An investigation into the role of crowdsourcing in generating information for flood risk management

By

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Abstract

Flooding is a major global hazard whose management relies on an accurate understanding of its risks. Crowdsourcing represents a major opportunity for supporting flood risk management as members of the public are highly capable of producing useful flood information. This thesis explores a wide range of issues related to flood crowdsourcing using an interdisciplinary approach. Through an examination of 31 different projects a flood crowdsourcing typology was developed. This identified five key types of flood crowdsourcing: i) Incident Reporting, ii) Media Engagement, iii) Collaborative Mapping, iv) Online Volunteering and v) Passive VGI. These represent a wide range of initiatives with radically different aims, objectives, datasets and relationships with volunteers. Online Volunteering was explored in greater detail using Tomnod as a case study. This is a micro-tasking platform in which volunteers analyse satellite imagery to support disaster response. Volunteer motivations for participating on Tomnod were found to be largely altruistic. Demographics of participants were significant, with retirement, disability or long-term health problems identified as major drivers for participation. Many participants emphasised that effective communication between volunteers and the site owner is strongly linked to their appreciation of the platform. In addition, the feedback on the quality and impact of their contributions was found to be crucial in maintaining interest. Through an examination of their contributions, volunteers were found to be able to ascertain with a higher degree of accuracy, many features in satellite imagery which supervised image classification struggled to identify. This was more pronounced in poorer quality imagery where image classification had a very low accuracy. However, supervised classification was found to be far more systematic and succeeded in identifying impacts in many regions which were missed by volunteers. The efficacy of using crowdsourcing for flood risk management was explored further through the iterative development of a Collaborative Mapping web-platform called Floodcrowd. Through interviews and focus groups, stakeholders from the public and private sector expressed an interest in crowdsourcing as a tool for supporting flood risk management. Types of data which stakeholders are particularly interested in with regards to crowdsourcing differ between organisations. Yet, they typically include flood depths, photos, timeframes of events and historical background information. Through engagement activities, many citizens were found to be able and motivated to share such observations. Yet, motivations were strongly affected by the level of attention their contributions receive from authorities. This presents many opportunities as well as challenges for ensuring that the future of flood

crowdsourcing improves flood risk management and does not damage stakeholder relationships with participants.

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List of Publications

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Baruch A., Yu, D. and May, A. 2017. Empowering communities to contribute to flood risk management policy through citizen science. *Citizen Science Association Conference* 2017

Baruch A., Yu, D. and May, A. 2016. Improving our understanding of flood risks through citizen science *British Society of Geomorphology Conference* 2016

Baruch A., Yu, D. and May, A. 2016. How can online crowdsourcing campaigns engage millions of volunteers and generate high quality data? *European Citizen Science Association Conference* 2016

Baruch A. 2016. Inspiring citizen scientists to contribute to flood risk management research. *East Midlands University Association Conference* 2016

Baruch A. 2016. How can citizen science influence the way we manage flood risk? *Loughborough University Inspiring Research Conference* 2016

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Chapter 1: Introduction

This thesis is concerned with the role that crowdsourcing plays or could play in flood risk management. As an introduction, this chapter outlines the general topics and the phenomenon addressed in this thesis, as well as providing suitable background information. The problem space, scope, aims, objectives and research questions are presented along with the thesis structure.

1.1. The fundamental issues

1.1.1. Flooding and flood risk management

Flooding covers a wide variety of processes including overbank flow from rivers, surface water accumulations, dam-breaks and the intrusion of seawater on to land (Handmer et al., 1999). Floods are among the most common climate-related disasters, reporting an annual loss of tens of billions of US dollars and thousands of deaths each year (IPCC 2012; Joyce et al. 2009). Between 1980 and 2013, the global direct economic losses due to floods exceeded $1 trillion, and more than 220,000 people lost their lives (Hirabayashi et al. 2013). The costs of flooding are expected to rise in future with an increase in urbanisation and a more volatile climate (Hirabayashi et al. 2013; Winsemius et al. 2016; Arnell and Gosling 2016). In fact, by 2050, $1 trillion in damages is expected to be the global annual losses due to flooding (Hallegatte et al. 2013). These impacts are also coupled with a range of harmful effects on humans including damage to: health, livelihoods, infrastructure, cultural heritage, ecological systems, industry and the economy in general (Messner & Meyer 2006).

Flood risk management can be defined as the "continuous and holistic societal analysis, assessment and mitigation of flood risk" (Schanze 2006). As such, it includes the process of managing an existing flood situation as well as the planning of a system, which will reduce further flood risks (Plate 2002; Feyen et al. 2012). Key to informed decision making on flood risk management is the inclusion of stakeholders and an accurate risk assessment. Assessments of risk not only describe the flood hazard, but also the potential exposures and their vulnerability (Smith 2004; UNISDR 2013; Kron 2005). Hence, there are two principle methods of hazard mitigation: abating the physical force behind the threat and reducing the vulnerability at the point of impact. This vulnerability can range from factors which influence people's capacity to anticipate, cope with, resist and recover from the impact of the hazard (Wisner et al. 2003).

Since the industrial revolution, flood risk management has typically involved 'technocratic' hard engineering solutions to control the natural flow of water such as dikes and dams (Wesselink et al. 2015). However, in recent years, there has been a growing consensus that non-structural 'soft' and more holistic solutions are needed (Machac et al.,2 017; Bracken et al. 2016; Forrester et al. 2015). As a result, flood risk management approaches are increasingly focussing on measures such as improved land-use planning, soft engineering, adaptation, flood forecasting, warning and insurance (Edelenbos et al. 2017b). These measures are typically supported through the use of flood risk assessments from models and are thus highly dependent on the data on which they are built (Merz et al. 2010). As such, flood risk management is strongly affected by the quality and quantity of data in the nature and impacts of past, present and potential future flooding events. Over the last 20 years, there have been many developments in methodologies for data collection and modelling techniques, yet many challenges remain to producing holistic analysis for flood risk management.

1.1.2. Data needs for flood risk management

A wide range of practitioners with different data needs are involved in flood risk management across the globe. Flood risk can be studied using a wide range of approaches including remote sensing, field monitoring, inundation modelling, socio-economic assessment and surveying. Most macro-scale studies into flood occurrence and impacts have focused on changes in extreme and infrequent disasters (e.g. Tarhule 2005; Tessler et al. 2015; Muir Wood et al. 2005; Wahl & Chambers 2016). Disasters are defined as events which result in a minimum of either: 10 deaths, 100 affected people, a declaration of a state of emergency or a request for international support (EM-DAT 2018). However, far less attention has been given to the potential costs of nuisance events around the world despite their rising occurrence (Rowling, 2016; Karegar *et al.*, 2017). Flood risk research, and as a result – management – is often affected by a lack of relevant data on the cumulative costs of these nuisance events (Moftakhari et al. 2017). In recent years, there has been a growing interest in traditionally under-reported catchments showing regional patterns of changing flood occurrence (Slater and Villarini 2016). Hence, gathering and analysing information on all flood events can play a key role in improving flood risk management (J. W. Hall et al. 2003; de Moel et al. 2015).

Despite the progress in flood risk research and management practises, flooding continues to be a major challenge and incidences of floods have been on the rise (Alfieri et al. 2017). In addition, future planning is hampered by the uncertainty in the magnitude and impact of regional flood forecasts under climate change (Arnell and Gosling 2016). A key challenge in any natural hazard management policy is getting useful, up-to-date information which can support management strategies. As first-hand witnesses of floods, many members of the public have local knowledge which can support a broad range of practitioners. As a result, there is a growing interest among researchers and policymakers in the use of public participation to inform environmental management (McEwen et al. 2017). This need has been emphasised in both domestic and international policies since the 20th Century. The United Nations conference on Environment and Development held in Rio de Janeiro, June 1992 declared the importance of public participation to the principle of sustainable development (UNCED 1992). The Aarhus Convention, (1999) in Europe specifically promoted public participation in decision-making on environmental issues. In 2007, the European Flood Directive 2007/60/EC required the establishment of public participation mechanisms to ensure citizens' involvement in the flood management cycle. In the UK, following the devastating floods during the winter of 2015/2016, the government commissioned the National Flood Resilience Review 2016. This acknowledged the value of public participation and pledged to facilitate citizen science for future flood risk estimation and planning (HM Government 2016).

1.2. The opportunity for crowdsourcing

1.2.1. What is crowdsourcing?

The term 'crowdsourcing' was first coined by Jeff Howe in a seminal article for Wired magazine in 2006 as:

> *"The act of a company or institution taking a function once performed by employees and outsourcing it to an undefined (and generally large) network of people in the form of an open call. This can take the form of peer-production (when the job is performed collaboratively), but is also often undertaken by sole individuals. The crucial prerequisite is the use of the open call format and the large network of potential laborers."* (Howe 2006)

In the years that followed, crowdsourcing as a concept has evolved rapidly with numerous studies providing different and often contradicting definitions. In fact, some authors present specific examples of crowdsourcing as paradigmatic, while others present the same examples as the opposite (Estellés-Arolas and González-Ladrón-De-Guevara 2012). As a result, Eitzel et al. (2017) argue that no single term is appropriate for all contexts and terms should be chosen carefully and their usage explained. To this end, the Howe (2006) definition is not used for this thesis as it restricts the relevance of crowdsourcing to a more business orientated internet phenomenon. Rather, a more general term from Oxford Dictionaries (2018) is used heron in as it is far more applicable for the purpose of flood risk management:

> *"The practice of obtaining information or input into a task or project by enlisting the services of a large number of people, either paid or unpaid, typically via the Internet."*

While crowdsourcing is a relatively recent term, it encompasses many practices which have dated back centuries albeit without the use of the internet. Throughout history, the public have played a part in scientific research and discovery. For the majority of this time, the role of the citizen has been minimal and only significant in exceptional circumstances such as discovering ancient ruins or a new species. Similarly, despite some notable exceptions cartography has traditionally only been employed by elite groups to represent people and places (Pickles 2012). However, since, the dawn of Web 2.0, there has been a growing cartographic literacy among non-professionals as more intuitive participatory tools become available (Goodchild 2007; Muki Haklay, Singleton, and Parker 2008; Liu and Palen 2010). This has led to an exponential rise in both the scale and scope of crowdsourcing activities. Currently, members of the public are playing a key role in a diverse range of disciplines from scientific research to business innovation and humanitarian response (Wazny 2017; O'Leary et al. 2017; Follett and Strezov 2015; Meier 2013; Brabham and Brabham 2016). These ventures are benefiting from unprecedented amounts of data and the building of stronger relationships with the communities they aim to help. It is clear from the success of such studies, that crowdsourcing is capable of playing a substantial role in a vast range of fields. As geographic research studies get ever more ambitious and the need for localised up-to-date information becomes integral to managing issues such as floods, more scientists and practitioners are turning to the layperson.

1.2.2. Crowdsourcing for flood risk management: An emerging discipline

Historically, the layperson has always played a role in generating information on food events and hydrological processes. Records of public observations of flood events have been found since before the 10th Century and collected using the British Hydrological Society's Chronology of Hydrological Events (Black and Law 2004). These records come from contemporary newspaper reports, published diaries, accounts of major events and field observations such as floodstones on bridges or buildings. Given the ability of citizens to contribute useful local knowledge and a genuine interest in tackling hazards, interest in public observations of floods have grown in recent years.

Local residents who have experienced flooding are increasingly being engaged by scientists to share their narratives, radically changing the way scientific research on flooding is conducted (Lane et al. 2011; Landström et al. 2011a; Forrester et al. 2015; Bracken et al. 2016). In the UK, studies such as Lane et al. (2011) and Bracken et al. (2016) found local people who have no professional responsibility for flood management have a strong understanding of key processes. Globally, community workshops have provided valuable flood data in many contexts, from Vietnam (Tran et al. 2008) to Japan (Yamada et al. 2011) and New Zealand (Connell et al. 2001). On a larger scale, observations of localised floods can support a broader range of practitioners involved with flood risk management.

Given the ability of citizens to use a range of technologies and a genuine interest in tackling hazards, crowdsourcing projects for flood risk management have grown in number in recent years. Organisations including local governments and water companies are capitalising on this resource by crowdsourcing data through online reporting forms. In addition, specialised apps are being piloted by academics to generate public observations of events (Wehn et al. 2015). From documenting hazards to simply discussing floods on social media, members of the public can contribute to our knowledge of flooding in a number of ways (Yulong Yang et al. 2014). However, collecting and organising interoperable flood data to support different practitioners remains a significant challenge.

In addition to sharing knowledge, new types of crowdsourcing projects such as micro-tasking platforms are making use of the public's analytical ability. One example is Tomnod[1] – a project that tasks participants with tagging objects of interest such as flooded buildings in satellite imagery. These contributions analysed for consensus and used to map the impacts of an event. The rapid evolution of crowdsourcing as a phenomenon comes with several of scientific and ethical challenges as motives of both participants and project organisers can be complex. Crowdsourcing projects have varied significantly in their approach and strategies. Yet, their success has often hinged on their level of engagement with their target community (Buytaert et al. 2016; Prestopnik and Tang 2015). By addressing challenges and embracing the diverse range of opportunities, crowdsourcing is a field which can only grow in importance. As such, there is significant

[1] www.tomnod.com

demand and potential for the implementation of flood crowdsourcing schemes for supporting risk management in a variety of contexts.

1.3. Aims and research questions

This PhD thesis aims to investigate the use of crowdsourcing for improving flood risk management through an examination of the public's participation in: i) micro-tasking for satellite imagery analysis and ii) the sharing of local flood observations. These two fields represent the most rapidly evolving elements of crowdsourcing, yet their importance to the management of flood risk remains understudied. In its nature, the topic of crowdsourcing for flood risk management involves both human and physical components. As such, the research focuses on both: i) public motivations, enablers and barriers for participating in crowdsourcing projects, ii) the added value of citizen contributions for modelling, governance and improving our understanding of risks. To address these aims, the following research questions are posed and addressed in the thesis:

1. What are the characteristics of crowdsourced flood data, and how are they evolving?
2. How do human factors affect participation in flood crowdsourcing projects?
3. What roles can crowdsourcing play in supporting flood risk management?
4. What role does platform design play in maximising the efficacy of crowdsourcing for flood risk management?

1.4. Thesis structure

The research aim and questions of this PhD thesis cover several different aspects of both crowdsourcing in general and its application for flood risk management. A multi-faceted approach is used to addresses both the social and physical processes involved in crowdsourcing for flood risk management. This is outlined in the structure of this thesis (Figure 1.1).

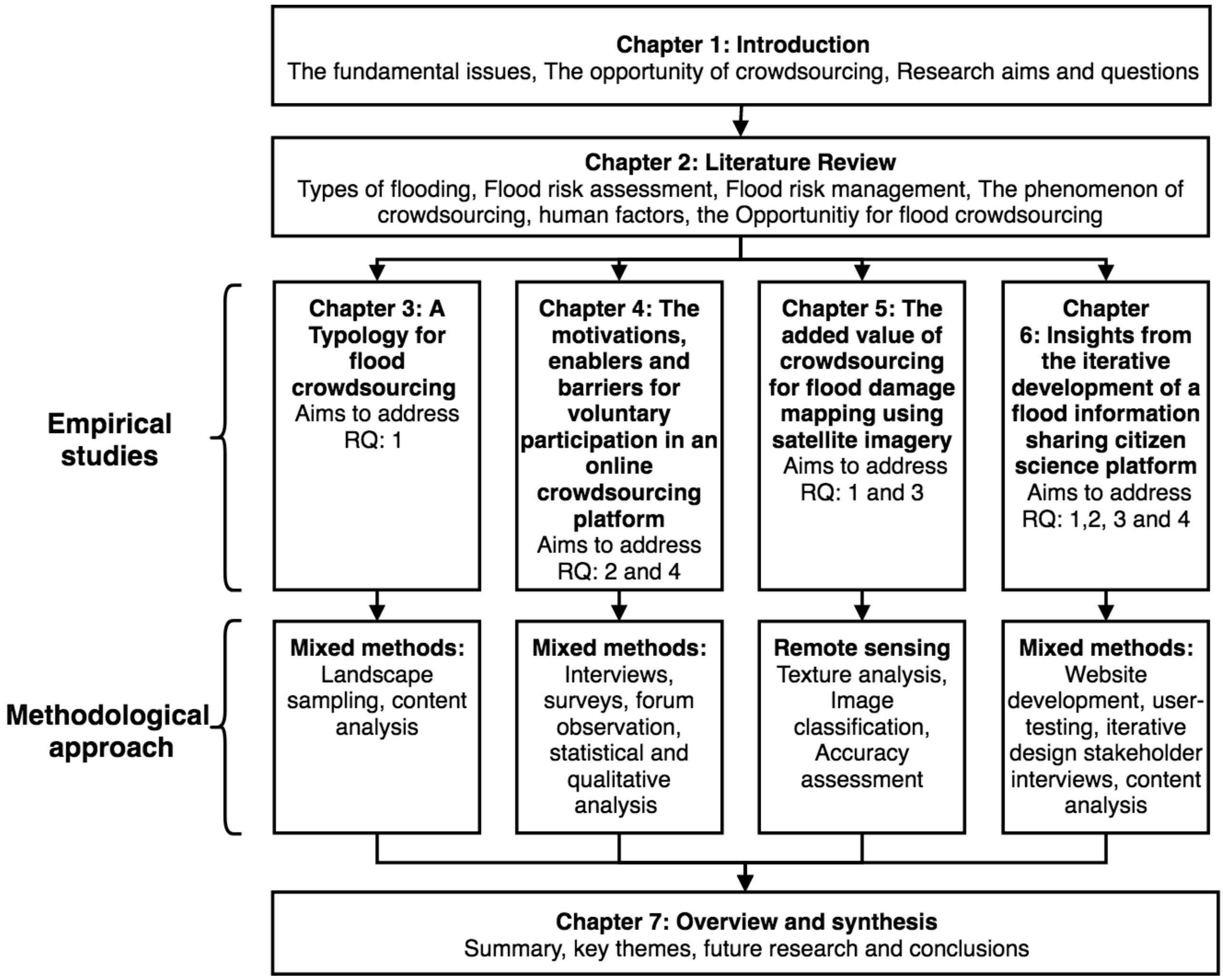


Figure 1.1: Thesis structure

Chapter 2: Literature review

2.1. Introduction

This chapter aims to provide a comprehensive review of the existing and wide-ranging literature which informs the contemporary understanding of the role crowdsourcing can play in supporting flood risk management. It does so, through a framework outlined in Figure 2.1. This outlines how a range of practitioners contribute to flood risk management strategies through the use of key data. While several sources of professional data exist, this chapter illustrates how these are limited, leaving an opportunity for public participation. Three forms of public participation that can produce information needed for flood risk management are outlined as: Crowdsourcing, Citizen Science and Volunteered Geographic Information (VGI). The literature concerning these terms illustrates a significant degree of overlap, yet a clear prevalence of developments in the world of crowdsourcing.

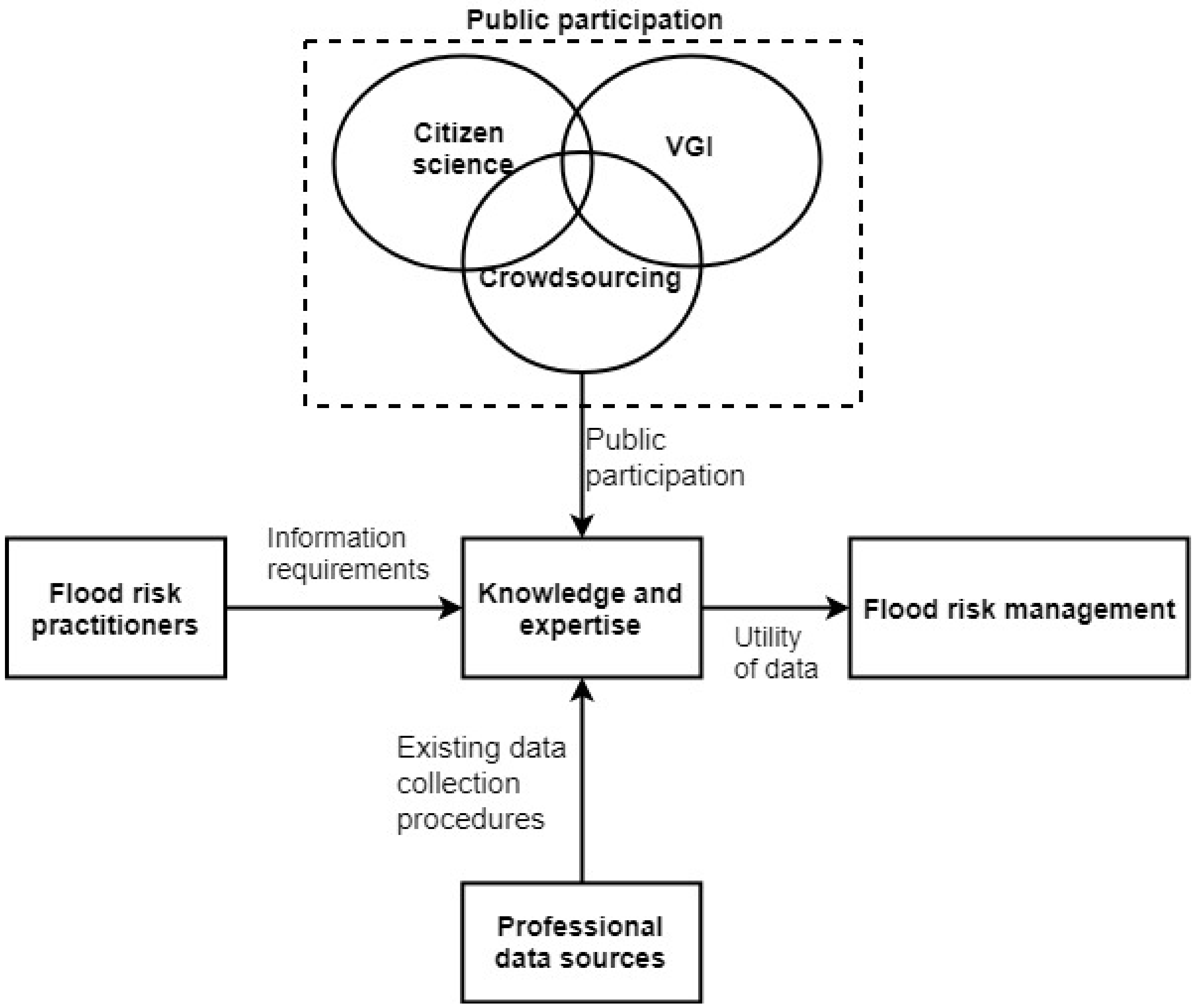


Figure 2.1: Structure of the literature concerning the role crowdsourcing plays in supporting flood risk management

2.2. Flood risk management framework

Flood risk management can be broadly divided into three main components: Flood risk analysis, flood risk assessment and flood risk reduction (Schanze 2006). Flood risk describes the product of a hazard and the vulnerability in the exposed areas (Kron 2005). As such, flood risk analysing involves both modelling the flood hazard's physical components and determining the vulnerability of affected peoples. Flood risk assessment builds on these analyses by classifying the risk, with damage estimation at its centre. Flood risk reduction involves the utility of these assessments and analyses to take action to mitigate flooding before, during and after the event.

2.2.1. Flood risk analysis

2.2.1.1. Modelling flood hazards

Inundation modelling using 1D and 2D flood models are frequently employed to identify flood prone regions and improve community awareness (Teng et al. 2017). The latter is far more widespread as these are better suited to representing multidimensional aspects of river dynamics. In addition, 1D models are unable to simulate lateral unsteady flow dynamics including backflow in floodplains. Systematic efforts within the research community since the 1970s have greatly improved the capability of flood inundation modelling. Two dimensional models are widely used for a range of purposes including: flood risk mapping (Apel et al. 2009), flood damage assessment (Merz et al. 2010), real-time flood forecasting (Krajewski et al. 2017), and flood related engineering (Pregnolato et al. 2016). Such maps have enabled the prioritisation of high risk areas for management at the point of impact in a bid to reduce flooding inequality (Communities and Local Government 2010).

The ability of a 2D model to produce reliable estimates is dependent on several factors. Inundation models rely on the parametrisation of variables including, surface roughness, rainfall, elevation, drainage capacity and hydraulic conductivity. Each of these can dramatically affect the representation of the flood with significant implications (Merwade et al. 2008; Yu 2010). In addition, there remain many uncertainties about processes and the impacts of factors such as connectivity (Bracken and Croke 2007; Parsons et al. 2015). As a result, complex, physically based, spatially distributed models can be subject to equifinality (Salamon and Feyen 2009). Therefore, there is a need to incorporate more data in flood models and conduct a sensitivity analysis to ensure that the flooding process is being correctly represented (Yu and Coulthard 2015). When using information in flood models, there is a need to consider: its role in risk modelling, the gaps in data required for effective flood models and what improvements can be made to the data quality.

2.2.1.2. Determining vulnerability

As emphasised by the hazard risk equation, the vulnerability of populations in floodplains is an important factor to consider in flood risk assessments (Kaźmierczak and Cavan 2011). By knowing the flood vulnerability zones, the appropriate measures can be taken to reduce the potential damages of a hydrological event (Romanescu et al. 2018). Vulnerability can be determined through examination of their: exposure, susceptibility and capacity to cope and adapt. Vulnerability is further categorised into asset vulnerability, institutional vulnerability and perception of vulnerability. The vulnerability of people to flooding is a function of the characteristics of people and households, which influence the following four types of issues: access to information, ability to prepare for flooding, ability to respond to flooding and ability to recover from flooding (Kaźmierczak and Cavan 2011). As such, the production of population vulnerability assessments can be complex. Nevertheless, quantitative techniques have been used by several studies (Koks et al. 2015; Walker and Burningham 2011; Chakraborty, Tobin, and Montz 2005). For example, Chakraborty et al. (2005) used a geophysical risk index, based on the National Hurricane Center and National Flood Insurance Program data, and a social vulnerability index, based on census information. Remote sensing is increasingly offering a way of assessing population vulnerability. For example, recent advances in image analysis have been used to turn data into insight for decision-makers on the ground (Schwarz et al. 2018).

2.2.2. Flood risk assessment

2.2.2.1. Flood risk classification

The purpose of flood risk assessment is to establish where action needs to be taken to mitigate a hazard. Producing assessments of current and potential future damages is crucial to the effective management of flood hazards in both urban and rural flood areas (Merz et al. 2010). Classifications are produced using models which consider the magnitude of the flood hazard as well as socio-economic vulnerability of elements exposed to floodwater (de Moel and Aerts 2011). As such, they can be very complex, particularly in urban areas where hydrological and hydraulic processes and vulnerability are associated with a high degree of uncertainty (Yin et al. 2015; Yu 2010). GIS has played a fundamental role in the improvement of catchment and urban planning to mitigate flooding since the 1990s (Deckers et al. 2009). Maps describing flood risk can be categorized into three types (Moftakhari et al. 2017):

1) **Minor:** (nuisance flooding) typically have an annual exceedance probability (AEP) greater than 0.5 but with relatively small public impacts
2) **Major:** events have an AEP between 0.05 and 0.50 and can cause considerable infrastructure inundation/damage, and even loss of lives
3) **Extreme:** events have an AEP less than 0.05 and can cause extensive property damage, structural failure, injury, and death (National Weather Service 2012).

2.2.2.2. Flood damage estimation

The evaluation of measures to mitigate flooding is largely achieved by cost-benefit analysis. The costs of a certain measure can be compared with their benefits in terms of risk reduction. This procedure aims to facilitate the efficient allocation of funds to an optimised protection against flooding. As such, modelling the costs of flood damage is an important component for risk analyses, and forms the basis for risk-oriented flood management, risk mapping, and financial planning. However, damage cost models are typically associated with a significant degree of uncertainty (Merz et al. 2004; de Moel and Aerts 2011). This uncertainty in flood cost predictions is largely due to a limited understanding of spatial variations in property value as well as the items likely to be damaged in a flood (Poussin, Wouter Botzen, and Aerts 2015). Depth-damage curves are widely used for flood damage cost estimation and are based on market values of typical assets. There are a range of depth-damage models, each with highly varied equations. The Commission for the Protection of the Rhine (ICPR) model estimates the typical proportion (in percentages) of damages to different land covers with no consideration of flood depth (de Moel and Aerts 2011). Merz et al. (2004) suggest that depth-damage functions are more appropriate, as they can produce cost estimations independent from absolute asset values. As such, three further European models: Rhine Atlas, Flemish (Vanneuville et al. 2006) and the Netherlands methods are used which include different depth-damage functions. There is a lack of reliable information about the potential impact to businesses. Yet these costs can be the greatest and most variable (Poussin, Wouter Botzen, and Aerts 2015). Incorporated further variables into predictions, can however make it harder for the resulting model to be reproduced in a wider area (de Moel and Aerts 2011).

2.2.2.3. Catastrophe modelling

A major component of assessing flood damage costs is catastrophe modelling. This provides insurance companies with a robust way of business planning for disasters. It comprises the probabilistic event-based quantification of natural catastrophe risk within a geographical information system environment (Woo 1999). The purpose of catastrophe modelling is to capture all the ways in which losses can affect multiple locations within the same event. As a result, they have been widely adopted for the integrated high-resolution modelling of storms and multi-hazard flooding events (Wood et al. 2005). This makes them especially applicable to assessing risks in the insurance industry (Royse et al. 2017).

2.2.3. Flood risk reduction

2.2.3.1. Reducing the magnitude of the hazard

Since the industrial revolution, many hazards have been typically dealt with through the use of 'technocratic' solutions, aiming to control the natural phenomena that result in hazards. While in many cases, the use of hard engineering is perfectly feasible, when used in isolation they are often not the best solution (Machac et al., 2017). Natural hazards such as floods occur in systems whose spatial and temporal complexity enables management intervention opportunities at several points before the threat becomes a hazard. River flooding is affected by a number of variables, both in the catchment and in the channel itself (Kirkby et al. 2002; Thompson & Croke 2013; Bracken and Croke, 2010). Flood hazards can be mitigated at their source, pathway and point of impact. Hence, flood mitigation typically includes a combination of measures in the catchment and the floodplain to abate the flood waves and protect vulnerable areas. Technological advances and improvements in our understanding of hazard dynamics have enabled the development of new risk management approaches. For many countries emphasis is shifting from 'hard' engineering, such as dikes, towards non-structural 'soft' measures, such as planning restrictions or early warning systems (Wesselink et al. 2015).

Amid calls for more sustainable hazard mitigation strategies, schemes in developed countries are increasingly treating development and the environment in an integrated rather than separate way (Klijn et al. 2015). Natural flood risk management in particular is growing in popularity globally. This includes a broad range of measures that alter, restore or use landscape features to manage flood risk. Flood management strategies beyond the point of impact include the reduction of water flow into river systems from the catchment, through soft engineering projects such as reforestation (Wesselink et al. 2015). By working with catchment-wide hydrological and morphological processes, natural flood management aims to manage the sources and pathways of floodwaters through interventions such as 'leaky dams' (Maskrey et al. 2016). These strategies tackle the problem of flooding at its source by reducing rapid rises in river discharge. Soft engineering schemes have yielded a lot of success, marking an increased popularity of management intervention along the hazard pathway (Brody and Highfield 2013). Nevertheless, the power of such measures varies between river systems, as flooding can be largely determined by specific inter-catchment interactions (Kusumastuti et al. 2006). There is wide agreement that catchment friendly management is an integral part of flood mitigation in all river systems (Wesselink et al. 2015). Extensive catchment and basin management plans have subsequently been established across the UK, as well as other countries, as part of a sustainable national flood mitigation strategy (Communities and Local Government 2010). These are also a requirement of the Water Framework Directive. However, there are fundamental challenges in modelling the contribution of natural flood management strategies because they are often highly distributed and influence multiple catchment processes (Hankin et al. 2017).

2.2.3.2. Reducing vulnerability in exposed areas

While the understanding of hazard and exposure has greatly improved over the years, knowledge of vulnerability remains one of the biggest hurdles in flood risk assessment to date (Mechler et al. 2014; Koks et al. 2015). The capacity of households to adapt and respond to hazards is integral to the assessment of hazard impacts and the successful implementation of flood risk management policies (Koks et al. 2015). Vulnerability is largely a function of a household's socio-demographic status and their risk perception (Cutter, Boruff, and Shirley 2003). Informing communities of the risk of natural disasters may help improve their understanding of the science. However, to be effective, it is important to ensure citizens are motivated to act on the information they receive. As a result, communicating actionable risk by capacity building at the point of impact have become the most prioritised strategies in many areas (Cinner et al. 2018).

Urban floods in particular are considered as one of the most challenging risks affecting urban areas due to the increasing demographic changes in exposed zones and more frequent extreme climatic events (Wilby and Keenan 2012). Koks et al. (2015) argue that although vulnerable populations are highly heterogeneous, their different circumstances are often ignored in traditional flood risk management studies. Vulnerability has not been robustly considered in projections of losses under climate change yet it is a key component for understanding and better managing risk (Mechler and Bouwer 2015). As a result, the reduction of social vulnerability at the point of impact remains the most effective albeit understudied methods of mitigating flooding disasters.

2.3. Flood risk management stakeholders

2.3.1. Government departments

Globally, government departments are investing significantly in developing more effective disaster response and preparedness strategies. As the costs of flood protection are often lower than the benefits, countries can often justify further investments in adaptation measures. In particular, emerging economies in Southeast Asia have much to gain from reducing exposure through urban planning, given that much of the risk is strongly impacted by increased vulnerability associated with projected socio-economic development (Jongman et al. 2014). In recent years, many countries have implemented policies to reduce the residual risks from flood hotspots. These typically focus on producing emergency plans for transportation routes and residential areas (Lumbroso, Stone, and Vinet 2011; Ajmar et al. 2015). The impact of flooding on vulnerable groups can be exacerbated if critical infrastructure, such as utility providers, hospitals, emergency services and transport links are affected (Douglas et al. 2010). In data rich countries such as the UK, much progress has been made by government in the production of emergency services accessibility impact assessments (Green et al. 2017; Coles et al. 2017). These utilise the Ordnance Survey Integrated Transport Network (ITN) which contains a set of pre-defined rules of network connectivity (e.g. speed limit, turn restriction and one-way traffic). This dataset, together with high quality weather, elevation and GIS data on the emergency response nodes, facilities and vulnerable populations can be used to produce a network analysis. For example, the quickest routing between facility and destination is employed by (Green et al. 2017) using network routing weighted by travel time rather than distance, allowing the inclusion of travel impedances and restrictions. Alternative methods for assessing risk have also been developed. However, the implementation of such analysis can be significantly affected by the availability of data and local response systems.

2.3.2. Meteorological organisations

Meteorological organisations such as the Met Office and NOAA support flood risk management through weather forecasting. In the UK, this involves the collaboration with environment agencies through the Flood Forecasting Centre. Meteorological organisations forecast precipitation and streamflow in rainfall-runoff and streamflow routing models to forecast flow rates. These also forecast water levels for periods ranging from a few hours to days ahead, depending on the size of the watershed or river basin. Limited understanding of local weather systems have been largely blamed for hindering the preparedness and response to floods, storms, droughts and wildfires (Silvestro et al. 2012). The Met office has just over 200 weather stations across the UK which means that large swaths of the country need to be interpolated or estimated based on the nearest weather stations (Met Office 2016).

2.3.3. Businesses

Companies in both engineering and water sectors build and manage large infrastructures that are exposed to flooding. Their ability to deliver their respective products and services is affected by a variety of factors relating to flood risk (Berkhout, Hertin, and Gann 2006). For a water company, their main functions are providing reliable water supplies, effluent treatment, maintenance of the sewage infrastructure and water quality. As such, water companies typically work alongside the government agencies to help minimise the impacts of the floods on drinking water and sewerage services.

2.3.4. NGOs

NGOs play a major role in flood risk management, particularly in a number of capacities. In the UK, several charities are involved in reducing the impacts of flooding. A prominent player is the National Flood Forum who has three main functions:

1) Helping people to recover after they have been flooded
2) Supporting and listening to communities so they feel empowered to manage their flood risk
3) Representing people at risk of flooding to make sure the authorities and government develop a community perspective (National Flood Forum 2018).

Across the globe a range of charities such as the Red cross help support flood prone communities build resilience, prepare for and respond to events (Red Cross 2018).

2.3.5. Insurance companies

Insurance is an individual risk-bearing strategy which, provided the uptake is high, removes pressure from the government who would otherwise have to provide additional assistance following flooding (Johnson et al., 2015). Insurance companies are a valuable player in flood risk management as they send loss adjusters to assess affected properties, providing those in need with finances for repairs and replacements. In addition, they will often make demands on government for flood defence investment to limit their liabilities. However, while in theory all those at risk of flooding have an equal opportunity of taking out flood risk insurance, in practice this is dependent on affordability. The extent to which insurers can support flood risk management depends on how flood insurance cover is arranged – a system that varies significantly globally. In countries without a close association between the public provision of flood defence and the private provision of insurance, it is not common practise (Treby, Clark, and Priest 2006). The number of ways in which insurers can support flood risk management are outlined in Crichton (2008) as:

1. Assistance with identifying areas at risk
2. Catastrophe modelling
3. Economic incentives to discourage construction in the flood plain
4. Collection of data on the costs of flood damage to feed into benefit cost appraisals for flood management schemes
5. Promotion of resilient reinstatement techniques
6. Promotion of temporary defence solutions.

2.3.6. Communities

Perhaps often overlooked in flood risk management reviews, the communities affected by flooding play a substantial role in responding to and mitigating the risks of flooding. Enhancing community resilience has been identified as a core element of disaster management, risk reduction and efforts to reduce vulnerability (Adger 2000; Lwasa 2010; Whittaker, McLennan, and Handmer 2015). Failures of top-down, technical approaches to control flood hazards have resulted in a rethinking of disaster management strategies and an increasing emphasis on the notion of “living with risk” rather than simply trying to prevent the occurrence of hazards. For example, in a case study of flood prone communities in Puerto Rico, López-Marrero & Tschakert (2011) illustrated how local action proved to be effective in diminishing the loss of life and property. As well as taking action to mitigate flooding, community action has been proven to have a big influence on the level of assistance they receive. Mendes (2017) argue that individuals and groups that are integrated in society receive more support than those defined as disposable through both the Global South and the little colonies of the North. Yet, this phenomenon is also prevalent in many developed countries to an extent. For example, in 1993, the Midwest USA endured a ‘‘one-hundred-year flood.’’ Although aid was available from public and private sources, some communities were much less successful than others in obtaining assistance and resources (Sherraden et al. 1997).

2.4. Flood risk management in the UK

2.4.1. The impact of flooding in the UK

Flooding is the UK's most serious natural hazard, putting over 5 million properties and significant portions of the nation's key infrastructure at risk (Thorne 2014). In recent years, the UK have experienced multiple extreme flood events, affecting several communities across the country (HM Government 2016). These have been exacerbated by indirect impacts such as related infrastructural failures (Pescaroli and Alexander 2015). Following devastating floods during the winter of 2015/2016, in the UK, government committed to the protection from and resilience to flooding through spending £2.3 billion from 2015- 2021 to strengthen the country's flood and coastal defences, better protecting 300,000 homes (HM Government 2016).

2.4.2. UK flood trends

Despite clear evidence of a rising cost of flooding in the UK, there is much debate around recent trends in occurrence. While Hannaford & Marsh (2006) and Pattison & Lane (2012) suggested that occurrence of fluvial flooding is rising, Marsh & Harvey (2012) found a reduction in maximum flood levels. There have been a variety of hydrological climate change impact studies in Britain (Charlton and Arnell 2014; Cloke et al. 2013; Christierson, Vidal, and Wade 2012). These largely indicate that Britain is likely to see increased occurrence of flooding in future, but with spatial variations because of local catchment characteristics as well as spatial differences in climatic changes (Bell et al. 2016). While 3.8 million people in the UK are affected by pluvial floods, these often occur spontaneously which makes them hard to study (Pitt 2008). Conversely, coastal and river floods are well studied, being the most dominant in the UK in terms of their frequency and magnitude. These are primarily triggered by storms surges and severe precipitation respectively (Black and Burns 2002). Flood risk in the UK is also expected to increase due to population growth and urbanisation. Sayers et al. (2018) argue that flood risks in the UK are higher in socially vulnerable communities than elsewhere. This phenomenon is shown to be particularly profound in coastal areas, economically struggling cities, and dispersed rural communities. The evidence provided to national policy-makers has however, been limited in geographic detail on which socially vulnerable communities need to be specifically targeted. Hence, there is a need for additional data to complement existing records (Stevens, Clarke, and Nicholls 2014).

2.4.3. Flood response in the UK

Since Handmer (1987) argued for improved warning systems, flood management has shifted from protection against floods to managing the risks of floods (Mostert and Junier 2009; Butler and Pidgeon 2011). This has involved a greater emphasis on soft engineering and land use planning. The 'Making Space for Water' (DEFRA 2004) strategy document marked a shift to a more integrated approach to flood management in England and Wales (J. W. Hall et al. 2003). The report also highlighted the need to manage all types of flooding, including sewer, surface water and groundwater flooding alongside traditional coastal and riverine flooding (Johnson, PENNING-ROWSELL, and PARKER 2007). The UK Civil Contingencies Act 2004 established the framework for civil protection, including the Local Resilience Forum, a group of multi-agency emergency responders (DEFRA 2014). These include fire and rescue, police and ambulance services in the UK are required by legislation to conform to strict incident response time. For example, ambulance services are required to reach 50% and 90% of "Red 1" incidents in under than 7 and 15 min respectively. These include incidents such as cardiac arrest, life- threatening injury, road accidents, and individuals trapped in floodwaters. However, these response targets are affected by flood situations that limit the ability of emergency responders to navigate a disrupted road network (Albano et al. 2014).

2.4.4. Mapping UK floods

Flood risk maps play a key role in the UK in terms of providing guidance to the public. These are important not just for defining and communicating flood risks, but also for regulating them. The risk of flooding from surface water maps and data products are available to insurers who may use it alongside other information to inform their decisions. Whilst the Environment Agency's information is not property specific, making it available to be included in these assessments, allows the prospective purchaser to understand risks in the area of the property and make better informed decisions about their purchase. During summer 2007 emergency responders needed more information on the location of critical sites, their vulnerability to flooding, the likely consequences and the interdependencies between sectors (Pitt 2008). The information available was at best inconsistent, and at times unavailable. Agencies were severely hampered in their ability to respond quickly as events unfolded.

In the reviewing the 2007 floods, Pitt (2008) argues that flood risk management strategies should include reducing vulnerability through increased access to technology and assistance, land use planning, early warning systems, emergency services response and insurance policies. Since, 2007, efforts have been made to improve the investigative nature of flood risk documentation. According to the Flood and Water Management Act 2010, on becoming aware of a flood in its area, a lead local flood authority must, to the extent that it considers it necessary or appropriate, investigate it. In addition, where an authority carries out an investigation, it must publish a 'section 19 report' and notify any relevant risk management authorities. Following devastating floods during the winter of 2015/2016, UK government commissioned the National Flood Resilience Review 2016. This emphasised the importance of enabling communities affected by flooding to themselves engage in exploring flood risks. The government pledged to make rainfall and flow gauge data publicly available and facilitate citizen science for future flood risk estimation and planning (HM Government 2016). This marks a new era for government policy in the UK towards the greater engagement of citizens in the flood risk management process.

2.5. Knowledge and expertise requirements for flood risk management

A wide range of knowledge and expertise are required to support flood risk management. As outlined in Figure 2.1, these can be generated by practitioners, professional data sources and members of the public. The dynamics of these relationships are continuously changing and as technologies develop and members of the public become ever more engaged in participating.

2.5.1. Flood model parameters

Since the 1970s, there have been significant advances in flood inundation modelling for surface water events, coastal and river flooding (Teng et al. 2017). Yet, a major challenge to the greater application of inundation modelling is in the reduction of uncertainty in outputs (Teng et al. 2017). When modelling water flows, the roughness of both channels and the floodplain require parametrisation as they directly affect the flood velocity and depth. Water velocity is estimated using Manning's et al. (1890) velocity equation:

$$\mathrm{V} = \frac{(\mathrm{D} \times \mathrm{W})^{2/3} \times \mathrm{S}^{1/2}}{\mathrm{n}}$$

where V = velocity (ms^{-1}), D = median water depth (m), W = the river's wetted perimeter, S = the slope of the river and n = Mannning's 'n' coefficient of channel roughness. This has been found to be associated with uncertainty as high as ±25% (Smith et al., 2007). Therefore, there is a significant demand for data on these parameters to minimise the uncertainty of model outputs.

Unlike channel characteristics such as coefficient of channel roughness, depth and width, most catchment characteristics can be effectively represented using remotely sensed imagery. Radar and optical satellites can be used to produce digital elevation models (DEMs) which are an essential component of any inundation model (García-Pintado et al. 2013). Further parameters in flood models include: hydraulic conductivity, drainage capacity, rainfall, temperature (Yu 2010; Yu and Coulthard 2015; J. Yin et al. 2013).

2.5.2. Flood characteristics

Geographical data describing flooding can support mitigation and adaptation measures at several stages during the disaster management cycle (Kreibich et al. 2016). For smaller, yet nonetheless impactful events it can advance understanding of their impacts and support long term management (Moftakhari et al. 2017; Demir and Krajewski 2013). As a result, further sources of flood information are being increasingly explored to gather localised flood information for use in governance, scientific research and capacity building.

The identification of temporally coincident data sources for flood model validation has become a major field in which modelling practises can be iterated and results, more widely accepted. Water stage time series’ can provide a valuable source of validation for modelling outputs (Merz et al. 2010; Jiang et al. 2009; de Moel et al. 2015). These are increasingly being used in model calibration, validation and assimilation due to the scale, accuracy and value of data collection. Professional surveys undertaken by authorities and researchers are typically employed to provide evidence for validation.

Remote sensing from satellite imagery and Unmanned Aerial Vehicles (UAVs) plays an important role in mapping areas affected by flooding (Taubenböck et al. 2011; Voigt et al. 2016; Jain et al. 2005; Feng, Liu, and Gong 2015a). Both optical and microwave range imagery are utilized for mapping and assessing flood risk. Optical satellite imagery is limited by cloud cover, rain conditions and is not practical during night time. In comparison, Synthetic-Aperture Radar (SAR) provides satellite-derived flood extent that is independent of daytime and weather conditions (Cossu et al. 2009; Dekker 2003; Joyce et al. 2009). This is invaluable for calibration and validation of hydraulic models as well as the production flood extent maps in near real-time (Cossu et al. 2009; Ajmar et al. 2015; See et al. 2016). Combining satellite-derived flood extents with a digital elevation model (DEM) allows indirect retrieval of water stages which can be assimilated into a hydrodynamic models to reduce uncertainty (García-Pintado et al. 2013). Another method of extracting inundation extents during cloudy conditions can be seen in the use of geodetic satellites such as GOCE. These provide global and regional models of the Earth's gravity field and the geoid (ESA 2009). Through the use of these measurements along with topographic maps, absolute water elevation measurements referenced to a local ellipsoid or global geoid are possible (Bates et al. 2014).

