular attention in a disaster management such as schools, hospitals, fuel stations etc. (Reimer et al. 2014; Schelhorn et al. 2014; Herfort et al. 2015).

However, while one main advantage of OSM is that their contributors mainly focus on their well-known local surroundings (Goodchild 2007; Neis & Zipf 2012), Crisis Maps originate largely from mappers who work remotely. Therefore, due to the fact that OSM is a crowdsourced map and that a main part of the data in Crisis Maps originates exclusively from contributors that work remotely, humanitarian-aid agencies and first responders have doubts about the quality of the OSM data and therefore sometimes refrain from utilising it (Harvard Humanitarian Initiative 2011). Furthermore, activity areas of remote mappers generally lack official cross-reference data, making it difficult to apply usual quality assessment methods, which are based on comparisons with reference data. In this manner, an important direction for future research is to develop methods for assessing and improving the quality of the geo-information produced by remote volunteers, especially considering the particular needs and requirements of the field of disaster risk management.

Conclusion

Crowdsourced geographic information (CGI) holds a big potential not only for coping with the effects of disaster events, but also for implementing preventive measures for improving the resilience of urban areas against natural hazards and extreme events. We presented and discussed three main types of crowdsourced geo-information that can be explored for this purpose: social media, crowd sensing and collaborative maps.

CGI of these different types can be incorporated into disaster risk management in many different ways. As shown in the previous sections, the most important usage of CGI in this context is improve situation awareness in the monitoring of unfolding events, i.e. to complement conventional information sources with first-hand geographic information from the crowd shared in social media, citizen sensing platforms and/or collaborative maps. In this manner, it is possible to get more fine-grained and up-to-date spatial information about what is happening on the ground. Clearly, this information is of great value for creating maps to support emergency agencies in disaster relief, both in field missions and in emergency operation centres. Although CGI is becoming more and more used for this purpose, significant challenges remain in filtering and prioritising useful and valuable information amidst the large stream of non-relevant data. Since most existing studies are still focused on a single source of CGI, the integration and fusion of the different types of CGI

with other authoritative data sources and processes of emergency agencies is a still underexplored topic that should be addressed in future research efforts in this area.

Furthermore, the use of CGI in mitigation and preparation phases should be emphasised in future studies. This could be done for instance by leveraging initial examples of using CGI from collaborative maps to support activities in disaster risk management, such as in the identification of critical infrastructures to support emergency planning (Herfort et al. 2015; Schelhorn et al. 2014), for instance for performing evacuation simulations (Bakillah et al. 2012, Goetz & Zipf 2012) and estimating the vulnerability of urban areas based on synthetic information about the potentially affected population (Bakillah et al. 2014).

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