2.5.3. Flood damages

Damage to residential property, caused by flooding has grown steadily since 1980, largely due to an increased value of household possessions (C. Green and Penning-Rowsell 2004). To operate effectively response teams require accurate and up-to-date information about flood damages and risks both during and after the main event (Deckers et al. 2009; Van Westen, 2013). In particular, there is a significant demand for estimations of building and infrastructure damage in the early stages of a disaster (Wex et al. 2014). GIS data describing complex impacts such as landslides and damaged buildings can also support reconstruction, risk reduction (J. Yin et al. 2015) and disaster preparedness (Atif, Ahsan Mahboob, and Waheed 2016). The delivery of accurate damage estimation data products represents a powerful opportunity for improving the efficacy of flood risk management. Sending operations teams to affected areas can provide useful information during a disaster. However, field surveys are typically only confined to priority locations and are thus unable to describe flood risks in many rural areas. Remote sensing is a powerful tool for classifying damages by identifying damaged infrastructure and land cover types (Gerl, Bochow, and Kreibich 2014; Cees J Van Westen 2013). Both remote sensing and post-flood field surveys have been combined in previous studies, and together have played a major role in mapping risk and informing policy (Lumbroso and Gaume 2012).

2.6. The phenomenon of crowdsourcing

2.6.1. Terminology

As discussed in the introduction, a large number of terms referring to crowdsourcing exist with radically different interpretations. These have resulted in a significant degree of confusion amongst academics, practitioners and the general public. As such, Eitzel et al. (2017) argue that no single term is appropriate for all contexts and terms should be chosen carefully and their usage explained. To this end, the following section aims to define the key terms relating to crowdsourcing to ensure that they are correctly interpreted for throughout the thesis. The degree to which they interrelate is further outlined through Figure 2.2 with examples to further clarify where overlaps and differentiations exists.

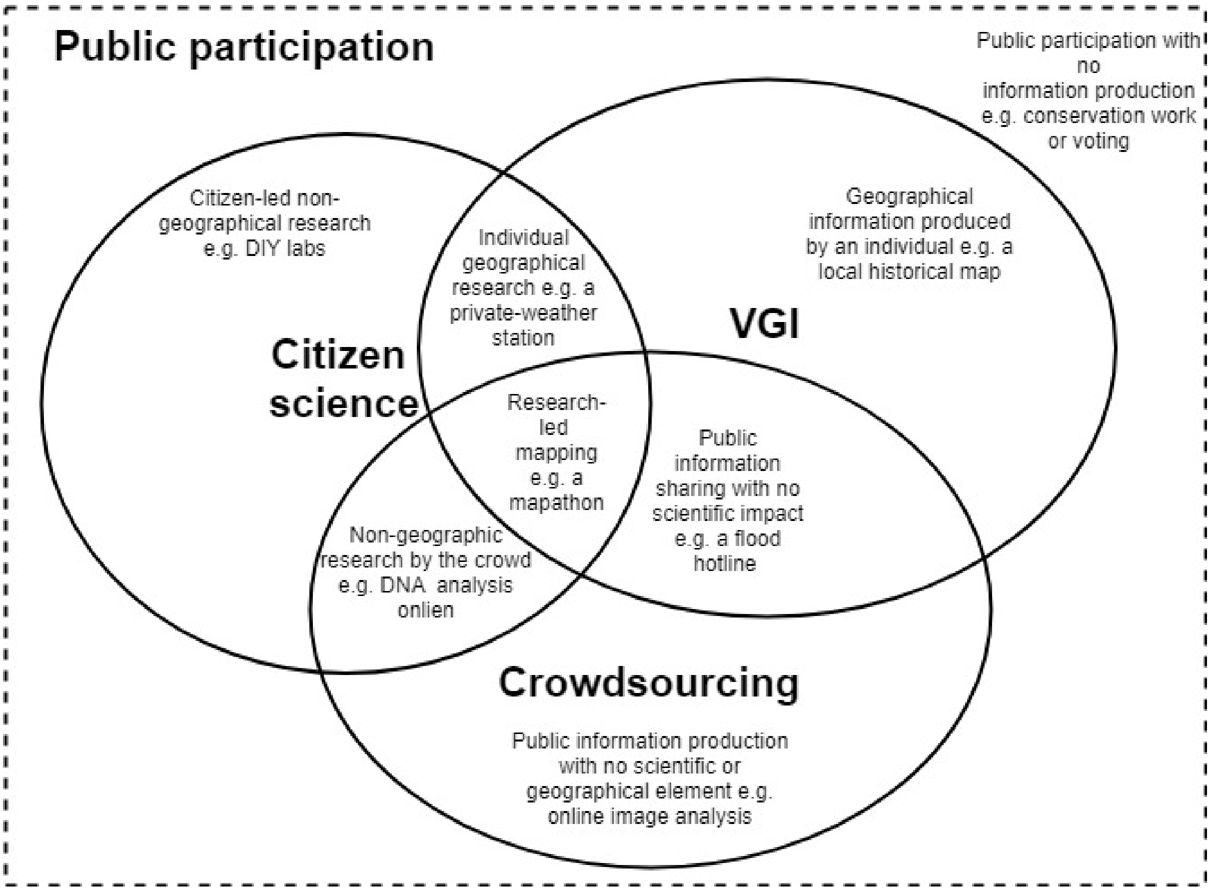


Figure 2.2: Relationship between public participation, citizen science, VGI and crowdsourcing with examples

2.6.2. Public participation

Throughout this thesis, public participation is a phrase often used to describe engagement in crowdsourcing activities. This phrase can, however, refer to a far broader range of activities. Arnstein's (1969) seminal article ‘The ladder of citizen participation’ serves as a starting point for most debates on quality and purpose of citizen participation. Along the ‘ladder,’ different forms of participation are ranked from manipulation (the lowest in the group of non-participation steps) to citizen control (the highest step; also the highest degree of citizen power). The ladder’s aim is to be provocative and encourage a more enlightened dialogue. It does so by examining who has power when important decisions are being made using examples from three federal social programs: urban renewal, antipoverty, and Model Cities. As such, its relevance extends beyond crowdsourcing, citizen science and VGI by also including public activities that extend beyond information production. The eight rungs of the ladder are outlined below:

1. **Manipulation:** People are placed on rubberstamp advisory committees or advisory boards for the express purpose of “educating” them or engineering their support

2. **Therapy:** The aim is to cure or educate the participants. The proposed plan is best and the job of participation is to achieve public support through public relations.
3. **Informing.** A most important first step to legitimate participation. But too frequently the emphasis is on a one way flow of information. No channel for feedback.
4. **Consultation.** A legitimate step attitude surveys, neighbourhood meetings and public enquiries but activities still feel like a window dressing ritual.
5. **Placation.** For example, co-option of hand-picked 'worthies' onto committees. It allows citizens to advise or plan ad infinitum but retains for power holders the right to judge the legitimacy or feasibility of the advice.
6. **Partnership.** Power is in fact redistributed through negotiation between citizens and power holders. Planning and decision-making responsibilities are shared e.g. through joint committees.
7. **Delegation.** Citizens holding a clear majority of seats on committees with delegated powers to make decisions. Public now has the power to assure accountability of the programme to them.
8. **Citizen Control.** Have-nots handle the entire job of planning, policy making and managing a programme such as neighbourhood co-operation with no intermediaries between it and the source of funds.

2.6.3. Citizen science

Irwin (1995) coined the term "Citizen Science" in 1994 in the context of describing expertise by lay people as:

> "Developing concepts of scientific citizenship which foregrounds the necessity of opening up science and science policy processes to the public"

Irwin sought to reclaim two dimensions of the relationship between citizens and science:

1) That science should be responsive to citizens' concerns and needs
2) That citizens themselves could produce reliable scientific knowledge.

The term was soon modified to describe a research technique using members of the public to gather or analyse scientific data (Bonney et al. 2009). As a consequence, citizen science is more widely referred to using the European Commission's 2013 Green Paper as:

> "General public engagement in scientific research activities where citizens actively contribute to science either with their intellectual effort, or surrounding knowledge, or their tools and resources" (Socientize Project 2013).

Laypeople have a long and varied history of participation in scientific observation, either through contributing their own skills and experiences or simply engaging with scientists. Scientific discoveries by laypeople in fields such as archaeology, astronomy and natural history have dated back many centuries (Nascimento, Pereira, and Ghezzi 2014). During the 19th Century, rainfall and temperature levels in America were measured by volunteer observers who donated their data to the National Weather service (Firehock and West 1995). More structured programmes such as the United States' National Audubon Society's annual Christmas Bird Count date as far back as 1900 (National Audubon Society 2018). Similar initiatives can also be seen across Europe for a range of species in the early 20th century. Since the dawn of the 21st century, many further initiatives have been set up and the type of projects are constantly evolving and diversifying. The rise in citizen science projects has also been reflected by a dramatic increase in publications in the last decade (Follett and Strezov 2015).

Various typologies of citizen science have been produced, some according to the level of collaboration while others have focussed on the type of activity. Wiggins & Crowston (2011) develop a typology which identifies five types of citizen science projects: Action, Conservation, Investigation, Virtual, and Education. Bonney et al. (2009) divided citizen science projects into three major categories:

1) **Contributory projects**, in which volunteers contribute data to projects designed by scientists
2) **Collaborative projects,** designed by scientists, but where volunteers can not only contribute data but also aid in the project design
3) **Co-created projects**, where both scientists and volunteers are involved in all parts of the project.

Each of these approaches comes with their own set of challenges and opportunities. Haklay (2013) further unpicked the rapidly evolving field of citizen science by identifying four distinct typologies:

1. **Crowdsourcing:** Citizens as sensors
2. **Distributed intelligence:** Citizens as basic interpreters

3. **Participatory science:** Citizens involved in problem definition and data collection
4. **Extreme citizen science:** Citizens involved in problem definition, data collection and analysis.

Using Howe's (2006) definition, all Haklay (2013) types of citizen science would be defined as crowdsourcing. Yet, Haklay (2013) typology defines crowdsourcing in a way which is specific to citizen science and as such it is different in several respects to the term used in this thesis. While there are forms of citizen science such as citizen labs which do not fit into the crowdsourcing definition, none of these are discussed in the thesis. Hence, for the purpose of this thesis, citizen science is discussed as a subset of crowdsourcing to describe crowdsourcing projects which have a scientific theme.

2.6.4. Volunteered Geographic Information

In 2007, Goodchild (2007) defined volunteered geographic information (VGI) as:

> 'The widespread engagement of large numbers of private citizens, often with little in the way of formal qualifications, in the creation of geographic information, a function that for centuries has been reserved to official agencies.'

VGI is used to describe local information such as civilian cycle routes, perspectives on political or cultural issues or just geotagged photos of ongoing events. Mapping and spatial data collection are two practices that have been revolutionised through VGI. OpenStreetMap serves as excellent real-world examples where crowdsourcing has provided an immense wealth of information to be further used by organizations and communities worldwide.

The definition of VGI bares many similarities to that of crowdsourcing. The key distinguishing aspect of VGI is its clear reference to geographical information. Like crowdsourcing, it differs slightly from citizen science in that, it does not necessarily serve a scientific purpose. In many cases crowdsourced data is displayed alongside expert knowledge such as in Apple Maps (Goth 2013). This helps achieve a certain critical mass of data which is needed in order to reach desired levels of utility (Cardonha et al. 2013). A significant quality of VGI is 'currency or the degree to which the database is up-to-date' (Goodchild 2007). However, the qualitative value of VGI is being increasingly noted and emphasised. May et al. (2014) suggest that information from volunteers should be included in map-based products where it provides unique information that can be used to supplement professional sources.

2.6.5. The rise of crowdsourcing

Throughout history, members of the public have played a part in scientific research, the co-production of knowledge and cartography (Buytaert et al. 2014; Miller-Rushing, Primack, and Bonney 2012). For the majority of this time, the role of the citizen has been minimal and only significant in exceptional circumstances such as discovering ancient ruins or a new species. The earliest records of amateur data collection date as far back as A.D. 500 where locust outbreaks in China were recorded by the public (H. Tian et al. 2011). Evidence of non-professionals contributing to mapping efforts can be seen as far back as 1507 where Martin Waldseemüller drew an outline of America. He was reported to have been particularly influenced by the Soderini Letter – the work of Amerigo Vespucci, an amateur author (Goodchild 2007). In the 20th Century, participation approaches have progressed through a series of phases: awareness raising in the 1960s, incorporation of local perspectives in the 1970s, recognition of local knowledge in the 1980s and participation as a norm in the sustainable development agenda in the 1990s (M. S. Reed 2008). The proliferation of Web 2.0 in the 21st Century introduced new opportunities for crowdsourcing projects and enabled novel forms of public contributions and knowledge creation to emerge (Goodchild 2007; Muki Haklay, Singleton, and Parker 2008). This has led to an exponential rise in both the scale and scope of crowdsourcing. Crowdsourcing is becoming a powerful tool for health (Wazny 2017), business innovation (O'Leary et al. 2017) and citizen science (Follett and Strezov 2015). Popular websites such as TripAdvisor, Wikipedia, Twitter, Airbnb and most modern e-commerce platforms exploit the potential of crowdsourced data. With a number of different methods available, research campaigns using crowdsourced information have had contrasting approaches to data collection. Whether using, new technologies, novel ideas or just effectively engaging with local communities, crowdsourcing projects often provide us with new insights into ways of conducting research in the 21st century (D. Brabham 2013).

Over the last few decades, international policy changes have helped support public participation in a range of fields. The conference on "Environment and Development" held in Rio de Janeiro, June 1992 made a declaration to link public participation to the principle of sustainable development:

> "Environmental issues are best handled with the participation of all concerned citizens, at the relevant level. At the national level, each individual shall have appropriate access to information concerning the environment that is held by public authorities … and the opportunity to participate in decision-making processes.

States shall facilitate and encourage public awareness and participation by making information widely available.” (UNCED 1992)

Since this declaration, the principle of crowdsourcing and citizen science have appeared in numerous government policies as a means of gaining understanding of public perspectives and knowledge (Aitamurto 2012; Lehdonvirta and Bright 2015). This recently culminated in the USA passing the Crowdsourcing and Citizen Science Act of 2015 which specifically acknowledged the value, and growing importance of public participation in science and governance (Coons 2015).

2.6.6. Brabham's (2013) crowdsourcing typology

Crowdsourcing encompasses a wide range of activities and practices (Goodchild 2007), ranging from the hobbies such as birdwatching (Trumbull et al. 2000) to assessing earthquake damage (Kryvasheyeu et al. 2016). In ‘The participatory cultures handbook’, (D. Brabham 2013) identifies four typologies for crowdsourcing: Peer-Vetted Creative Production, Broadcast search, Knowledge Discovery and Management and Distributed human intelligence tasking (also known as distributed intelligence).

2.6.6.1. Peer-Vetted Creative Production

This describes the process of an organisation tasking the crowd with selecting and creating original ideas. It is ideal for identifying problems where solutions are a matter of taste or market support such as design or aesthetic problems. Examples include Threadless – an online clothing company that holds an ongoing t-shirt design competition on its website (Daren C Brabham 2010).

2.6.6.2. Broadcast search

This describes the process of an organisation tasking the crowd with solving empirical problems. This is ideal for ideation of problems with empirical, provable solutions such as scientific problems. Examples include Innocentive, a platform where users have access to problems from a diverse set of corporations, public sector agencies and non-profits from around the world (Seekers). If a user’s solution is chosen by a Seeker they receive will receive an award. The average award amount for a Challenge is $20,000 but some offer awards of over $100,000 (Innocentive 2018).

2.6.6.3. Knowledge Discovery and Management.

This describes the process of an organisation tasking the crowd with finding and collecting information into a common location format. This is ideal for information gathering, organisation and reporting problems such as the creation of collective resources. Examples include SeeClickFix – a tool enabling citizens to identify issues that need fixing such as broken pavements and potholes (SeeClickFix 2018). Given the breadth of this category, it also describes most citizen science projects which rely on members of the public to share their observations of the environment.

2.6.6.4. Distributed intelligence

Organisation tasks crowd with analysing large amounts of information. It is ideal for large scale data analysis where human intelligence is more efficient or effective than computer analysis. Examples include Amazon's Mechanical Turk and Subvert and Profit. These involve individuals and businesses (known as Requesters) coordinating the use of human intelligence to perform tasks that computers are currently unable to do and reward participants with pay (Amazon Mechanical Turk 2018). However, in recent years, several voluntary platforms such as Zooniverse and Tomnod have emerged.

2.7. Participation

2.7.1. Factors affecting participation

2.7.1.1. Participant motivations

Motivation forms a critical component of understanding the human factors which affect the participation and resulting achievements of a crowdsourcing project. Batson et al. (2002) identified four types of motivations for social participation towards common goals: egoism, altruism, collectivism, and principlism. Egoism occurs when the ultimate goal is to increase one's own welfare. Altruism has the goal of increasing the welfare of another individual or group of individuals. Collectivism has the goal of increasing the welfare of a specific group that one belongs to. Principlism has the goal of upholding one or more principles dear to one's heart such as justice or equality. These motivational theories apply differently to projects depending on their context (Forte and Bruckman 2008; Nov, Anderson, and Arazy 2010; Rotman et al. 2012).

In citizen science projects, motivations can be complex collection of factors that dynamically change throughout a project cycle. Motivations are strongly affected by personal interests as well as external factors such as attribution and acknowledgment (Rotman et al. 2012). Citizen science often emerges at the interface of political activism and volunteering (Buytaert et al. 2014). For some communities whose livelihoods depend on the local environment, participation may serve to improve their understanding of the environment or even raise political pressure for action (Overdevest and Stepenuck 2004). For example, localised citizen science projects such as Florida's Lakewatch program motivates people to contribute by engaging them in local environmental issues, thus focussing on more collectivist themes (Hoyer et al. 2014). Similarly, in a Nepal water resourced management project, citizens were primarily motivated to better understand the complexity of their own environments (Buytaert et al. 2014). Involvement may be also driven by an environmental concern, scientific curiosity and a sense of fulfilment (Cohn 2008).

In distributed intelligence platforms such as Galaxy Zoo motivations are broad with 'interest in science' and 'fun' rating highly in Raddick et al. (2013). Hence, egoism plays a significant role in motivating participants in such platforms. Games, with their intrinsically rewarding mechanics, may be used to attract people who are not initially interested in a less appealing topic or engage them further in a topic of their liking. Addressing these issues may serve to help in the planning and implementation of future initiatives.

2.7.1.2. Barriers to participation

Understanding the barriers to participation represents a vital step towards developing and building thriving crowdsourcing campaigns (Massung et al. 2013a). Even in the most successful crowdsourcing projects, recruiting volunteers can be challenging, particularly when target participants are minorities (May et al. 2014b). Particular attention needs to be paid to first contact as well as in the final stage when volunteers decide whether they will contribute to other initiatives (Rotman et al. 2012). For both designers and contributors, creating a sustainable collaborative environment necessitated trust and credibility. These occur when volunteers can see that deliverables are being accomplished as a result of the data that they are collecting (Rotman et al. 2012)..

Rotman et al. (2012) argues that where motivations are ignored (even if this is done inadvertently) volunteers, participation will decline. Award systems can help overcome these challenges by using competition as motivation, pitting teams and individuals against each other. Platform features such as gamification, quizzes and podcasts are frequently cited as key enablers for many crowdsourcing campaigns (J. Reed et al. 2013). Gamification in the form of leader-boards of the most active participants can be seen in other large crowdsourcing campaigns such as Biotracker (Bowser et al. 2013). However, this approach can discourage and drive away some participants (Eveleigh et al. 2013).

2.7.1.3. Ethical factors

Given the reliance of volunteers in crowdsourcing projects, there are numerous ethical factors that require consideration including trust, safety and data protection. Trust building is a long process that largely depended on both sides fulfilling each other's expectations and motivations (Rotman et al. 2012). For example, in the 1970s at Love Canal, at Three Mile Island, and at Wolburn, Massachusetts a citizen science assessments to better understand the risks associated with their own exposure to toxics appeared to produce unreliable and biased results (Elliott 1984; Brown 1997). This also demonstrates the need to take great care in interpreting the results from citizen science projects and to ensure that they are held to the same critical and ethical standards as traditional scientific investigations.

Personal information and copyright is becoming an increasingly important aspect to consider in the growing prominence of crowdsourcing. For example, where individuals contribute information in forms that are independently considered works (e.g. photographs), license agreements need to ensure that the rights of contributors are clearly outlined (Scassa 2013). Rigorous ethical and regulatory controls are needed to ensure data are collected and analysed appropriately (Wazny 2017). For example in an earthworm monitoring project citizens needed to be asked to traverse dangerous terrain or dig pits (Rossiter et al. 2015).

Perhaps one of the most covered citizen science story by the media in recent years has been the response to the Flint, Michigan water crisis. This crisis arose when the water supply in Flint, Michigan was discovered to be dangerously contaminated by local citizen scientists together with academics from Virginia Tech University. Community members collaborated with scientific experts to collect tap water samples that demonstrated the existence of high lead levels in drinking water (Chari et al. 2017). However, following the crisis, the Water Defence organisation (an NGO founded by the actor Mark Ruffalo) caused undue panic by spreading propaganda based on bad science and inaccurate data. This case study outlines how citizen science can be exploited for profits as well as needlessly jeopardising the health of citizens (Roche and Davis 2017).

While crowdsourcing can often empower communities, co-creation of knowledge can continue to constrain marginal groups (Postma 2008). For example, in a water resources study using a river monitoring app, elderly users unfamiliar with social networks and smartphones struggled to participate effectively (Lanfranchi et al. 2014). In many field data collection projects, the safety of members of the public represents a major issue that requires addressing in the design of a crowdsourcing project. Iannone et al. (2012), argue that a data collection method for citizen science must meet three criteria: (1) ease, (2) safety, and (3) reliability.

2.7.2. Design approaches

Design approaches are a crucial component of the development of a successful crowdsourcing project. The selection and implementation of suitable design approaches provide a framework on which to engage both users and contributors in a project.

2.7.2.1. User-centred design

A user-centred design approach is a framework of processes in which usability, user characteristics, environment, tasks and workflows are given extensive attention at each stage of the design process. The importance of user-centred design is outlined in Norman & Draper (1986, P1):

> "User-Centred Design emphasises that the purpose of the system is to service the user, not to use a specific technology, not to be an elegant piece of programming. The needs of the users should dominate the design interface, and the needs of the interface should dominate the design of the rest of the system."

The concept of user-centred design was strongly advocate by Medyckyj-Scott & Hearnshaw (1993) for web cartography systems. A significant level of innovation has since been used to ensure that web platforms are designed to enable users without cartographic knowledge or GIS experience to navigate through mashups and contribute data (Tsou 2011). Understanding how users navigate and interact when they connect to information sharing web platforms creates opportunities for better interface design, richer studies of social interactions, and improved design of content distribution systems (Benevenuto et al. 2012). User-centred design is a particularly important consideration for the design of crowdsourcing projects. These need to be designed with clearly outlined concepts and language as they are only as effective as their participants (Nguyen, Frisiello, and Rossi 2017).

2.7.2.2. Iterative design

Iterative design is the process of prototyping, testing, analysing, and refining a product or process. Based on the results of testing, changes and refinements are made before the process is repeated. This process is intended to ultimately improve the quality and functionality of a design. Gould & Lewis (1983) argue that iterative design should not be thought of as a luxury method that puts finishing touches on a design. Rather, it is a way of addressing the reality of unpredictable user needs and behaviours that can lead to fundamental design changes. Hence, Gould & Lewis (1983) argue that designers have to be prepared for radical change and be ready to abandon old ideas in pursuit of new ones.

2.7.2.3. Platform format

A large component of any crowdsourcing project is the platform in which citizens contribute data. Platform designs vary from hardcopy questionnaires to online surveys and specialised mobile applications. Questionnaires are popular and fundamental tools for acquiring information on public knowledge. In a disaster context, surveys have been used to establish the public's perception of natural hazards and produce mental models (Bird 2009). These are explanations of someone's thought process about how something works in the real world and can be valuable in reconstructing events (Wagner 2007). In addition, surveys are often used to provide valuable information on issues such as health infrastructure from communities with little access to internet technologies (Okotto et al. 2015).

With the introduction of multicore phones with GPS systems in the 21st Century, mobile software has benefited from increased speeds and performance, thus enabling specially designed apps to become used globally (Ogundipe 2013). One group to fully embrace this new medium are young people, with recent studies suggesting that 83% of those aged 18–29 years use social networking sites (Duggan and Brenner 2013). As a result, many businesses and entire industries have based their business model on using the collective contributions of members of the public. Social media platforms as Facebook have been particular beneficiaries as their apps are often readily installed mobile phones. The rise of social media has provided mechanisms for the public to self-broadcast their experiences. Social media are increasingly seen as a vehicle for public debate and for sharing and broadcasting experiences to the wider world or within online groups (Shen, Lee, and Cheung 2014). Understanding how users navigate and interact when they connect to social networking sites creates opportunities for better interface design, richer studies of social interactions, and improved design of content distribution systems (Benevenuto et al. 2012). As a result, popularity of social media platforms such as Facebook and Twitter has encouraged a number of crowdsourcing campaigns to adopt similar user interfaces to facilitate increased engagement. For example, Tomnod and FreshWater Watch, two global crowdsourcing projects enable participants to create profiles and participate in discussions on a forum.

As many crowdsourcing projects involve field based data collection, mobile phones are typically used for uploading information. However, in studies using crowdsourced data from social media, inaccurate, inconsistent and offensive contributions can bias results (Kusumo, Reckien, and Verplanke 2017). For a large number of research programmes, specific data or metadata are required for campaigns which can only be achieved by developing a specially designed app. This enables the information to align specifically with the goals of the research. In addition, the proliferation of mobile phone technology has enabled even some of the poorest communities in the world to access and share information on the internet. However, specialised platforms often do not have the added benefits of a lower risk of software malfunctions associated with successful brands.

2.8. The opportunity for flood crowdsourcing

2.8.1. Implicit knowledge of flooding

The value of implicit knowledge of flooding events have been emphasised by Wagner (2007) who used surveys to analyse mental models of flash floods in the Bavarian Alps. In 2007, the Ryedale Flood Research Group was formed in Pickering– a UK town devastated by flooding. In a series of pioneering community workshops from 2007-2010, Lane et al. (2011), found that locals have detailed knowledge of particular places and issues that a scientist could not possibly attain without help. This phenomenon has also been observed in other studies such as Bracken et al. (2016) who found that local people with no professional responsibility for flood management have a strong understanding of the sorts of flood information that are required for management and post-event modelling. In addition, they have been able to contribute qualitative information on ideas about possible management interventions to reduce risk, coupled with understanding of what may or may not suit the local community. Despite these strengths, Bracken et al. (2016), argue that the views of local communities are often not well represented in the flood risk management decision making process.

Globally, mixed methods research has revealed a growing interest in citizen observations of floods. In a study of flood impacts in New Zealand, Connell et al. (2001), found that flood level data gathered from floodplain residents were found to be both valid and useful. These complemented flood extent data gathered by regional government staff. Huq & Bracken (2015) strongly urge introduction of evidence-based flood policy in Bangladesh to give people and communities a voice in the decision-making process. In a study of flooding in Vietnam, Tran et al. (2008) found the integration of local knowledge into the mapping process provided important factual data. It also generated ideas about the social and physical environment, while identifying community vulnerabilities to disasters. This helped local communities to actively participate in the risk management process and other science-based activities. On a larger scale, crowdsourced flood data are being generated through social media, micro-tasking projects and specialised observation sharing platforms. These can support a broader range of practitioners involved with flood risk management including researchers, engineers and policymakers.

2.8.2. Citizen participation for flood risk management

Members of the public are increasingly motivated to contribute to flood risk management, both in their actions and in sharing their knowledge. In many cases, rather than fully operating within the restrictions of government-organized participatory processes, citizens organize themselves locally and take the initiative for collective action (Edelenbos et al. 2017a; Thaler and Levin-Keitel 2016). In the UK, movement towards engaging the public through resilience forums and other community self-help approaches can be seen in flood warden schemes (Martin 2016). These were established following the UK 2007 floods, supporting resilience forums on flood related issues such as removing obstructions and clearing overgrowing waterways.

From documenting potential hazards such as broken utility poles prior to a storm, to simply discussing hazards on social media, citizens have contributed to our understanding of hazards on the ground in a number of unexpected ways (Yang, Sherman, and Lindqvist 2014). A major new development in citizen participation can be seen in the emergence of numerous micro-tasking platforms. Micro-tasking describes the process of splitting a large job into small tasks that can be distributed, over the internet, to many people. A significant player in this field is Tomnod – a project owned by Colorado-based satellite company DigitalGlobe that uses crowdsourcing to identify objects and places in satellite images. This capitalises on the unique ability of the human eye to identify ambiguous objects which computer algorithms may struggle with. Tomnod volunteers are given the task of tagging objects of interest to add attributes to an image (e.g. a destroyed house). These tags are collated, processed for consensus and used for a range of targeted campaigns, including assisting in disaster response (Meier 2013), tracking wildfires (Bowser et al. 2013) and even searching for the missing Malaysian Airlines flight MH370 (Carmen Fishwick 2014).

A large number of these campaigns have aimed to map flood impacts such as blocked roads (e.g. Figure 2.1).

Figure 2.3: Sample image of the user interface on Tomnod for a mission to identify flooding damages in England (Tomnod, 2015).

As well as tagging, other campaigns have enabled users to draw polygons around damaged buildings. For example, in response to the Christchurch earthquake in 2011, users categorised buildings into damage levels which could help assess the spatial patterns of devastation (Figure 2.2).

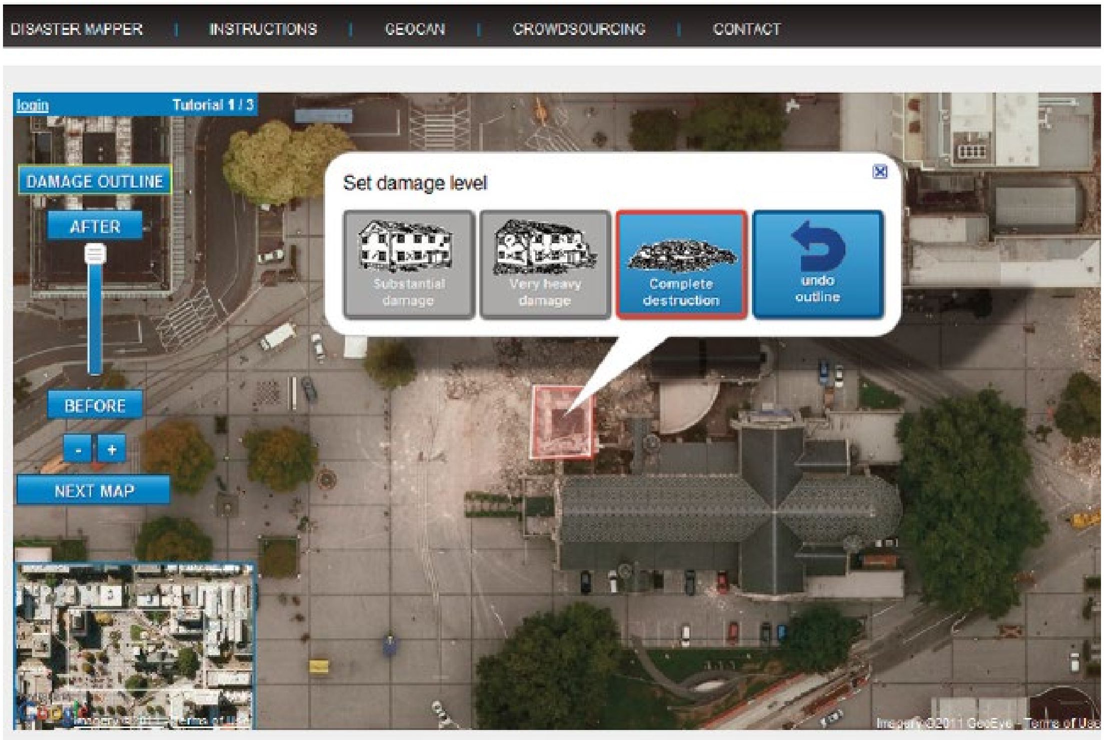


Figure 2.4: Sample image of the user interface on Tomnod for a mission to identify the damage level in different buildings in Christchuch (Barrington et al. 2011).

2.8.3. Specialist platforms

In recent years, members of the public have been increasingly engaged by governments and academics, interested in their knowledge and expertise. Local governments and water companies are capitalising on civilian resources by crowdsourcing data through specialised online reporting forms (Wehn et al. 2015). Using a pilot crowdsourcing platform, Degrossi et al. (2014) found that a website could be effective in obtaining useful and accurate volunteer information on flooding in Brazil. Starkey et al. (2017) also demonstrate how a website is able to support a local network of community-based observers to contribute hydro-information alongside traditional sources. These were found to characterise catchment hydrological responses more accurately than the use of traditional observations alone. As part of the response to severe floods in India’s Northern state of Uttrakand in 2013, crowdsourced data was compiled using a specially designed app (Murphy, Keating, and Edgar 2013). Using a network of low-cost sensors, Mazzoleni et al. (2015) show that citizen science can complement traditional physical sensors and improve the accuracy of flood forecasting. DIY equipment, together with a specialised app has been used by the EU funded WeSenseIt project to support local governance (Mazumdar et al. 2016; Wehn and Evers 2015). Wehn et al. (2015) argue that such approaches can have added benefits by creating a two-way communication mechanism where public views and feedback help in identifying problems and needs.

For rapid flood damage estimation, Poser & Dransch (2010) interpolated flood inundation depth from crowdsourced survey data. This study produced estimates comparable to interpolated in-situ measurements as well as model predictions. Recent studies have demonstrated a growing utility of crowdsourced data of floods to improve flood risk management and to validate two-dimensional inundation modelling (Wang et al. 2018; Yu, Yin, and Liu 2016). McDougall & Temple-Watts (2012) estimated flood extent by using crowdsourcing and river gauge data to create an elevation map which was then compared to the natural topographic surface. By fusing multiple sources of crowdsourced data Schnebele et al. (2014) found it possible to create an estimate of flood extent when remote sensing data were lacking or incomplete. These assessments had the added benefit of being able to identify potential areas of road damage or inaccessibility from flooding (E Schnebele, Cervone, and Waters 2014).

2.8.4. Open data

One of the greatest sources of crowdsourced information on flooding can be seen in the widespread use of social media. The availability of highly useful data on the internet is constantly improving. Popular social media platforms such as Twitter, Facebook, Flickr, Tumblr, Instagram and YouTube have facilitated mass sharing of information, photos and videos on the internet. Extracting usable data for hazard research is highly challenging given the level of noise in online platforms (Meier 2013). Yet, the sheer volume of up-to-date data makes it potentially valuable for a number of fields. In addition, the tools used to extract value are constantly improving, with tools using artificial intelligence to analyse big data from platforms such as Twitter becoming better develop (Wang et al. 2018). However, when harvesting data from social media platforms such as Twitter, the inability to affect the type of information being shared, produces many challenges as few contain geotags. In comparison, geotags are very common in some photo sharing apps which can improve their utility for flood model validation. For example, through repositories such as Flickr, McDougall & Temple-Watts (2012) were able to reconstruct flood extents and assess both area and depth of inundation in Brisbane’s 2011 floods.

Videos taken by witnesses of flood events are increasingly available on audio-visual sharing websites. They include potentially valuable information on hydraulic processes such as flow velocity which can help improve the post-flood modelling and reconstruction.

YouTube does not have geotagging capabilities, yet its popularity for sharing videos of natural hazards has enabled it to be used as a suitable platform for estimating river discharge during flooding events (Le Boursicaud et al. 2016) and water levels (Michelsen et al. 2016). Using YouTube as a data source of the catastrophic flood of June 18th 2013 in the French Pyrenees, Le Boursicaud et al. (2016) identified a number of good quality videos of the water flows. On request, the locations of the videos were provided by the YouTube members and fieldwork was carried out to calculate the dimensions of the bank. This enabled a particle image velocimetry and discharge estimations to be made at the peak of the flood event. Fieldwork during such hazards is both difficult to organise due to the short notice and often too dangerous to pass health and safety procedures. Therefore, the ability to effectively use amateur videos for discharge modelling clearly demonstrates a significant step forward in understanding flooding dynamics (Le Boursicaud et al. 2016).

2.9. Summary

Flooding is a major and increasing global hazard which requires significant multi-level mitigation measures to be managed effectively. Flood hazard risk management strategies include reducing vulnerability through increased access to technology and assistance, land use planning, early warning systems, emergency services response and insurance policies. Mitigation beyond the point of impact helps sustainably deal with the threats posed by different natural hazards in a more holistic fashion. The extent to which such strategies are viable is, however, largely defined by social, political and economic realities. Therefore, when responding to the threats posed by hazards, it is incumbent to research and consider all aspects which influence the system, in and beyond the point of impact. The viability of mitigation strategies, both at the point of impact and beyond, are constrained by social, economic and environmental factors which must be addressed in the evaluation of different measures. All these actions require up-to-date information about flooding on the ground in order to direct resources to the appropriate areas.

Throughout history, the public have played a part in scientific research and discovery. For the majority of this time, the role of the citizen has been minimal and only significant in exceptional circumstances such as discovering ancient ruins or a new species. However, as geographic research studies get ever more ambitious and the need for localised up-to-date information becomes integral to managing environments, more scientists and organisations are turning to the layperson. Crowdsourcing provides a major opportunity for flood response and research teams in search of additional information about events. Given the ability of citizens to contribute useful local knowledge and a genuine interest in tackling hazards, interest in crowdsourcing for flood risk management has grown in recent years. The knowledge that citizens can contribute to help manage hazard risk is broad. From documenting hazards, to participating in micro-tasking projects and simply discussing floods on social media, citizens have contributed to our understanding of flooding in a number of unexpected ways. The specific motives of different individuals and communities to get involved remain complex. As a consequence, tailoring the design of crowdsourcing platforms to the needs of their current and potential future users is challenging. It is therefore imperative to evaluate the different approaches taken in user centred design for flood crowdsourcing and their relative successes. However, many questions remain as to the efficacy of crowdsourcing for supporting flood risk management. As a result, there is significant demand and potential for further research into the implementation of flood crowdsourcing schemes for supporting risk management in a variety of contexts.

Chapter 3: A typology for flood crowdsourcing

Research questions addressed in this chapter
1. What are the characteristics of crowdsourced flood data, and how are they evolving?
2. How do human factors affect participation in flood crowdsourcing projects?
3. What roles can crowdsourcing play in supporting flood risk management?
4. What role does platform design play in maximising the efficacy of crowdsourcing for flood risk management?

3.1. Introduction

An online search for academic journals using 'flood crowdsourcing' will return literature such as Horita et al. (2015), Holderness & Turpin (2015) and Degrossi et al. (2014). All of these studies refer to the development and use of specialised reporting apps or social media for flood information production. Such tools are growing in scale and practicality, yet perhaps some of the most recognizable forms of crowdsourcing such as incident hotlines and media outreach are missing. In addition, while newspaper reports using public observations of flooding have long been a useful source of information for academia (Tarhule 2005; Wei et al. 2011), these are rarely referred to as crowdsourcing.

In a study focussing on crowdsourcing in ornithology, Cooper et al. (2014) note an invisible prevalence of literature due to the different terminologies in use. It is argued that many other areas of inquiry such as studies of land-use change, invasive species, and environmental pollutants, are also likely to be affected by 'invisibility.' This is particularly evident for flood risk management. Key contributions to literature examining the importance of community workshops such as Tran et al. (2008), Lane et al. (2011) and Bracken et al. (2016) do not reference 'Crowdsourcing', 'Citizen Science' or 'VGI'. Yet consideration of these studies is integral to the understanding of the phenomenon of flood crowdsourcing. For practitioners looking for new datasets on flooding or ways of producing specific types of information, these studies may also be missed. Likewise, for academics researching the world of flood crowdsourcing, it is important to understand its entire scope as a phenomenon.

A prominent metaphor of citizen participation is Arnstein's ladder describing eight distinct rungs: Manipulation, Therapy, Informing, Consultation, Placation, Partnership, Delegated power and Citizen Control (Arnstein 1969). This serves as a starting point for many discussions on the purpose of citizen participation. With the changing face of crowdsourcing and citizen science, several typologies have since been developed. Bonney et al. (2009) divided citizen science projects into three major categories: contributory, collaborative and co-created. In Wiggins & Crowston (2011), it is argued that citizen science typologies have historically focussed on the integration of public participation in different steps of scientific research. Little attention is paid to sociotechnical and macrostructural factors influencing the design and management of participation. As a result, Wiggins & Crowston (2011) develop a typology which identifies five types of citizen science projects: Action, Conservation, Investigation, Virtual, and Education. These categories are largely self-explanatory (aside from 'Virtual') as they define projects based on their primary project goals. Virtual projects have goals similar to Investigation projects, but are entirely ICT-mediated. Citizen science was also characterised by Haklay (2013) in the definition of four key typologies: 'Crowdsourcing', 'Distributed Intelligence', 'Participatory Science' and 'Extreme Citizen Science'. For crowdsourcing in particular, Brabham (2013) identifies four distinct typologies: 'Peer-Vetted Creative Production', 'Distributed Human Intelligence Tracking', 'Broadcast Search and Knowledge Discovery and Management' (KDM). Other interpretations and contextualisation of crowdsourcing provide their own prism to the activities of participants and the resulting data products.

In recent years, the number of emerging flood crowdsourcing platforms has risen substantially. With a variety of scopes and new data sources, it is evident that many platforms are radically different to those mentioned in the wider crowdsourcing literature. Yet, these are largely understudied. This raises significant challenges for the characterisation of flood crowdsourcing practises and their relevance to the other forms of crowdsourcing (or in some cases – citizen science). For example, discussing a government incident reporting hotline for flooding in the context of crowdsourcing platforms in general may bring about some confusion. For practitioners scoping new VGI on flooding, an understanding of the entire landscape will help make informed decisions about where data and tools can be found, applied or developed. Flood crowdsourcing platforms certainly differ from many others discussed in the literature in their variety, aims and data. These variations make it difficult to relate key implications from typologies of platforms described by Arnstein (1969), Bonney et al. (2009) Wiggins & Crowston (2011) Brabham (2009) and Haklay (2013) to a flooding context.

3.2. Research objectives

This chapter aims to characterise the use of crowdsourcing for generating different types of flood information and produce a typology which specifically supports theoretical and practical innovations for flood crowdsourcing. In doing so it aims to address RQ1 of the thesis. The specific objectives are to:

1. Characterise existing tools and design approaches for a range of flood crowdsourcing projects
2. Characterise crowdsourced flood data as observed on a range of projects
3. Propose a typology for flood crowdsourcing projects based on their goals and format.

3.3. Methods

3.3.1. Sampling approach

Identifying a wide variety of flood crowdsourcing projects across the globe requires a thorough academic literature and website trawl as they appear under a wide range of contexts. In addition, with new crowdsourcing campaigns being launched on a regular basis, and others retiring, characterising the landscape can be challenging. In response to such challenges, a purposive sampling method called 'landscape sampling' (Bos et al. 2007, P.657) was devised to produce a sample as comprehensive as possible in type, but not in frequency. This method was used to identify projects which generate crowdsourced flood data both in the UK and globally. This approach was most appropriate as it aims to identify all unique types in an environment prior to assessing frequency of occurrence. The selection process specifically focused on identifying as broad a range of project types as possible, concluding when the addition of more projects no longer yielded particularly distinctive characteristics or combinations of features. 'Crowdsourcing,' 'Citizen Science,' 'Community Mapping' and 'Flood Reporting' were all used to identify projects. Two major crowdsourcing project hosting platforms (CrowdMap and Urshahidi) were used to identify all flood related projects using their database. A total of 31 projects hosted on Urshahidi were omitted as they had no submissions and thus did not represent a meaningful example of flood crowdsourcing in action. In addition, platforms found by coincidence including Facebook's 'Crisis Response' and Waze were also included. From sampling a range of government and water company reporting platforms, it was evident that only one of each was needed to represent the wider class of platforms. Similarly, only five social media sites were discussed as, they too represented a broad field of similar trends.

3.3.2. Characterising flood crowdsourcing projects

Through an examination of each project, their characteristics relating to accessibility of their data, project theme, scope and quality assurance were reviewed. Accessibility of crowdsourced data was classified as closed, partial or open access. Project themes were inducted using mission statements or platform aims and classified as either: Scientific, Informing Decision Making, Model Validation, Community Support, Operations, Navigation, Media, Humanitarian or a Multiple of several themes. Project scopes were classified geographically as: community level, city, regional national or international. The measures taken by each project for quality control were summarised. Each project was then placed within each of the following typologies using their descriptions according to Bonney et al. (2009), Arnstein (1969), Wiggins & Crowston (2011) Brabham (2009) and Haklay (2013). Where possible, the availability of crowdsourced data produced through each project was requested. Where crowdsourced data from projects was public or made available, it was analysed using descriptive statistics and geographical maps. In cases where qualitative data was present, they were coded using a data driven thematic approach. This enabled the prevalence of key data types including depths and timeframes of events to be assessed for selected campaigns. After each project was examined, they were manually clustered using an inductive, qualitative approach. This enabled a typology to be developed which described the landscape of five distinct types of flood crowdsourcing projects based on their aims and formats. These were defined, outlined and illustrated using a selection of unique and relevant case studies.

3.4. Results

3.4.1. Characteristics of flood crowdsourcing projects

The projects identified ranged from community reporting tools for sharing current information about traffic disruption to flood mapping social media campaigns. In fact, other than the governmental and water company reporting tools which aimed to generate operational intelligence, each of the projects had unique aims. These ranged from scientific research, informing fellow community members of issues or simply sharing knowledge (Appendix 1). These exhibit a range of different themes and scopes (Table 3.1). Scientific projects tend to be more localised despite the immense power of flood information for macroscale research. Approaches to quality control vary and different sampling architectures are used making any assimilation of data highly challenging. The majority of projects identified in this chapter are partially or fully open access. Cases of partial open access include Waze where traffic issues can be seen on a map, but raw data cannot be downloaded. The number of submissions to BBC's 'Have Your Say' is unknown, yet a select few are presented online. The results from the Haltwhistle Burn platform are published in scientific journals but not downloadable on the website.

Table 3.1: Flood crowdsourcing projects and their characteristics

Platform	Data accessibility	Theme	Scope	Quality control
Ryedale Flood Research Group	Closed	Scientific	Community	Consensus
Haltwhistle Burn	Partial	Scientific	Community	Participants are trained
The City of Boulder 'Community Flood Assessment' (CB-CFA)	Open	Informing decision making	City	Verified and unverified users
Weather Observations Website (WOW)	Open	Model validation	International	None
The Scottish Environment Protection Agency's 'Report a Flood' (SEPA-RAF)	Partial	Community support	National	None
#Chennai Rains	Open	Community support	City	None
Floodbook	Open	Community support	City	None
Floodstones	Open	Scientific	National	None
#PetaJakarta and #PetaBencana	Open	Operations	City	None

FEMA Disaster reporters	Open	Operations	National	Verified and unverified users
WeSenseIt	Closed	Operations	City	None
SWIM	Closed	Operations	National	None
Leicestershire County Council reporting form	Closed	Operations	County	None
Thames Water reporting form	Closed	Operations	Regional	None
Floodline	Closed	Operations	National	None
BHS Chronology of British Hydrological events (BHS-CBHE)	Open	Scientific	National	Sources required
Tomnod	Conditional	Humanitarian	International	Consensus
Zooniverse	Conditional	Humanitarian	International	Consensus
Twitter	Open	Multiple	International	None
Flickr	Open	Multiple	International	None
YouTube	Open	Multiple	International	None
Waze	Partial	Navigation	International	Consensus
BBC 'Have Your Say' (BBC-HYS)	Partial	Media	International	Reviewed by journalists
Facebook crisis response	Open	Humanitarian	International	None
SnapMap	Open	Multiple	International	None
BGS Crowdmap	Open	Scientific	International	None
VT Irene Crowdsmap	Open	Humanitarian	Regional	None
Brisbane Storm and Flood Map	Open	Humanitarian	Regional	None
Red River Flood of 2018	Open	Humanitarian	Regional	None

Sri Lanka Floods	Open	Humanitarian	Regional	None
Floodmsa	Open	Humanitarian	Regional	None

The position each flood crowdsourcing project held within each typology produced by Wiggins & Crowston (2011), Haklay (2013), Wiggins & Crowston (2011), Brabham (2013), Arnstein (1969) and Bonney et al. (2009) was not always clear (Table 3.2). In particular, for the social media platforms, it was difficult to find an appropriate category from Wiggins & Crowston (2011). Where projects did fit a specific category in a typology, the majority fitted the same category within each typology. These were as follows: ‘Crowdsourcing’ for Haklay (2013), ‘Action’ for Wiggins & Crowston (2011), ‘KDM’ for Brabham (2013), ‘Informing’ for (Arnstein 1969) and ‘Contributory’ for Bonney et al. (2009) (Table 3.2). Yet, these typologies were often overly general, covering almost all the different platforms. For example, aside from Tomnod and Zooniverse all the other case studies can be characterised by Brabham's (2013) typology of knowledge, discovery and management: *‘Organization tasks crowd with finding and collection information into a common location and format.’* Yet projects such as the #Chennai rains map are radically different from Media Engagement activities. In other cases such as CB-CFA, the typologies were not always wholly fitting as the main aim of the platform was to *‘provide a venue for residents and businesses to share their Boulder Flood data and stories.’* These stories can be both characterised as participatory science or simply crowdsourcing according to Haklay’s (2013) typology. Likewise, using the Wiggins & Crowston (2011) typology, a flood mapping project such as the SEPA-RAF platform could lead to action as well as investigation. The ambiguity of a platform’s typology was most notable for Arnstein's ladder of participation where ‘*informing’* was regarded as the most appropriate rung for most projects. Yet, many platforms include several cases of participants going above and beyond what would be expected of them in an ‘*informing’* form of public participation. As a result, the characterisations of projects were highly subjective in many cases.

Table 3.2: Flood crowdsourcing projects and position within existing typologies (KDM refers to Knowledge Discovery and Management and DI refers to distributed intelligence).

Platform	(Muki Haklay 2013)	(Wiggins and Crowston 2011)	(D. Brabham 2013)	(Arnstein 1969)	(Bonney et al. 2009)

Ryedale Flood Research Group	Extreme citizen science	Investigation	KDM	Placation	Co-created
Haltwhistle Burn	Participatory science	Investigation	KDM	Informing	Collaborative
CB-CFA	Crowdsourcing	Action	KDM	Informing	Contributory
WOW	Crowdsourcing	Investigation	KDM	Informing	Contributory
SEPA-RAF	Crowdsourcing	No clear type	KDM	Informing	Contributory
#Chennai Rains	Crowdsourcing	Investigation	KDM	Informing	Contributory
Floodbook	Crowdsourcing	Investigation	KDM	Informing	Contributory
Floodstones	Crowdsourcing	Investigation	KDM	Informing	Contributory
#PetaJakarta and #PetaBencana	Crowdsourcing	Action	KDM	Informing	Contributory
FEMA Disaster reporters	Crowdsourcing	Action	KDM	Informing	Contributory
WeSenseIt	Crowdsourcing	Action	KDM	Informing	Contributory
SWIM	Crowdsourcing	Action	KDM	Informing	Contributory
Leicestershire County Council reporting form	Crowdsourcing	Action	KDM	Informing	Contributory
Thames Water reporting form	Crowdsourcing	Action	KDM	Informing	Contributory
Floodline	Crowdsourcing	Action	KDM	Informing	Contributory
BHS-CBHE	No clear type	Investigation	KDM	Informing	Contributory
Tomnod	Distributed intelligence	Virtual	DI	Informing	Contributory

Zooniverse	Distributed intelligence	Virtual	DI	Informing	Contributory
Twitter	Crowdsourcing	No clear type	No clear type	Unclear	Contributory
Flickr	Crowdsourcing	No clear type	No clear type	Unclear	Contributory
YouTube	Crowdsourcing	No clear type	No clear type	Unclear	Contributory
Waze	Crowdsourcing	No clear type	KDM	Manipulation	Contributory
BBC-HYS	Crowdsourcing	Investigation	KDM	Informing	Contributory
Facebook crisis response	Crowdsourcing	Action	KDM	Informing	Collaborative
SnapMap	Crowdsourcing	Virtual	KDM	Informing	Contributory
BGS Crowdmap	Crowdsourcing	Investigation	KDM	Informing	Contributory
VT Irene Crowdsmap	Crowdsourcing	Action	KDM	Informing	Contributory
Brisbane Storm and Flood Map	Crowdsourcing	Action	KDM	Informing	Contributory
Red River Flood of 2018	Crowdsourcing	Action	KDM	Informing	Contributory
Sri Lanka Floods	Crowdsourcing	Action	KDM	Informing	Contributory
Floodmsa	Crowdsourcing	Action	KDM	Informing	Contributory

Through an examination of each project, five distinct types of flood crowdsourcing emerged. These are: 1) Incident Reporting, 2) Media Engagement, 3) Collaborative Mapping, 4) Online Volunteering and 5) Passive VGI. This typology describes flood crowdsourcing platforms based on their aims and design approaches. While, for many projects, each type is mutually exclusive, some initiatives can have qualities of more than one type of flood crowdsourcing. All five types are described and outlined below.

3.4.2. Incident Reporting

Incident Reporting describes the process by which members of the public report issues to relevant authorities with the primary purpose of prompting an operational response. In this chapter, it describes: England Environment Agency's SWIM tool, Council reporting forms, Water company reporting forms and Floodlines. It is by far the most widespread adoption of crowdsourcing flood platforms since the vast majority of countries that are flood prone provide their citizens with the means of reporting incidents.

3.4.2.1. Case study: Incident Reporting in the UK

In the UK, a range of institutions from local government, environment agencies, highways agencies and water companies all have forms or phone-lines (Table 3.3). These different platforms can all be characterised as tools which aim to gain from the public's eyes and ears on the ground for operational management. Data is shared between relevant authorities including water companies, blue light services and environment agencies.

Table 3.3 Guidelines for citizen flood reporting in the UK[2]

Type of flood data reported	Responsible institution	Crowdsourcing system
• Blocked sewers • Burst water mains	Local water companies	Most water companies typically use online reporting forms (e.g. Thames Water[3]). These typically ask for observations such as type of flood, location, timescale, scale (trickle or major burst).
• A blockage • Collapsed or badly damaged river or canal banks • Unusual changes in river flow • Flooding from the sea or a main river	Environment Agency	Environment Agency incident hotline.

[2] https://www.gov.uk/report-flood-cause
[3] https://www.thameswater.co.uk/Help-and-Advice/Report-a-problem/Report-a-problem?type=leak

• Public drains • Flooded roads • Flooding from other rivers, brooks or streams. • Groundwater flooding	Local council	Reporting forms vary from pdf attachments which can be posted or emailed[4] to online reporting forms. The fields within each form vary but often include: type of building, location, type of flood, depth, cause of flood, impact and source of water.
• Floods caused by private drains	Property owner	None
• Emergency event with immediate risk to life or health	Blue light services	999 phone-line
• Roadside drains	Highways Authority	Typically use phone-lines, emails and online reporting forms.

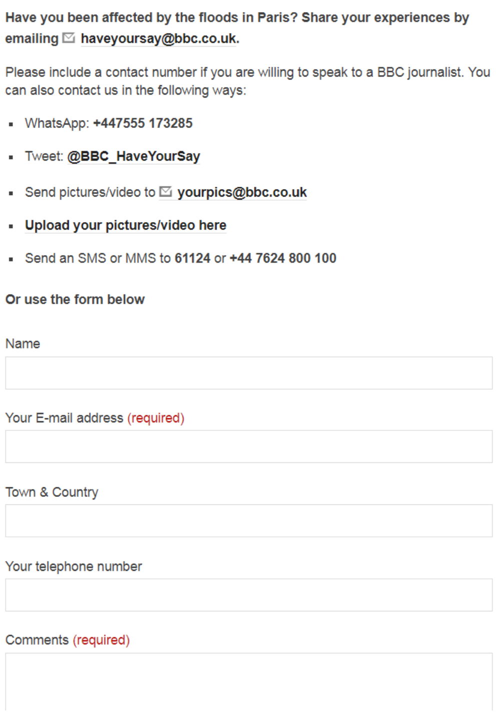
3.4.3. Media Engagement

The media represents a major source of crowdsourced flood information. In this chapter, Media Engagement is portrayed using BBC-HYS as a case study. While some reports may have traditionally been produced by sending expert journalists into the field, news stories are increasingly relying on members of the public for submitting data.

3.4.3.1. Case study: Outreach at the BBC

In recent years, the BBC has made a significant push to encourage viewers and listeners to share their narratives about their news stories. A dedicated 'Have Your Say' page has been developed and is often referenced in specific news stories such as the Paris 2018 floods (Figure 3.1). The BBC compiles reports from several tools on their 'Have Your Say' website including email, WhatsApp, Tweets, online forms and SMS. A select few are often then presented in their news reports e.g. Figure 3.2.

4 https://www.leicestershire.gov.uk/sites/default/files/field/pdf/2017/5/31/Revised_Flood_reporting_form_v3.pdf



Have you been affected by the floods in Paris? Share your experiences by emailing haveyoursay@bbc.co.uk.

Please include a contact number if you are willing to speak to a BBC journalist. You can also contact us in the following ways:

- WhatsApp: **+447555 173285**
- Tweet: **@BBC_HaveYourSay**
- Send pictures/video to **yourpics@bbc.co.uk**
- **Upload your pictures/video here**
- Send an SMS or MMS to **61124** or **+44 7624 800 100**

Or use the form below

Name

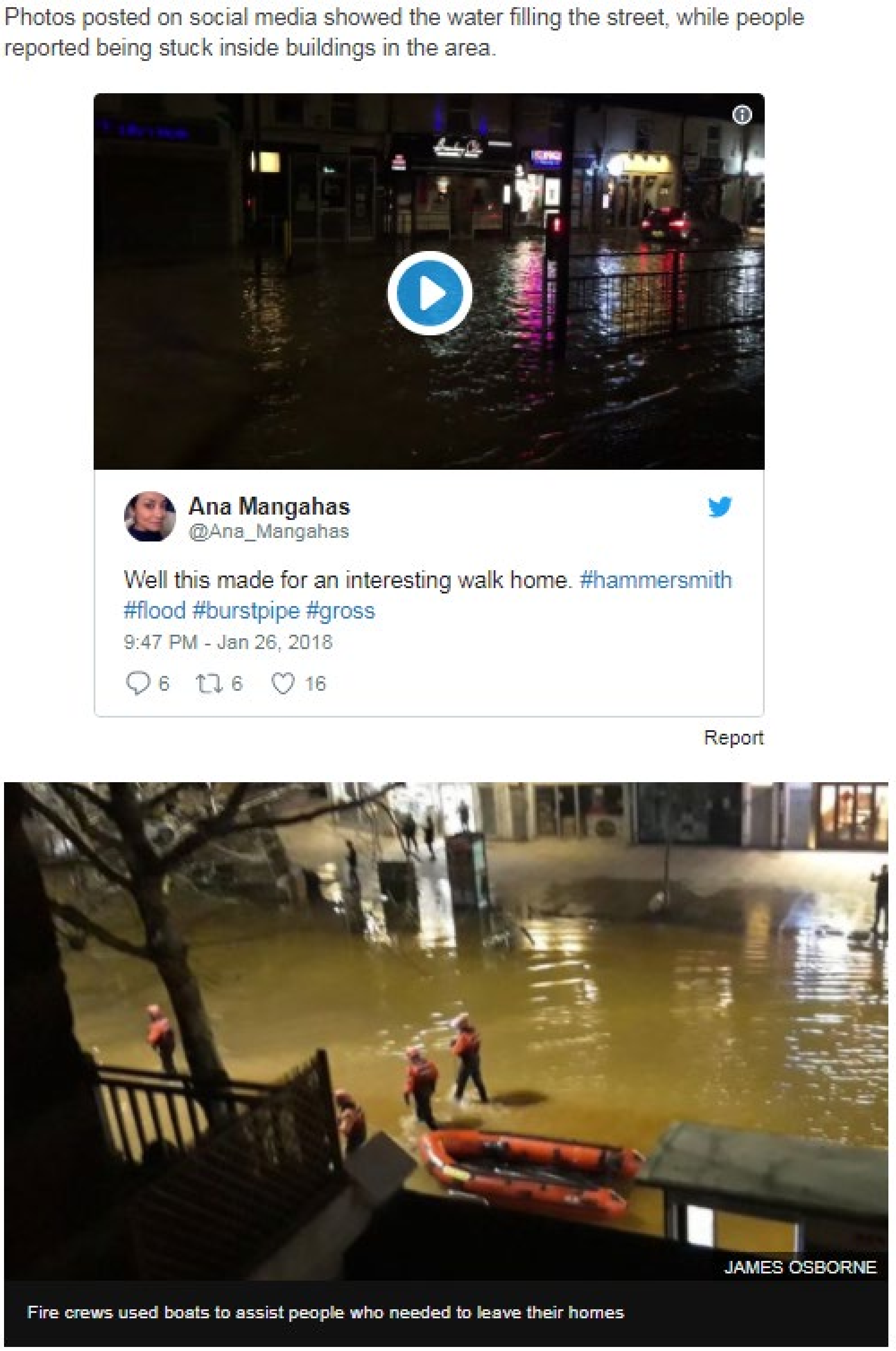
Your E-mail address (required)

Town & Country

Your telephone number

Comments (required)

Figure 3.1: Comment form for BBC's 'Have Your Say' system for Paris 2018 floods (BBC 2018a)



Photos posted on social media showed the water filling the street, while people reported being stuck inside buildings in the area.

Ana Mangahas
@Ana_Mangahas

Well this made for an interesting walk home. #hammersmith #flood #burstpipe #gross
9:47 PM - Jan 26, 2018

6 6 16

Report

JAMES OSBORNE

Fire crews used boats to assist people who needed to leave their homes

Figure 3.2: Extract from BBC news story about 2018 Hammersmith floods in the UK (BBC 2018b)

3.4.4. Collaborative Mapping

Collaborative Mapping describes a broad array of projects which despite having different aims and objectives, all involve a call for members of the public to share their knowledge of events for the benefit of the wider community. In this chapter, it describes: CB-CFA, WOW, SEPA-RAF, #Chennai Rains, Floodbook, Floodstones, #PetaJakarta and #PetaBencana, FEMA Disaster reporters, Ryedale Flood Research Group, Haltwhistle Burn, WeSenseIt, BGS Crowdmap, VT Irene Crowdsmap, Brisbane Storm and Flood Map, Red River Flood of 2018, Sri Lanka Floods and Floodmsa. Few large scale citizen science led initiatives on flood crowdsourcing exist at present as most projects tend to be locally focussed.

3.4.4.1. Case study: The City of Boulder 'Community Flood Assessment' (CB-CFA)

Following widespread flash flooding in the Denver-Boulder metro area in September 2013, the City of Boulder launched platform to *'provide a venue for residents and businesses to share their data and stories about the 2013 Boulder, Colorado floods.'* This was designed to assist in flood assessment and informing future planning efforts. An Ushahidi[5] platform was produced with several fields asking residents for: *Flood type, Date and time, further details, further sources, basement depth, property type, attach a photo, Ground floor or Lowest level depth (inches), Did your electricity go out during the flood? Did you call the EOC Call Center or Public Works Call Center?*

In total, 255 observations were shared on the platform and made available for analysis. The majority (75%) of observations occurred in residential areas while 6% occurred in public areas. Basement flooding was reported as a significant issue with 53% of submissions providing an estimation of basement flood depth. A further 16% of submissions mentioned basement flooding in the further details field. This suggests that some participants prefer more qualitative ways of reporting impacts than simply providing depth estimations. The content in the further details submissions varied from three to ~600 words describing the event. The majority (78%) included management implications or recommendations. Property damage (75%) and the flooding process (73%) were also a prominent component of the further details provided (Table 3.4).

Table 3.4 Content analysis of BC-CFA submissions (n=255)

Content within data	Proportion of observations with data formats
Management Recommendation/ Implications	78%

[5] https://www.ushahidi.com/

Property Affected	75%
Flooding process	73%
Depth reference	48%
Qualitative description of flood extent	42%
Water quality	34%
Time-frame of flood	32%
Velocity	8%
Description of risk (no flood event)	6%
Impact on traffic	5%
Repeat events	3%
No flood	2%

Despite their sensitive nature, references to the cost of damages existed in 10% of submissions:

> *'I had damage to my finished lower level which has a living room, 3/4 bathroom, walk in closet, laundry room, furnace room, hallway, under the stairs storage and carpeted stairs. Expenses so far exceed $5000.00' [Submission 21]*

The sheer quantity of these sorts of posts emphasises both the physical and socioeconomic dimensions of flood impacts and the will of members of the public to have their voice heard. One particularly striking element in the BC-CFA data is the differences between the dates that the data were submitted and those of the event itself. Only 10 observations were shared on the day of the event while 91% of were shared over two weeks later. This reduces the applicability of the submissions to practitioners involved in the immediate aftermath of an event.

3.4.4.2. Case study: SEPA's report a flood (SEPA-RAF)

In December, 2015, SEPA launched an interactive tool for reporting flooding. Its aim – '*to enable members of the public to share information on current flooding issues in order to help reduce the disruption flooding can have on people's lives and make communities more resilient'*. This represented a unique approach to their traditional incident reporting system by letting members of the public share information about events which required '*no operational activity'*. The platform (displayed in Figure 3.3) asked members of the public for the type of flood, date, time and further details. It included a map showing all observations submitted in the last 24 hours. In its first year of operation, 450 observations were shared by members of the public. These spanned across Scotland with clusters forming in major cities such as Glasgow (Figure 3.4). These observations contained further details texts which were dominated by descriptions of the flooding process (71%) and impacts on traffic (59%) as well as management recommendations or implications (50%) (Table 3.5).

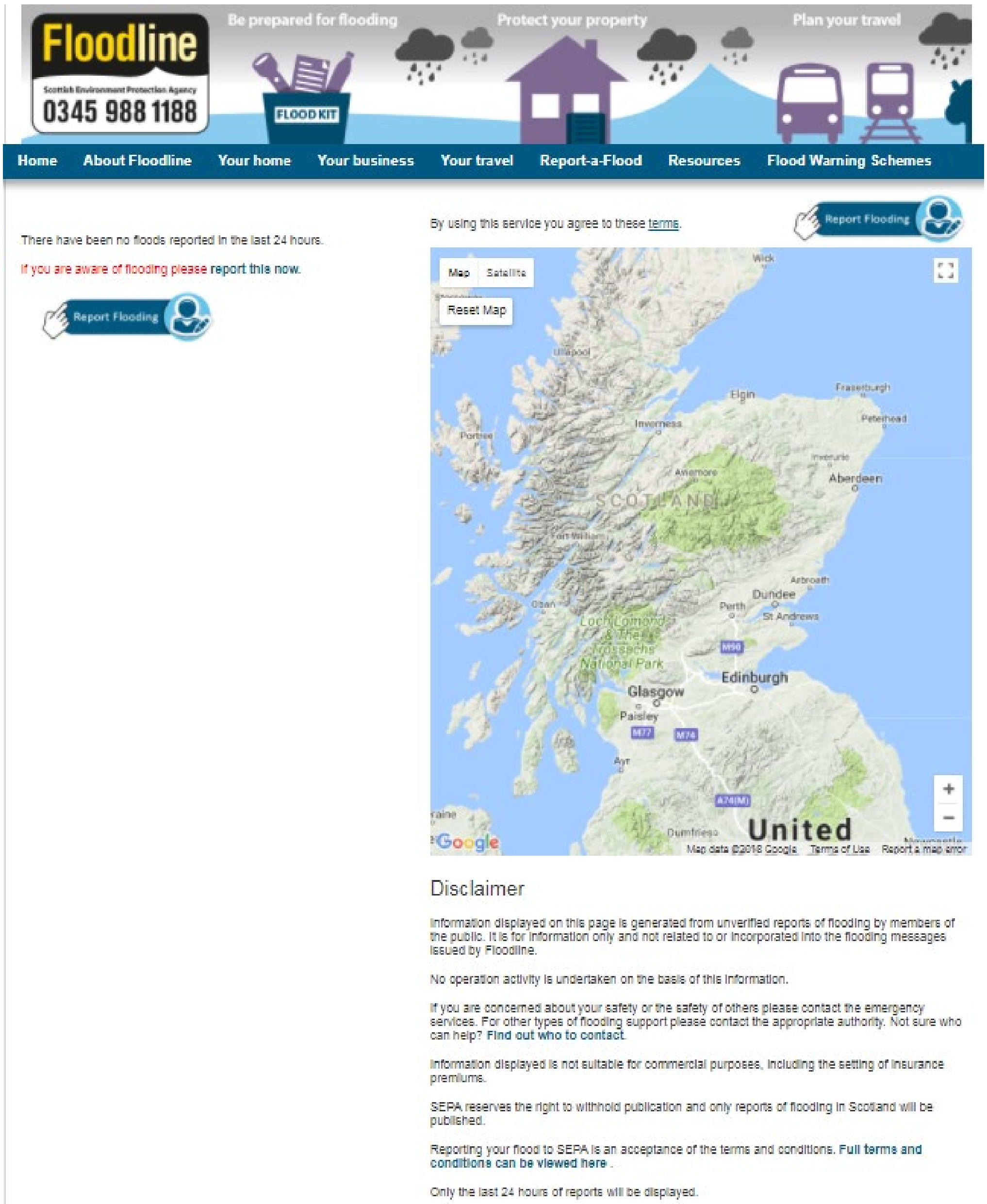


Figure 3.3: Interface of SEPA-RAF platform

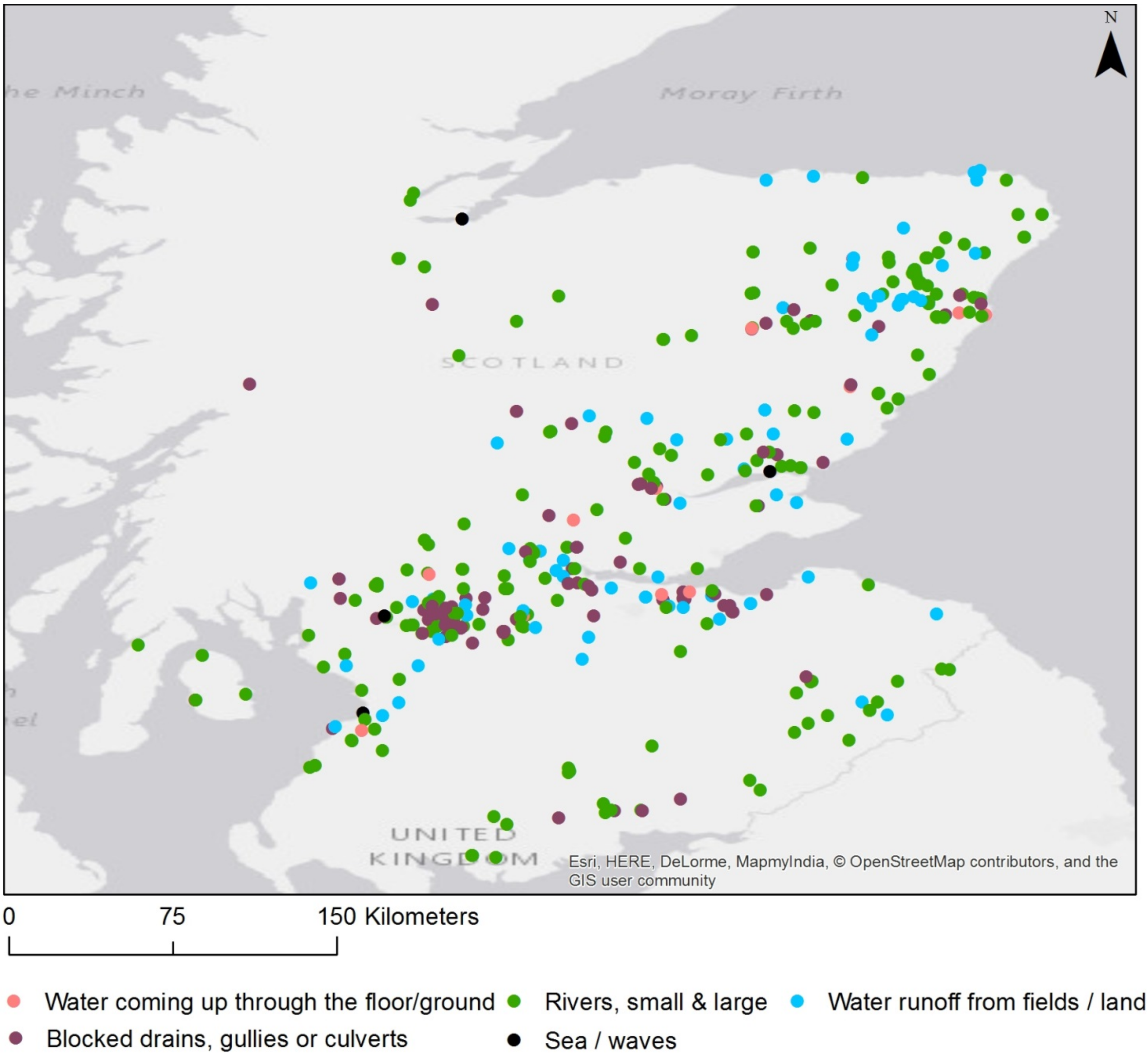


Figure 3.4: Map of SEPA’s ‘report a flood’ observations during 2015/2016 winter floods

Table 3.5 Content analysis of SEPA's 'report a flood' submissions (n=450)

Content within data	Proportion of observations with data formats
Flooding process	71%
Impact on traffic	59%
Management recommendation/implications	50%
Property effected	27%
Qualitative description of flood extent	25%
Depth reference	23%

Time-frame of flood	7%
Description of risk (no flood event)	4%
Repeat events	4%

3.4.4.3. Case study: Met Office's Weather Observations Website (WOW)

WOW's stated aim is *'to collect citizen weather observations from dedicated volunteers'*. The website also includes an option to record weather impacts and their approximate severity, of which flooding is one option. Using a list of predefined classifications, one or more options can be selected. In October 2017 4,100 geolocated submissions of weather impacts existed in the whole archive, of which 900 referred to floods. Observations are widely spread across the UK and sparse globally (Figure 3.5). This makes the WOW platform one of the largest science based flood crowdsourcing platforms currently in operation. Observations are used for validating weather warnings, near real-time identification of localised severe weather events and public information. Travel disruption was listed in 74% of observations while property damage also featured significantly (32%) (Figure 3.6).

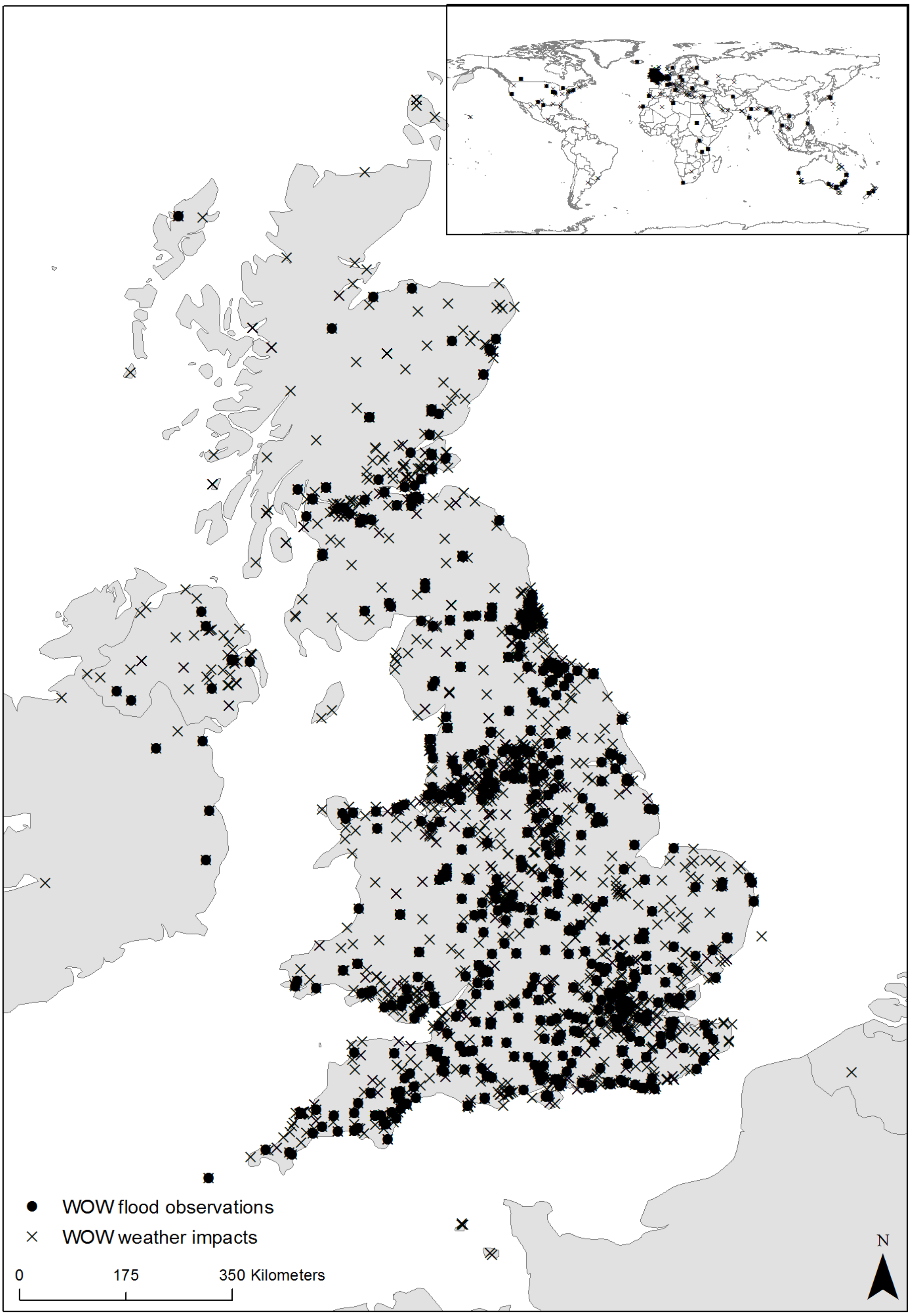


Figure 3.5: WOW observations of weather impacts from the beginning of the initiative in 2011 to January, 2018

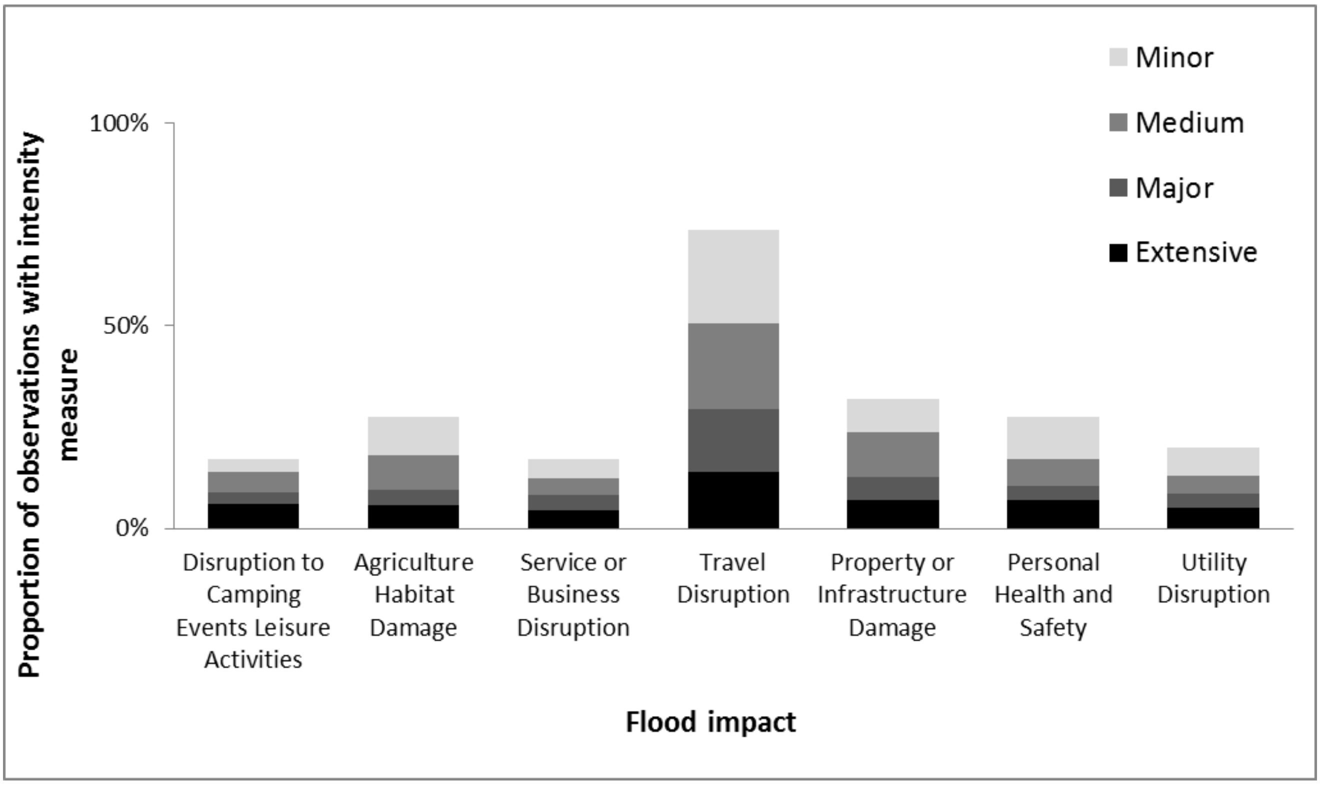


Figure 3.6: Type of flood impacts reported on the WOW platform

3.4.5. Online Volunteering

Online Volunteering describes an array of purposeful activities which can be undertaken online from translating important materials to organizing charitable events (Amichai-Hamburger 2008). In this chapter, it includes BHS-CBHE, Tomnod, Zooniverse and Facebook Crisis Response. Distributed intelligence platforms such as Tomnod represent the primary form of project to enlist the help of volunteers to map flood impacts. For flood crowdsourcing, Online Volunteering extends beyond distributed intelligence as contributors of BHS-CBHE and Facebook Crisis Response are only able to contribute with a *priori* knowledge of an event.

3.4.5.1. Case study: Chronology of British Hydrological events (BHS-CBHE)

The BHS-CBHE asks participants to submit information about historical events with sources of evidence and additional information. These data are then made available as part of a historical hydrological record. It currently contains 7,961 entries, although these do not contain precise locations (e.g. Figure 3.7) and only 65 refer to floods in the 21st century.

ID	Date	Quotation	Area	Contributor
13489	1991	". ..Situated at the meeting of the rivers Skell, Laver and Ure, there is a long history of flooding in Ripon. Recent flood events in 1982, 1991, 1995 and 2005 were caused by the River Ure. In 2000 it was the River Skell which caused flooding. In all cases significant numbers of properties were flooded.....	027 - Ouse (Yorkshire)	Frank Law
13793	1991	Drought year on River Wylye	043 - Avon and Stour	Frank Law
12338	1992	"...There were minor floods in 1990, 1992 and 1994/5 with larger floods occurring in 1999 and 2000...."	043 - Avon and Stour	Frank Law

Figure 3.7: Sample data from the BHS-CBHE database

3.4.5.2. Case study: Tomnod

Tomnod is a project that uses distributed intelligence to identify objects and places in satellite images for a range of emergency response campaigns. Tomnod volunteers identify affected locations with tags such as blocked roads and areas of major devastation. These tags are collated and processed by Tomnod for consensus using an in-house developed ‘Crowdrank Algorithm’, generating high-confidence clusters. The data are then made available for a range of targeted campaigns, including assisting in disaster response (Meier, 2013), tracking wildfires (Hansen, 2015) and even searching for the missing Malaysian Airlines flight MH370 (Fishwick, 2014). Among its campaigns are several flood mapping tasks including a 2015 mission to map the devastation from the Chennai floods in India (Figure 3.8). The project typically generates between 7,000 and 14,000 ‘tags’ of flood impacts such as flooded buildings and blocked roads. Data generally include information on blocked roads, damaged buildings, area of major devastation and other flooded areas. These are associated with a confidence rating generated by an in-house algorithm at Tomnod.

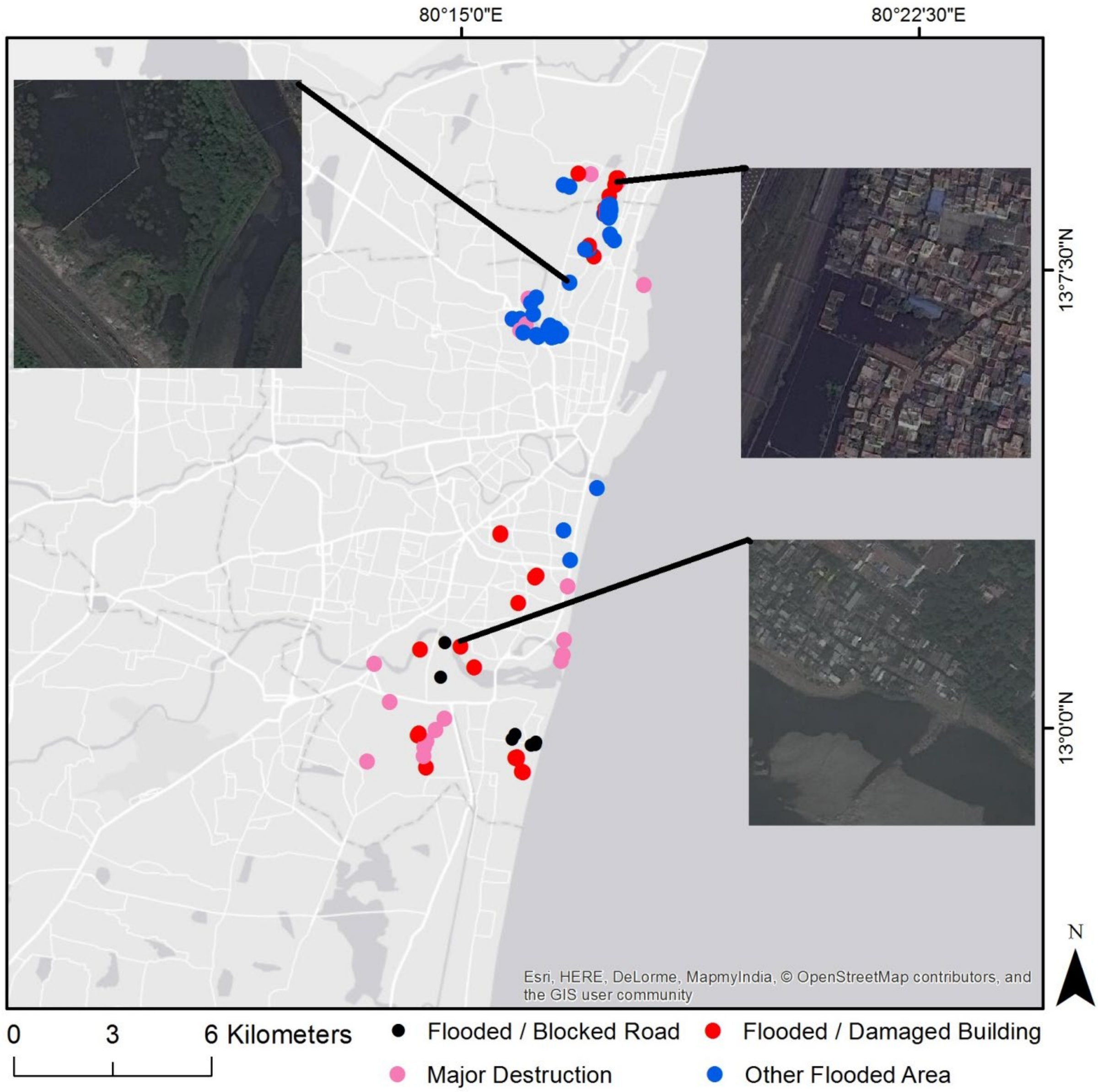


Figure 3.8: Tomnod high confidence clusters with associated imagery in Chennai, India, 2015

3.4.5.3. Case study: Facebook crisis response

Following crises, Facebook typically asks its users in the affected area to mark themselves as safe, providing their friends with notifications about ongoing safety concerns. To date, the focus of most of these campaigns has been for terrorist attacks, yet they are increasingly launching response efforts for hazards such as flooding. In recent years, Facebook have added tools to enable members of the public to offer help through accommodation, transport or even information in these areas. In November, 5th 2017 Kuala Lumpur was impacted by a flooded event. Soon after, Facebook activated its Safety Check feature for Penang allowing people to mark themselves as safe from the floods

(Figure 3.9). Using VGI from the platform, it listed eight areas in Penang as affected including George Town, Bayan Lepas, Batu Feringghi, Sungai Puyu, Sungai Pinang, Balik Pulau and Bukit Mertajam (Veena Babulal 2017).

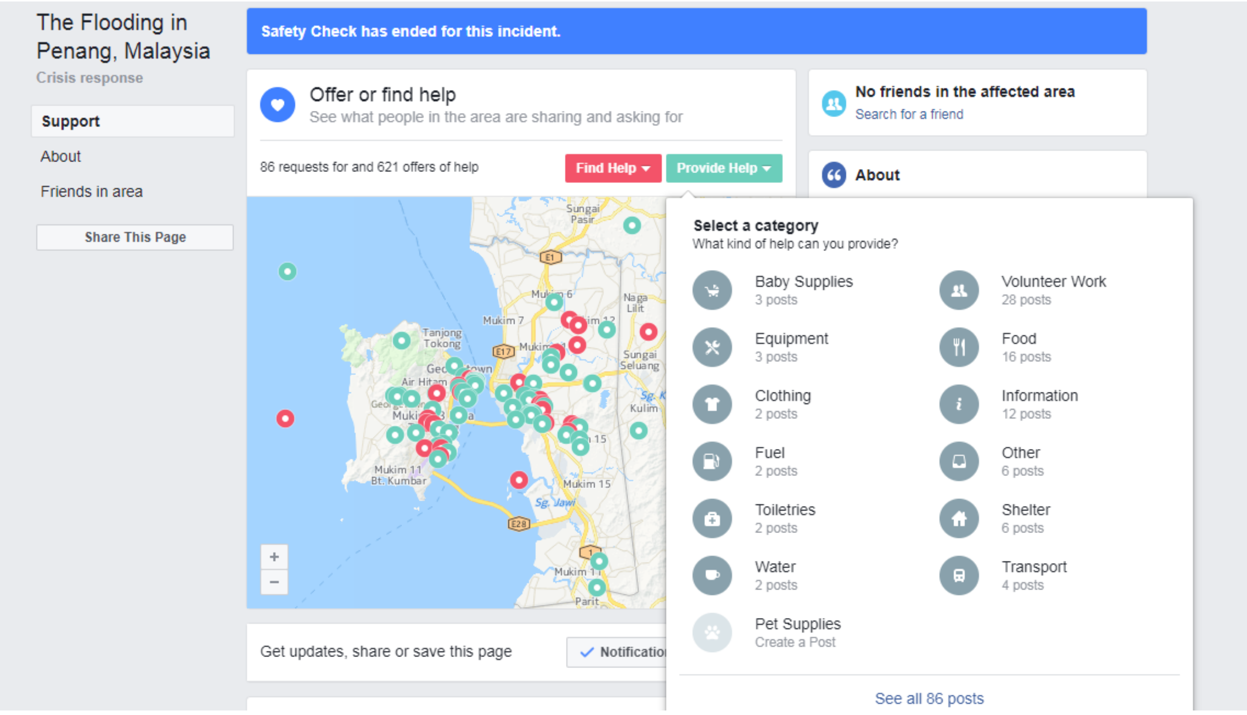


Figure 3.9: Interface of Facebook crisis response platform for Penang, Malaysia floods in 2017

3.4.6. Passive VGI

Passive VGI describes the process of providing geographic information consensually over the internet yet perhaps without a clear understanding of its purposes. This type of crowdsourcing covers a wide range of internet applications from social media to applications which track the geolocation of users. In such projects, contributors are often unaware of data usage since they did not read the terms of participation in detail or modify their privacy settings if available (Estima et al. 2016). In this chapter, Passive VGI is used to refer to YouTube videos, trends on Twitter, Snapchat and Flickr as well as the use of geolocation services on apps such as Waze. In navigation apps, geolocation is typically fed into aids without explicitly examining floods. Yet, their data undeniably describe the footprints of flooding events on road networks by showing road closures and delays. There are few VGI projects established without explicit profit motives (Haklay 2017), yet social media trends relating to flooding can often be used to generate useful information to support action. Perspectives on participation may vary substantially as in some cases, those contributing may not be aware of the precise nature of their contributions.

3.4.6.1. Case study: Twitter

Geotagged tweets relating to flooding can be accessed in their millions. In real-time, social media has helped support response teams in a variety of contexts. For example, following the two storms in Newcastle, UK in 2012, the hashtags '#toonflood' and '#newcastleendofdays' trended nationally, generating over 8,000 tweets such as Figure 3.10. By looking for key words such as 'ankle' 'knee' 'height' and 'depth', a number of general patterns of flooding across the city could be determined (Smith et al. 2015). However, users of these data have noted significant data quality issues including false reports, inappropriate tweets and recycled observations. This type of crowdsourced flood data is distinguished from campaigns such as #Petajakarta and #PetaBencana as these have been aiming to gather higher quality tweet data by encouraging members of the public to use these hashtags to provide specific information about events.

Figure 3.10: Tweet of Newcastle 2012 floods[6]

3.5. Discussion

Through an examination of 31 different platforms and several further examples of VGI on flooding, this chapter has outlined the wide variety of approaches to flood crowdsourcing. What has been particularly striking about the methodological process in this chapter has been the small proportion of flood crowdsourcing platforms that are specifically referred to as *crowdsourcing* in their description. Even platforms with a clear crowdsourcing objective such as SEPA-RAF can only be found by searching for 'report a flood' and are not mentioned in the academic literature. The incident reporting, media outreach and the Facebook Crisis Response tools do not use the words 'Crowdsourcing', 'VGI' or 'Citizen Science'. Governmental reporting forms and incident hotlines, perhaps one of the most widespread forms of flood crowdsourcing globally are also largely absent from the crowdsourcing literature. Nevertheless, studies such as Tkachenko et al. (2016) have

[6] https://twitter.com/adamliptrot/status/218481975349096448

made great use of crowdsourced data from flood incident hotlines to characterise the temporal profile of flood events following Hurricanes Bertha in 1996. By not mentioning crowdsourcing, VGI and other related words, such studies are likely to be often missed from the growing literature of flood crowdsourcing. Yet their relevance for the discipline is vital given the ubiquity of incident reporting tools across the globe. This may be impacting the ability of the crowdsourcing practitioner community's ability to learn from each other.

When it is viewed within the context of critical, participatory or feminist geography, Elwood (2008) notes that grassroots public participation is fraught with technical, semantic and epistemological complexities. These can be addressed to some extent through stronger engagement with GIScience research, helping to understand the phenomena and to consider the relevant applications of its products. The development of appropriate typologies forms a central part of this process as contradicting definitions for citizen science and crowdsourcing can lead to confusion. As such, Eitzel et al. (2017) argue that no single term is appropriate for all academic contexts and terms should be chosen carefully and their usage explained. It is abundantly clear that flood crowdsourcing is too broad to be largely defined by Brabham's (2013) *knowledge discovery and management* and *distributed intelligence*. Brabham's (2013) typology aims to represent all forms of crowdsourcing and thus pays little attention to initiatives such as flood mapping. While a number of platforms such as Haltwhistle Burn can be likened to more typical forms of participatory science as defined by Haklay (2013), others cannot. Evidently, the field of crowdsourcing for flood risk management has grown in scale and impact to such an extent in recent years that it benefits from a bespoke typology.

This chapter addresses a number of challenges through the delineation of five types of flood crowdsourcing: Incident Reporting, Media Engagement, Collaborative Mapping, Online Volunteering and Passive VGI. This helps tackle the issue of terminology for flood crowdsourcing by explicitly outlining the vast range of crowdsourcing projects and providing a starting point for any form of enquiry into the field. The development and illustration of this typology, based on a number of characteristics can be useful for project design and technological development. The findings summarised here not only list several sources of information which can be called on, but also helps inform future developments and platforms in their design approach. It does so by providing a comprehensive and wide ranging overview of the world of flood crowdsourcing – a much needed resource given its increasing utility. Projects in the early stages of development can use it to identify similar initiatives as potential sources of inspiration for research and campaign design. Wiggins &

Crowston (2011) argue that funding organizations could use the characteristics highlighted for each project in their typology to help evaluate proposals for congruence with funding objectives. The same can be argued for this chapter's characterisation of flood crowdsourcing platforms.

This chapter has revealed a wide range of sources of publicly submitted flood data describing depth, timing and extent information. The majority of observations contained disparate information, with datasets ranging from 11 points scattered across the UK on Floodstones to thousands on WOW and over 255 for one city-level event in the CB-CFA. A major limitation of many of the crowdsourced datasets identified in this chapter for practitioners is the time taken to generate the data. Nevertheless, despite their lack of currency, such datasets remain useful by providing data on depth-damage curves, infrastructure damage, the costs of emergency management and temporal relocation (de Moel et al. 2015; Jongman, Winsemius, et al. 2015). Data from platforms such as the CB-CFA and SEPA-RAF have very similar characteristics, albeit different project formats. Much of these included management recommendations with an implied expectation of action. This suggests a potential degree of confusion among members of the public about the purpose of flood crowdsourcing platforms which are not run for operational management purposes.

Citizen science often emerges at the interface of political activism and volunteering (Buytaert et al. 2016). While for many, they are a hobby, motivations are complex and can be driven by environmental concerns, scientific curiosity or a sense of community (Cohn 2008; Bonney et al. 2009). Landström et al. (2011) used an extended research collective to harness the energy generated in public controversy to contribute to flood knowledge. However, given the breadth of the field, as outlined in this chapter, further motivations in all the different flood typologies need investigating. For example, the demographics and motivations of citizens who share information with newspapers may significantly differ with those of Collaborative Mapping projects such as Haltwhistle Burn. Understanding the impact of human factors on data quality and quantity is integral for future flood crowdsourcing initiatives, yet they remain understudied.

While citizen science offers numerous benefits for science and society, it may also raise ethical questions and concerns (Resnik and Kennedy 2010). One of these is the issue of data accessibility. A strategy for responding to conflicts of interest in scientific research, including citizen science, is to make data publicly available so that the data analysis and interpretation can be independently evaluated (Soranno et al. 2015). Furthermore, Riesch & Potter (2014) argue that members of the public have an active stake in the production of data, not merely as taxpayers, but as co-producers of the data. A core principle of many of the world's leading citizen science platforms including eBird is providing free and open access to data for a broad spectrum of data consumers (Sullivan et al. 2014). Democratising data use will engage a wider user community, therefore increasing the likelihood of stimulating new, disruptive innovations (P. Mathieu et al. 2018). However, the issue of open access is complex with respect to the crowdsourcing of flood data and needs to be addressed sensitively. Where data can make a positive impact on flood response, it could be argue that it should be made available. Yet, laws such as the Data Protection Act 1998 (HMG 1998) prevent information from Incident Reporting tools being open access.

The potential negative effect of flood data on insurance premiums and house prices of affected peoples represents a further issue of controversy. Whittle et al. (2010) highlight instances of distrust between members of the public and insurance companies in relation to flood information. Yet flood crowdsourcing platforms such FEMA disaster reporters and BC-CFA have made data open access in order to inform a wider community of participants. In BC-CFA, members of the public readily described property damage, often citing the estimated cost of repairs. There is also ample evidence of flooded properties and estimated costs on social media which can be accessed by anyone. For projects that are not open access, this controversy is avoided. Given the substantial value of flood data for scientific and humanitarian purposes, further work should be dedicated to combating the potential negative implications of data sharing.

Flood crowdsourcing has become a global phenomenon and varies with context. However, the sampling approach in this chapter was undertaken from the perspective of an English-speaking academic. This is likely to have resulted in several non-English platforms being omitted (DiCicco-Bloom and Crabtree 2006). For example, Yu et al. (2016) demonstrate the value of flood data submitted on a Chinese government data platform to validate 2D inundation models in Shanghai. Yet, such datasets are difficult to identify without an understanding of the Chinese language and governmental reporting systems. As such, many platforms in non-English speaking countries which did not have academic outputs in English journals or a strong online presence were likely missed out. Likewise, platforms which made no mention of any of the key words such as crowdsourcing, citizen science and VGI may have also been missed from the chapter. Future developments of this field would benefit from further examining platforms in non-English speaking countries and those with different cultural and governmental relationships. This may help expand on the perspectives of ethics and governance of flood information as well as driving forward issues of accessibility.

Flood crowdsourcing is a field that is evolving at an exponential pace. During this chapter, several platforms including Cyberflood which had generated flood data (Wan et al. 2014) were no longer in operation. Meanwhile new platforms such as BBC's Weather Watchers, a weather crowdsourcing platform with the aim of providing the media corporation with viewers' weather observations (primarily temperatures) have emerged. This produced a number of flood event data observations although the number and detail of these remains unknown to the wider public. With no open access database and no specific focus on flooding, BBC's Weather Watchers was not included in this chapter. Yet, during a flood it has the potential to be a platform which generates thousands of flood photos in real-time. In addition, the sheer number of flood narratives that are shared with most media corporations remains unknown and would benefit from further research.

Given the pace at which the field of flood crowdsourcing is progressing, it is likely that further types of platforms will emerge in the coming years. A particularly powerful development could be an increase in the active recruitment of volunteers using the gig economy. Big tech companies are increasingly exploiting crowdsourcing through projects such as Facebook Crisis Response. While this platform has been included in the Online Volunteering typology, it must be acknowledged that it is evolving and could radically change its focus. By offering help, members of the public may extend beyond simply Online Volunteering to actively going into the field and providing information and support. This would not just make it more of a Collaborative Mapping project, but an on-the-ground response tool. Meanwhile, Google actively target members of the public using its 'Maps' application to request reviews and photos of businesses. Such mapping efforts typically do not occur for flooding events, yet they are technologically possible. For example, weather alerts for floods in affected areas can be distributed via the mapping application. These alerts could be sent accompanied by a request for further information. If developed, such a system could generate a real-time GIS dataset of flood impacts. New techniques are being made available for manipulating data for flood response and management. Crowdsourcing flood photos can be processed by computer vision algorithms to generate usable flood information (Wang et al. 2018; Maurizio Mazzoleni et al. 2018). In particular, artificial intelligence is enabling researchers and practitioners to increasingly turn to social media and VGI of flooding. Hence, flood crowdsourcing, particularly the utility of Passive VGI platforms are likely to grow in significance in the coming years.

3.6. Conclusion

This chapter has characterised the current and potential future landscape of flood crowdsourcing through the synthesis of a typology. This complements existing participation-oriented typologies by focussing on the world of flood crowdsourcing through an analysis of 31 different projects. This sample represents a wide range of initiatives with radically different aims, objectives, datasets and relationships with volunteers. When these flood crowdsourcing projects are viewed with respect to existing typologies for public participation, crowdsourcing or citizen science, their distinct characteristics are often not reflected in the typologies. The majority fit within the same category or none at all. This chapter has revealed five distinct types of flood crowdsourcing: i) Incident Reporting, ii) Media Engagement, iii) Collaborative Mapping, iv) Online Volunteering and v) Passive VGI. The development and illustration of this typology, has shown that much of the research on flood crowdsourcing to date has omitted several key initiatives such as media outreach. By explicitly outlining the vast range of flood crowdsourcing projects, this chapter has provided a more appropriate starting point for any form of enquiry into the field than a more general typology. While passively shared data from social media has generated usable information, there remain many uncertainties associated with the reliability of the time, location and content of posts. In contrast, Collaborative Mapping has provided more detailed information which can support a range of practises, despite often being limited to a smaller area. While requesting the same types of data from participants, some flood Incident Reporting platforms appear to express radically different aims and objectives. Media Engagement generates a vast quantity of photos and narratives of flooding events across the globe which may, on occasion be validated by sending reporters to the scene. Yet, often these are not verified using a robust approach, raising an open-ended question as to their value. Online Volunteering platforms vary significantly, ranging from micro-tasking exercises such as Tomnod to community action initiatives such as Facebook Crisis Response, yet they all occur in a virtual space. A major divergence from the rest of the ever-growing field of crowdsourcing is the degree to which citizen observations of floods are routinely utilised operationally by authorities. Therefore, this chapter not only identifies and evaluates several sources of information which can be called on, but also helps inform future developments. Projects in the early stages of development can use the typology to identify similar initiatives as potential sources of inspiration for research and campaign design. In addition, in order to advance theoretical and practical innovations for flood crowdsourcing, the typology can play an important role by illustrating the ways in which flood crowdsourcing relates to the wider crowdsourcing literature.

Chapter 4: The motivations, enablers and barriers for voluntary participation in an online crowdsourcing platform

Research questions addressed in this chapter
1. What are the characteristics of crowdsourced flood data, and how are they evolving?
2. How do human factors affect participation in flood crowdsourcing projects?
3. What roles can crowdsourcing play in supporting flood risk management?
4. What role does platform design play in maximising the efficacy of crowdsourcing for flood risk management?

This study has been published as:

Baruch, A., A., May, A. & Yu, D., 2016. The motivations, enablers and barriers for voluntary participation in an online crowdsourcing platform. *Computers in Human Behavior*, 64, pp.923–931.

4.1. Introduction

To succeed, crowdsourcing campaigns often have to be organized, facilitated, and nurtured (Fischer 2000). Most crowdsourcing campaigns can typically be classed as either ‘bottom-up’ or ‘top-down’. The former are not conceived or planned by scientists, but instead by citizens, and usually involve long-term engagement in local environmental concerns. The latter are organisationally initiated forms of organizing campaigns (Wiggins and Crowston 2011). While many highly successful top-down crowdsourcing campaigns have maintained a traditional format of asking amateur volunteers to participate in data gathering protocols, a growing number are trying new methodological approaches to data collection (Liu and Palen 2010). With the emergence of Web 2.0, novel ideas such as citizen science problem solving games, apps and large-scale online activities have become remarkably popular (Kawrykow et al. 2012). This has opened the door to many exciting and never-before possible research opportunities for individual academics and organisations (Díaz et al. 2012; Kittur, Chi, and Suh 2008). As has been outlined in the literature review, a significant player in this field is Tomnod – a project owned by Colorado-based satellite company DigitalGlobe that uses crowdsourcing to identify objects and places in satellite images. This capitalises on the unique ability of the human eye to identify ambiguous objects which computer algorithms may struggle with. Tomnod volunteers are given the task of tagging objects of interest to add attributes to an image (e.g. a destroyed house). These tags are collated, processed for consensus and used for a range of targeted campaigns, including assisting in disaster response, tracking wildfires and even searching for the missing Malaysian Airlines flight MH370 (Meier 2013; Carmen Fishwick 2014). Tomnod differs from many other crowdsourcing platforms in the immediacy of most of its campaigns. These generate geospatial data for use by response teams within hours of satellite imagery becoming available. With participation frequently in the thousands (Tomnod 2018a), it is clear that Tomnod has attracted the interest of many volunteers. In 2014, when Tomnod's search for the missing Malaysian Airlines flight MH370 attracted over eight million participants (Topsfield 2015), it became clear that the breadth of its appeal reached well beyond that of most other crowdsourcing platforms.

Successful crowdsourcing campaigns will typically be both attractive to potential participants and fulfil sufficient data quality standards (Cox et al. 2015). As a result, there is often a trade-off in crowdsourcing research campaigns between maintaining high data quality standards and keeping the platform's design simple, engaging and enjoyable for prospective participants (Prestopnik and Crowston 2011). While this is challenging, there are many cases where groups of amateur volunteers have contributed data which are of equal or even superior quality to professional sources (Hung, Kalantari, and Rajabifard 2016; Silvertown 2009). In contrast, a number of other studies such as Smith et al. (2015), Butt et al. (2013) and Galloway et al. (2006) have found that the crowdsourced data can be limiting in both quality and quantity. Hence, more important than pure numbers of participants for most campaigns, is their loyalty, trustworthiness and competence in the field (Q. Tian et al. 2014). Studies which rely on data collected by lay people benefit from explicitly facilitating the continued involvement of participants to both contribute to, and publicise campaigns (Dickinson et al. 2012). Understanding the enablers and barriers for the millions of people who have volunteered on them is a vital step towards developing and building thriving crowdsourcing campaigns (Massung et al. 2013b).

Online volunteering is a broad term which describes an array of activities from translating important materials to organising charitable events. It appears to be largely derived from prosocial motivation (Amichai-Hamburger 2008). Prosocial behaviour refers to ‘‘voluntary actions that are intended to help or benefit another individual or group of individuals’’ (Eisenberg & Mussen 1989, p. 3). These can be characterised by different types of motivations: altruism, egoism, collectivism, and principlism (Batson, Ahmad, and Tsang 2002). Altruism aims to increase the welfare of others. Egoism refers to when the ultimate aim is to increase one's own welfare. Collectivism has the goal of improving the welfare of one's own community and principlism aims to uphold one or more moral principles.

Amichai-Hamburger (2008) advocates a model to explain the potential and promise of online volunteering, separating the phenomenon into three separate subdivisions: the personal, the interpersonal, and the group. These centre on motivations, emphasising the importance of E-learning, information accessibility, reframing identity and overcoming disabilities. Further research on online volunteering also emphasise that older volunteers benefit through online volunteering by establishing new connections and increasing social capital (Mukherjee 2011). However, both these studies do not make any consideration for crowdsourcing activities, many of which rely on attracting and retaining volunteers.

Volunteer motivations for participation in bottom-up crowdsourcing campaigns have been described by Buytaert et al. (2014) as being at the interface of political activism and volunteering. This can help foster a strong sense of community and responsibility. However, with the creation of large-scale online top-down campaigns such as OpenStreetMap in 2004, Zooniverse in 2009 and Tomnod in 2010, many campaigns are becoming enticing to volunteers for different reasons. Amichai-Hamburger (2008) argues that understanding the characteristics behind Internet volunteering from the perspective of the volunteer may enhance the positive potential of the Internet. To date, a large number of studies into the engagement and motivations of citizen observers, including Budhathoki et al. (2013), Haklay et al. (2008) and Dodge and Kitchin (2013) have used OpenStreetMap[7] as a case study. These largely point to a wish of participants to share their local knowledge, experience community, learn new things and advance their career. To some extent, such findings can be related to broader crowdsourcing phenomena as OpenStreetMap provides a useful example of a well-used and respected crowdsourcing campaign (Dodge and Kitchin 2013). However, for studies into other forms of crowdsourcing, different motivations have been revealed (Cohn, 2008). As Raddick et al. (2013) outline, the motivations for participation in Galaxy Zoo are radically different to those of OpenStreetMap as the platform caters to a very different user-base. For example, the most frequently cited reason for participating in Galaxy Zoo is a desire to contribute to scientific discovery (Raddick et al., 2013). Evidently, there is no clear consensus on how to get volunteers effectively engaged in crowdsourcing campaigns in general. Yet, achieving loyalty and engagement among volunteers is an essential step towards creating a thriving campaign.

[7] OpenStreetMap is a web crowdsourcing platform available at: https://www.openstreetmap.org

4.2. Research Objectives

For many crowdsourcing campaigns, particularly in geographical sciences and humanitarian campaigns, there is a need for further research into the motivations and experiences of users (Cohn 2008; Cashman et al. 2008; Sheppard & Terveen 2011). With a rapidly growing number of crowdsourcing platforms relying on distributed intelligence via the internet, there is a particularly high need to explore motivations for online volunteering. This chapter focuses on addressing this key research gap. Tomnod is used as a case study as it represents by far the most popular online crowdsourcing platform to date which has generated flood information. Tomnod provides a suitable platform for expanding the research into crowdsourcing as an online volunteering activity. As its campaigns are unique and largely altruistic, aiming to help disadvantaged communities, it helps draw on the altruistic nature of flood crowdsourcing compared with others such as incident reporting which cater more to egoistic motivations. The current literature on crowdsourcing is still nascent and needs mixed-methods research to provide an additional depth of insight into the phenomenon (Cox et al. 2015; Raddick et al. 2013). In particular, there is a need to identify the drivers for attracting the large numbers of participants in platforms which are different than Galaxy Zoo and OpenStreetMap.

The overall aim of this chapter is to address this research gap by investigating the human factors affecting volunteer participation in Tomnod and the application of these to the wider crowdsourcing phenomenon. There were two specific objectives:

1. To implement a multi-methods approach to investigate the experience of Tomnod participants and their perspectives on the platform's design.
2. To identify broader implications for maximising volunteer numbers, ensuring effective data contributions and creating satisfying user general experience with online crowdsourcing platforms.

4.3. Methods

4.3.1. Methodological approach

A case study approach is employed, using Tomnod to help build insight and understanding of the human factors affecting volunteer participation of online crowdsourcing campaigns (Onwuegbuzie and Leech 2006). Its large user-base helps identify a broad range of factors affecting different participants both in enticing them to the platform and keeping them involved. Given the diversity of its campaigns, examining Tomnod participants (selflabelled ‘Nodders’) enables investigation of campaign preferences to be conducted in a controlled manner as they are all launched through the same platform.

Both qualitative and quantitative data were collected from multiple sources to enhance their credibility (Patton 1990; R. Yin 1994). This helps generate both representative response rates (Baxter and Jack 2008; Y. Baruch and Holtom 2008) and detailed arguments to trace causal mechanisms and complex emotions (Harrits 2011). Hence, the quantitative phase of the chapter does not inform or drive the qualitative phase or vice versa (Onwuegbuzie and Leech 2006; Yeager and Steiger 2013).

4.3.2. Data collection and analysis

Three sets of online surveys were undertaken over 14 months, each with a specific purpose (Table 4.1). All surveys were sent to the accounts of all registered users. However, response rates are difficult to determine as many accounts were dormant or inactive during the time of receiving the survey. Participation on Tomnod during the survey periods were ~800,000, ~1,000 and ~700 for Surveys A, B and C respectively. Survey C were advertised on the Tomnod website forum (which had 1,400 views).

Table 4.1: List of data collection methods, their details and research purpose

Data source	Date(s) undertaken	Number of participants	Purpose
Survey A	August, 2014	2,329	Online survey to identify participant demographics plus open ended questions to infer how these affect general perspectives of the platform. This yielded the most response (including ~1,000 open ended comments), largely due to the high publicity of Tomnod through its campaign to search for the missing MH370 aircraft.
Survey B	July, 2015	166	Online survey to identify participant motivations, asking volunteers: ‘Why do you participate in Tomnod campaigns?’
Survey C	September, 2015	188	Online survey to identify participant demographics plus open ended questions to infer how these affect their relationship with, and behaviour on the platform.

Forum observation	December, 2015	60	Analysis of key quotes from an online forum that was set up by Tomnod in December, 2014. This identified volunteer views on the platform, participant motivations and factors affecting data quality.
Participant interviews	September, 2015	6	Semi-structured interviews with the most active participants on the platform to enable them to expand on their views and establish how the most engaged volunteers compare to the larger population.
Tomnod campaign coordinator interview	September, 2015	1	Semi-structured interview to explore the extent to which the perspectives of Nodders are represented in the design of the platform and its campaigns.

A data-driven approach using grounded-theory was used to identify themes in the data relating to the research objectives using Nvivo 10 to code the data. Each pertinent comment coded according to a clear theme. Salient themes are exemplified with quotes from the questionnaires, forums and interviews. Particular emphasis is placed on where there was consensus, or clear divergence of opinions. Divergent themes among different demographic groups were also evaluated both qualitatively and quantitively using Chi-Square statistics using SPSS 22. Demographic groups are divided by gender and age of over or under 50 to enable a differentiation between baby boomers and generation X,Y,Z who tend to exhibit different voluntary behaviours (Yu et al. 2005).

4.4. Results

4.4.1. Participant demographics and their influences on motivations

Tomnod has an aging population which is well balanced in gender (Figure 4.1).

A large number of participants confirm that they are retired while 23% of participants state that they have a disability or a long-term heath problem *[Survey C*]. For many participants, this a primary reason for participation:

> *'I am retired so using Tomnod is a better use of my time when I have some free time.' [Survey A, Response 2383]*

'This is the perfect site for people to help. Especially the disabled people that want to help in the world but can't leave home. This site allows people to do just that...help in anyway possible!' [Survey A, Response 1873]

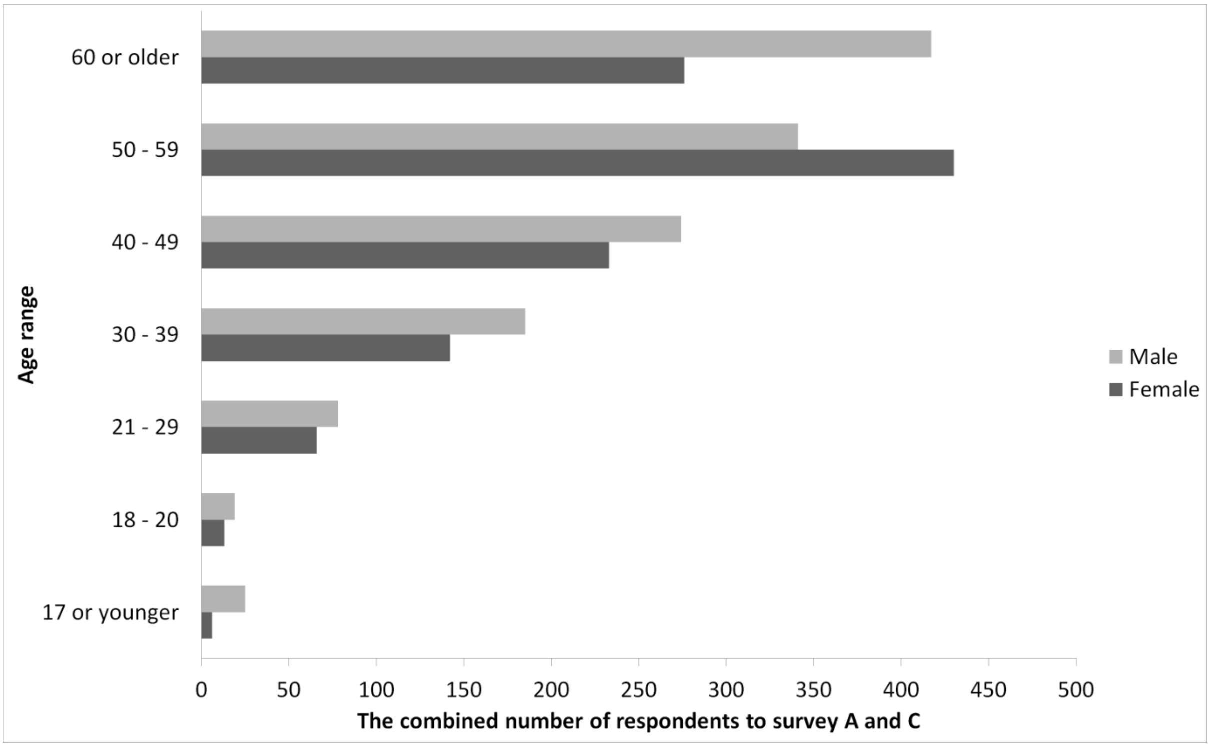


Figure 4.1: The combined number of respondents by age range and gender identity [Survey A and C].

In addition, entries on the online forum suggest that this is a common theme amongst many Nodders with one comment on disability leading to a snowball of comments on how participating in online campaigns can be highly rewarding:

'I retired after a stroke. Not one to throw in the towel I started looking for ways to help with my limitations.' [Forum, Response 10]

'I fell ill with an auto-immune illness that impacted my mobility and stamina. I still want to contribute to the world, however, and value this opportunity.' [Forum, Response 17]

People with disabilities are thus clearly highlighted as a niche participant in online crowdsourcing campaigns:

'Almost all the crowd are retired. And at least 2 of our top 10, have recently had strokes… our top contributor has tagged over 100,000 locations in just one campaign.' [Interview, Tomnod coordinator]

Furthermore, comments made by Nodders relating to a wish to help when not working, either through disability or retirement suggests that the personal circumstances of volunteers plays a significant role in affecting their participation on the platform.

For the vast majority of Nodders, the campaigns were based on locations far away from their home location: Nepal, Swaziland, Malaysia etc. despite the largely USA centred user-base. This has a knock on effect on the motivations for participation, with enjoying the exploration forming a key theme in both the surveys and the interviews:

> *'I live near Coco Island… I've never taken a boat out there so I got to see the island. It was fun.' [Nodder interview 6]*

> *'It allows me to see things I would never see or know about.' [Survey B, Response 95]*

Hence, for many participants, motivating factors for volunteering and behaviour on the platform are directly linked to their social context. The simplicity and social currency of Tomnod tasks makes them both enticing and straightforward for people who may not typically engage in online content creation.

4.4.2. General motivations for participation

The feedback from participants, gained from all the data collection protocols, covers a wide range of topics. At least 17% of comments relate directly to participant motivations *[Survey A]*. The majority of motivational comments (59%) aligned with an altruistic theme; however most are vague in who exactly they want to help:

> *'I do not have much free time that I could use to help others nor money I could donate to others. But being on Tomnod and helping with the campaigns only if it's one or two hours a week let me feel like I do something to help others. That's the least that I can do, offer some of my time.' [Survey A, Response 508]*

> *'To help in searches in the hope it will save lives and provide valuable other information to this country as well as others.' [Survey B, Response 84]*

Furthermore, a number of comments explicitly mention the requirement for campaigns to be helping people in urgent need of assistance as a decisive motivating factor:

> *'Any situation where there is a time sensitive situation and searching is needed.' [Survey A, Response 172]*

'I do this for fun but I also do it to help. If it's not going to help no need to waste my time.' [Survey B, Response 97]

'I will always choose first to participate in campaigns that help people who are suffering, no matter whether a particular campaign might be difficult or tedious.' [Forum, Response 168]

These qualities also help Tomnod develop effective campaigns:

'Campaigns with high social currency were shared on social media and helped grow the crowd' [Interview, Tomnod coordinator]

The comments on Nodder motivations for participating in campaigns emphasise how important the cause is to the volunteers. The majority of comments liken mapping on the Tomnod platform to an alternative to charity work:

'Although users volunteer on Tomnod, because of their good hearts, they would also like to document their volunteer activity, much in the same way people do that volunteered for the Red Cross. Many people would like to list volunteer activity on their job applications.' [Survey A, Response 792]

'I can't be on the ground to help Nepal citizens, but I can bear witness to their isolated homes, poverty, and desperation for rescue and assistance.' [Forum, Response 36]

In addition to altruistic themes, a number of more collectivist sentiments were expressed:

'It helps me feel involved in the global community.' [Survey B, Response 1]

'Looking for loved ones' [Survey B, Response 155]

For some, the platform, like many other crowdsourcing campaigns, motivates participation for egoism. A number of survey respondents described tasks as *'an enjoyable experience' and 'a fun and useful pastime' [Survey B, Response 740]*. Words such as '*addicted'*, '*interesting'* and '*community'* have appeared multiple times in all three surveys and the internet forum:

'It's the feeling of being an explorer. I feel like I need to check another row before I can go to bed because there might be something there… Sometimes I spend 8-10 hours a day.' [Interview, Participant 3]

4.4.3. The participant experience

Participants have diverse preferences of campaign type (Table 4.2) and views of what qualities a campaign should have (Table 4.3). 'Helping people and the environment' is the most important feature for all age groups and genders with no significant differences between them. Participants also have strong preferences for other qualities such as 'educational' and 'easy to do'.

Table 4.2: Responses to the question: Which campaign are you most interested in? (Survey A)

Search and rescue	Natural disaster	Environmental plotting	Political unrest	Other
2253	1697	877	618	239

Table 4.3: Responses to: 'Please tick three of the following qualities of a campaign that you think are most important:' Represented as a percentage of a specified demographic group [Survey C].

	Over 50 female	**Over 50 male**	**Under 50 female**	**Under 50 male**
Fun	8%	13%	10%	16%
Give recognition for contributions	8%	8%	10%	13%
Help people and the environment	33%	32%	33%	32%
Easy to do	18%	16%	20%	13%
Educational	23%	25%	18%	23%
Sociable	10%	6%	8%	4%
Total responses per demographic group	120	234	105	102

The search and rescue campaigns are the most preferred campaign type (Table 4.2). However, the forum comments largely indicate that while search and rescue campaigns such as the MH370 were '*intriguing*', the natural disasters such as the Nepal campaign were the most '*rewarding*':

> *'Favourite campaigns would be the anti-poaching, illegal fishing one as there is no sense of urgency to them so can take more time looking around. The ones I get the greatest satisfaction and sense of achievement from are the likes of the Nepal earthquake, the Vanuatu cyclone or the tornado strikes Illinois, then I suppose the more frustrating ones would be the air or sea campaigns when nothing is found.' [Forum, response 1]*

This quote emphasises that while Nodder motivations are largely altruistic, 'helping' alone may not be enough to keep all participants engaged. Successful campaigns will benefit from giving participants a sense of satisfaction and achievement on their contribution.

Feedback was a central theme in the open ended survey questions, the interviews and the forum responses. About 23% of comments can be linked directly to aspects of user engagement, with Nodders largely unsatisfied with the level of updates they receive about their contributions and impact on the ground *[Survey A]*. A follow-up on how the data were used and feedback on qualities of data are dominant concerns in all age groups and genders (Table 4.4). However, perspectives on gamification aspects (leaderboards and awards for the most active nodders) differed with age with under 50s showing significantly more support (chi-sq $p<0.05$). Educational games and quizzes in comparison were significantly more popular among females under the age of 50 (chi-sq $p<0.05$).

A number of participants go further, asking for '*something like a certificate of participation or some kind of award' [Survey A, Response 1681]* to be recognised for their work. These comments add to the sentiments expressed on a participant's wish to be more engaged. However, concerns expressed over the gamification of the platform suggest that such actions may cause some to feel ignored:

> *'Leaderboards and awards for the most active Nodders. This is good AND bad. It can really backfire. If Person A has 78,000 why should Person C at 18,000 even bother trying?' [Survey C, Response 2]*

Table 4.4: Responses to question: 'Which features would you would like to see more of?' Represented as a percentage of a specified demographic group [Survey C].

	Over 50 female	Over 50 male	Under 50 female	Under 50 male
Feedback on the quality of my contributions	28%	29%	25%	30%
Educational games and quizzes	1%	3%	8%	4%
Leaderboards and awards for the most active Nodders	3%	4%	10%	12%
Short training exercises to improve my image analysis skills	25%	20%	20%	21%
A follow-up about how the data was used	28%	28%	27%	29%
More engagement with the Tomnod team and DigitalGlobe	16%	15%	11%	4%
Total responses per demographic group	120	234	105	102

All comments on current levels of engagement with the campaign managers were negative, with the vast majority of participants referring to how they received no emails or feedback on the quality of their tags. Almost every comment mentioned a desire for more information about the campaigns and updates on new campaigns. A lack of clarity over how their data is used, lack of follow-up information and news on how much they are actually helping are all cited as reasons for becoming less active on the platform. As a result, a number of respondents stated categorically that they would not return. Participants specified that they want to know if they are actually making a difference. One Nodder pointed out that he felt he was *'shouting down a well' [Survey A, Response 584]* while others wrote:

> *'There was no feedback and it made me feel as though what I was doing wasn't even for real.' [Survey A, Response 2037]*

> *'I enjoy helping. Just wish I understood more about exactly how we are helping.' [Forum, Response 3]*

Many point out that they don't have Facebook so they cannot keep up-to-date with latest discussions. As with many topics relating to social media, there is a diverse range of opinions on the matter as not all participants use or like social media. These comments often came from older participants:

> *'I do not use Facebook. Twitter, etc., and suspect that my efforts are wasted. More communication via your website might help.' [Survey A, Response 330]*

Clearly, while using social media to engage participants may be effective for many, it may also isolate those who are not included in the discussions. This is a particular concern given the demographics of the participant base. Limited feedback also has a substantial impact on the most active participants:

> *'When older/ill/disabled people can't give money, we give ourselves…. we invest our very beings… we need them to give feedback, acknowledgement, recognition to us?... There's a brick wall between us and them' [Interview, Participant 2]*

A key feature of most campaigns is an 'agree' score which shows how many participants also tagged the same location. Some of the participants comment that they see this as a sign that they are wasting their time:

> *'Would help to see how examined my map is. I work hard only to find that 100 other people tagged the same thing. I don't feel helpful.' [Survey A, Response 1002]*

> *'Why did I never hear anything about the results?... Shame on you.' [Survey A, Response 1488]*

The diverse community of participants on the platform have varying needs and motivators. Some like to be challenged while others prefer easier tasks with greater guidance:

> *'Yes (more campaigns at the same time are better). The variety is really important. Our brains can only take so much monotony.' [Interview, Participant 2]*

> *'I'm retraining my brain since my stroke. Tomnod helps with that as it's repetitive. It's healing my brain.' [Interview, Participant 1]*

Tomnod will typically have at least three campaigns running at any given time to provide participants with a range of activities to take part in. This directly enhances the experience of volunteers:

> *'It helps sometimes switch back and forth between campaigns.' [Interview, Participant 6]*

Given the number of comments relating to feedback, it is clear that this is an area which is highly important to the participants. The online forum has become popular with many hundreds of posts (Tomnod 2018b) while 54% of respondents said it helped them stay interested in the campaigns [Survey C]:

> *'When you have a comradery and you get responses, you are showing them that you have worth. As people become familiar with it, you make it more personal and intimate. The forum adds the human link that is needed to keep interest growing…. For example, someone can say 'hey, look at this', then others will say 'here's what Wikipedia says it is… oh that's really cool'. This makes a better foundation for Tomnod as people feel more loyal.' [Interview, Participant 1]*

> *'We need to communicate how each specific campaign is going to be used' [Interview, Tomnod coordinator]*

Technical issues comprise 8% of comments *[Survey A]* and are frequently cited as reasons for not returning to the platform (Table 4.5). Hence, the functionality and aesthetics of the website also play a key role in determining its popularity. This has a direct effect on the level of participation as design issues (e.g. image quality) are the most cited reason for ending a session. In comparison, males under the age of 50 were significantly less concerned by technical issues, citing time constraints as the main reason for ending a session (chi-sq $p<0.05$).

Table 4.5: Responses to question: 'What are the three most common reasons for ending a session' Represented as a percentage of a specified demographic group [Survey C].

	Over 50 female	Over 50 male	Under 50 female	Under 50 male
I lost interest	9%	8%	10%	14%
I was happy with my session and plan to have another one soon	12%	15%	17%	18%
Poor image quality	20%	20%	16%	13%
Technical issues	18%	12%	18%	11%
I was short of time	15%	16%	16%	24%
I did not understand the task	3%	2%	2%	4%
The load time was too slow	13%	16%	14%	11%
Other	11%	11%	7%	5%
Total responses per demographic group	120	225	105	111

The majority of the survey comments on the platform's design suggested that participants wanted greater control over how they use it. In particular, most comments illustrated people's desire to have a transparent platform:

> *'Need link maps to google maps or other to know where I am looking at.' [Survey A, Response 1619]*

> *'It would be nice to see what other volunteers are doing. This would give a feel of cooperation.' [Interview, Participant 4]*

> *Campaigns seem too focused on US interests… you should have a vote from a list of possible campaigns. [Survey A, Participant 124]*

In order to tackle this, the participant's experience has become the focus of the platform's design:

> *'We tried not letting people navigating freely and oh man, people didn't like that because half the fun is being able to explore that map… even if it meant we weren't getting better quality results faster.' [Interview, Tomnod coordinator]*

The results highlight that volunteers have strong feelings about how the platform should be designed. A prevalent theme in their comments is a desire for the platform to be as transparent as possible. Participants want to have control over where they are tagging and the ability to discuss their observations with each other. Letting these volunteers contribute to the design of the platform by listening to their feedback evidently plays a critical role in keeping them engaged.

4.4.4. Factors affecting quality of contributed data

Both the clarity of the satellite imagery and the training given to participants are highlighted as areas which can affect volunteer contributions (Tables 4.4 and 4.5). For some images, e.g. Figure 4.2, volunteers struggled to tag certain targets:

> *'The main difficulty I'm finding in this campaign is that the built up commercial/residential areas are cast in so much shadow this time of year it's hard to make out anything one the ground let alone flood water.' [Forum, Response 46]*

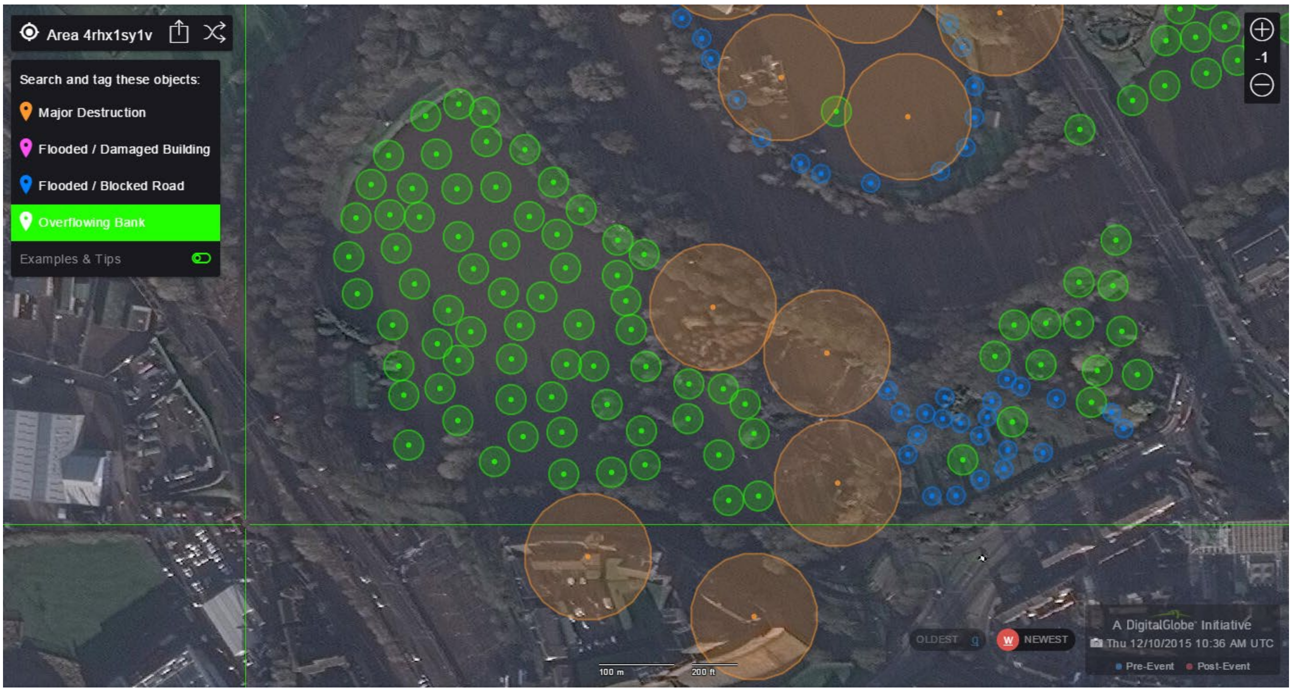


Figure 4.2: User interface on Tomnod England Flooding campaign

At least 10% of comments referred to a concern about the accuracy of their contributions with 84% of respondents requesting more information on the accuracy of their tagging [Survey A]. Many want further training on how to identify objects with examples and guides on what to tag and what not to tag:

> *'Both myself and no doubt legions of others kept mistaking and reporting waves as possible remnants of the lost Malaysian jet liner.' [Survey A, Response 427]*

> *'A little more education for novices. That would help us make better tags.' [Survey A, Response 1008]*

Since Survey A was conducted, the Tomnod platform has been improved to include training for participants. However, despite these improvements both quantitative results (Table 4.4) and qualitative comments suggest that increased training remains central to participant motivations and willingness to volunteer:

'Their taking time to educate us is going to be their trade-off for taking free labour.' [Interview, Participant 2]

In particular, for the older participants, opportunities to practise are likely to significantly increase the quality of the data they generate:

'There was a learning curve… My brain did not have the capacity to process what I was doing (the first time). The next time, I was able to work far quicker. You become more effective as you go.' [Interview, Participant 1]

In addition to the level of training given to volunteers, the simplicity of tasks can also feed directly into better quality results:

'When we ask the crowd to do one task at a time, they do a much better job because they can focus … in the past we used to have eight different tag types: a fallen tree, a block road, a damaged house, a destroyed house, water damage, flooding. It was difficult sometimes to distinguish between those different tag types, so we found that by simplifying the tag types and not having any more than three or four per campaign.' [Interview, Tomnod coordinator].

In order to quality check the data, the Tomnod team use a '*CrowdRank algorithm'* to triangulate the data and determine which tags had the most consensus across volunteers. An increased consensus of tags then feeds into each volunteer's reputation. The higher their reputation, the greater weight Tomnod gives to their data. Improvements to the CrowdRank algorithm and the training given to volunteers have had a knock on effect on data quality:

'We have definitely seen an improvement in the quality of the tags, as well as how quickly we can finish a campaign. In the past, we needed to get a minimum of 10 people looking at every map tile and voting on a polygon, and now we're getting high confidence results after 3-5 people have looked at the image…. Once we have this confidence, we stop sending people there… This is incredible in urgent situations such as natural disasters.' [Interview, Tomnod coordinator].

The CrowdRank algorithm allows Tomnod to maximise the value of contributions from volunteers. Yet, the strong support for increased training (Table 4.4) and concerns about data quality in specific campaigns e.g. MH370 airliner search emphasises the value that guidance can have for many volunteers.

4.5. Discussion

This chapter uses a mixed-method approach to examine the phenomena of online crowdsourcing from the perspectives of both volunteers and the campaign coordinator of Tomnod. The use of Tomnod as a case study enables an exploration of many core themes on crowdsourcing as a wider phenomenon and helps build on the current literature on the human factors affecting volunteer participation.

The motivations and behaviour of volunteers on online crowdsourcing campaigns have been strongly linked with their age and gender. Our findings show that like crowdsourcing platforms such as Galaxy Zoo (Raddick et al. 2013) and many online volunteering websites (Mukherjee 2011) the most active Tomnod participants are mostly over 50. This finding contrasts with Brabham (2008) who argues the most productive individuals in the crowd are young and likely to be under the age of 25. Younger groups are also the most active in contemporary content creation phenomena such as blogging (Lenhart and Madden 2005). The balanced gender ratio in Tomnod is in stark contrast to some of the most popular crowdsourcing platforms such as Galaxy Zoo and Citizen Sky which are dominated by males – 82% and 78% respectively – (Raddick et al. 2013). This suggests that the appeal of different campaigns varies with demographic groups. The results of this chapter help explain what may drive some of these variations.

By aiming to tackle geographical and humanitarian challenges across the globe, Tomnod attracts volunteers who may not typically be able to volunteer outdoors and in the field. Consequently, many general observations in the literature about the characteristics of crowdsourcing campaigns in developing and developed countries do not appear to fit Tomnod. For example, Gura (2013) argues that the objectives of crowdsourcing science campaigns in developed countries largely focus on increasing awareness and scientific literacy. In contrast, campaign goals in developing regions mostly relate to the enhancement of community well-being such as poverty alleviation. Yet for Tomnod volunteers, while many key altruistic motivators such as helping people and the environment are important to all demographic groups, other motivations vary significantly between participants. Tomnod appeals particularly to those who are retired, disabled or suffer from a long term health issues. Among these participants, the dominant motivations are to undertake tasks comparable to charity work with their free time from the convenience of their home. For many participants, particularly those with health problems such as recovering from strokes, the simplicity and humanitarian nature of tasks makes them both enticing and rewarding. For some, they may even help in promoting positive health outcomes – a finding which is prevalent in research into more specialised cognitive games (Whitlock, McLaughlin, and Allaire 2012). This emphasises the need to update Amichai-Hamburger's (2008) model of online volunteering to take consideration of prosocial online crowdsourcing campaigns such as Tomnod. These have formed an increasing share of online voluntary activities since the date of the publication. In particular, a greater emphasis on both the enablers and barriers to participation are needed to help improve the design of online voluntary crowdsourcing platforms.

Platform features such as gamification, quizzes and podcasts are frequently cited as key enablers for many crowdsourcing campaigns (J. Reed et al. 2013). Gamification in the form of leaderboards of the most active participants can be seen in other large crowdsourcing campaigns such as Biotracker (Bowser et al. 2013). This chapter emphasises that despite being more popular amongst many younger participants, gamification may detract from the user experience of others. However, even for younger participants, a feeling of cooperation as opposed to competition is far more important. This strengthens arguments made in Eveleigh et al. (2013) that leaderboards can discourage some participants. In addition, Tomnod volunteers are more interested in the quality of their data and the impact it has on the ground. Volunteers are also highly motivated by the ability to explore the world through an online portal and want to influence the way they do so. Hence, this chapter reinforces the argument that campaigns that do not allow participants to have a fun, engaging and interesting experience risk losing popularity (Graham et al. 2015). While volunteers may be drawn to the platform with altruistic intentions, their continued participation is also related to egoism and collectivism.

Tomnod serves as a great example of a crowdsourcing platform that is able to extract both a large number and high quality of results from a global volunteer population. By keeping numerous campaigns active at all times, Tomnod has enabled some participants to dedicate unprecedented amounts of time towards relatively simple tasks that suit their individual preferences. These steps can help crowdsourcing platforms hold on to a diverse set of volunteers. This can play a significant role in improving collective intelligence gathering (Engel et al. 2015), although a diverse crowd will vary in what they want from the platform (Sullivan et al. 2014; Budhathoki and Haythornthwaite 2013).

Both the number and content of comments relating to engagement emphasise that it is one of the most important issues concerning Nodders. Blogs, forums, polls and training exercises are all cited as key enablers for volunteers. Likewise, a lack of communication and non-dissemination of outputs is a major disincentive to continued participant involvement. Other studies have also highlighted the importance of communication with participants (Rotman et al. 2012). However, it is clear from the responses in this survey, that for many, limited engagement between volunteers and campaign organisers discourages users from returning to the platform. Evidently, by largely providing prosocial campaigns that aim to directly help in emergency situations and environmental conservation, the platform is held up to a high level of scrutiny by volunteers who expect tangible, well communicated outputs.

This research shows that crowdsourcing campaigns will benefit from increased interaction between coordinators and volunteers, both in providing feedback and in the design of the platform. Enabling citizens to communicate with each other can play a significant role in improving satisfaction (Newman et al. 2010) and participation (Daren C Brabham 2010). This chapter highlights the importance of the forum in generating a sense of collectivism and breaking down barriers between volunteers who participate in isolation. Indeed, Harris & Srinivasan (2013) argue that there is a clear need for a more bottom-up approach to the identification of most pertinent campaigns and platform design characteristics. Volunteers should be allowed to contribute to the management of the platform as well as contributing to campaigns. For example, they could introduce democratic aspects such as polls to select campaigns to help keep volunteers engaged and valued.

4.6. Conclusion

This chapter has highlighted a number of divergent themes from previous research into the human factors affecting participants of online crowdsourcing platforms. The results demonstrate that online crowdsourcing campaigns are not always dominated by males and that volunteers have diverse preferences in relation to how the platform should be designed. Differing participant populations and experiences between platforms is evident in the literature (Budhathoki & Haythornthwaite 2013; Haklay et al. 2008; Dodge & Kitchin 2013; Raddick et al. 2013) – and this chapter helps shed light on the mechanisms behind some of these different observations. Tomnod can be characterised as a prosocial platform. Although Tomnod volunteer motivations are largely altruistic, many participants are more interested in exploring the world, the quality of their contributed data and the impact it has on the ground. Volunteers expect well-communicated tangible results and a greater degree of communication with those behind the platform. As a result, this chapter has found that if those who ultimately use the results of volunteered campaigns do not disseminate results, provide feedback and training to participants, a platform risks losing volunteers. This chapter also provides some managerial insights on how to encourage participation in crowdsourcing.

The main limitation of this chapter was that it focussed on only one platform. Hence, further research is needed to continue to enrich this line of study by exploring the different roles these factors play for a diverse community of volunteers using alternative crowdsourcing platforms. Research is also needed to consider the role that campaign features – in particular training and democratic aspects – can play in fostering loyalty and improving data quality among participants.

Chapter 5: The added value of crowdsourcing for flood damage mapping using satellite imagery

Research questions addressed in this chapter
1. What are the characteristics of crowdsourced flood data, and how are they evolving?
2. How do human factors affect participation in flood crowdsourcing projects?
3. What roles can crowdsourcing play in supporting flood risk management?
4. What role does platform design play in maximising the efficacy of crowdsourcing for flood risk management?

This chapter has been submitted as:

Baruch, A., Yu, D. and May, A. 2017. The added value of crowdsourcing for flood damage mapping using satellite imagery. *Remote Sensing of Environment. Submitted.*

5.1. Introduction

The management of natural disasters such as floods is often organised using the disaster management cycle. While relief agencies and organizations may conceptualize the disaster management phases differently, most models generally include mitigation, preparedness, response, and recovery (UN-SPIDER 2014). Response typically involves a multi-stakeholder approach with various actors from national or governmental organizations, international organizations, civil society, and the private sector (Thabrew, Wiek, and Ries 2009). To operate effectively they require accurate and up-to-date information about flood damages and risks both during and after the main event (Deckers et al. 2009; Van Westen, 2013). Hence, information about flooding can support management at several stages during the disaster management cycle (Kreibich et al. 2016). In particular, there is a significant demand for estimations of building and infrastructure damage in the early stages of the disaster (Wex et al. 2014).

Satellite imagery has seen significant advances in its quality and quantity in recent years, enabling the generation of unrivalled flood information products to practitioners (P.-P. Mathieu et al. 2017; Voigt et al. 2016; Ajmar et al. 2015). Humanitarian organisations, businesses and communities benefit by having access to information portals such as the ReliefWeb platform of the United Nations Office for the Coordination of Humanitarian Affairs. Through programmes such as UNOSAT[8], the international charter on space and

[8] UNOSAT is an autonomous UN body that delivers integrated satellite-based solutions for human security, peace and socio-economic development. Available at: http://www.unitar.org/unosat/unosat-rapid-mapping-quick-introduction

major disasters[9] and Copernicus emergency management service (EMS)[10] remote sensing teams are available 24/7 to provide GIS products during humanitarian emergencies. These organisations typically use free multispectral products from Sentinel satellites which have global coverage and generate image products in short timescales ranging from hours to a few days.

Flood inundation data products from satellite imagery are typically produced using supervised image classification. This has been achieved using both spectral and texture analysis (Amini 2010; Mallinis et al. 2011; Gstaiger et al. 2012; Schnebele et al. 2014). Texture analysis has been used to extract flood information from imageries when incorporated with Red, Green, Blue colour (RGB) imagery (Feng, Liu, and Gong 2015b). Commonly used methods to extract flooded areas include thresholding, maximum likelihood and decision trees. Once inundated areas are classified, evaluating the impact of floods on urban populations and infrastructure offers a powerful way of taking the research forward to support decision making for responders (Taubenböck et al. 2011; Coles et al. 2017; D. Green et al. 2017a). However, the delivery of robust mapping products to end-users during the relief phase can be hampered by delays. To date, the Copernicus Emergency Mapping Service has been activated 216 times. For most of these, damage maps were produced three to four days after the satellite images were taken – a significant delay within the context of disaster relief. For example, one day following a major flooding event in Cumbria, UK on 5th December, 2015, the UK Government activated Copernicus. This led to the generation of an inundation map five days later. Similarly, a recent campaign by UNOSAT to map the impacts of the 2015 floods in Chennai, India used satellite imagery on the 12th November but maps were not made available until the 26th November, by which time, the situation on the ground had changed (Pandey & Natarajan 2016; Narasimhan et al. 2016). Methods of reducing these delays offer a significant opportunity to maximise the efficiency of disaster response during the relief phase.

Further challenges are caused by imagery characteristics. Factors such as clouds or view angle affecting the image quality can all make supervised image classification unfeasible (Schnebele et al. 2014). The spatial resolution of free image products represents a third

[9] International Charter for space and Major disasters. Available at: https://www.disasterscharter.org/web/guest/home;jsessionid=6FF62313043E824478CEDB5EFB4E6527.jvm1

[10] International Charter for space and Major disasters. Available at: https://www.disasterscharter.org/web/guest/home;jsessionid=6FF62313043E824478CEDB5EFB4E6527.jvm1

key challenge. While the presence of standing water can be detected using Sentinel (10m), this approach fails to detect most building and road damages. In fact, higher resolution, cloud penetration products such as TerraSAR-X (1.5m) have struggled to detect flooded buildings (Giustarini et al. 2013). Moreover, such imaging products are not always available in the immediate response phase of an event. As a result, it is often necessary to acquire other types of imagery which differ significantly in their resolution and quality (Pohl and van Genderen 2014) or employ qualitative techniques (Lwin, Murayama, and Mizutani 2012). These techniques refer to manual interpretation of the imagery such as visually inspecting an image for certain attributes. Where qualitative methods have been employed to analyse imagery, they have generated high quality products (Lwin et al. 2012; Wästfelt et al. 2012). In fact, many of Copernicus' emergency management service activations have included some form of manual digitisation. GIS data describing complex impacts such as landslides and damaged buildings can also support reconstruction, risk reduction (J. Yin et al. 2015) and disaster preparedness (Atif, Ahsan Mahboob, and Waheed 2016). However, manual digitisation of large swaths of imagery can be highly time consuming and therefore represents a major cause of delays when producing emergency damage maps.

Crowdsourcing offers a powerful method of overcoming the significant labour demands of qualitative image analysis (Meier 2013). As outlined in the literature review and Chapter 4, organisations such as Tomnod, Geotag-X, Zooniverse, and Carberus are capitalising on the unique ability of members of the public to contribute their time to image digitisation and produce emergency crisis maps. A growing movement of volunteers are eager to help wherever possible to contribute to disaster response through crowdsourcing (Whittaker, McLennan, and Handmer 2015; McCallum et al. 2016). Tomnod volunteers identify affected locations with tags such as blocked roads and areas of major devastation. These have radii of ~10m for ~100m respectively. These tags are collated and processed by Tomnod for consensus using their 'crowdrank algorithm[11]', generating high-confidence clusters (HCCs). The HCCs are then made available for a range of targeted campaigns, including assisting in disaster response (Meier, 2013). Tomnod taggers have generated tens of thousands of such tags within days. Crowdsourcing the task of digitising satellite imagery offers a unique opportunity to overcome a number of key challenges of supervised classification. Human input for example, may help identify damaged buildings and details in poorer quality imagery which may not be detected using quantitative

[11] Tomnod crowdrank algorithm. Available at: http://ainibot.com/osgoh/crowdrank-algorithm-used-for-search-flight-mh370/

techniques. This could have a significant impact on the usability of the data and the efficiency of the image analysis phase. As a result, practitioners who require rapid high-confidence infrastructure damage assessments during a disaster represent a major potential beneficiary of these emerging crowdsourcing projects. Therefore, there is a need to examine the added value that volunteers can contribute to satellite images of floods. In particular, where the only available imagery is of poor quality and inappropriate for supervised image classification, the utility of crowdsourcing needs to be explored.

5.2. Research aim and objectives

The main objectives of this chapter are to:

1. Investigate the value of crowdsourcing qualitative image analysis, compared with traditional remote sensing techniques to produce detailed flood damage assessments from both high and low quality images
2. Explore the efficacy of implementing crowdsourcing to provide information suitable for supporting all phases of the disaster response cycle.

5.3. Methods

5.3.1. Overview

This chapter explores the current and potential future role of crowdsourcing as a tool for the rapid qualitative analysis of satellite imagery for disaster response. The methodological approach employed in this chapter is outlined in Figure 5.1. Both high and low-quality imagery that is digitised by volunteers is also classified using supervised image classification techniques. The accuracy of these assessments is then determined using both ground-truthed field observations and photo-interpretations of the imagery.

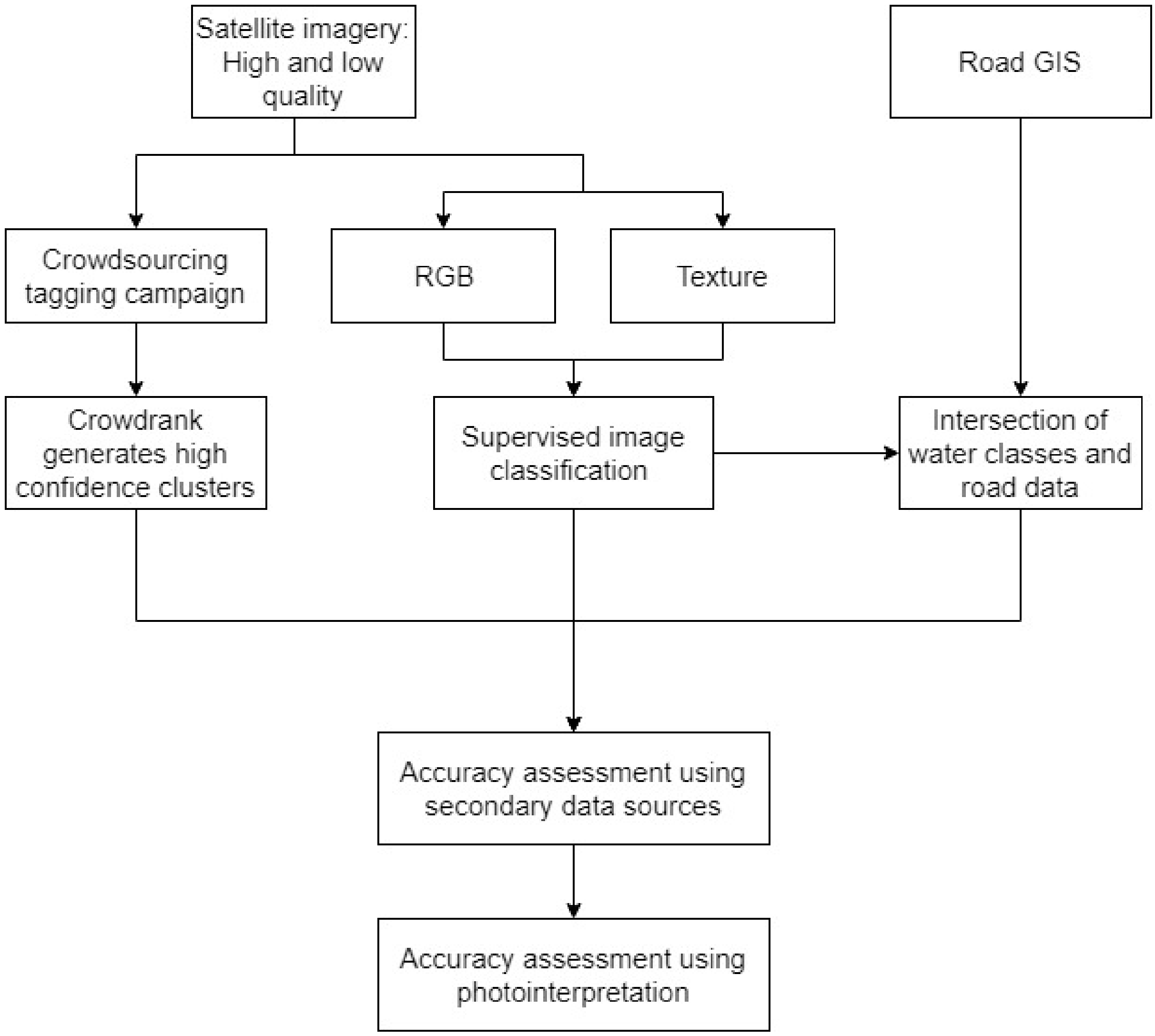


Figure 5.3: Flowchart of methodological process

5.3.2. Study sites

The GIS data produced by the Tomnod community were investigated for two different sites (Cumbria, UK and Joso, Japan) which both experienced major floods in 2015. The satellite imagery that was made available for volunteers differed significantly in attributes (Table 5.1) and quality (Figure 5.2 and Figure 5.3). Shortly after each event, through the Tomnod platform, volunteers visually scanned imagery covering the entirety of these sites and were given basic instructions to assist them in identifying damages including: (i) flooded/blocked roads and (ii) flooded/damaged buildings. The imagery used in the Cumbria campaign was taken four days after the flood peak, by which time much of the flood waters had receded. As a result, participants were given further tagging options to increase the information generated from the campaign. These were: iii) other flooded areas and iv) areas of major devastation. The cloud cover and view angle of imagery is significantly higher in Cumbria (Table 5.1). The resulting impact on the quality of the imagery is evident through a greater presence of deep, dark shadows, haze and clouds in Cumbria (Figure 5.2), compared to the Joso (Figure 5.3). The shadows in the city centre are evidently compounded by the Nadir of the imagery while the shadows across the entire study site are largely caused by the large cloud cover. Together, these factors result in a very low-quality image product for Cumbria. These differences allowed both the campaign type and the impact of image quality on output datasets to be evaluated.

Table 5.1: Imagery and Tomnod campaign metadata

	Joso, Japan	**Cumbria, UK**
Satellite	Worldview 3	Worldview 2
Resolution (m)	0.3	0.5
Off-Nadir	13%	43%
Cloud cover	1%	10%
Data of peak flood (Yamazaki and Liu 2016; Environment Agency 2015)	09/09/2015	06/12/2015
Date of acquisition	11/09/2015	10/12/2015
Date of campaign launch	11/09/2015	11/12/2015
Coverage (km^2)	530	100
Number of participants	1107	720
Total number of tags	153,822	13,665
Number of HCCs	7,538	809
Flooded/blocked road	660	32
Flooded/damaged building	6877	24
Other flooded area	N/A	557
Major destruction	N/A	196
Duration of campaign (days)	6	7

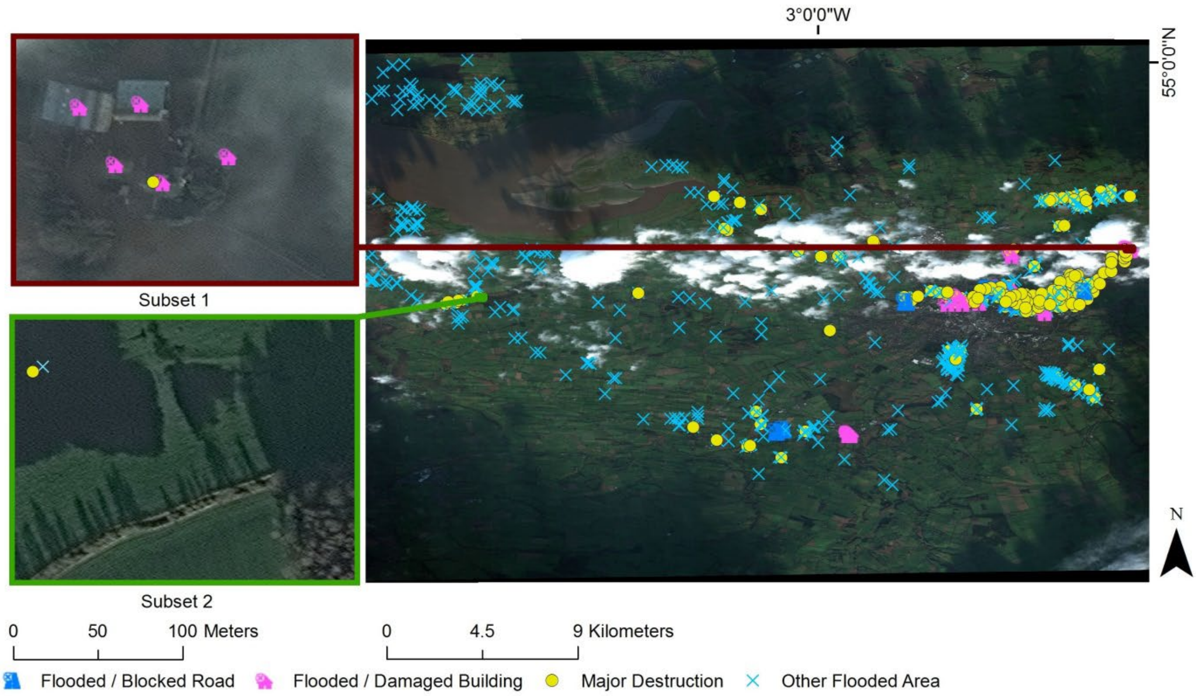


Figure 5.4: Tomnod high-confidence clusters (HCCs) of floods across a hazy and cloudy satellite image (Cumbria, UK, 2015).

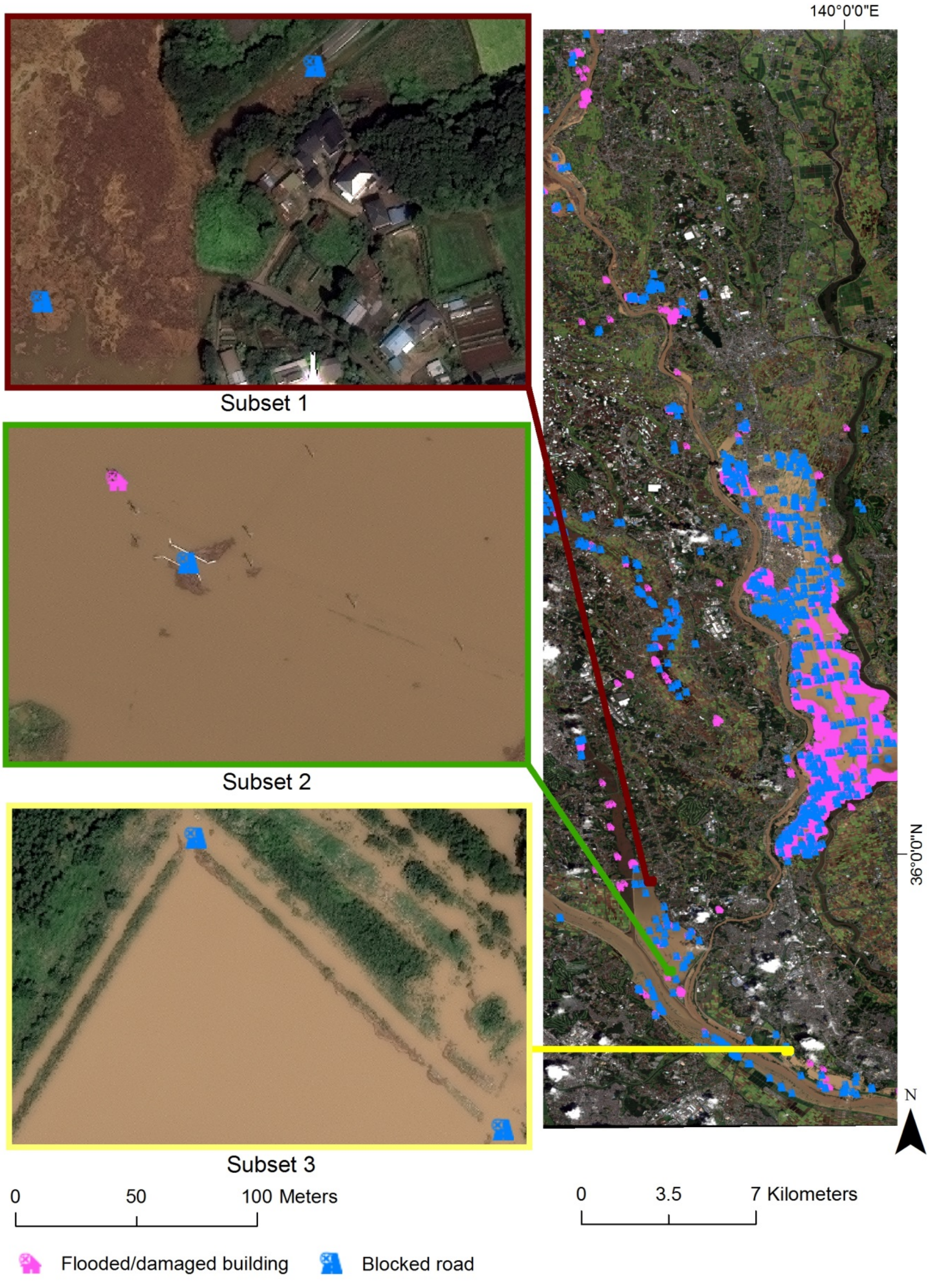


Figure 5.5: Tomnod HCCs across a cloud-free satellite image of floods with low off-Nadir angle (Joso, Japan, 2015)

5.3.3. Texture analysis

High spatial resolution enables the classification of local texture patterns in images by grouping neighbouring pixels (Safia and He 2015). In the study sites, inundated areas are typically characterised by smoother regions with different shades of brown (Figures 5.2 and 5.3). Hence, the same imagery (in RGB format) that is explored and mapped by Tomnod participants is processed using four first-order texture routines to help differentiate between smooth and rough land cover (Pratt 1991). Kurtosis, Variance, Skewness and Mean Euclidean Distance, outlined in equations 1-4 were used from Erdas Imagine 2015 to examine the smoothness of the imagery and in doing so, identify the textures of flood water. This is a widely used and effective parameter in identifying areas of standing water for flood mapping (Dekker 2003; Feng, Liu, and Gong 2015a; Feng, Liu, and Gong 2015b):

1. $Mean\ Euclidean\ Distance = \frac{\sum[\sum_{\lambda}(x_{c\lambda}-x_{ij\lambda})^2]^{1/2}}{(n-1)}$
2. $Variance = \frac{\sum(x_{ij}-M)^2}{(n-1)}$
3. $Skewness = \frac{[\sum(x_{ij}-M)^3]}{(n-1)\mathrm{v}^{3/2}}$
4. $Kurtosis = \frac{\sum(x_{ij}-M)^4}{(n-1)(\mathrm{v})^2}$

where $x_{ij\lambda}$ = the DN value for spectral band λ and pixel i, j of a multispectral image, $x_{c\lambda}$ = the DN value for spectral band λ of a window's centre pixel, n = number of pixels in a window, v = Variance (see Variance formula, eq. 2) and M = Mean of the moving window (Irons and Petersen 1981) where:

5. $Mean = \frac{\sum x_{ij}}{n}$

Kurtosis, Variance, and Mean Euclidean Distance defined waterbodies optimally at five pixel moving windows while Skewness performed the best at seven. All four texture layers were layerstacked with the RGB to enable supervised image classification of inundation areas using both spectral and texture features.

5.3.4. Supervised image classification and intersection with ground data

Between 20 and 30 signatures of different land cover types were identified in both sites. Maximum likelihood classification which is the most common technique in the literature (e.g., Benediktsson et al. 1990; Sunar Erbek et al. 2017), was applied using Erdas Imagine 2015 (Pradhan et al. 2013). A random trees classification technique was tested using ArcGIS 10.4 as a method of classifying inundated areas using 250 different decision trees. However, it generated results of a lower accuracy than maximum likelihood classifications and was therefore not applied in this chapter. The training samples were assessed using spectral signature separability statistics in Erdas Imagine 2015.The transformed divergence (TD) method was used to test signature separability. This method statistically compares all spectral signatures in a signature set among themselves, assigning a TD index number between 0 and 2000, with a value of 2000 indicating total separability and 0 the opposite. This method is fully explained in the Erdas Field Guide (1999). The TD lower bound value of 1900 was used to ensure that classes did not overlap (Jensen 1986).

Blocked roads were identified by intersecting road networks from OpenStreetMap (OSM)[12] with image classification results and areas within Tomnod tag radiuses. The majority of flooded buildings were surrounded by, but not completely submerged by water. This made it difficult to identify flooded buildings by intersecting OSM building outlines as they often corresponded to dry rooftops and not water. This made producing a reliable assessment of flooded buildings from the image classification results unfeasible.

5.3.5. Measures of Accuracy

Two methods were employed to assess the accuracy of the Tomnod and image classification data products. The first method measured the level of agreement between the flood information with a set of validation data. The most common approach for assessing accuracy is to compare classified land cover with alternative but spatially and temporally coincident data, which are considered to be of higher accuracy (Comber et al. 2012). In the context of a rapidly changing environment such as an inundating floodplain, the collection of temporally coincident data is essential. For example, a ground-truthed outline of the Cumbria floods was produced by the UK Environment Agency[13], yet as the imagery for the Cumbria campaign was taken four days after the flood peak, a number of locations within the extent area appear to no longer be flooded in the imagery and thus may be a poor reference material. A Copernicus mission was activated to map the Cumbria floods and this effort generated an estimated outline based on Sentinel 1 imagery, captured on the 10th December 2015. These high-confidence data were intersected with Environment Agency outlines of the flood extent creating a suitable 6 km^2 alternative dataset for validation of the image classification results. In addition, fieldwork was conducted post-event to identify a 1.3 km^2 part of the city which did not flood as further reference material to enable an accuracy assessment of false positives produced in the image classification and Tomnod campaign. In Joso, results are compared with outlines of

[12] OpenStreetMap data download centre http://download.geofabrik.de/index.html
[13] https://data.gov.uk/dataset/recorded-flood-outlines1

flood extents across 30 km^2, produced by the Geospatial Information Authority of Japan (GSI). These were produced by visual inspection of aerial images, also captured on the 11th September 2015 (GSI, 2015) and have been used as a reliable source for validation in Nagumo et al. (2016).

The second accuracy assessment was made by manually inspecting all the Tomnod tags. Each point was identified as one of the following: flood impact correctly identified, not enough evidence to determine flood impact, no actual flood impact occurred, or flood impact, incorrectly tagged. In addition, 300 randomly generated points from the image classification results and the intersections of flood waters and roads were also assessed using the same criteria.

5.4. Results

5.4.1. Accuracy assessment of flood classifications in validated areas

The texture of flooded areas imagery (both submerged roads and grasslands) is far more homogenous than the fragmented bare soil and vegetation. This improved the between-class separability (all were >1900 TD), through the inclusion of texture features. The majority of the land cover within the GSI flood outlines was water and urban areas surrounded by water classifications (likely to be flooded), indicating a high classification accuracy. The areas confirmed to have flooded in Cumbria was comprised of 37% flood water and 29% urban features. The number of buildings which were submerged could not be detected using the supervised classification. The areas confirmed as unflooded comprised of 10% flood water classes indicating a significant over-estimation of floods from the supervised image classification routines in Cumbria.

Within the GSI confirmed-flood outlines, 2021 roads were identified, 78% of which intersected with water classifications (Table 5.2). Many of the roads which did not intersect with the confirmed GSI flooded areas appeared to not be flooded (e.g. Figure 5.4). This disparity, caused by the fine resolution of the OSM dataset indicates that a more realistic accuracy assessment is likely to be higher than 78%. Just 16% of the flooded roads were identified in HCCs by Tomnod. HCCs of damaged buildings were far more comprehensive, producing 60% coverage. Only 7% of the blocked roads in the validation area in Cumbria were identified by image classification compared with 34% from the Tomnod HCCs.

Table 5.2: Classification accuracy of infrastructure damage assessments in validation areas

Classification	Joso	Cumbria

	Coverage	coverage
Flood/road intersections	78%	7%
Tomnod HCCs of roads (all intersect with flood classifications)	16%	34%
Tomnod HCCs of damaged buildings	60%	0
Total number of roads	2,021	44
Total number of buildings	9,638	0
Validation area size (km²)	30	6

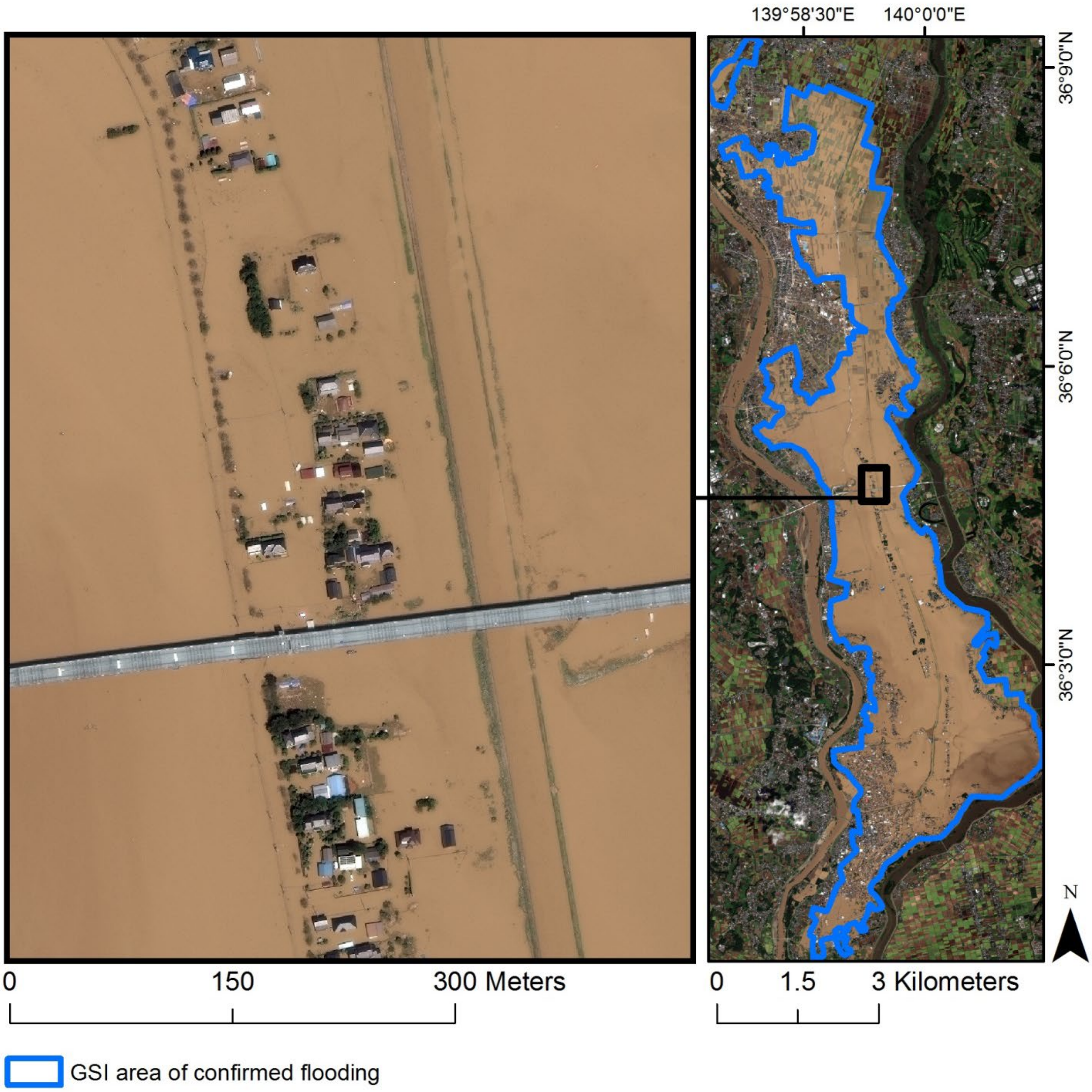


Figure 5.6: GSI confirmed flood outline overlaid on the raw satellite imagery and road datasets in Joso indicates a number of roads which were not flooded.

5.4.2. Accuracy assessments from image inspection

5.4.2.1. Inspection of Tomnod tags and HCCs

Tomnod volunteers tagged a wide range of flood impacts from inundated fields to buildings, roads and even landslides (Figures 5.2 and 5.3). On inspection, all of the Tomnod HCCs in Joso were judged to have identified flood impacts. However, volunteers did not always accurately tag the correct type of impacts. For example, two HCCs in the Joso imagery shown in Figure 5.3 (subset 3) appeared to confuse flooded roads with fields. From the GIS analysis it is clear that no roads exist in the OSM dataset for the subset 3 location (Figure 5.5). Tomnod volunteers while missing out on some impacts, were able to identify impacts such as flooded buildings (Figure 5.5: subset 3) and landslides (e.g. Figure 5.5: subset 1) which supervised image classification failed to detect. This clearly illustrates how contextual information in the surrounding imagery can play a crucial role in helping volunteers identify damages which supervised image classification struggles to differentiate.

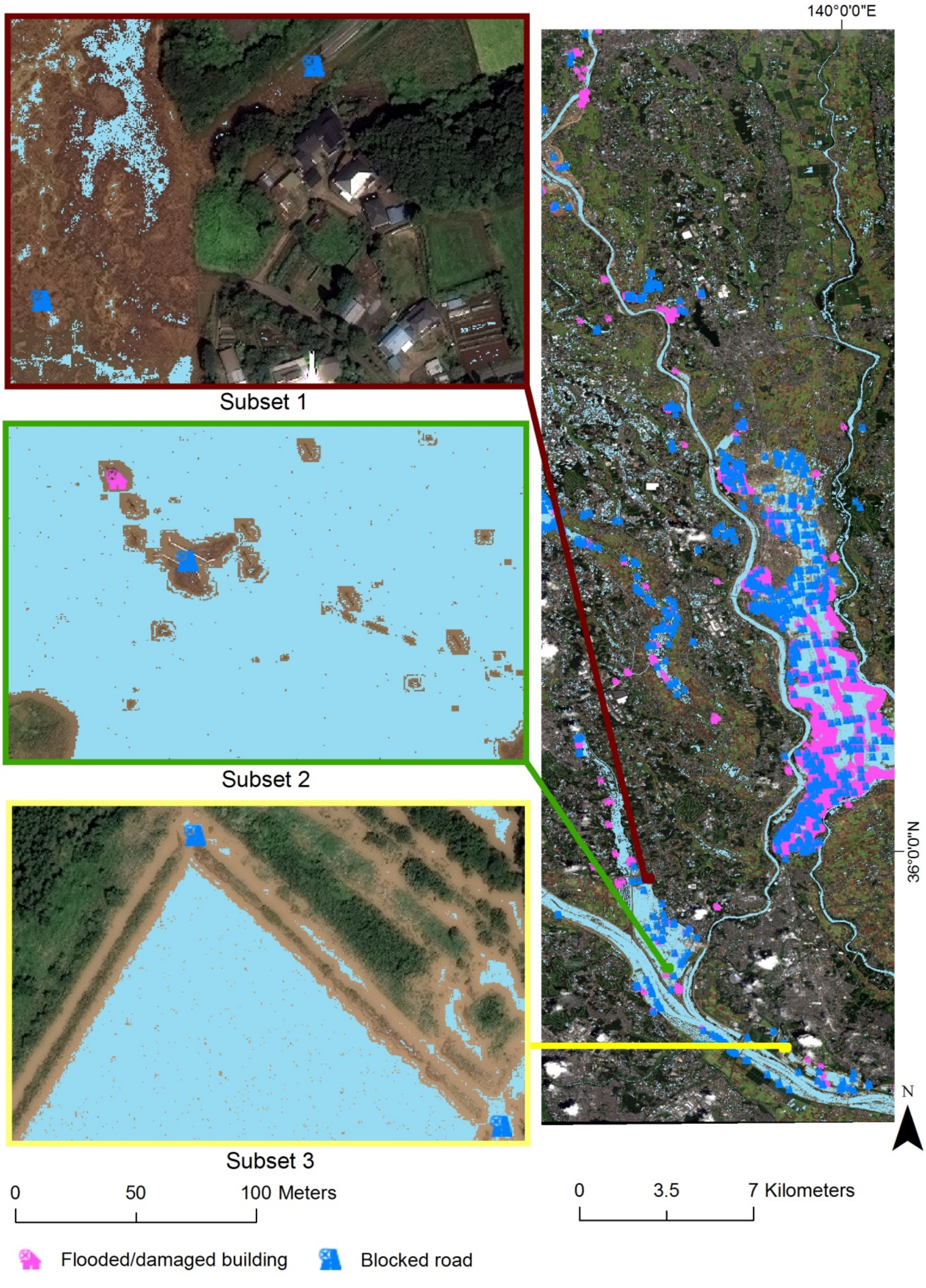


Figure 5.7: Tomnod HCCs, flood classifications with road and flood intersections in Joso, Japan

HCCs also had a high accuracy of correctly identified damages (99%) in Cumbria (Table 5.3). Volunteers were able to distinguish between water overtopping a river and shadows in fields despite their almost identical colour and texture (Figure 5.2: subset 2). Inconclusive tags were largely located in areas of intense shadow (e.g. Figure 5.6). This was a significant challenge for individual taggers who placed 63 tags in areas confirmed not to have been flooded. Nevertheless, while as individuals, Tomnod taggers made a number of mistakes – these were mostly removed in the HCC dataset. In fact the crowdrank algorithm removed all the individual tags in the confirmed no-flood areas (Figure 5.6).

Table 5.3: Accuracy assessment of Cumbria HCC accuracy

Tag type	Not enough evidence to determine if flood impact	Flood impact, correctly identified	No actual flood impact occurred	Flood impact, incorrectly tagged
Flooded/ Blocked Road	6%	94%	0%	0%
Flooded/ Damaged Building	12%	88%	0%	0%
Major Destruction	1%	99%	0%	94%
Other Flooded Area	0%	100%	0%	0%
Overall accuracy	1%	99%	0%	0%

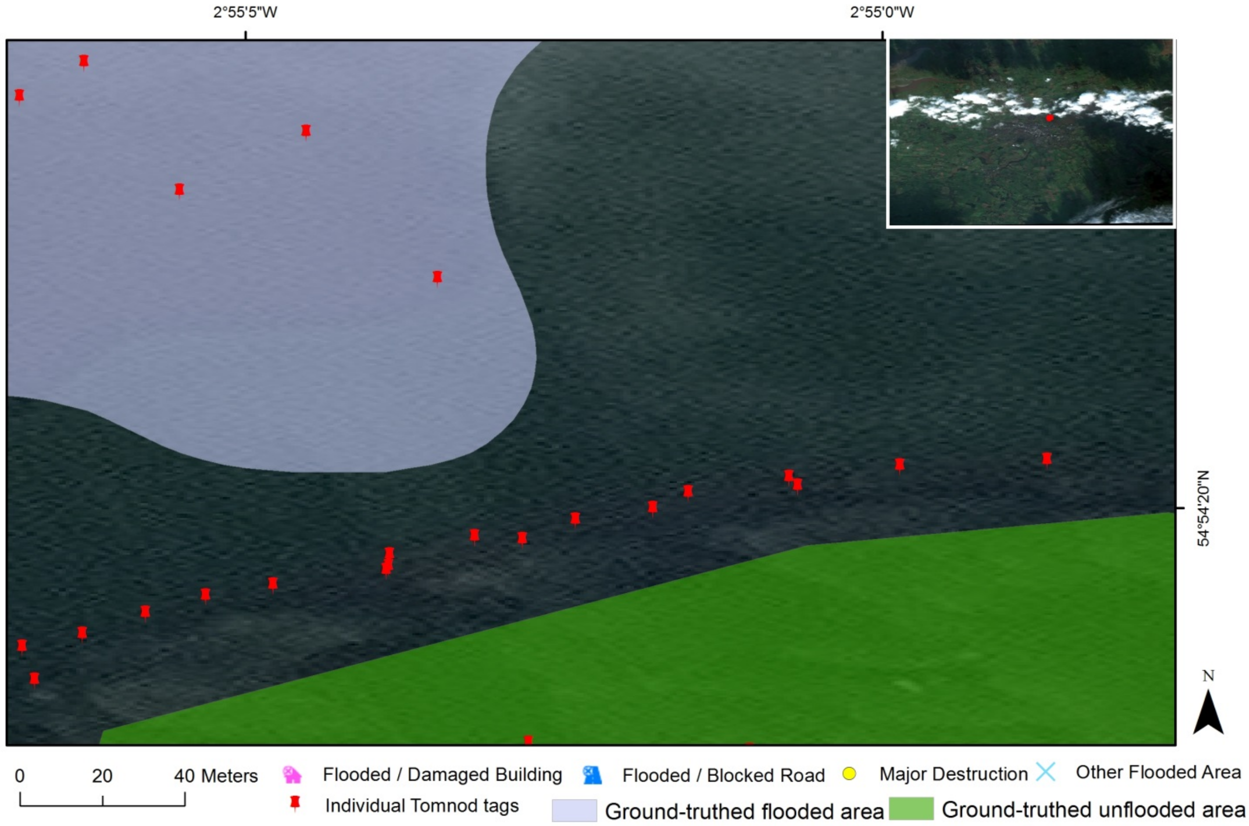


Figure 5.8: Validation of individual tags and HCCs in Cumbria

Despite the poor quality of the Cumbria imagery, Tomnod participants were able to generate intuitive damage assessments (Figure 5.2). In comparison, the remote sensing assessments for the same image were fragmented (Figure 5.7: subset 2), making it challenging to infer any infrastructure impacts with any degree of confidence.

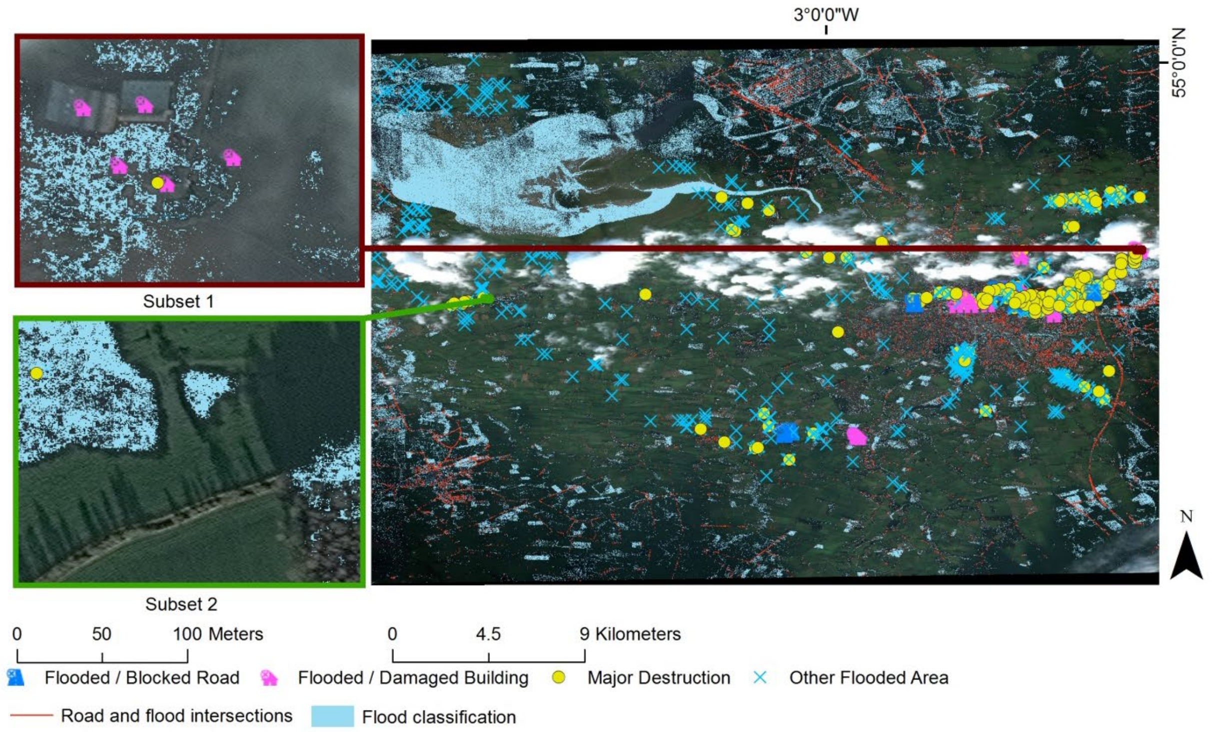


Figure 5.9: Tomnod HCCs, flood classifications from supervised image classification and road and flood intersections in Cumbria, UK

5.4.2.2. Inspection of image classifications

The accuracy of the image classification in Joso, Japan was high, with 81% of the randomly sampled imagery being identified as flood damage and only 5% as inaccurate (Table 5.4). The inconclusive tags were largely due to muddy fields appearing to have a similar colour and texture to flood waters. Intersecting classified areas of inundation with road networks (flooded roads) produced a comprehensive assessment of the impact of flooding in Joso with 7,325 roads identified as flooded at 74% accuracy (Table 5.5).

Table 5.4: The accuracy of flood classifications based on the manual inspection of 300 randomly generated control points.

Land covers	Joso	Cumbria
Flood impact, correctly identified	81%	33%
No actual flood impact occurred (shadow)	0%	20%
No actual flood impact occurred (other land cover)	5%	23%
Not enough evidence to determine if flood impact	14%	24%

Table 5.5: The accuracy of flood classifications intersecting with roads based on the manual inspection of 300 randomly generated control points.

Intersection of road and water	Joso	Cumbria
Flood impact (blocked road), correctly identified	74%	2%
No actual flood impact occurred	2%	32%
Not enough evidence to determine if flood impact	2%	57%
Geo-rectification error	22%	9%

The accuracy of the image classification results was far lower in Cumbria than in Joso (Table 5.4). This can largely be attributed to the deep dark shadows (particularly in the urban centres) from trees, clouds and buildings. These shadows and the unclarity of the imagery resulted in the supervised classification producing an over-estimation of inundation extents (Figure 5.8). Affected roads in Cumbria were calculated at 190 although the real figure is likely to be far lower given the low accuracy (2%) of the inundated road assessments (Table 5.5). The presence of flood and road intersections in area confirmed as unflooded adds further evidence for this (Figure 5.8). Hence, it is likely to contain too many false positives for it to be used for effective response or flood risk analysis. All the HCCs of blocked roads from both Tomnod campaigns intersected with roads within 10m from OSM road maps. Yet, there were only a total of 698 and 32 HCCs in Joso and Cumbria respectively. In Joso, 496 HCCs corresponded to the remotely sensed assessments. This disparity can be partly explained by the misinterpretation by the Tomnod participants and non-flood impacts that are observed by the volunteer taggers.

At the same time, with the landslide covering an entire section of the road, volunteers missed a crucial impact. This demonstrates the potential utility of OSM infrastructure data in supporting volunteers by clarifying the positions of roads etc.

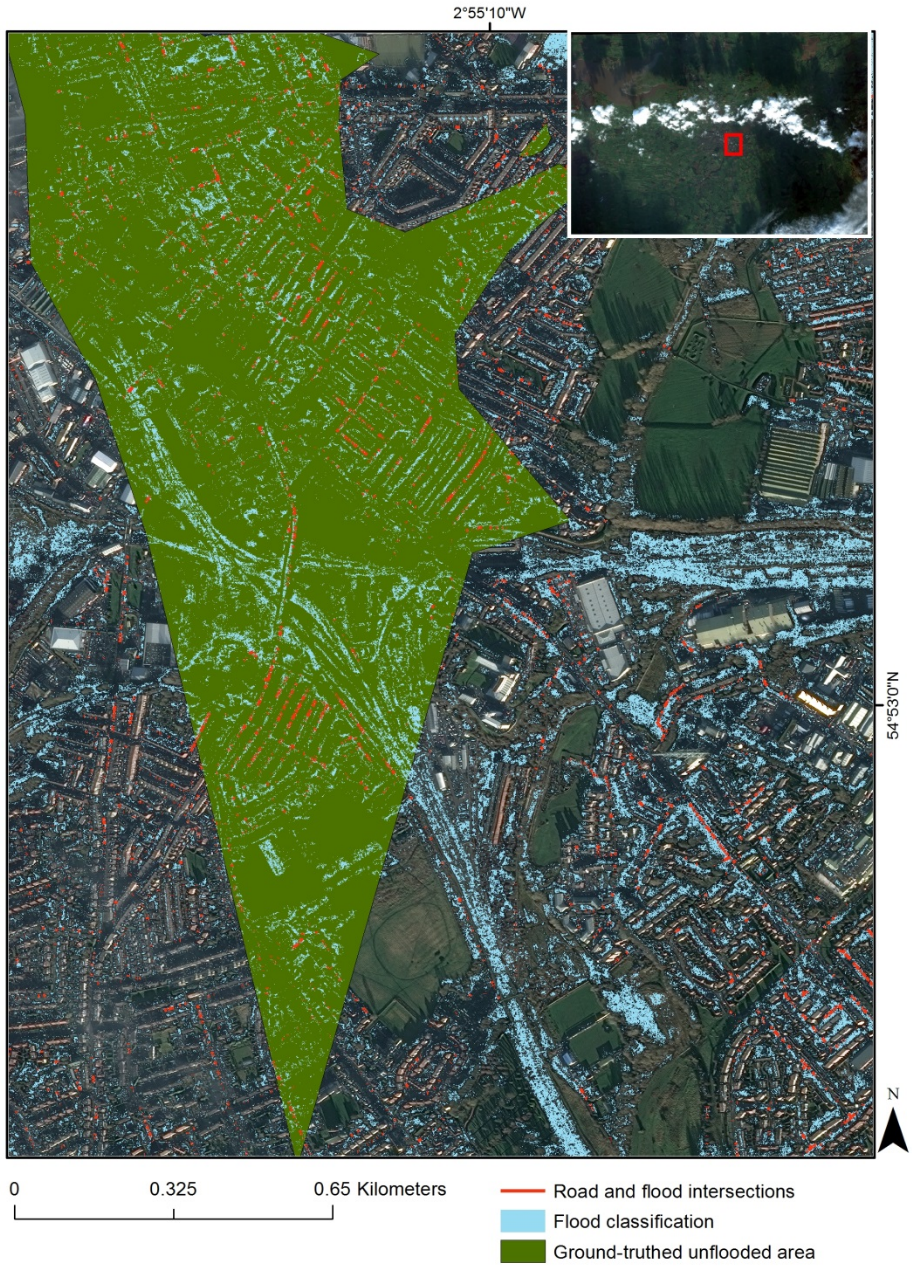


Figure 5.10: Flood classifications and flood/road intersections within the outline of areas confirmed unflooded by field observations by the Environment Agency released July, 2016

A significant proportion of inaccurate assessments of flooded roads from image classification intersections were caused by a mismatch of the OSM and satellite imagery. Such issues have been observed by Leichtle et al. (2017) and are likely due to the tilt effect of the Worldview 3 satellite. For example, a number of road datasets did not align with the satellite imagery of the road itself (Figure 5.9).

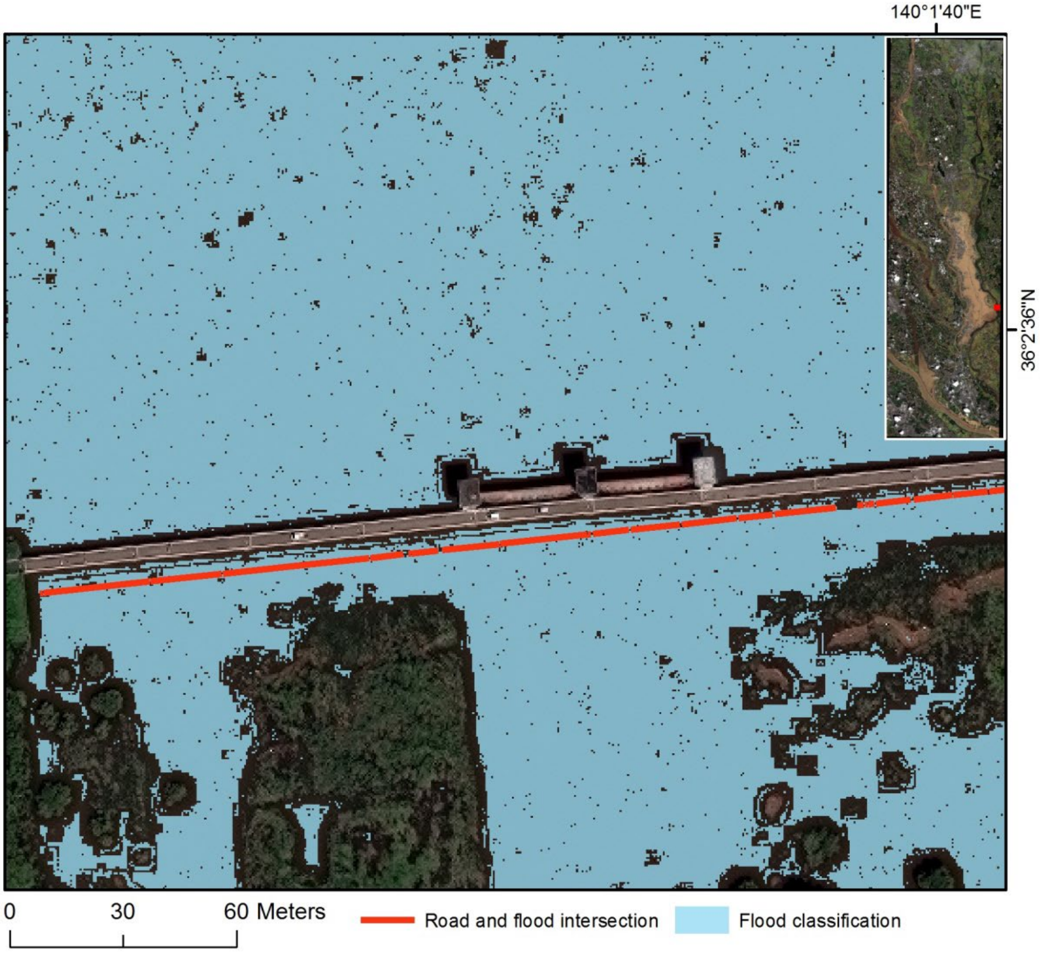


Figure 5.11: Mismatch between a OSM road dataset and flood classification resulting in an incorrectly classified blocked road in Joso, Japan.

5.4.3. Spatial coverage

While there is much agreement between the Tomnod HCCs and the results from the image classification, there are a number of discrepancies. Of the blocked roads identified by the Tomnod participants, only 43% and 25% of tags corresponded to flood classifications from the supervised image classification in Joso and Cumbria respectively. Evidently, the majority of the impacts in Joso, Japan were near the river and most of these were tagged on the Tomnod platform. However, there is evidence, particularly in more rural areas across Joso and Cumbria of floods and blocked roads that were missed by Tomnod volunteers (Figures 5.4 and 5.6).

There are portions of urban areas with a comprehensive coverage of HCCs. However, many other affected urban and rural areas are only sparsely digitised (Figure 5.2). In Cumbria, ground data was only gathered for the city of Carlisle by the Environment Agency while Copernicus' EMA only identified flooding in where it was extensive. Tomnod HCCs, in comparison, show damage well beyond the city, indicating that flooding was more widespread than previous assessments suggested (Figure 5.10).

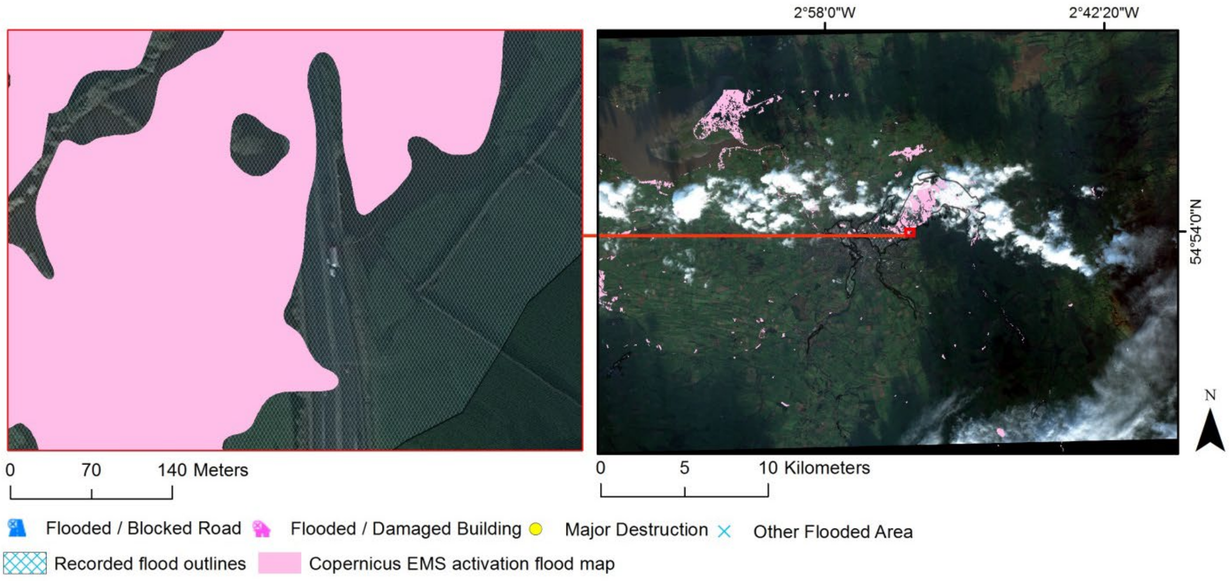


Figure 5.12: Tomnod HCCs and flood classifications are present well beyond the Environment Agency recorded flood outlines and the Copernicus EMS activation flood map in Cumbria, UK

5.5. Discussion

5.5.1. The unique contribution of crowdsourcing to damage assessments

This chapter has illustrated both the power and limitations of crowdsourcing as a method of satellite image analysis. By following basic instructions, members of the public accurately identified several thousand locations of damaged or flooded buildings and roads in both study sites. While a number of tags were ambiguous, these at the very least indicated areas in need of further examination. Unlike the supervised classification method, Tomnod HCCs generated a highly accurate and extensive assessment of flooded buildings in Joso. However, the unique contribution of crowdsourcing for the detection of roads was largely superfluous in the high-quality imagery, given the power of image classification. Like Feng et al. (2015b), this chapter proves sub-metre scale RGB imagery can generate effective urban flood classifications – which can be intersected with roads. Moreover, compared to the Tomnod tags in Joso, the supervised image classification routines generated a more systematic inundation map. Nevertheless, the HCCs of blocked roads can still be used to identify complex impacts such as landslides and validating blocked road classifications where necessary.

The unique contribution of volunteers in the poorer quality imagery (Cumbria) was radically different. While image classification was not able to extract any accurate output from the imagery, Tomnod volunteers detected many flooded fields, roads and buildings. As such, this demonstrates that crowdsourcing can both generate a valuable output from an otherwise unusable image and add value to a high-quality image. We hence propose a workflow (Figure 5.11) which describes a process in which crowdsourcing can be integrated into the image analysis phase of disaster impact mapping. When supervised image classification is unfeasible, we propose a crowdsourcing campaign to identify potential impacts. Yet once the raw image quality is suitable for classification, this workflow outlines a process which ensures that volunteers and professional remote sensing teams are able to support each other's efforts rather than duplicate them. This will help improve the efficiency and reduce time taken for high quality data products to be prepared, particularly in the early phases of the disaster management cycle.

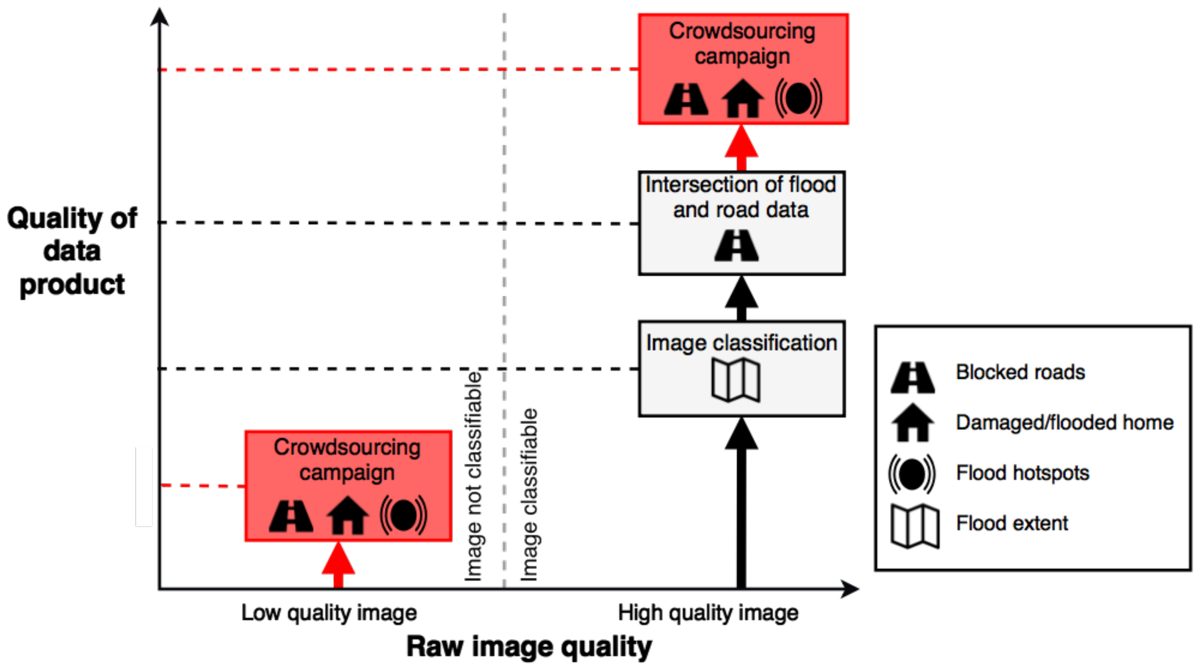


Figure 5.13: Workflow demonstrating the different value crowdsourcing can add to both high and low-quality imagery, defined by the ability to conduct image classification on the data or not. The role of crowdsourcing in adding value to the raw imagery is highlighted in red.

While Tomnod HCCs were largely accurate, there were a small number of errors. Volunteers occasionally confused different land covers, particularly in the Cumbria campaign. Tomnod participants expressed their concerns about the accuracy of their contributions, many blaming clouds and a lack of colour in the imagery (A. Baruch, May, and Yu 2016). These factors also severely affected the capabilities of supervised image classification as a method of flood inundation mapping. Shadows obscure impervious surfaces, increasing the difficulty of extracting both thematic and cartographic information (Zhao and Du 2016). This caused significant confusion between shadows and inundated areas in the image classification. In addition, a number of HCCs on deep shadows appear to not be flooded, suggesting that while the Tomnod HCC dataset is largely correct, some data points may benefit from further examination to verify their accuracy. The small number of misclassified HCCs in Cumbria is a result of several participants tagging objects which they identified (incorrectly) as potentially flooded. This can be attributed to Tomnod's directions to tag objects of interest. Therefore, this outcome can be considered as a limitation of the campaign design which can be accounted for when interpreting and utilising the data.

Bias in the distribution of tags is evident in parts of both study sites with some sections of the imagery receiving more attention than others. This has major implications for the usability of the HCC datasets, as despite identifying some areas of damage, they cannot be considered as comprehensive or systematic as automated image classification routines. One explanation for this pattern is that volunteers enjoy being able to explore a map and tend to gravitate to the most affected areas (A. Baruch, May, and Yu 2016). Moreover, many volunteers share regions of significant destruction on an online forum[14] drawing yet further people to certain areas and creating a non-uniform coverage of the study site. Enabling such freedom is essential for keeping participants motivated, yet, this study emphasises that it caused a spatial data bias, affected the quality of the end-product. Indeed, many blocked rural roads remained untagged. Therefore, encouraging volunteers to explore areas further outside of major flooding hotspots may facilitate a more holistic coverage of damage assessments.

5.5.2. Utilisation of damage assessments in the disaster management cycle

Recent research has highlighted how a range of different image products can support action at several stages during the disaster response cycle (Kreibich et al. 2016). In the initial stages of a disaster near-real time data is needed to support fire, medical and police departments in their response (Jha, Bloch, and Lamond 2012). Geospatial data on flooding extents and damage enables these practitioners to visualize and react to potential problems (Jongman, Wagemaker, et al. 2015). Tomnod's flood crowdsourcing campaigns aim to generate such data by running search and rescue and emergency response campaigns during natural disasters. Yet the campaigns examined in this chapter took six to seven days to produce high-confidence data (for Cumbria and the Joso respectively). By the time these were made available, the situation on the ground had changed from disaster relief phase to a reconstruction phase (Matsumoto et al. 2016; Environment Agency 2015). This introduces a significant challenge for crowdsourcing projects such as Tomnod to efficiently produce high quality data which can support disaster relief.

[14] http://discourse.tomnod.com/t/japan-flooding-getting-oriented/1718

Nevertheless, it can be argued that the same data can become a valuable resource in later phases of the disaster response cycle.

The value of contributions to different practitioners can vary depending on the management systems in place and the availability of other datasets. During the recovery period, issues of unemployment, sustainable business operations, housing, and medical care for victims require long-term consideration. Blocked roads and damaged building datasets such as the Tomnod HCCs can play a key role in modelling these longer-term impacts. Spatial inequalities in flood impacts have meant that data on affected rural communities may help support efforts to reduce social divisions after the event (Thorne, 2014). Beyond the recovery phase, the identification of urban flood hotspots is a highly sought after data-source for integrating flood risk assessments with mitigation (Jiang et al. 2009; Jalayer et al. 2014; Atif, Ahsan et al. 2016). For example, geospatial data on the impacts of past floods play a fundamental role in the improvement of urban planning through validating both physical and economic impact models (Slater and Villarini 2016; Yu, Yin, and Liu 2016).

At present, each of Tomnod's campaigns encompasses a vast area, which significantly affects the time taken to produce comprehensive HCC data for emergency response. One method of reducing the time taken to generate HCCs could be to reconsider the scale and format of campaigns. For example, a two-phase approach could be adopted whereby smaller sections of imagery are prioritised for emergency response, before larger areas are made available for examination as part of a longer-term recovery and risk reduction campaign. For the latter, different tag types such as destroyed crops, livestock, shelter developments and fallen power lines could provide useful data for supporting the recovery. These could generate more information on potential impacts such reduced employment opportunities (Uddin et al. 2013). Such an approach has been employed by professional digitisation teams following the Great East Japan tsunami of 2011, producing a digitised general overview map of the flood outlines within four days of the event (Nakajima and Koarai, 2011). Any such plan would, however, need to ensure that the data are useful for end-users and do not overlook affected rural communities.

5.5.3. Implications for future crowdsourcing campaigns

This chapter has outlined both the strengths and weaknesses of using crowdsourcing to digitise imagery for disaster response. In doing so, a number of opportunities for improving the efficacy of crowdsourcing campaigns have been identified:

- One major weakness of the remote sensing technique used in this chapter and the Tomnod campaign is the absence of multispectral imagery. As the imagery was limited to three spectral bands (RGB), the spectral reflectance of water in NIR and beyond could not be examined. Utilising only RGB imagery in the supervised image classification enabled a like-for-like comparison between volunteers and supervised image classification techniques. This made it more challenging to yield high classification accuracies – particularly in Cumbria – as many of the fields and flood waters had similar RGB spectral features. Given the power of NIR and the prevalence of issues concerning shadows, in Cumbria, we recommend that crowdsourcing projects test the efficacy of utilising NIR bands in crowdsourcing campaigns. Alternatively, multispectral imagery could be used to map floods prior to the launching of a crowdsourcing campaign. This would enable participants to both validate remotely sensed assessments and identify further impacts which are missed by the image classification results. Doing so could maximise the efficiency of the work of volunteers.
- By only generating *points*, tagging campaigns omit the sorts of spatial data that could be generated by drawing polygons on a map. These could enable the production of inundation outlines that are useful both for modelling and governance (Dottori et al. 2017). In fact, there is a strong motivation for such tools among volunteers, with some participants even drawing flood extents on images of flooding extents and sharing their images on the forum, noting:

  > *'It´s very time consuming to mark every flooded house and road. In this case it would be much better to make the whole area visible from the beginning and then to enable drawing of polygons around the affected* areas*. This would take a fraction of the time needed to flick through all tiles* (Binocolo 2015)*.'*

  These sorts of tools could be incorporated into a two-phase approach whereby volunteers draw outlines of significant impacts before undertaking a more thorough analysis.
- While an object orientated analysis can be highly challenging in identifying damage in residential areas, it is increasingly being utilised as an alternative to manual digitisation campaigns for humanitarian response (Knoth and Pebesma, 2017). Thus, in the future, it may also be included in the processing of imagery before it is made available to the public to enable a preliminary assessment of priority locations (Van Der Sande, De Jong, and de Roo 2003).

- This chapter has emphasised the power of utilising OSM datasets both for assisting in the identification of flooded roads from image classification and Tomnod HCCs. However, georectification problems can result in significant inaccuracies when OSM road datasets are intersected with image classification results. Hence, further post-processing of the imagery and an analysis of the OSM is required to assess the quality level of infrastructure datasets, especially when their completeness or currency is in question (Ajmar et al. 2015).
- Amateur online volunteers are not only just able to identify flooded areas, but also damaged buildings, blocked roads, landslides and hotspots of major devastation. Little training is needed to perform these tasks enabling members of the public to swiftly begin tagging once they visit the website. Nevertheless, the tasks given to volunteers, despite their relatively simple nature, did involve discerning noisy and challenging satellite imagery. Evidently, for more challenging campaigns, further training may be required to avoid misclassifications. There is therefore, a need to test different training schemes on volunteer performance and participation.

5.6. Conclusions

Classification of satellite imagery is a powerful tool for assessing the impacts of major disasters. However, it has often been limited in the degree of detail it can generate without the employment of manual digitisation techniques. Crowdsourcing projects such as Tomnod aim to address this challenge through micro-tasking. Online volunteers are able to ascertain with a high of accuracy, many features in satellite imagery including blocked roads, flooded buildings and areas of major devastation. Compared with supervised image classification, crowdsourcing was far more effective at classifying damaged buildings. Where imagery was of a poorer quality, the Tomnod community were able to add real value and high-confidence information which supervised image classification was unable to match. Consequently, Tomnod tags, while occasionally including some minor errors were able add useful information about disaster impacts which are suitable for both emergency response and longer term planning. This indicates that where image quality is so poor that image classification becomes almost futile, crowdsourcing can still infer valuable information from the imagery. However, supervised classification is far more systematic and succeeded in identifying impacts – particularly blocked roads – in many regions which were missed by volunteers. Hence, in order to improve the efficiency of crowdsourcing, a number of issues must be addressed. In particular, ensuring that volunteers are both free to explore the map *and* cover all sections of the imagery is critical to generating comprehensive assessments. In addition, avoiding the duplication of efforts between volunteer taggers and remote sensing experts may significantly reduce the time taken to produce assessments for response teams. This chapter outlines how crowdsourcing can support supervised image classification techniques through a workflow which takes consideration of raw image quality, state-of-the-art image classification techniques and the abilities of online volunteers. While, the added value of crowdsourcing is highly dependent on the image quality and the context in which the data is used, these findings demonstrate its potential application in several contexts. It is clear that crowdsourcing needs to be optimised through a format which takes greater consideration of the capabilities of image classification and the needs of the end-user. There are many opportunities for combining these two approaches through the utilisation of street data and initial remote sensing campaigns to identify the most affected areas of a disaster. Therefore, crowdsourcing could play a more efficient role in all phases of the disaster response cycle through a system that has a more integrated supervised image classification and tagging design. In particular, an initial supervised image classification of each study site may help direct volunteers to critical areas and ensure that their contributions complement existing knowledge of the disaster.

Chapter 6: Insights from the iterative development of Floodcrowd – a flood information sharing citizen science platform

Research questions addressed in this chapter
1. What are the characteristics of crowdsourced flood data, and how are they evolving?
2. How do human factors affect participation in flood crowdsourcing projects?
3. What roles can crowdsourcing play in supporting flood risk management?
4. What role does platform design play in maximising the efficacy of crowdsourcing for flood risk management?

6.1. Introduction

As first-hand witnesses of floods, many members of the public have local knowledge which can be crucial for supporting flood response and risk management. At present, organisations including local governments and water companies are capitalising on this resource by crowdsourcing data through specialised online reporting forms. Yet, information about flooding often has the potential to be used for a variety of purposes, with researchers and practitioners in disaster response, recovery and risk management all having specific data requirements. The literature review emphasises the increasing number of ways in which Volunteered Geographic Information (VGI) is supporting flood response alongside Professional Geographic Information (PGI). Information about fluvial-geomorphological processes during flooding, hydraulic variables (e.g. depth, extent and velocity/timing), causes and impacts of floods are all highly valuable to various practitioners (Demir and Krajewski 2013). There is also an increasing attention among scientists and practitioners towards the impact of lesser reported nuisance flooding (Moftakhari et al. 2015; Sweet and Park 2014). The cumulative cost of frequent nuisance events over time – according to some estimates – may exceed the costs of the extreme but infrequent events (Moftakhari et al. 2017). As a result, in the UK, there is a significant demand for data on floods which receive less media attention (HM Government 2016).

Implicit knowledge within affected communities can help build a unique insight into specific micro-level challenges and identify potential solutions (S. N. Lane et al. 2011). In addition, even onlookers of floods possess information which can support practitioners in understanding the magnitude of an event. Depending on their contents, quantity, quality, spatial distribution and timing, data on flood events can be used for a variety of purposes. However, collecting and organising flood data to support different practitioners remains a significant challenge (Horita et al. 2015). In recent years, a number of crowdsourcing projects have been launched to gather localised flood information for use in governance, scientific research and capacity building. Chapter 3 outlined the utility of crowdsourced datasets of depth, timing and extent information for flood model validation. Yet, the majority of flood observations found on the 31 different projects identified as part of the chapter contained disparate information. One particularly striking element in the crowdsourced data has been the differences between the dates that the data were submitted and those of the event itself. The majority of the observations were shared weeks after the event took place, reducing their applicability to practitioners involved in the immediate aftermath of an event.

Platforms from different organisations each offer a unique approach to the crowdsourcing of flood observations from members of the public. However, the extent to which these emerging crowdsourced datasets can support flood risk management on an institutional level remains under-researched. On a larger scale, crowdsourcing has the power to support a far broader range of practitioners in responding to, and managing floods. Yet, since the Environment Agency’s introduction of flood risk maps affected insurance premiums in the UK, there have been reports of increased public distrust in government and companies bodies involved with flood response (Whittle et al. 2010). A major challenge to the implementation of institution driven crowdsourcing initiatives is motivating volunteers. There is therefore an urgent need to explore ways in which crowdsourcing flood event information can work effectively for large institutions without deterring contributors.

A major gap exists between the data that has been previously shared by members of the public on the platforms outlined in Chapter three and the sorts of data that are required by practitioners for flood response and risk management. As a result, there is a need to develop tools which can engage volunteers in supporting a broader range of practitioners. One way in which this could be achieved is to focus on engaging members of the public in the science of flooding (Starkey et al. 2017). Through the development of a citizen science platform for sharing flood information for use in management and response, this chapter sheds light on practitioner views and opinions of crowdsourcing tools and practises. It also identifies user requirements and design implications for platforms which aim to engage the public in flood risk research as well as citizen science in general. In doing so, it identifies opportunities for further development of tools for citizen science and crowdsourcing projects.

6.2. Research aims and objectives

This research aims to identify ways in which members of the public could be more effectively engaged in sharing their knowledge of flooding to support practitioner action. Through practitioner and public engagement, a citizen science focused web-platform called *Floodcrowd* was iteratively developed to incorporate feedback into its design. The process of developing the project provides insights into the opportunities and challenges of using crowdsourcing to support flood risk management. The specific objectives are to:

1) Develop a citizen science website for flood reporting and test its ability to generate new crowdsourced knowledge about flooding events
2) Identify key conceptual and interaction-based barriers and enablers for citizen science contribution
3) Identify potential end-users of crowdsourced flood data and their perspectives on its utility
4) Explore the current, and potential future role that crowdsourcing can play in helping institutions understand and respond to flooding.

6.3. Methodology

6.3.1. Overview

An overview of the methodological approach is outlined in Figure 6.1. This describes a series of steps taken to iteratively develop a flood citizen science web-platform. A package of events was used to gain feedback from members of the public and potential end-users of crowdsourced flood data. These included the identification of improvements for the platform's interface and functionality. Iterations to the platform were applied and tested on further groups of participants and practitioners (Figure 6.1).

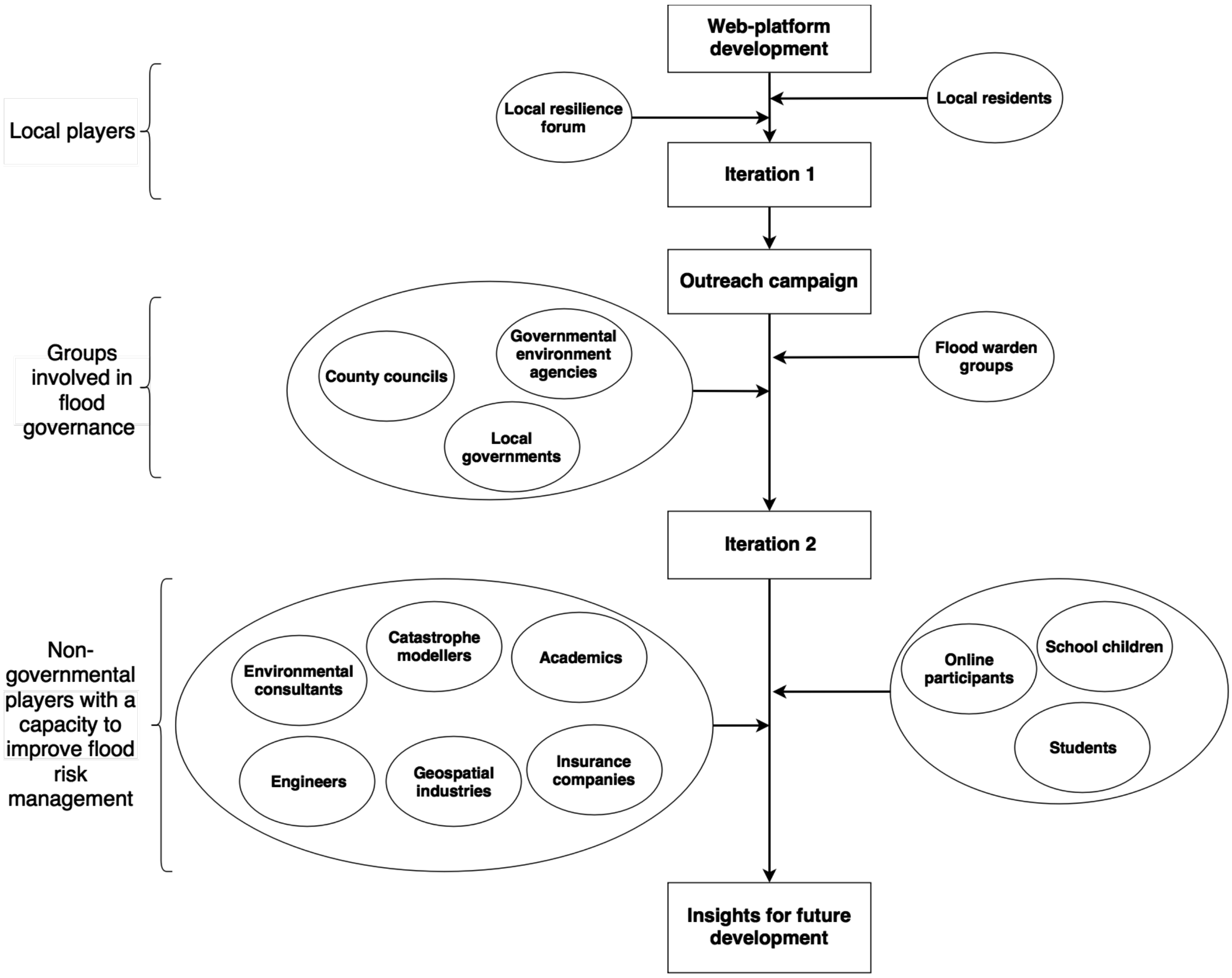


Figure 6.1: The iterative design process used to inform the development of Floodcrowd

6.3.2. Website development and first iteration

A web-based HTML5 flood observation sharing platform (http://floodcrowd.co.uk) was developed using Drupal 7 (a content management system). Several ready-to-use modules were used and modified to improve the website interface. From the landing page, visitors were informed that Floodcrowd is a citizen science platform for sharing observations of floods in the UK for use as part of a PhD research project. An initial web-form included a location field and ten optional fields requesting information on: type of flood, date and time, status of flood, depth, duration, damage estimation, cause of flood, speed of flood onset, water quality and further comments. The form included a disclaimer and a terms of use with appropriate information for university ethical and legal cover (Appendix 2) which uses Scassa (2013) as a guide. Feedback was encouraged via email or a web-form. Once the website was developed, a mixed methods process was used to investigate the efficacy of employing crowdsourcing to generate a range of flood information. As a first step, the platform was presented to ~100 local residents and a resilience forum in Leicestershire.

These events included user-testing and discussions about the sorts of changes that were needed to make the platform more effective.

6.3.3. Outreach and participation

Following the first iteration, several outreach events were carried out to encourage participation in the project and an opportunity to provide further feedback. These involved:

- **Workshops:** Six community resilience days were held government offices in regions affected by flooding involving a talk, a stand and leaflet distribution (Appendix 3). These events were attended by between 13 and 30 participants. During events, a tablet and laptop were made available and use of the website was encouraged.
- **Conferences:** Floodcrowd was presented as a poster or a PowerPoint presentation at 13 different academic conferences including the Citizen Science Association, European Citizen Science Association and The British Society of Geomorphology (see Appendix 4 for full list). These events were also used to gain feedback from those affected by flooding.
- **Media, blogs and newsletter features:** A Loughborough research[15], Wordpress[16] and Floodmeadows[17] blog were written to promote Floodcrowd. The project has also been featured in Prof. Haklay's[18] and Dr Vetra Carvalho's blog[19]. Media stories also covered Floodcrowd in Discover Magazine[20], SAGA[21], Citizen Science[22] and Crowdsourcing News[23].
- **Social media:** The website was publicised on social media – using a dedicated Twitter handle (>250 Tweets[24]) and >45,000 impressions. A Facebook page[25] with several posts and news stories was created, attracting 32 followers.

[15] http://blog.lboro.ac.uk/research/changing-environments-infrastructure/citizen-scientists-flooding-research/
[16] https://avibaruch.wordpress.com/blog/
[17] http://www.floodplainmeadows.org.uk/sites/www.floodplainmeadows.org.uk/files/Newsletter%20summer%202016%20v12.pdf
[18] https://povesham.wordpress.com/2017/05/19/citizen-science-2017-day-1-afternoon-tools-overcoming-barriers-and-project-slam/
[19] http://blogs.reading.ac.uk/dare/files/2017/03/DARE_meeting_Feb2017_Sanita.pdf
[20] http://blogs.discovermagazine.com/citizen-science-salon/2017/05/31/snorkeling-selfies-heres-can-advance-scientific-research/#.WgV1y1Vl-Uk
[21] https://www.saga.co.uk/magazine/home-garden/craft-hobbies/hobbies/citizen-science-projects-get-involved
[22] http://www.citizensciencecenter.com/assessing-flood-risks-crowdsourcing-floodcrowd/
[23] http://gettopical.com/crowdsourcing/933fd58001c3a6b0a1860adb851e4057?src=twitter
[24] https://twitter.com/Floodcrowd
[25] https://www.facebook.com/floodcrowd/

- **Online listings:** Floodcrowd was listed on several websites including: Wikipedia[26], The Crowd and Cloud[27], and Scistarter[28], Floodstones[29], Yale Data Driven[30], Innovation Essence[31], Pinterest[32] and WOW[33].

Over the course of two years, 160 observations were shared on the website, a response rate of 0.5% of all website visitors. All submissions were coded using a content analysis in a data-driven approach to identify and categorise key themes in responses. Key user statistics were also derived using Google Analytics of website usage.

6.3.4. Insights for second iteration and future developments

Three workshops with flood warden groups (held in government offices) in flood-prone areas were held to identify ways in which Floodcrowd could be adapted to better support them. These were attended by roughly 20 participants of all ages, each including representatives from police, fire and rescue, Environment Agency services and community action groups. Additional events with schools and academics helped ensure that a wider range of potential participants who had witnessed flooding but may not have been affected themselves were also sampled. Such events can help identify the problems users are confronted with when using technological products (Fisk et al. 2009). This approach is needed in projects and research wishing to improve the use of the technology and its applications (Mordechai Haklay and Tobón 2003).

Feedback from 22 practitioners from both public and private sectors was gained through interviews between January and December 2017. These included leading figures in flood risk management in the Environment Agency, Flood Forecasting Agency, insurance companies, risk management companies engineering companies and consultancies. The interviews were conducted face-to-face or by phone. During these, a report summarising different crowdsourcing campaigns along with Floodcrowd was discussed (Appendix 5). A semi-structured interview format was utilised, with a question guide (Appendix 6) to ensure consistency between interviews. Each session lasted approximately one hour and focussed on the examination of crowdsourced flood datasets, Floodcrowd as a platform, the phenomenon of crowdsourcing and opportunities for future innovation. The participants

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[26] https://en.wikipedia.org/wiki/List_of_citizen_science_projects
[27] http://crowdandcloud.org/floodcrowd
[28] https://scistarter.com/project/1421-Share-a-flood-observation#sthash.SNYDExZ2.dpbs
[29] http://floodstones.co.uk/external-links/
[30] http://datadriven.yale.edu/wp-content/uploads/2017/01/Third_Wave_Citizen-Science_FINAL.pdf
[31] http://www.innovationessence.com/involvement-scientific-investigations/
[32] https://www.pinterest.com/pin/547187423460794185/
[33] http://www.wow.com/wiki/List_of_citizen_science_projects

offered a wide range of perspectives to the research, including: data requirements, data availability, industry standards, ethical considerations, motivations, and future directions. Where appropriate, feedback was utilised to inform a second iteration of the website which was then tested with members of the public during the outreach events (Figure 6.1). Each interview was transcribed and coded to enable a thematic analysis of practitioner perspectives. While questionnaires would have produced more discrete, quantifiable data on aspects such as data requirements, interviews were chosen in order to produce extended accounts from informants (Li and Moyer 2008). This was necessary for exploring theoretical and practical implications from flood crowdsourcing.

6.4. Results

6.4.1. Practitioner requirements for crowdsourced data

The practitioner interviews (which used Floodcrowd as a key prompt) revealed a growing interest in crowdsourced flood data from both government and commercial organisations. During a flood event, local authorities mobilise operations teams and receive reports through dedicated phone lines. Insurance data, flood models, remote sensing and on-site reconnaissance are also frequently utilised to respond to floods and help validate 2D flood inundation models. However, the practitioners emphasised that these datasets are not always fit for purpose and further sources of information need to be considered. As a result, several data types were identified which could be generated through crowdsourcing to support flood management before, during and after an event (outlined in Figure 6.2).

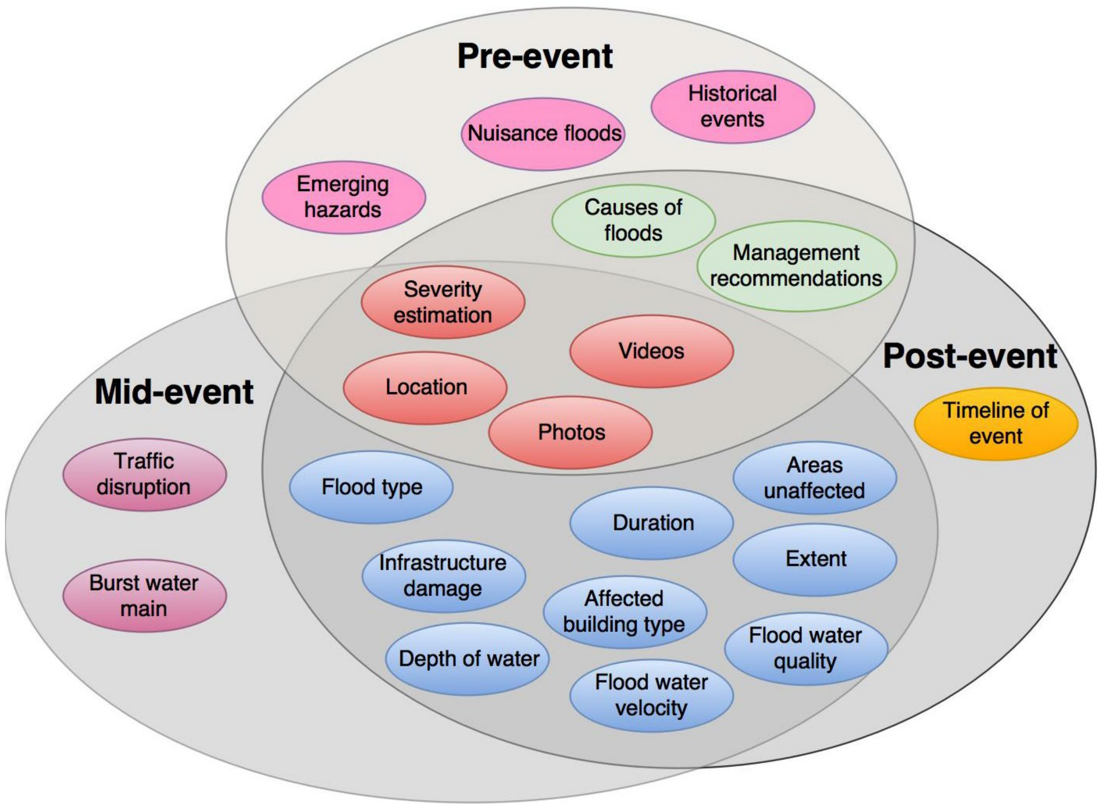

Figure 6.2: The types of flood data practitioners would value for operational use before, during and after an event.

In the initial phases of event response, information on burst pipes and traffic disruption are highly sought after. For flood relief, both businesses and government departments require near real-time data to provide initial reports assessing the damage as well as informing insurance companies on where to send loss adjusters. While reports are of most value during a flood, many observations are highly useful for a variety of purposes in the weeks and months after the event by the Environment Agency. Most data types such as flood depths and extents remain useful for post-event analysis. Given the prevalence of depth-damage curve models in the literature, most practitioners had an interest in real-time and historical estimations of inundation:

> *'We look out for buildings where you can get flood depths to help them in their model validation work. If we can get that information through the public, it may reduce the need to send someone out.' [Multinational Insurance Company – Research Manager]*

> *'Most of these waterbodies are small so there are no gauges. The only option is to validate using photographs and level markers.' [UK Midlands County Council – Flood Risk Manager]*

These sentiments are echoed by environmental consultants who emphasise that for depths to be useful, you must first establish whether the level that is observed is at the peak of the flood, on the recession or on the climbing limb. From a damage modelling perspective, some practitioners prefer information on duration:

> *'The problem is that the relationship between water depth and damage is non-existent. Much more reliable is the duration of the event and the speed of the water. Fast moving water does more damage than slower moving water and the quality of the water – debris or pollutants in it require a more extensive clean-up. All those things are highly correlated with damage. But we don't have enough of that sort of information so we have to use depth' [Multinational Risk management Company – Director]*

Information such as flood depth can be difficult to extract from post-event surveys, but is often known to local residents who witnessed the floods. There is a significant demand from practitioners to learn from those who have witnessed flooding events:

> '*Flood data is ephemeral. People are keen to wipe down all traces of the flood. It can be an emotional event. They want to get rid of it and return to normality, so there is a need to collect the data in the immediate aftermath and crowdsourcing can play a part there. Also in terms of getting people to tell their narrative of the event, not just where the water mark is.' [Multinational Environmental Consultancy – Technical Director]*

> *'If we've run a model and we're looking for some information for validation, we read old newspapers and get images which show how far it went.' [Environment Agency – Flood modelling and forecasting specialist]*

For many governmental agencies, the format in which many of these reports take makes it difficult to process in time sensitive situations:

> *'During the times when it's really needed and valuable – we're stretched as a business because we're running 24/7 and we don't have the staff available to go and do the processing of submissions.' [Environment Agency – Risk management advisor]*

A more active engagement with the public typically occurs after the event with both private companies and governments investigating the impacts of an event:

'We leaflet door-to-door and have surgeries to gather as much information from as many people as possible.' [Environment Agency – Scientist]

'We send out flood risk specialists with field data capture equipment to observe the extent, depth, impact etc. of a flood event.' [Multinational Environmental Consultancy – Director]

Collecting field data however, can be costly and incomplete:

'If there's a flood, the thing we've done in the past is send three of four people to go there and have a look to figure out how much flood damage there has been. But that's inconvenient, they never get there on time and the flood has always gone down by the time they get there and if it's three people, they can't cover the whole domain….Even in a well-documented place like the UK, we missed villages and a few other locations so some of our estimates came out a little low.' [Multinational Risk Management Company – Catastrophe Modeller]

Given the different uses for local information, requirements about data resolution, detail and reliability differed:

'A flooded or not flooded is more beneficial than a smaller amount of high resolution data as we can then send our teams there.' [Multinational Risk Management Company – Catastrophe Modeller]

'If you're capturing information that tells you things like building age and size and number of stories then that's useful. But there's also scale, so if you're capturing 1% that's probably not going to be enough. [Multinational Risk Management Company – Director]

While few of the practitioners interviewed have utilised crowdsourced data from specific platforms, many have examined public posts on social media. At present, the practitioners interviewed confirmed that they are increasingly utilising social media for supporting a range of activities. These include emergency response, forecasting, inundation modelling, catastrophe modelling, damage estimation and risk management. These are being utilised by both the private and public sector as a source of evidence of flooding in near-real time:

'*Our press office monitor when Leicestershire twitter account gets tagged in… whether we get it late on is another thing.' [UK Midlands County Council – Flood Risk Manager]*

'The first thing I do (during a flood event) *is go on YouTube because people don't report it to the council, they put it on YouTube.' [UK Midlands City Council – Flood Risk Manager]*

Photos shared on Twitter have proven a particularly useful data source both during and after an event. For example, Katrisk display tweets on their website as validation of their flood inundation models (Figure 6.3).

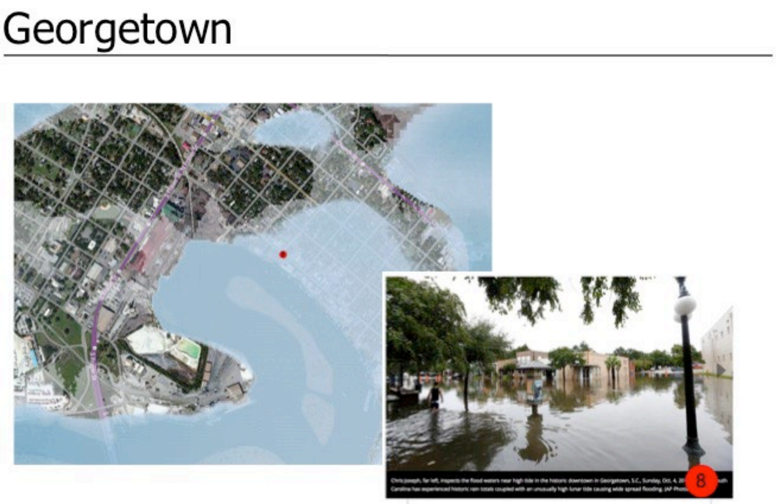

Figure 6.3: Screenshot of Katrisk website displaying sample of flood model for South Carolina, USA 2015 floods (Katrisk 2017).

However, during the interviews it was revealed that these tweets were limited in their ability to influence management due to several issues including a lack of trust and control over data collection:

'Something that gets missed is the rough direction of where that camera was pointing.' [Multinational Environmental Consultancy Company – Catastrophe Modeller]

'Social media is focused in where people live but not in more industrial or commercial areas which are often just as big a loss driver… The task of trawling through a vast, vast amount of textual information which is low quality and quite possibly has no value at all is inhibiting.' [Multinational Risk Management Company – Vice President]

As a result, a number of practitioners simply use VGI as a tool to help identify locations where further investigation is needed:

'It draws our attention to areas where we may not necessarily have flood warning schemes (which is the majority of the country). The problem we have is that in small villages we don't get a great deal of information… We sometimes get conflicting information so anything we can get which could help to verify that information… It also gives great indication of what the status was like at that point because we were being overwhelmed with a limited number of resources.' [UK Environment Protection Agency – Scientist]

Other datasets of interest include information on areas that were close to flooding e.g. in driveway but not house, type of property affected, quality of flood waters, velocity, blocked drains, runoff from fields and whether the event was recorded at peak flood. All the practitioners interviewed expressed a concern about either the quantity or quality of the available crowdsourced data. Nevertheless, many saw it as a potential tool to help support their work:

'*The challenge is coming up with a platform that people are comfortable enough with to contribute to and can be done in a structured manner.' [Multinational Environmental Consultancy – Geospatial Technologist]*

6.4.2. Iterations to the platform and their impacts

6.4.2.1. First iteration

Feedback from local residents helped identify aesthetic, content and functional issues with the website that required addressing. Following criticisms of the website landing page and a lack of clarity over its aims, a *beta* design was produced and used in subsequent workshops. This received a far more positive feedback by participants. In the beta version, a particular emphasis was placed on encouraging members to report any flood they had a recollection of: *'Help us by sharing your observations of flooding. These citizen science records will help improve our understanding of flooding in the UK. If you have witnessed a flood, no matter how big or small, old or recent, share it here'* (Figure 6.4). A Twitter feed, *case study*, *frequently asked questions* and an *about* page all helped visitors understand more about the project's aims. Using modern styles and colours gave it slick design which participants preferred as it gave the platform an intuitive feel.

Alpha welcome page Beta welcome page

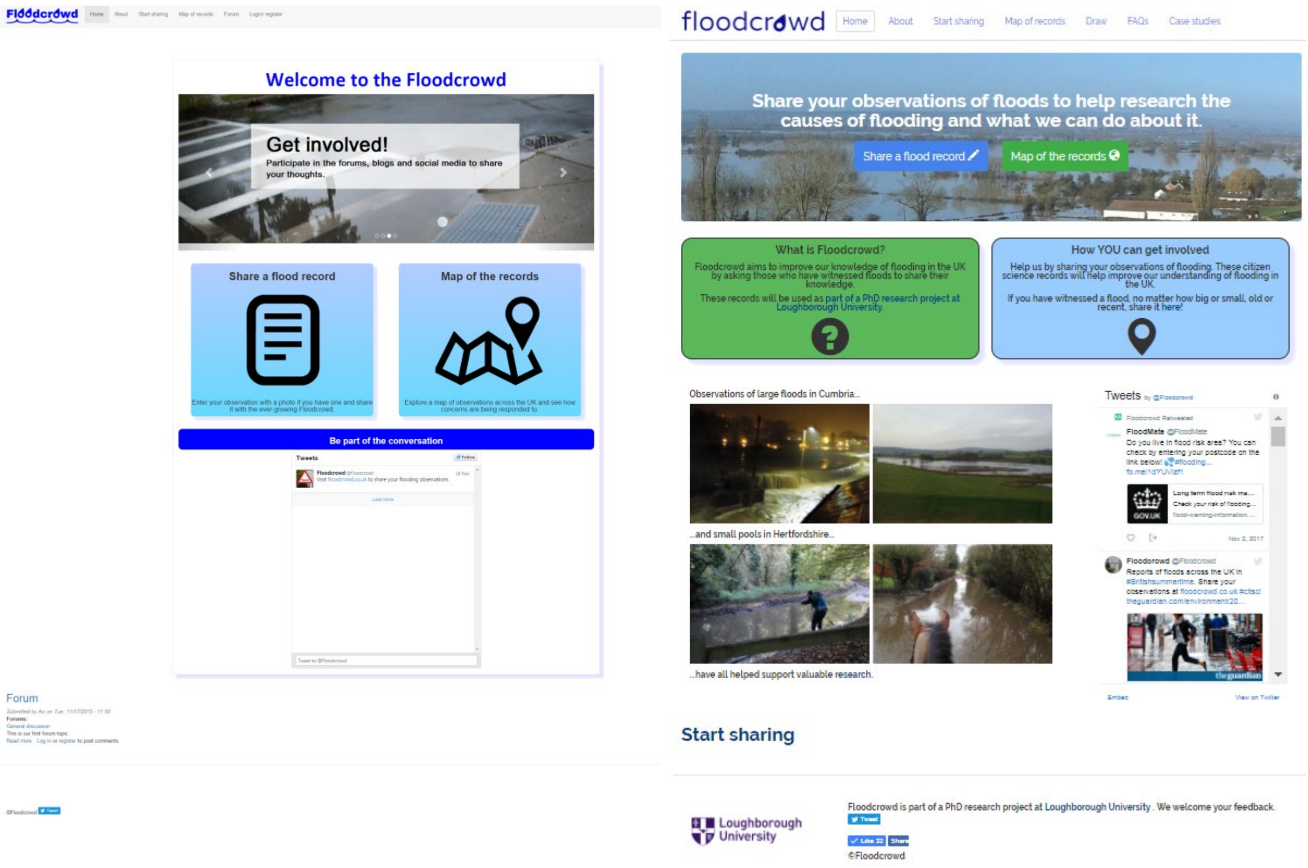

Figure 6.4: Alpha and beta versions of the Floodcrowd website landing page

Local residents also complained that 10 fields in the form made contributing cumbersome. In response, the beta web-form only included five fields to enable visitors to rapidly submit observations (Figure 6.5). The web-form fields consisted of:

1) Location: Using a geolocation field users could use a GPS or a Google map to mark their location on mobile and desktop devices
2) Type of flood: Using a drop down list
3) Date and time: Using a built in application
4) Further details: Using an open ended text field
5) Photo: Using a phone camera of a file upload.

6.4.2.2. Second iteration

Between 1st December 2015 and 27th March 2018, the Floodcrowd website was visited 4000 times, 4% of which resulted in a submission being shared. The majority of these (66%) of these were made during the workshops and outreach events. However, there is little evidence of participation continuing beyond the outreach events. While the *@floodcrowd* twitter profile attracted 260 followers and made 20,000 impressions in a series of 300 tweets encouraging participation resulting in 413 website hits, only 16 social media clicks ended in a submission. Eight of these were removed for being deemed to be invalid. For example, one UK submission included a photo of a flood traced to a well-publicized event in Bangladesh.

In response to a number of blank submissions, the first three fields were made compulsory to ensure a minimum level of information is shared. In response to requests by users, the website included a map of records for instant open access data viewing on the *'map of records'* and an option to keep submissions private (Figure 6.5). Based on requests, the websites also included an option for participants to submit data anonymously or create a profile associated with submissions.

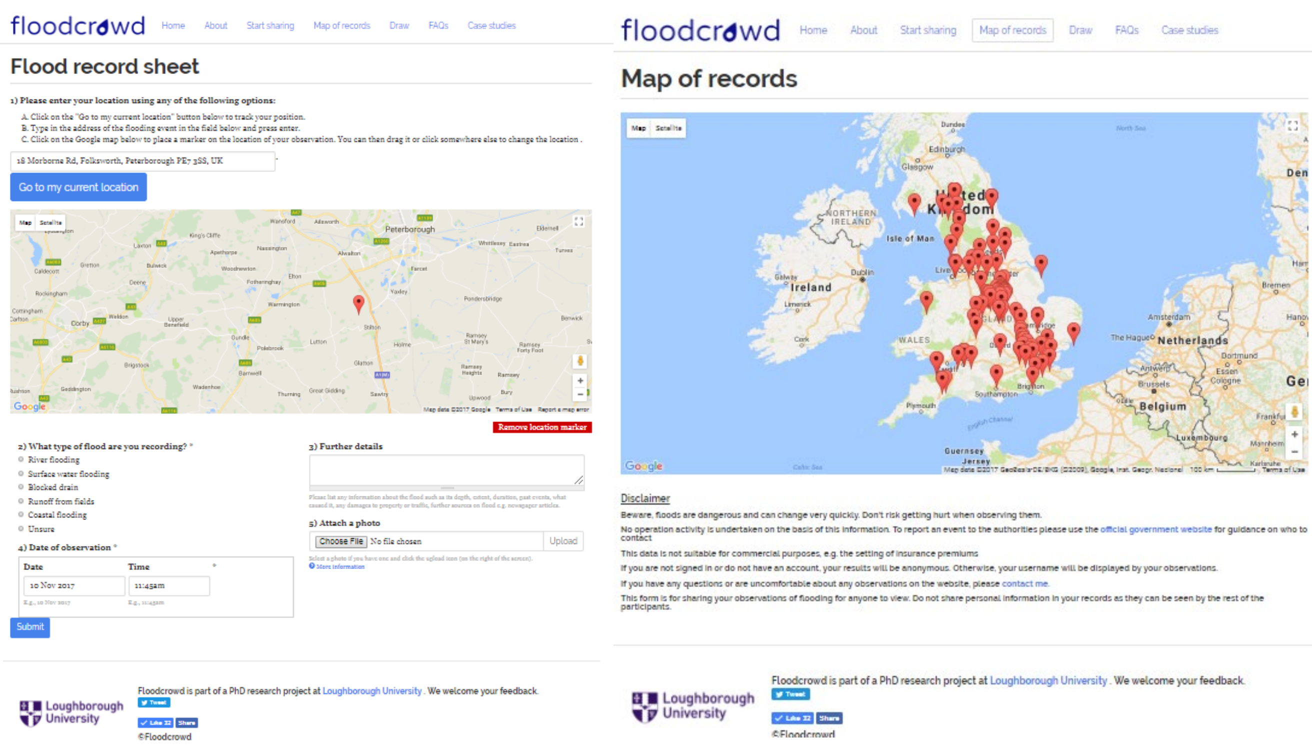

Figure 6.5: Floodcrowd reporting form (left) and map of records (right).

Practitioner feedback on data requirements was incorporated into the website design to ensure that '*run-off from fields*', and '*blocked drain'* were listed as flood types. After a number of submissions appeared to confuse flood types, an '*unsure*' option was also included. In addition, recommended data submissions such as '*flood depth, extent, duration, past events, what caused it, any damages to property or traffic, further sources on flood e.g. newspaper articles'* data were added in the further details section.

During outreach events, members of the public who had frequently witnessed flooding shared observations using a tablet or their own phones (Figure 6.6). Tablets were particularly popular amongst children, 25 of which submitted data during a STEM outreach event at Loughborough University. Observations shared on the Floodcrowd platform were varied in both the type of data and their level of detail. The data consistently included a degree of qualitative information in the *further details* section. During the workshops with flood wardens, it quickly emerged that many flood prone residents did not own smart phones, yet still wanted to participate in the research. In response, hard paper maps were printed (e.g. Figure 6.6), allowing the public to draw and add post-it-notes to the map. These were digitised after each event (Figure 6.7).

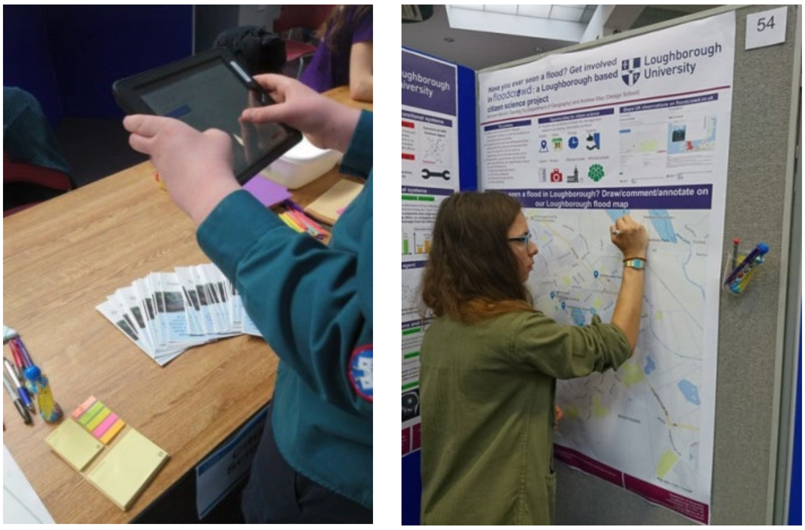

Figure 6.6: Participants entering observations on the Floodcrowd website (left) and on a printed poster of a map (right).

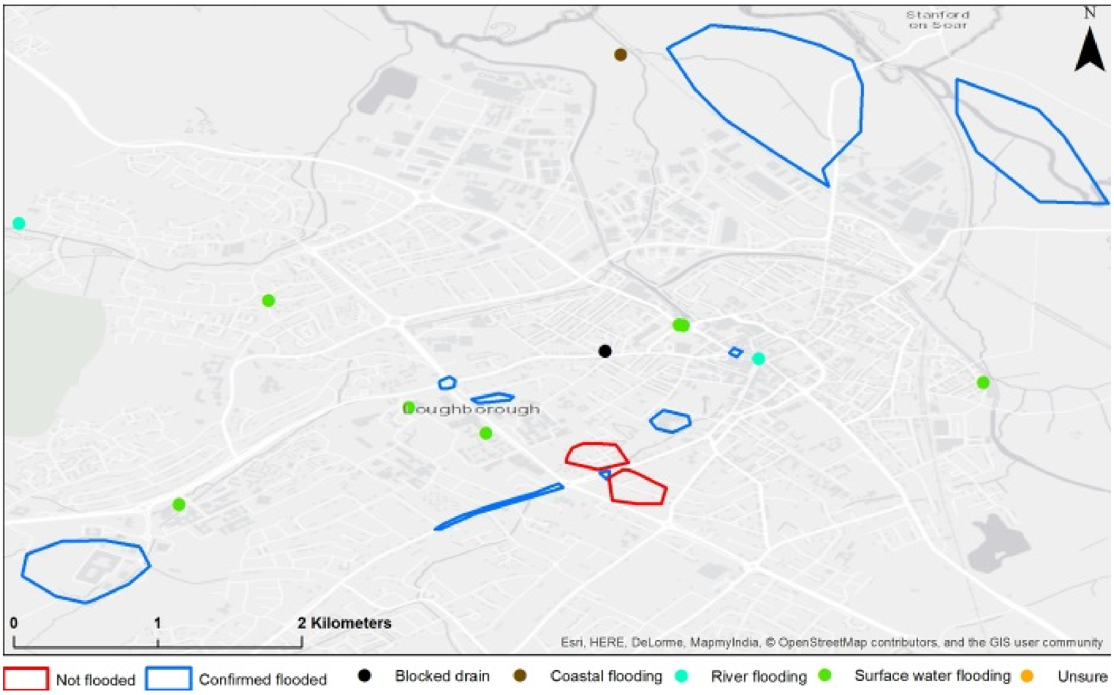

Figure 6.7: Digitised map of flood drawings in Loughborough produced during school community outreach day

In response to the high level of engagement in delineating activities, a *draw* tool was introduced to the website as part of the second iteration (Figure 6.8) but only yielded 5 polygons to date. During outreach events, members of the public described unease about potentially making mistakes when drawing exact extents of floods.

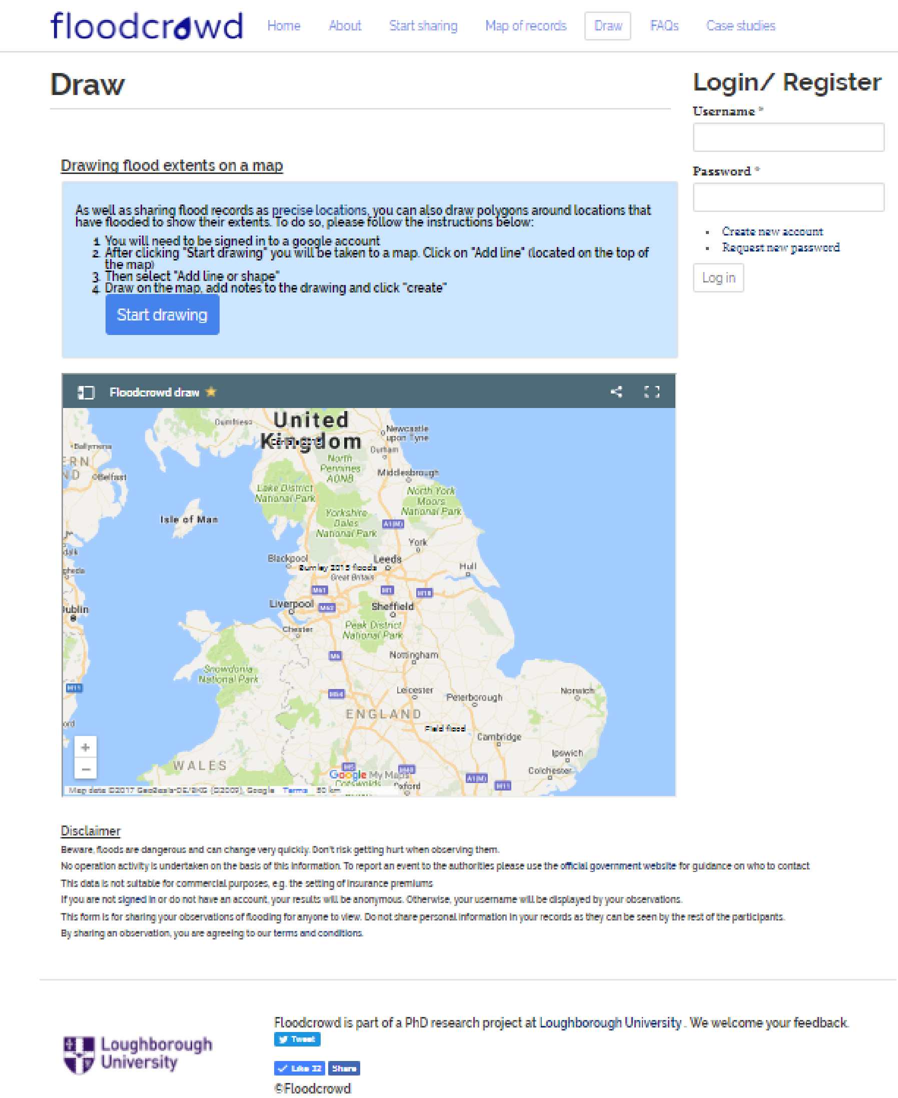

Figure 6.8: Screenshot of Floodcrowd drawing tool

Views about the platform format were also mixed with some participants eager to see a mobile app while others preferred a basic website which they did not need to download. As a result, no mobile application was developed. Through discussions with flood victims, the vast majority of prospective participants expressed an interest in submitting observations through collectivist motivations:

> *'The Environment Agency maps say my area is not at risk but I've been flooded every year… If we all share observations in the local community will that help our cause?' [UK Midlands Community Participant – Flood Warden]*

6.4.3. Extracting value from Floodcrowd submissions

Observations shared on the Floodcrowd platform contained disparate information (Figure 6.9), ranging from detailed accounts of events to one line sentences with a photo.

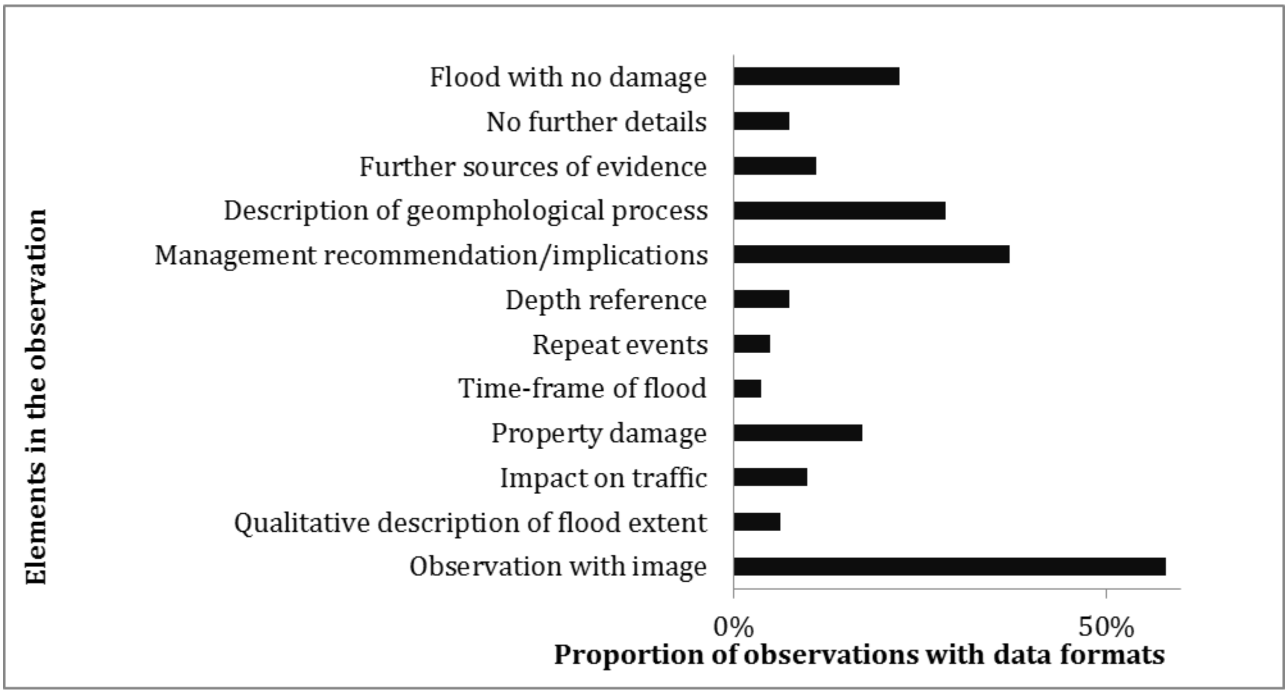

Figure 6.9: Content analysis of Floodcrowd submissions (n=160)

The majority (53%) were small surface water flooding events with minimal damage (e.g. Figure 6.10). Other observations consisted of river floods (35%), coastal floods (5%) and unsure of flood type (7%). A large proportion of the events were sparsely located in rural areas across the country.

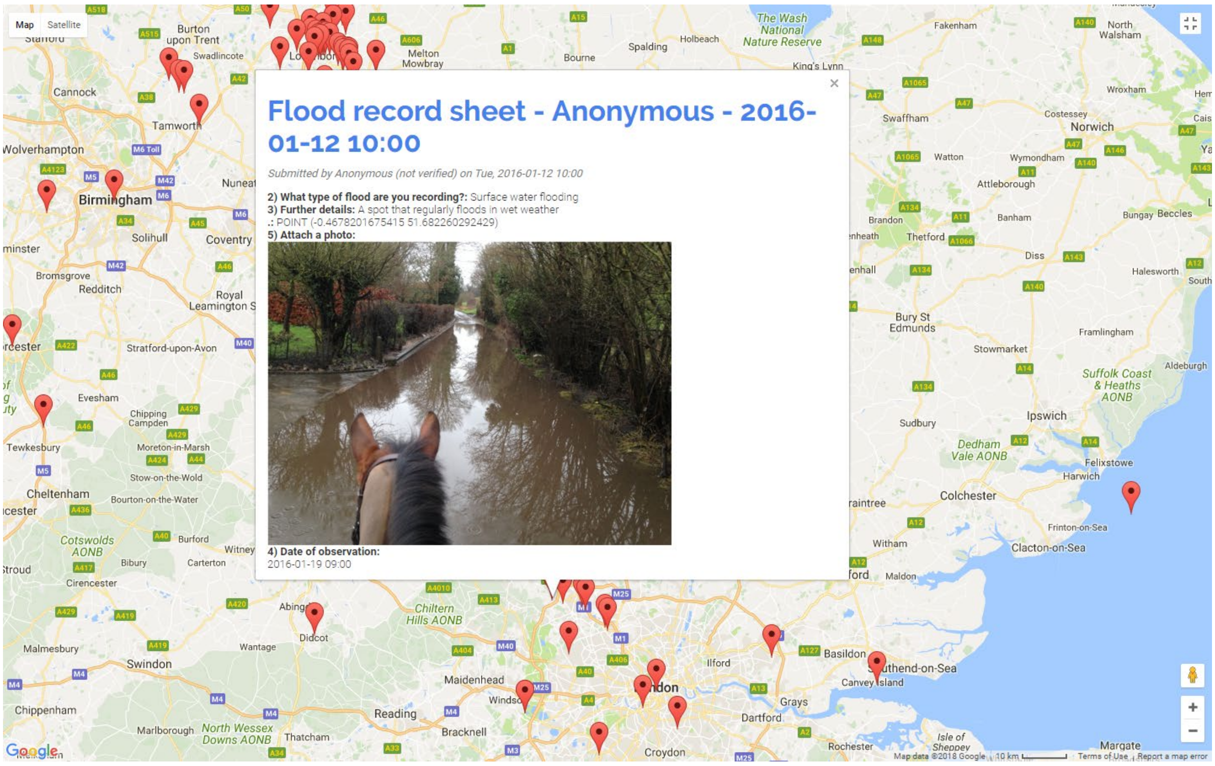

Figure 6.10: Sample Floodcrowd observation from map of records

Isolated rural reports can play a supporting role to local authorities in a number of ways:

> *‘If the general public were reporting a field flooding, we don’t have the time and resources to investigate it… but if we knew about it, then if that field then starts coming on to the highway, it could give us an early warning because we can’t be in all four corners of the county at the same time.’ [UK Southern County Council – Head of Flood Risk Management]*

> *‘This would be very useful to us as it can add random observations e.g. from trains from those who aren’t traditionally flooded… This could be a very useful behind the scenes tool.’ [UK Environment Agency – Head of Incident management]*

> *‘Surface water events are difficult to capture because they quickly appear and disappear so it’s great to have that hard evidence.’ [UK Environment Agency – Scientist]*

According the UK Flood and Water Management Act 2010, on becoming aware of a flood in its area, a lead local flood authority must, to the extent that it considers it necessary or appropriate, investigate (Department for Environment Food and Rural Affairs 2010). As a result, any evidence generated by the public can be highly beneficial:

'The photos are a massive help – I'm flooding and it's a puddle or it's in the house.' [UK Midlands City Authority – Head of Flood Risk Management]

However, for several practitioners, there was not enough data on the Floodcrowd platform during the time of interview for it to be of much value:

'We're interested in smaller events but in terms of us creating a model for an event it would need to be a fairly large one.' [Multinational Risk Management Company – Head of Modelling]

'From what I can see, it's (Floodcrowd) not there yet but it is more useful than just a random photo of a flood.' [Multinational Risk Management Company – Chief Executive]

In such cases, crowdsourcing can only be a tool to indicate where might need further research. A more robust product would need more information:

'The problem with crowdsourcing is you get all sorts of random and varied observations coming through… That's why I don't think crowdsourcing will work in the long term. Given the commercial value of this information, I'd rather send a drone out.' [Multinational Risk Management Company – Chief Executive]

Only 6% of observations on the Floodcrowd platform referred to the timeframe of the event. For post-event reports, local authorities in the UK will typically conduct surgeries and field surveys to collect information about the flood:

'The department need to produce a report under section 19, but it's sometimes difficult to know exactly what happened. Floodcrowd could help us produce this report. At the moment, it can become a door-to-door knocking exercise. The problem with the EA is that we are a transient service with a lot of corporate memory. As people retire, their understanding of local flood issues is lost with them. Floodcrowd could address that…. We need historical data.' [UK Midlands County Council – Head of Flood Risk Management]

Outlines of flood extents such as those produced during the workshops and on the website are highly sought after as they can be overlayed with exposures to give an indication of total damages. They also provide an indication of where it has not flooded – a critical dataset when validating flood models. At present, outlines are increasingly being produced by commercial unmanned aerial vehicle companies, yet for some their costs remain inhibitive:

> *'Lots of companies come to us with extremely complex solutions with a very high price… A 'more than 10 buildings in this area are flooded' would be preferable, it's kind of threshold for us to say 'maybe we should look at that.' [Multinational Risk Management Company – Head of Model Development]*

Hence, drawings on maps shared on Floodcrowd could be useful although practitioners questioned their value as they were not collected to a standard specification. A major barrier to the utilisation of Floodcrowd data for flood management is the quantity and timing of submissions. Over two years of operation, the majority of the 160 submissions that were made, referred to historic events (Table 6.1). These were sparsely distributed over the UK which made them less appealing for use by most commercial organisations:

> *'10 houses in an urban area or 3-9 in a rural area, that's the sort of number where we'd think there's actually something happening here.' [UK Environment Agency – Scientist]*

> '*If there's a three or four day delay, then it's not going to be as useful…If it's a significant flood, it really needs to be a quick turnaround, so a 24 hour cut-off.' [Multinational Insurance Company – Flood Risk Modeller]*

Table 6.1: Time lag between submissions on Floodcrowd and the event they are describing

Days between event occurrence and report	Number of observations
0	46
1	14
2-10	21
11-100	30
>100	30

In the longer term, these data can still be used for model validation:

> *'It doesn't stop having value in five, it's still valuable in 10 years' time, it's all about the cumulative… even if you have 5% of damaged buildings, if you did that over 10 years that would also be useful.' [Multinational Risk Management Company – Managing Director]*

‘In a smaller catchment, it has a higher likelihood of being beneficial to validate flood model runs for specific events.’ [Multinational Environmental Consultancy – Geospatial Technologist]

‘One observation could say something dramatically different to what our model is showing and that would be useful.’ [Multinational Engineering Company – Head of Modelling]

‘Even flood stones are good for conducting extreme value analysis.’ [Multinational Environmental Consultancy – Geospatial Technologist]

Yet, the suitability of Floodcrowd submissions for model calibration is disputed amongst practitioners. Several concerns about data quality and reliability were raised. The vast majority (90%) of submissions were made anonymously. This limited their usability for practitioners who emphasised the added value of knowing the people behind the submissions:

‘We’d rather observations from 15-20 trusted users than thousands from really not accurate observations.’ [Multinational Insurance Company – Flood Risk Modeller]

‘We’re coming from a position where we have almost no publicly available information…. The current data is so bad we don’t really care about bias.’ [Multinational Environmental Consultancy – Geospatial Technologist]

6.4.4. Design implications

6.4.4.1. Remaining challenges

All practitioners suggested that a more effective crowdsourcing platform would need to be run centrally and from a government agency. This could help keep a level of consistency between datasets and increase their utility for a variety of purposes:

‘We’d like some work to go into benchmarking and getting some standards in place.’ [UK Flood Forecasting Agency – Modeller]

‘All cities having their own platforms– it would be much easier just focussing on one, they should be trying to centralise it rather than do their own.’ [Multinational Insurance Company – Research Manager]

However, developing such a tool is not straightforward due to personal and data safety issues:

'The way we work now is to make all our products open data. To add an extra complication in in terms of user's privacy may add extra value but if we can't pass it on then it's got limited use.' [UK Environment Agency – Risk Management Advisor]

The issue of trust was a concern raised in all the interviews and represents a major barrier to the effective implementation for a crowdsourcing project. For some institutions, key to the development of trust is a distancing between themselves and insurers. RMS explained how during field data collection, members of the public will first ask if they are an insurance company before helping:

'If your house is flooded but you're not going to make an insurance claim, you are better off if the insurance company doesn't know it was flooded.' [Multinational Risk Management Company – Head of Model Development]

This distrust of insurance companies has a knock-on effect on type of information members of the public are prepared to share in some government flood surveys:

'Location has always been an issue for us. We get the paper forms back but they don't want to put the location on because they're concerned about the impact on their insurance... It would be great for the public to submit photos for us but we are very aware of all minefields associated with privacy issues.' [Southern County Council, Flood risk manager]

This concern was raised by other practitioners including the National Flood Forum. Yet, the insurance experts that were interviewed in this chapter reaffirmed that information shared as part of a citizen science project such as Floodcrowd was not appropriate for the setting of premiums:

'It's redundant for that because we have the third-party data to tell us where it has been flooding... We also have schemes like Flood Re. It's in their interest, there's a benefit not a punishment …From an insurance perspective, it would help with making sure that they receive quicker help from their insurance company… If they find out it's more at risk than what has been said, then they can lobby the government to act.' [Multinational Insurance Company – Research Manager]

In fact, *'it helps build flood models which is ultimately results in a fairer price of insurance and not harm consumers.'* However, the submissions could affect those affected by floods in other ways:

'If I was going to buy a house and I read on a website that it had been flooded two years ago then that would really give me pause before I bought the house, so I, myself would be wary of giving away that information.' [Multinational Risk Management Company – Head of Model Development]

6.4.4.2. Opportunities for future developments

Given the issues associated with crowdsourcing data quality and privacy, a number of the practitioners indicated that it may not currently be of significant interest to them. However, all practitioners agreed that the value of crowdsourcing could be increased significantly with future technological advances in the field or adaptations of existing apps:

'I think the only way to get it to be used more widely is for it to be a website that someone doesn't have to go to specifically.' [Multinational Engineering Company – Head of Modelling]

One particularly useful development could occur with an increase in active recruitment of volunteers. Big tech companies are increasingly exploiting crowdsourcing. Following crises, Facebook typically asks members of the public in the affected area to mark themselves as safe. Meanwhile, Google actively targets members of the public using its maps application to request reviews and photos of businesses. Such mapping efforts typically do not occur for flooding events, yet they are technologically possible. For example, weather alerts for floods in affected areas can be distributed via Google maps. These alerts could be sent accompanied by a request for further information on smart phone mapping applications. If developed, such a system could generate a real-time GIS dataset of flood impacts. Actively targeting users and asking them to share photos and information about an event brings with it a range of ethical implications:

'Health and safety comes first... You see members of the public trying to take photos of coastal flooding, and they are the wrong side of the sea defence…. the last thing we want to do is give the impression that data is more important than safety.' [UK Environment Agency – Head of Incident Management]]

'It would need to be relevant to our users and privacy aware.' [Technology Industry, Geospatial Technologist at Google]

Such an approach however, is not currently being exploited:

‘To take a more proactive route, you need to make it more of a standard part of people’s day to day interactions. I’m a lot more interested in passive data collection and machine learning and remotely sensed imagery. If you collate this data from different sources, it’s probably going to give you a better representation than the sample data you’ll get from more active crowdsourcing.’ [Technology Industry, Geospatial Technologist at Google]

As a result, more passive approaches have proved more popular*:*

‘We’re monitoring the movements of mobile devices to identify how people are moving around … we could assess whether if flooding occurs, would you expect less people to go to these areas than we would have done previously. If we see that happening, maybe that could be a way of us monitoring the extent.’ [Technology Industry, Geospatial Technologist at Google]

Alternatively, some practitioners also expressed an interest in the gig-economy. An application which was financed by a group from the different practitioners could be used to compensate members of the public for submitting evidence of certain events. Such an application would have a significant value to all the practitioners:

‘If we wanted to do this thoroughly, we would have to go down this gig economy route or having some kind of system that gets people on the ground. For example we could have a number of steps. Step 1: Social media analysis… Step 2: We mobilise a huge army of local workers who then go out and fill in some kind of simple app which they use to report damage to different buildings… Step 3: we send our recon team to particular locations which are important for research purpose… You could use social media as step 1 to find out where flooding is occurring, then pay people to do a more thorough job of walking up and down the streets and noting the postcodes.’ [Multinational Risk Management Company – Head of Model Development]

‘An app that provided guidance on how to record data would also have value…. That would improve your confidence in it… There’s an issue of simply free-form crowdsourced data as opposed to this sort of app where members of the public are given directions.’ [Multinational Environmental Consultancy – Geospatial Technologist]

6.5. Discussion

Through mixed method approach using web-development, interviews, workshops outreach events and meetings with a wide range of practitioners, this chapter has emphasised the scale of, demand for, and interest in crowdsourced flood data. Practitioners from the insurance industry, engineers, risk management companies, governmental organisations and flood forecasters all have an interest in a range of data types which can be generated using crowdsourcing. However, governments, businesses and scientists frequently lack key local knowledge, causing considerable uncertainties for model validation, calibration, and assimilation tasks (Jongman et al. 2015). Systems for reporting flooding are typically limited in scope and not open access, resulting in a significant level of key information being unavailable to those who need it to support flood response and research. As a result, practitioners are often turning to other forms of VGI for supporting emergency response, forecasting, inundation modelling, catastrophe modelling, damage estimation and risk management. The efficacy of using crowdsourced data to support flood response has been demonstrated through the widespread adoption of data extracted from social media platforms such as Twitter (Smith et al. 2015; Fohringer et al. 2015; Kryvasheyeu et al. 2016) and Tomnod (Chapter 5). With institutions increasingly relying on social media for information on flooding, the role of VGI is growing in credence in relation to PGI. However, as Pandey & Natarajan (2016) and Smith et al. 2015) emphasise – social media feeds are limited in their efficacy at validating models. Practitioners expressed concerns regarding the accuracy and reliability of social media posts as well as the processing efforts required to extract value from texts and media. Hence, their interest in, and use of social media appears to reflect the limited availability of data in general as opposed to a significant value attributed to social media feeds. More filtered and quality controlled datasets which could be generated through crowdsourcing were far more appealing.

Crowdsourcing can provide flood and catastrophe modellers with additional data for model validation and calibration. Models for flood damage assessment typically rely on water depth as a main indicator of the hazard, with depth-damage curves considered as a standard approach of estimating costs (Merz et al. 2010). There are a wide range of damage models available in the literature for different sectors and regions (de Moel et al. 2015). However, issues of uncertainty in damage modelling remain due to the importance of additional variables including the flood duration and flow velocity (Scorzini and Frank 2017). Other data such as the presence of debris, water contamination, implementation of precaution measures – despite being influential – are rarely taken into account (Douglas et al. 2010). This is often due to the limited data which can be feasibly collected on a flood event. Models are typically based on post-event surveys, from which depths, extents and damages are more easily acquired. However, through the public outreach and the submissions on Floodcrowd, it is clear that these lesser known data are often known to, and can be shared by members of the public. This may have significant implications for future damage estimation studies if a sufficient level of detail regarding flood durations, speed and water quality can be shared by the public. Moreover, given the degree of implicit knowledge possessed by those who have witnessed floods, crowdsourcing could be used to support alternative modelling approaches and blue sky thinking for decision making.

A small number of observations submitted on Floodcrowd included information which could be utilised for traditional flood damage model validation. The majority were dominated by small, largely unreported, localised surface water events. Nevertheless, these can be highly valuable to other practitioners such as researchers and governmental agencies as they can help build a more holistic overview of flooding issues and risks (Moftakhari et al. 2017). In particular, a growing interest in repeat nuisance events is emerging given their cumulative impacts (Moftakhari et al. 2017) and importance for climate analysis (Slater and Villarini 2016). The interviews revealed that local authorities also highly value such observations as they provide context and forewarning which help them better support rural communities. In addition, observations shared on Floodcrowd included recommendations for management, anecdotes, sentiments and descriptions of processes which are also valued by a number of practitioners. Hence, this chapter supports Schnebele et al. (2014) in asserting that VGI on natural hazards has more potential applications than just capturing real-time information.

Crowdsourcing, in its nature, is a collaborative task which requires mutual trust between contributors and end-users. As a consequence, privacy, intellectual property and the ethics of VGI on flooding is an ongoing issue of debate in the field of crowdsourcing and citizen science (Scassa 2013). Whittle et al. (2010) highlight instances of distrust between members of the public and insurance companies in relation to flood information. Yet, members of the public are contributing VGI through social media and location based apps which can be exploited for flood risk research. By agreeing to the terms of use of social media sites such as Twitter, YouTube and Flickr, members of the public are consenting to sharing publicly accessible information. As a result, perhaps unwittingly, they are providing data of floods which are then used by governments and corporations (including insurance companies) to support response teams and validate flood extent and damages models.

The phenomenon of VGI use by corporations is not limited to social media. By consenting to sharing geolocation on Google Maps, the public are providing VGI which can be used in flood risk research. Insurance companies have reassured that VGI would not affect premiums. With the introduction of Flood-Re in the UK which offers flood insurance cover for high risk households, with fixed premiums (Flood-Re 2016) – it would not have that impact on individual insurance rates. Yet, given the specificity of this current policy to the UK, concerns over insurance premiums remain highly relevant in countries without such government provisions. For residents in the UK and beyond, the utility of social media by institutions could have implications for public participation if they feel it may have negative repercussions. For example, Debatin et al. (2009) found that Facebook's changed privacy policy has driven away participants concerned about the sharing of personal information. In the case of sharing flood information, while images of a flooded home may not affect its insurance premium, the ability of such information to dissuade a potential buyer of the house cannot be understated. This is particularly pertinent in 2018 with recent controversies surrounding the availability and purchasing of personal data from Facebook. Therefore, generating VGI on flooding which has no negative impacts on participants represents a significant challenge which should be tackled through improved co-ordination with local communities and grassroots movements. This phenomenon should be further investigated with respect to the wider debate over the ownership of information and the ethics of sharing media of public spaces.

In a stakeholder study, Mazumdar et al. (2017) argue that there should be mechanisms to enable citizens to see immediately or automatically the results of data collection, and communicate the end results of their activities and how they have contributed. Yet, in order to motivate volunteers, further engagement and education is needed, particularly with regards to ensuring that they are aware of how other forms of VGI can be used by practitioners and the wider community. Hence, the current research highlights a marked difference in human factors affecting participation than some other fields of citizen science such as bird watching where fewer areas of controversy exist. Through an iterative design process with contributors and end-users of crowdsourced flood data, this chapter has identified several issues and insights that would not have been possible without the iterations of the website. Rather than just engaging with the public, it is clear that different organisations with an interest in crowdsourcing can work together to co-produce better platforms and data flows of flood information. This will help avoid replication of crowdsourcing platforms and ensure data can support as many practitioners involved in flood risk management as possible. This chapter raises a number of key questions for further discussion amongst the academic, corporate and citizen science community: should crowdsourced data (like other citizen science projects such as e-bird) always be made open access? Who should be given access to the data? Beyond just crowdsourcing, should photos of flooded homes be kept from the media? Could a crowdsourcing platform supported by the insurance industry ever gain public support?

The level of public participation in Floodcrowd reveals a motivation by many witnesses of flooding to share their knowledge. The positive results derived from public workshops, seen in Lane et al. (2011), Starkey & Parkin (2015) and Bracken et al. (2016) indicate that discussions with flood-prone communities can yield information that can be useful to a range of practitioners. However, despite an extensive online outreach campaign, the Floodcrowd website received few independent submissions. The low participation on the platform is not necessarily due to a lack of public interest in citizen science for flood management. Rather, the website failed to engage and maintain interest over time, highlighting the need for platforms to provide a greater incentive for citizens. Such challenges have also been found by other citizen science projects. For example, Wehn et al. (2015) found that requesting people to respond and participate more actively in urban planning initiatives was not successful. Across the various specialised flood event sharing platforms, there remains a very limited degree of crowdsourced flood information available for informing flood risk management (Cristancho-Lacroix et al. 2014). Clearly, a one-size fits all crowdsourcing platform is unlikely to suit all flood affected communities. This emphases the need for further user-testing and innovation to engage participants in long term flood data collection and sharing.

Floodcrowd presents an opportunity to explore the key design challenges to effectively supporting practitioners in improving flood risk management. Central to motivating members of the public to participate during the outreach events was the expectation that authorities would pay attention to their submissions and use them to take positive action. As such, this chapter reaffirms that involving end-users from preconception stages is essential for the effective implementation of a flood crowdsourcing project. This chapter used interviews to ensure open and wide-ranging discussions were possible. An iterative design approach using practitioner interviews is shown to be an effective way of working towards identifying the design requirements of a more valuable and engaging platform

(Department for Environment Food and Rural Affairs 2010). However, further research may benefit from using questionnaire surveys to rank the importance/usefulness different aspects of crowdsourcing, such as data types.

Through workshops with community groups and resilience forums, this chapter has helped identify gatekeepers to communities whose experiences of flooding events would have otherwise been omitted from the research. Yet, it is acknowledged that an alternative design approach may be more suitable given the small number of contributions outside outreach events. Several areas of further research, recommendations and suggestions have been identified, based on analyses, contributor feedback and end-user interviews:

- Incentivising participation
- Addressing participant concerns over potential negative impacts of submissions
- Maximising the value of qualitative flood observations
- Long term engagement of citizens
- Alternative design approaches.

Human factors affecting participation represent a significant area in which progress can be made to improve platform design. Alternative visions including a project run centrally by government, a paid app or a system of active recruitment should be investigated further and appropriate prototypes tested. Such systems could connect contributors with end-users in a more dynamic way. At present, some of the greatest interest in developing innovative platforms such as these appears to be derived from the private sector. Therefore, designing these in such a way that can support, not hinder local communities and motivate them remains a significant challenge which requires significant further public engagement to overcome.

6.6. Conclusion

This chapter reveals that crowdsourcing is becoming increasingly appealing to a range of practitioners including the insurance industry, engineers, risk management companies, governmental organisations and meteorologists. Types of data which practitioners are particularly interested in with regards to crowdsourcing differ between organisations. Yet, they typically include flood depths, photos, timeframes of events and historical background information. Only a fraction of this important knowledge is currently shared by members of the public through flood event reporting tools. While some members of the public share information of use on social media, this has many limitations which has led to organisations exploring further ways of engaging members of the public. Many citizens are able and motivated to share additional implicit knowledge, but require certain triggers to encourage participation. Through an iterative design process of the Floodcrowd website, these triggers are explored and the platform was adapted accordingly. Workshops show that public are interested but not necessarily engaged with specialised platforms. From the observations that were submitted, several implications can be drawn for flood response and risk management. Local authorities and Environment Agency representatives indicated that even small surface water events shared on the website could be of value. These sorts of observations, while having little use for large scale flood model validation, could be applied for different purposes such as flood response and management. For experts in the risk management industry, crowdsourcing could not only help validate catastrophe models, but provide new data which could support the development of alternative modelling approaches. This research emphasised a significant interest into the principles behind Floodcrowd from both the practitioners and members of the public. In doing so, it highlights the importance of a crowdsourcing platform to engage both members of the public and end-users. Several challenges to the effective implementation of a crowdsourcing platform exist including a number of unique ethical implications related to the crowdsourcing of flood information. By analysing some of the challenges, key questions remain which need a thorough deconstructing in future studies.

Chapter 7: Overview and synthesis

7.1. Introduction

This thesis set out to investigate the phenomenon of crowdsourcing for flood risk management. To this end, the thesis has presented a unique framework for improving the role of crowdsourcing of floods by addressing four key research questions. This Chapter aims to summarise the main findings by outlining how each research question has been addressed. The key themes that have emerged through the research and recommendations for further research are then discussed. These aim to stimulate thought and provoke discussion about the potential and future implications of flood crowdsourcing.

7.2. Contribution to knowledge

7.2.1. Overarching aim

The overarching aim of this thesis was to investigate the use of crowdsourcing for improving flood risk management through an examination of the public's participation in: i) micro-tasking for satellite imagery analysis and ii) the sharing of local flood observations. To do so, both the physical and human components of flood crowdsourcing were outlined and studied using a multi-method approach. This process is broadly outlined in Figure 7.1 which demonstrates the interdisciplinarity and complexity of the flood crowdsourcing process. As emphasised in Figure 7.1 all these phases are examined and reflected on throughout the thesis. In the literature review, professional data sources including satellite imagery, water time series' and field observations are outlined. Through Chapter 3, the landscape of flood crowdsourcing is illustrated by developing a comprehensive typology. This demonstrates the role that crowdsourcing can play in addressing the limitations of professional sources of information. Two of the most rapidly evolving forms of flood crowdsourcing - collaborative mapping and online volunteering - are then explored in greater detail through Chapters 4-6. In these Chapters the role of practitioners and participants in shaping the campaign design and the resulting impact of the campaign on participation are investigated. Ultimately, the dynamic relationships between these factors illustrate the efficacy of using crowdsourcing for flood risk management. As such, this thesis has aimed to provide a holistic assessment of the world of flood crowdsourcing and identify ways in which its potential can be fully realised.

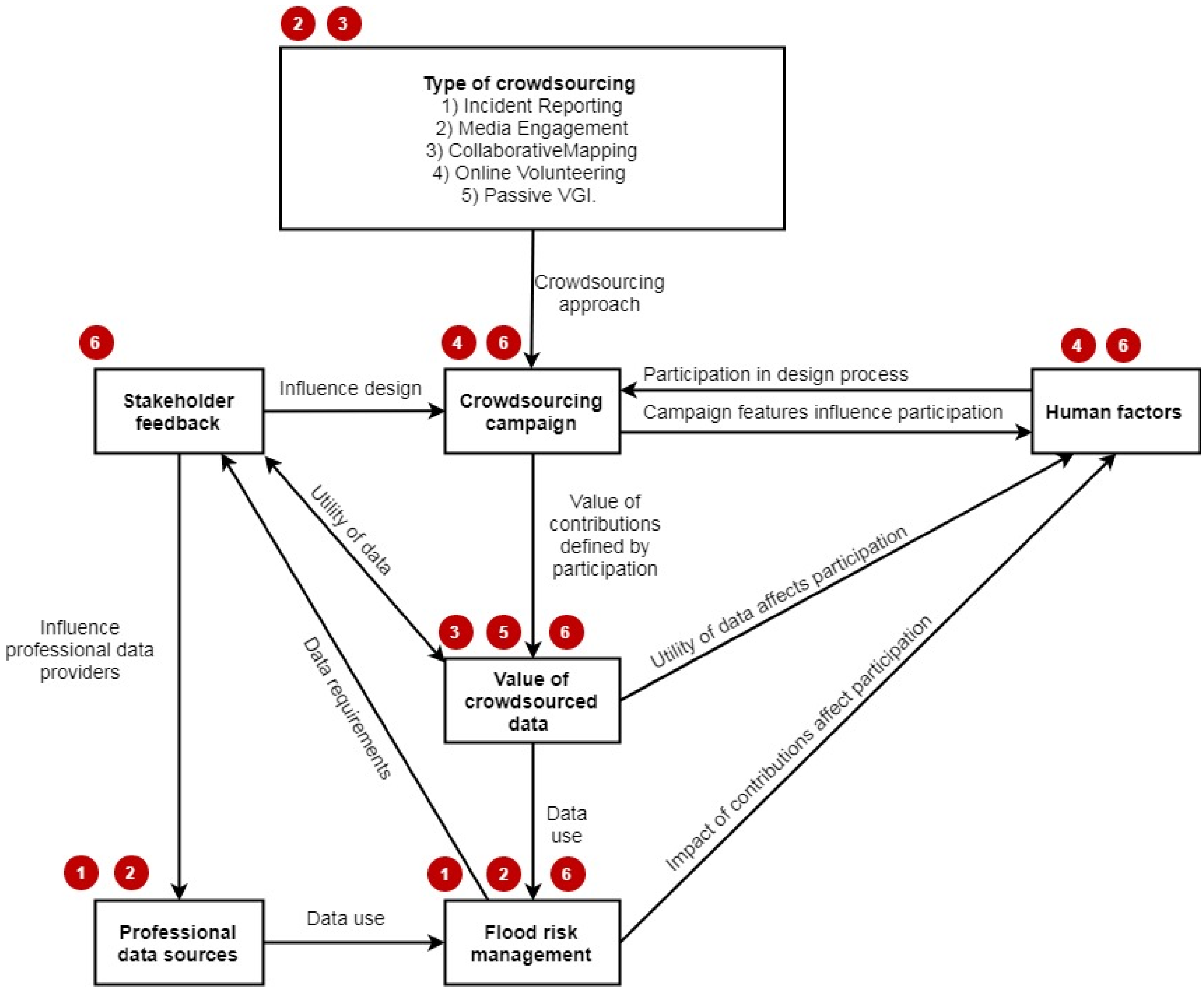

Figure 7.1 Thesis summary: process of using crowdsourcing to support flood risk management (numbers refer to Chapters where each topic is addressed in the thesis).

7.2.2. RQ 1: What are the characteristics of crowdsourced flood data, and how are they evolving?

Throughout this thesis, crowdsourced flood data have been examined, analysed, and their importance interrogated. The introduction and literature review outline the historical role of public participation in flood information sharing. With flood narratives from sources such as published diaries dating back to the 10th Century, the phenomenon of public participation in flood research is shown to be a longstanding one (Black and Law 2004). Flood crowdsourcing has only recently evolved and expanded with an increasing number of collaborative mapping exercises enabling citizens to share their narratives (Landstro *et al.*, 2011; Lane *et al.*, 2011; Bracken *et al.*, 2016; Cinderby and Forrester, 2016). Despite the success of some projects, such narratives are rarely made use of as crowdsourcing tools and engagement activities are not widespread. It is also evident through an examination of micro-tasking platforms, that sharing flood knowledge is not the only way for crowdsourcing to be used to generate information.

In Chapter 3, five key types of flood crowdsourcing are outlined: i) incident reporting, ii) media engagement, iii) collaborative mapping, iv) online volunteering and v) passive VGI. Through the development of this typology, Chapter 3 characterised the current and potential future landscape of flood crowdsourcing. The typology represents a wide range of initiatives with radically different aims, objectives, datasets and relationships with volunteers. When these are viewed with respect to existing typologies such as Arnstein (1969), Bonney et al. (2009), Wiggins & Crowston (2011), Brabham (2009) and Haklay (2013), their distinct characteristics are often not reflected. Yet, in Chapter 3, the flood crowdsourcing typology provides a more appropriate starting point for any form of enquiry into the field. Passively shared data from social media has provided usable information on depths and timings of events, yet as emphasised by studies such as Smith *et al.* (2015), their data are often associated with a high degree of uncertainty. Collaborative mapping campaigns have provided more detailed information which can support a range of practises albeit often being limited to a smaller area (Ping et al. 2016). Most governmental incident reporting tools do not provide open access data, making it is difficult to study their characteristics. Yet, their reporting forms typically mirror many of those collaborative mapping platforms, indicating a degree of similarity.

Media engagement generates a vast quantity of photos and narratives of flooding events across the globe which may, on occasion be validated by sending reporters to the scene. Yet, often these are not verified using a robust approach, raising an open-ended question as to their value. Data from micro-tasking platforms such as Tomnod aim to provide useful information for emergency response teams and risk assessments. ‘Damaged Buildings’, ‘Blocked Roads’ and ‘Areas of Major Devastation’ are all provided with an associated crowdrank rating (Carmen Fishwick 2014; Meier 2013). This measure of confidence is based on their consensus score and can be compared with raw imagery for validation. In many cases data produced through micro-tasking complement the existing imagery by producing useful digitisations. Through Chapter 5, their characteristics are outlined, showing a significant added value by identifying complex impacts in imagery of disasters. Yet, through Chapter 5, it is evident that some of these characteristics can be replicated by traditional remote sensing techniques.

The characteristics and the nature of crowdsourced flood data are rapidly evolving. During this PhD, several new platforms have emerged and existing campaigns have changed in their approach. For example, several Tomnod campaigns are now asking members of the public to validate their own remote sensing assessments. In these campaigns, the nature of the citizen contributions has changed from adding value to adding confidence to assessments. Campaigns such as Facebook crisis response have also evolved to include information sharing and offers of help such as accommodation. Technological advances are rapidly changing the way in which some crowdsourcing campaigns operate. Google crowdsource is one such example as it has the capabilities of very few other crowdsourcing platforms – it is readily available on almost every mobile phone. In Chapter 6, tools such as GPS tracking and machine learning are identified as having the potential to generate footprints of floods. By developing a typology and examining data from a range of campaigns, this thesis has illustrated the changing characteristics of crowdsourcing flood data leading up to the present day. In doing so, it has shed light on the immense and ever-increasing power of citizen participation in the production of flood information. For practitioners, the typology can be used as a framework to help find solutions to specific challenges using crowdsourcing where possible. This can be achieved by continuously evaluating the role of crowdsourcing alongside other knowledge gathering procedures to develop the most successful protocols.

7.2.3. RQ 2: How do human factors affect participation in flood crowdsourcing projects?

The literature review outlined a growing research interest in human factors for crowdsourcing and citizen science campaigns. Yet, it also emphasised that these have often been divergent with differing participant populations and experiences between platforms (Budhathoki and Haythornthwaite 2013; Dodge and Kitchin 2013; Muki Haklay, Singleton, and Parker 2008; Jordan Raddick et al. 2013; Rotman et al. 2012). For online volunteering, the effect of human factors was specifically investigated in Chapter 4. This demonstrated that unlike many other online crowdsourcing campaigns, participant populations are not always dominated by males as has been found in studies such as Raddick *et al.* (2013). Demographics are significant as age and gender have been linked with an impact on participation and engagement. Tomnod volunteer motivations are largely altruistic, with participants concerned by the impact of their contributions on the humanitarian situations which they are aiming to support. Hence, volunteers expect well-communicated tangible results and contact with those behind the platform. These findings relate strongly to those of Chapter 5 which argue that in many cases the contributions of volunteers are superfluous as some impacts can be mapped automatically using image classification techniques. Given similarities between campaigns run by Tomnod and other platforms such as Zooniverse and Galaxy Zoo, these findings may have far reaching implications for online volunteering and crowdsourcing participation. Many participants are highly interested in exploring the world and enjoy the browsing features on Tomnod. As such, the freedom given to volunteers to explore maps needs to be balanced with the data quality they produce. Chapter 4 found that if organisations responsible for crowdsourcing projects do not disseminate results, provide feedback and training to participants, a platform risks losing volunteers. These lessons were applied in the development of Floodcrowd as part of Chapter 6 by ensuring that participants were regularly engaged in the design process.

Chapter 6 provided evidence of the different human factors affecting participants of collaborative mapping campaigns adding studies such as Lanfranchi *et al.* (2014) and McCallum *et al.* (2016). Collaborative mapping is radically different to micro-tasking and this was reflected in the feedback acquired during the iterative design process. Flood prone communities and members of the public were primarily motivated by issues associated with local action when sharing their observations. With regards to platform design, the workshops showed that the public are interested but not necessarily engaged with specialised platforms. Certain triggers were needed to stimulate participation and these were largely related to the level or attention practitioners were paying to their contributions. Cutter et al. (2003) argue that even when communities may understand the issues posed by natural hazards, risk reduction and vulnerability are often not salient concerns until after the disaster occurs. However, for many citizens, sharing information on smaller nuisance events was an engaging and meaningful activity. This emphasises the importance of research into human factors for improving the engagement of participants in long-term flood data collection and sharing. In doing so, it builds on studies such as Landström *et al.* (2011) in identifying ways of better engaging with local communities to co-produce on flood risk management. For practitioners, this thesis emphasises the need to engage with participants at every stage of a crowdsourcing project, and be ready to change its direction where necessary. Failure to keep the dialogue open as has been the case in many crowdsourcing projects will inevitably lead to its failure.

This thesis has illustrated how flood crowdsourcing has both similarities and differences with other forms of crowdsourcing and citizen science. In the most part, participants of

Floodcrowd and Tomnod did not share the sorts of motivations to contribute to scientific discovery as has been seen in Galaxy Zoo (Raddick *et al.* 2013). Rather, participant expectations of action to be taken based on their contributions is a unifying theme amongst the feedback received for Floodcrowd and Tomnod. This reflects both the urgency and the politics of flood risk management and the importance of action to the communities who report on it. As such, these implications should be considered in the development and evaluation of further crowdsourcing platforms.

7.2.4. RQ 3: What roles can crowdsourcing play in supporting flood risk management?

The roles crowdsourcing can play in supporting flood risk management are investigated throughout this thesis. The need for more flood data both in quantity and quality is emphasised as a critical factor in supporting a range of flood risk management policies in the introduction and literature review. These outlined the nature of flood risk management, what it involves, the key players and their data requirements. Governments, businesses and scientists frequently lack key local knowledge, causing considerable uncertainties for model validation, calibration, and assimilation tasks (Jongman et al. 2015). Many practitioners have aimed to engage communities in observation sharing initiatives with the objectives of supporting a wider range of flood risk management policies. The positive results derived from public workshops, seen in studies such as Lane et al. (2011) and Bracken et al. (2016) indicate that discussions with flood-prone communities can yield information that can be useful for flood risk management. However, the extent to which implicit knowledge can support a broader range of practitioners has been largely understudied.

In Chapter 3, it is revealed that flood reporting differs from many other forms of crowdsourcing through the way in which observations are utilised by authorities and corporations. As well as broadly illustrating the roles that different types of crowdsourcing can play in supporting flood risk management, this thesis has focussed on two major types: collaborative mapping and micro-tasking. Through interviews with a range of practitioners, Chapter 6 investigated collaborative mapping as a tool for supporting flood risk management. In doing so, it supported Demir and Krajewski (2013) in arguing that a wide range of local flood information can be highly valuable for flood risk management. These data include information about fluvial-geomorphological processes during flooding, hydraulic variables, causes and impacts of floods. The types of data which practitioners are particularly interested in with regards to crowdsourcing differ between organisations.

Yet, there were some common themes. From catastrophe modellers to engineers, flood forecasters to local governments, key datasets such as inundation depths from members of the public are highly desirable. Other information including: flood durations, water speed, water quality and extents are all valuable to practitioners involved in flood risk management. Only a fraction of local knowledge is currently shared by members of the public through flood event reporting tools. While some members of the public share information of use on social media, this has many limitations which has led to organisations exploring further ways of engaging members of the public.

As part of Chapter 6, different authorities are shown to have varying perceptions on the use of crowdsourcing for flood model validation. Given the absence of many 2D datasets on flood duration, modelling approaches are often limited to the available depth data (Merz et al. 2010; Royse et al. 2017). Crowdsourcing could change this through the provision of more information on additional variables including the flood duration and flow velocity (Scorzini and Frank 2017; de Moel et al. 2015). Other data such as the presence of debris, water contamination, implementation of precaution measures – despite being influential – are rarely taken into account (Douglas et al. 2010). While previous studies have demonstrated the demand for these sorts of datasets (de Moel et al. 2015; Koks et al. 2015; J. Hall, Sayers, and Dawson 2005), this thesis has emphasised the role crowdsourcing can play in filling an obvious gap in the supply of such information. This thesis has outlined the different types and changing nature of crowdsourced flood information. In doing so, it has provided an opportunity to radically improve modelling approaches through further testing of crowdsourced data.

The ability of remote sensing to map flooding processes and impacts has been demonstrated in the literature review and in Chapter 4. As a discipline, it is revolutionising our understanding of, and ability to respond to flooding (Voigt et al. 2016). Yet, automated techniques have always been limited in their ability to detect certain impacts which only a human could ascertain. Chapter 5 highlights the unique role of the human for supporting remote sensing teams in generating key flood risk information including blocked roads, flooded buildings and areas of major devastation. Leveraging the crowd to analyse imagery proved effective in classifying damaged buildings. Where imagery was of a poorer quality, the role of crowdsourcing changed as humans could add high-confidence information which supervised image classification was unable to match. The identification of urban flood hotspots is a highly sought after data-source for integrating flood risk assessments with mitigation (Jiang et al. 2009; Jalayer et al. 2014; Atif et al. 2016).

Therefore, this thesis has demonstrated the utility of combining crowdsourcing with traditional remote sensing techniques to identify the most affected areas of a disaster and its ability to support flood risk management.

7.2.5. RQ 4: What role does platform design play in maximising the efficacy of crowdsourcing for flood risk management?

As emphasised in Figure 7.1, this thesis has explored a wide range of design approaches for flood crowdsourcing platforms. Platform design plays a crucial role in keeping participants engaged and making contributions valuable to practitioners (Haklay et al, 2008; Rotman *et al.*, 2012; Budhathoki and Haythornthwaite, 2013; Dodge and Kitchin, 2013; Raddick *et al.*, 2013). Chapter 3's flood crowdsourcing typology helps illustrate the different design approaches to flood crowdsourcing. From collaborative mapping exercises to incident reporting, many event sharing platforms have radically different design approaches. Yet, often these different platforms request the same types of data. Media engagement projects and online volunteering platforms offer alternative design approaches which succeed in engaging substantial numbers of participants (Wei et al. 2011). Hence, this thesis emphasises that a one-size fits all crowdsourcing platform is unlikely to suit all flood affected communities and practitioners. To this end, different design approaches are investigated through case studies including Floodcrowd and Tomnod.

When engaging with interdisciplinary research such as crowdsourcing, Bracken et al. (2015) argue that measures should be taken to engage all parties. Issues should not be pre-determined without involving non-academic experts and the public, since this is likely to alienate people from the process. This is reflected in the overall conceptual model of the thesis. In Chapter 6, through an iterative design approach, participant perspectives provided valuable insight into the usability of Floodcrowd. Suggestions for a shorter questionnaire and hard copies of maps for some participants were used to inform the platform's design. This helped make it easier for subsequent participants to contribute. In the iterative design process, governments and businesses outlined the sorts of data that they needed and these were then specifically requested in reporting forms. Central to motivating members of the public to participate during the outreach events was the expectation that authorities would pay attention to their submissions and use them to take positive action. As such, Chapter 6 reaffirms that involving end-users from preconception stages is essential for the effective implementation of a flood crowdsourcing project. This thesis has found that by taking steps to improve the usage of publicly submitted data, platforms can in turn expect more motivated and enthused volunteers. Chapter 6 also revealed that some of the greatest interest in crowdsourcing comes from the private sector. Such systems could connect contributors with end-users in a more dynamic way. Therefore, much work is needed to explore the ways in which platforms can be designed to support both businesses and flood affected communities.

Crowdsourcing projects typically falter when training and feedback is unclear or when volunteers feel patronized or perceive that they are undervalued by professionals (Rotman et al. 2012). This is particularly challenging in cultures where science and society are clearly demarcated. Participant feedback has been a crucial component of the research undertaken in Chapters 4 and 6. Through listening to volunteer perspectives, this thesis supports Aitamurto (2012) and Rotman *et al.* (2012) in arguing that hierarchical power structures should be as shallow as possible. This helps facilitate regular mentoring and the building of trust between volunteers and scientists (Bonney et al. 2009; Arnstein 1969). Platform features such as gamification, quizzes and podcasts are frequently cited as key enablers for many crowdsourcing campaigns (Lintott and Reed 2013). Gamification in the form of leaderboards of the most active participants can be seen in other large crowdsourcing campaigns such as Biotracker and FreshWater Watch (Bowser et al. 2013; FWW, 2016). Chapter 4 emphasises that despite being more popular amongst many younger participants, gamification may detract from the user experience of others. However, even for younger participants, a feeling of cooperation as opposed to competition is far more important. Hence this thesis strengthens arguments made in Eveleigh *et al.* (2013) that leaderboards can discourage some participants.

In Chapter 5, it is shown to be abundantly clear that micro-tasking platform design needs to be optimised through a format which takes greater consideration of the capabilities of image classification and the needs of the end-user. The literature to date has largely focussed on the role of projects such as Tomnod for disaster response (Meier, 2013; Fishwick, 2014). Yet this thesis has shown that crowdsourcing can play a more efficient role in all phases of the disaster response cycle through a system that has a more integrated supervised image classification and tagging design. Design changes such as adding layers of classified damages as recommended in Chapter 5 represent opportunities for improving the efficiency of this process. In turn, these design changes could reduce the time take to produce high quality datasets – a factor which can substantially increase their ability to support flood response (Deckers et al. 2009; C J Van Westen 2013; Kreibich et al. 2016). Overall, this thesis emphasises that crowdsourcing projects and platforms need to be designed with careful consideration of target demographics and the end-users of contributions. Chapters 4-6 aimed to identify design implications which could help improve two platforms: Floodcrowd and Tomnod. While many implications for design can be applied beyond these platforms, this thesis emphasises that a one-size-fits-all approach is not effective. Each project should be designed through consideration of a range of factors as emphasised in Figure 7.1.

7.3. Recommendations for policy and practice

7.3.1. The risks of flood crowdsourcing

While this thesis has outlined the many benefits of crowdsourcing for supporting flood risk management, it has also identified several risks. A major challenge for both practitioners and contributors is reducing the risk of negative consequences on those participating. Specialised platforms such as Boulder City's 'Community Flood Assessment' tool is open access and participants have readily shared the costs of the floods on the platform. Yet, flood information can negatively affect house prices and members of the public have expressed concerns about their impact on insurance premiums (Chapter 6). Several private companies have produced footprints of flood impacts using crowdsourcing including: Facebook, Google, Twitter and Snapchat. For residents in the UK and beyond, the utility of social media by institutions could have implications for public participation if they feel it may have negative repercussions. This is particularly pertinent in 2018 with recent revelations of Facebook's misuse of personal data. Issues such as images of flooded homes dissuading potential buyers cannot be understated. Given the altruistic nature of participation in Online Volunteering projects (Chapter 5), any negative impacts of contributions may erode trust and discourage participation. Therefore, generating VGI on flooding which has no negative impacts on participants represents a significant challenge which should be tackled through improved co-ordination with local communities and grassroots movements. This phenomenon should be further investigated with respect to the wider debate over the ownership of information and the ethics of sharing media of public spaces. There is therefore a pressing need to explore ways of addressing privacy concerns while ensuring that contributions are able to support as many practitioners as possible.

Public participation was largely introduced as a measure to create more trust and prevent conflict in environmental decision making (Irwin et al. 1994). Yaari et al. (2011) highlighted how increasing the amount of information available to users increased their perceptions of trust. However, despite the many opportunities offered by crowdsourcing, several concerns have been raised over the negative impact it may have on the judgement of the information set within which it is included (Das and Kraak 2011; Jackson et al. 2013). There is therefore a growing need for greater transparency. Floodcrowd as a platform enabled participants to view all submissions in order to be as transparent as possible and help create a feeling of co-production. However, as outlined in Chapter 3, not all platforms make their citizen contributions open access. In some cases, this may be to help protect private information, while in others – no explanations are provided. Yet given the ability of contributions to support risk flood risk management and help affected communities, this thesis argues that more needs to be done to create platforms that are as transparent as possible, both in data sharing and data use.

7.3.2. Keeping ahead of technological advances

The literature review illustrates a rapid evolution in the professional data sources available for flood risk management from satellite imagery to inundation models and forecasts. As these tools continue to be developed, the role crowdsourcing can play in adding value to existing knowledge will change. To be effective, crowdsourcing must ensure that it always provides a unique and valuable source of information which works together with traditional datasets. All five types of flood crowdsourcing outlined in Chapter 3 are experiencing change through technological advancements. From media engagement tools to GPS tracking on smartphones, crowdsourcing continues to provide new forms of unique data. In addition, mobile technologies are becoming more widely available in some of the less developed and remote corners of the world. More ubiquitous computing will create a population of data-aware, always connected citizens, allowing people to collect data and contribute to flood risk management asynchronously.

As outlined in Chapter 5, the issue of added value is particularly salient in micro-tasking platforms. In the case study of Tomnod, a major contribution of the thesis is the proposition for an initial image classification to be carried out prior to a micro-tasking campaign. This may help direct volunteers to critical areas and ensure that their contributions complement existing knowledge of the disaster. But, perhaps more importantly, it will illustrate to volunteers how valued they are as analysts. For crowdsourcing projects involving VGI, there is typically less control over crowdsourced metadata which can result in ecological fallacy. Yet, it has also been reported that in many instances, information collected informally can be more detailed and of higher quality than those provided by official institutions (Goodchild 2007; Sui, Elwood, and Goodchild 2013; Longueville et al. 2010).

This was emphasised in Chapter 6 where practitioners described crowdsourced flood data as being a valuable extra layer which they could consider alongside traditional datasets. For some practitioners, even one public observation could be invaluable in certain circumstances.

In the coming years, it is highly likely that many activities which are only possible for humans to do, such as complex image interpretation, may become achievable through artificial intelligence. For example, object orientated analyses are continuing to make steps towards the identification of damaged buildings, which may in turn reduce the need to ask citizens to do so. Crowdsourcing has been applied to solve tasks such as image labelling, product categorization, and handwriting recognition (Kamar, Hacker, and Horvitz 2012). These activities often train computer algorithms, helping to achieve improved automation of data analysis. Therefore, future crowdsourcing projects may need to focus on working to support rather than overlook artificial intelligence. As such, crowdsourcing campaigns must always question their added value, keeping ahead of technological developments.

7.3.3. The value of interdisciplinary research for flood crowdsourcing

Interdisciplinarity has become recognised as fundamental to dealing with many of the great challenges facing society in the early 21st Century (Bracken and Oughton 2009). Calls for interdisciplinary approaches to real-world problems are growing, particularly for research concerning the natural environment (Bracken 2017). The co-production of flood risk information has become an important priority for research (Landström *et al.*, 2011) and governmental policy (Mostert and Junier 2009; HM Government 2016). When co-producing knowledge with the public, academics must be reflexive and think creatively about the most useful way to communicate their science. To do so, Bracken et al. (2015) argue that interdisciplinary research should be realistic about what a project can deliver, not necessarily promising a solution.

Crowdsourcing in its nature involves a reliance on members of the public and a genuine utility for data contributions. Where many participants and in the case of flooding – many stakeholders exist, this thesis has proven that a mixed methods approach is an effective tool for understanding key issues. No matter what the topic of interest is, there is always a need to consider human factors affecting participations. Surveys, interviews and forum observations proved highly useful in gaining a broad insight into Tomnod participants in Chapter 4. Yet, these were highly related to the quality of their contributions which could only be fully understood through the remote sensing approaches employed in Chapter 5.

Similarly, Chapter 6 emphasised the need for both human methods (interviews and focus groups) and an analysis of the data (through a content analysis) to draw insights into the utility of crowdsourcing. Moreover, most of the practitioner interviews while touching on many social phenomena, focussed on data requirements and issues affecting different flood risk management approaches. Gaining an understanding of the data utility and the human component would not have been possible without an interdisciplinary approach.

Much of this thesis has been inspired by the series of flood community workshops undertaken by the Ryedale Flood Research Group (Landström *et al.*, 2011; Lane *et al.*, 2011). These workshops grew out of a project that advocated the need for interdisciplinarity for public participation in flood issues. In a reflection of the study Lane (2016) notes that:

> *'We had to learn to consult in new ways, to come to terms with the inadequacies of our own conceptualization of flooding problems, and ultimately to become sensitized to the questions posed by those for whom flooding was a matter of concern… the publications have appeared almost exclusively in social science facing journals. If judged in terms of conventional natural science, the project was a failure.'*

Yet, the Ryedale Flood Research Project proposed a radically different way of doing flood research and helped pave the way for new methodological approaches. On reflection, a similar conclusion can be made when examining the raw data submitted onto the Floodcrowd platform. Months were dedicated to organising outreach events and social media activity, resulting in fewer than 200 observations. These were of insufficient quantity and quality for several practitioners to use them as a resource. Fieldwork in a flood prone area would have surely yielded more data in a shorter space of time. Nevertheless, through the iterative design process of the platform, Chapter 6 was able to identify ways in which tools could be improved to find alternative ways of co-producing flood information. The feedback provided by participants of the study represents a valuable insight into the human factors affecting volunteers. For example, it was found that for some participants – hard maps were needed to enable them to fully participate. For others, web-platforms were suitable and even preferable to mobile applications. These design factors had a direct impact on the data quality.

Oughton and Bracken (2009) highlight the dynamic nature of research boundaries, emphasising the need for continued re-framing during the life-time of a research campaign.

During the iterative development of Floodcrowd, its scope did indeed evolve in response to the feedback and level of participation in the project. This was due to the fact that practitioner interest in the project was highly dependent on the data that were shared. Meanwhile, participation was strongly linked to the degree to which practitioners were using submissions to support local flood action. Therefore, this thesis emphasises the need for, and power of multi-methods research for drawing insights from crowdsourcing projects. Yet, interdisciplinary research can be made challenging due to differences in epistemologies, knowledges and methods as well as different ways of formulating questions (Oughton and Bracken 2009). Through the consideration of both human factors affecting participants, and the value of data contributions on Tomnod, purposeful implications have been identified. These have been achieved through a data driven thematic approach which was effective in deriving key insights in Chapters 1 and 4. The importance of data quality for both users and contributors emphasises the power of interdisciplinary research for identifying areas in which a crowdsourcing can be improved.

7.4. Recommendations for further research

Throughout Chapters 4-6, several areas in need of further research are outlined. Yet, from the overview of this thesis, several additional overarching questions remain. These (outlined below) would benefit from further research to continue to develop the ever-growing field of flood crowdsourcing and build on the findings of this thesis.

7.4.1. What is the nature and scale of media outreach as a form of flood crowdsourcing?

The sheer number of flood narratives that are shared with most media corporations is under-researched and remains largely unknown. This can partly be blamed on the lack of details on the success of media engagement activities and the limited accessibility of these datasets. Newspaper reports using public observations of flooding have long been a useful source of information for academia (Tarhule 2005; Wei et al. 2011). Yet, these are likely to only include a fraction of the total number of observations shared with media organisations. Collating and mapping these reports using a protocol that can support practitioner activities may significantly improve the information available for flood risk management. Therefore, working together with media organisations to interrogate publicly shared data on flooding and to co-develop tools represents a major opportunity to maximise its utility.

7.4.2. What information is shared through governmental incident reporting hotlines and how could these support a broader range of practitioners?

It is evident from the literature review, the development of the flood crowdsourcing typology in Chapter 3 and from interviews with practitioners in Chapter 6, that the value and utility of incident reporting remains under-researched. Yet, it remains by far the most widespread use of crowdsourcing flood since the vast majority of countries that are flood prone provide their citizens with the means of reporting incidents. Recent studies such as Tkachenko et al. (2016) have proven the potential of flood incident hotlines to characterise the temporal profile of flood events. However, this Chapter represents just the tip of the iceberg. A macro-scale study of flood incident reporting across different governments is needed to fully understand the potential of incident reporting to support a broader range of practitioners. This may help policymakers and researchers better leverage the crowd through direct appeals to participate in flood risk management.

7.4.3. How can micro-tasking projects reduce the time taken to produce high-quality data products following major disasters

The delivery of robust mapping products to end-users during the relief phase of a disaster can be hampered by delays. In Chapter 5, the limitations of programmes such as UNOSAT, the international charter on space and major disasters and Copernicus EMS charter are discussed. These take on average, three days to be triggered and a further three to four days for a useable event image to be produced. In Chapter 6, a two-phase approach to image classification is proposed whereby volunteers draw outlines of significant impacts before undertaking a more thorough analysis. There is a strong motivation for such features among volunteers, which vindicates a more thorough investigation into the efficacy of introducing additional mapping tools on platforms such as Tomnod.

7.4.4. How can crowdsourcing be better integrated with the image analysis phase of satellite imagery for supporting disaster response?

To date, crowdsourcing campaigns and supervised image classification for disaster response have largely been conducted separately. Yet for many natural disasters, Tomnod volunteers and remote sensing teams have been working on the same study sites, often duplicating each other’s efforts. For example, a large proportion of Copernicus’ EMS activations have also been mapped in Tomnod campaigns, including: Hurricane Matthew USA in 2007, Hurricane Irma USA in 2017, floods in Louisiana in 2016, Hurricane Maria in Caribbeanin 2017, Tropical Cyclone in Viti Levu in 2018, Haiti Earthquake in 2010, Nepal

Earthquake in 2015, and Floods in England in 2016. Chapter 6 identified how crowdsourcing could be used to add value to image classifications already produced by remote sensing teams. However, the ways in which both remote sensing analysts and the crowdsourcing community can support and complement each other in providing data which can be utilised in humanitarian responses this has not yet been tested. Therefore, further research is needed to prototype platform designs which better integrate crowdsourcing into the image analysis phase of a disaster mapping campaign.

7.4.5. How do attitudes to flood crowdsourcing differ between countries and cultures?

When interpreting this thesis, it is important to note that while several issues have been addressed, flood crowdsourcing has become a global phenomenon and varies with context. This thesis was undertaken from the perspective of an English-speaking academic. As a result, is likely to have resulted in several non-English phenomenon being omitted as well as potential bias regarding the field (DiCicco-Bloom and Crabtree 2006). Therefore, ensuring the policy relevance of these findings to other platforms across the globe requires further research and a reflection on geographical and socio-economic realities. In particular, with different cultural attitudes to volunteering and employment, the dynamic nature of public participation needs further global investigation to be internationally policy relevant.

7.4.6. What would incentivise members of the public to make contributions which are in line with professional data quality standards?

Crowdsourcing can be optimised through a campaign design which takes consideration of the capabilities of the public's knowledge and analytical abilities. Chapter 4 outlined how participant training and democratic aspects of crowdsourcing platforms was a major motivator for participants. These can play a large role in fostering loyalty and improving data quality among participants. Chapter 6 also highlighted how a major limitation of currently available crowdsourced flood datasets to practitioners is their reliability. In crowdsourcing research, biases are easily accrued as part of the recording process (Boakes *et al.* 2016). To combat this issue, approaches such as co-production with contributors and end-users offers a powerful way of democratising the design process. Hence, further research with participants is needed to consider the role that different design features can play in improving the participant experience and data quality. In addition, further research is needed to consider the role that campaign features – in particular training and democratic aspects – can play in fostering loyalty and improving data quality among different participant groups. At present, some of the greatest interest in developing innovative platforms such as these appears to be derived from the private sector. Therefore, designing these in such a way that can support, not hinder local communities and motivate them remains a significant challenge which requires further public engagement to overcome.

7.5. Conclusion

This thesis started by illustrating how flooding is a major global hazard which requires significant multi-level mitigation measures to be managed effectively. These measures are typically supported through flood risk assessments and are thus highly dependent on the data on which they are built. As such, flood risk management is strongly affected by the quality and quantity of data in the nature and impacts of past, present and potential future flooding events. Given the ability of citizens to contribute useful local knowledge and a genuine interest in tackling natural hazards, crowdsourcing represents a major opportunity for the future of flood risk research and management. Chapters 3-6 investigate a wide range of components of flood crowdsourcing using an interdisciplinary approach. Both human and physical factors are studied, providing a framework for the continued advancement of crowdsourcing for flood risk management as a discipline.

In Chapter 3, an examination of 31 different crowdsourcing projects including their data where possible was used to develop a typology of flood crowdsourcing. This identified five key types: i) Incident Reporting, Ii) Media Engagement, Iii) Collaborative Mapping, Iv) Online Volunteering and V) Passive VGI. These represent a wide range of initiatives with radically different aims, objectives, datasets and relationships with volunteers. Yet, their distinct characteristics are often not reflected in existing typologies for public participation, crowdsourcing or citizen science. While passively shared data from social media has provided much usable information for practitioners, there remain many uncertainties regarding the reliability of the time, location and content of its data. In contrast, Collaborative Mapping has provided more detailed information which can support a range of practises albeit often being limited to a smaller area. While requesting the same types of data, some Incident Reporting projects appear to express radically different aims and objectives. Media Engagement represents a widespread and popular method of crowdsourcing flood data, yet it remains largely understudied, in part due to practical constraints. Online Volunteering platforms vary significantly, ranging from micro-tasking exercises such as Tomnod to community action initiatives such as Facebook Crisis Response, yet they all occur in a virtual space. Through the development of this typology, Chapter 3 helped inform the rest of this thesis as well as academics and practitioners about the scope and nature of flood crowdsourcing.

The focus of this thesis has been on the public's participation in: i) Online Volunteering for satellite imagery analysis and ii) Collaborative Mapping. Chapters 4 and 5 explored a complex and interconnected set of factors affecting both participation and the quality of contributions on a micro-tasking platform. Through a mixed methods approach, Chapter 4 revealed that core motivations for voluntary online crowdsourcing were largely altruistic. Demographics of participants were significant, with retirement, disability or long-term health problems found to be major drivers for participation. In addition, the feedback on the quality and impact of contributions was found to be crucial in maintaining interest. Many participants emphasised that effective communication between volunteers and the head of the project is strongly linked to their appreciation of the platform. Chapter 5 highlighted how online volunteers can ascertain with a higher degree of accuracy, many features which supervised image classification struggles to identify. This was more pronounced in poorer quality imagery where image classification had a very low accuracy. However, supervised classification was found to be far more systematic and succeeded in identifying impacts in many regions which were missed by volunteers. Integration of the two approaches can provide considerable added value in terms of flood damage extent assessments in future disaster mapping efforts.

Using an iterative design approach, Chapter 6 tied together many key themes emerging in this thesis to explore how both participants and practitioners feedback could improve the design of a flood crowdsourcing platform. Through a series of workshops, interviews and outreach events, several design perspectives have been expressed regarding the development of Floodcrowd. These revealed a significant interest in crowdsourcing from both public and private practitioners involved in flood risk management. Types of data which practitioners are particularly interested in with regards to crowdsourcing differ between organisations. Yet, they typically include flood depths, photos, timeframes of events and historical background information. Many citizens are able and motivated to share additional implicit knowledge, but require certain triggers to encourage participation. These primarily include an expectation that authorities will pay attention to them and act to respond to concerns. An iterative design process serves as a suitable mechanism for identifying these triggers and adapting the platform to motivate contributors and generate suitable data for end-users.

Through an interdisciplinary approach, this thesis has investigated the world of flood crowdsourcing and identified factors affecting its efficacy. Interviews with practitioners, user-testing of tools and an evaluation of the crowdsourced data are all shown to be essential components for a holistic analysis of a phenomenon such as flood crowdsourcing. To this end, the main conclusion is that flood crowdsourcing is powerful and rapidly evolving phenomenon. It has grown from a relatively sparse and localised phenomenon to one that may radically change the way flooding, and indeed hazards in general are studied and managed. Central to its future success is the continued co-production of tools together with citizens and practitioners, taking consideration of the interdisciplinary nature of the field. Looking ahead, coupled with rapid technological advances, there is a growing number of practitioners with an active interest in crowdsourcing. This presents many opportunities as well as challenges for ensuring that the future of flood crowdsourcing improves flood risk management and does not damage relationships with participants. To achieve successful implementation of flood crowdsourcing in future, there is a demand for further research, workshops and product testing. These activities can ensure that the tools of the future are co-developed and suit both participants and their end-users.

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Appendix 1: List of flood crowdsourcing platforms and their primary aims

Platform	Primary aims	Functional aims	Responsible organisation	URL
Ryedale Flood Research Group	Research project to address the public controversies generated by the risk management strategies and forecasting technologies	Using workshops for the co-production of knowledge	University of Oxford	http://knowledge-controversies.ouce.ox.ac.uk/news/
Haltwhistle Burn	Citizen science project for monitoring, modelling and using established intervention techniques which will assist with managing runoff	Using workshops, paper forms and an online reporting form	Newcastle University	http://research.ncl.ac.uk/haltwhistleburn/
The City of Boulder 'Community Flood Assessment' (CB-CFA)	Enable flood affected communities to generate data on place-and-time flooding which will assist in the flood assessment and inform future planning efforts.	Web-platform reporting form to generate information	City of Boulder Council	https://boulderflood2013b.crowdmap.com/page/index/1
Weather Observations Website (WOW)	Weather reporting tool to collect of citizen weather observations for the Met Office's use	Web-platform reporting form to generate information	Met Office	http://wow.metoffice.gov.uk/

Report a Flood (SEPA-RAF)	Information reporting tool to empower communities to be flood-prepared, to increase awareness of local flood impacts and help keep communities moving	Web-platform reporting form for collaborative mapping	Scottish Environment Protection Agency	http://www.floodlinescotland.org.uk/report-a-flood/
#Chennai Rains	Information reporting tool enabling users to mark flooded areas using Google 'My Maps'	Web-platform reporting form for collaborative mapping	Independent weather watching community from Chennai.	https://www.google.com/maps/d/u/0/viewer?mid=1F54bkFfiULpzExvfAsiGyW67tlg&hl=en_US&ll=14.104705509660802%2C78.89870424635637&z=9
Floodbook	To improve our knowledge of flooding in the Turin by asking those who have witnessed floods to share their knowledge of both current and historical events	Web-platform reporting form for collaborative mapping	Gruppo Alluvioni (An Italian research group)	http://www.floodbook.it/googlemaps/
Floodstones	To compile a database of so called "coastal floodstones"	Web-platform reporting form for collaborative mapping	University of Sheffield	http://floodstones.co.uk/
#PetaJakarta and #PetaBencan	To enable Jakarta's citizens to report the locations of flood events to the government using the hashtag:	Reporting system using social media	Indonesian board for natural disaster affairs. I	https://petabencana.id/

a	#Petajakarta and #PetaBencana on Twitter			
FEMA Disaster reporters	To crowdsource and share disaster related information for events occurring within the United States	Web-platform reporting form to generate information	US Federal Emergency Management Agency	https://www.fema.gov/disaster-reporter
WeSenseIt	To harness environmental data and knowledge to effectively and efficiently manage water resources	Web-platform reporting form to generate information	Research group and local government collaboration	http://wesenseit.eu/
Environment agency's SWIM tool	To aid multiple agencies in their combined response to flooding both during an event and after	Web-platform reporting form to generate information	England Environment Agency	https://swim.geowessex.com/dorset/Report
Leicestershire County Council reporting form	Inform council of issues which need addressing	Web-platform reporting form to generate information	Leicestershire County Council	https://www.leicestershire.gov.uk/sites/default/files/field/pdf/2017/5/31/Revised_Flood_reporting_form_v3.pdf
Thames Water reporting	Inform water company of issues which need addressing	Web-platform reporting form to generate	Thames Water	https://www.thameswater.co.uk/Help-and-Advice/Report-a-problem/Report-a-

form		information		problem?type=leak
Floodline	Informing relevant authority of issues that need addressing	Telephone line for generating information	England Environment Agency	https://www.gov.uk/government/organisations/environment-agency
BHS Chronology of British Hydrological events (BHS-CBHE)	Documenting historical events and to bring into searchable view as much material as possible on the spatial extent of hydrological events, and their relative severity	Web-platform reporting form to generate information	British Hydrological Society	http://cbhe.hydrology.org.uk/
Tomnod	To use crowdsourcing to identify objects and places in satellite images	Micro-tasking platform for image analysis	DigitalGlobe	http://www.tomnod.com/
Zooniverse	Help with relief and response efforts	Micro-tasking platform for image analysis	Zooniverse	https://daily.zooniverse.org/2017/09/15/hurricane-irma-project-update/
Twitter	Social media	Platform for sharing freeform posts	Twitter	https://twitter.com/
Flickr	Social media	Platform for sharing freeform photos	Flickr	https://www.flickr.com/

YouTube	Video sharing website	Platform for sharing videos	YouTube	https://www.youtube.com/
Waze	Navigation application	Information reporting and real-time location sharing	Waze	https://www.waze.com/
BBC have your say (BBC-HYS)	Media engagement platform for reporting stories to BBC news	Web-platform reporting form to generate information	British Broadcasting Corporation	http://www.bbc.co.uk/news/have_your_say
Facebook Crisis Response	A central hub for all of the company's safety-related tools	A web and mobile application that allows users to share live media to friends and the public	Facebook	https://www.facebook.com/crisisresponse/
SnapMap	A web-platform for viewing live videos from members of the public	A mobile application that allows users to share live media to friends and the public	MapBox and Snapchat	https://map.snapchat.com/@42.728782,-84.480224,17.35z

BSG Crowdmap	A Crowdmap platform for the geological community where geologists (whether amateur or professional) can report a geological observation	Web-platform reporting form to generate information	British Geological Society	https://britishgeologicalsurvey.crowdmap.com/
VT Irene Crowdsmap	A Crowdmap platfor to crowdsource key locations and information in Storm Irene's wake	Web-platform reporting form to generate information	VT Response	https://vtirene.crowdmap.com/
Brisbane Storm and Flood Map	A Crowdmap platform to enable members of the public to add their information to provide a better view of the overall issues throughout Brisbane during its 2013 flood event.	Web-platform reporting form to generate information	Brisbane City Council	https://bnestorm.crowdmap.com/
Red River Flood of 2018	An Urshahidi map for reporting flooding along the red river.	Web-platform reporting form to generate information	Not specified	https://redriverflood2018.ushahidi.io/views/map
Sri Lanka Floods	An Urshahidi map for reporting and mapping flood disasters in Sri Lanka	Web-platform reporting form to generate information	Not specified	https://srilankanfloods.ushahidi.io/views/map
Floodmsa	An Urshahidi map for reporting and	Web-platform	Not specified	https://floodsmsa.ushahidi.io/vi

	mapping flood incidences in the coastal region of Mombasa	reporting form to generate information	ews/map

Appendix 2: Floodcrowd Terms of Use

The observations shared on Floodcrowd is sourced from reports made by members of the public and organisations and is not necessarily professionally verified.

Observations are not verified by Loughborough University. It is the responsibility of the user of this information to validate any information given and take appropriate action. All users of this information are bound by these terms and conditions.

Loughborough University hereby disclaims any and all liability for all loss, injury or damage (direct, indirect, consequential or special) arising out of or in connection with your use of the website
including without limitation, any and all liability:

1. Relating to the accuracy completeness, reliability, availability, suitability, quality,
ownership, non-infringement, operation, merchantability and fitness for purpose of the
Information
2. Relating to Loughborough University work procuring, compiling, interpreting, editing, reporting and publishing the information
3. Relating to any interruption, failure or cessation of operation or transmission;
4. Resulting from any acts or omissions of any third parties in connection with our use of
Floodcrowd
5. Resulting from reliance upon, operation of, use of or actions or decisions made on the
basis of, any facts, opinions, ideas, instructions, methods, or procedures set out in
Floodcrowd
6. Arising out of or relating to your mis-use of or inappropriate reliance on any information
7. Resulting from any virus, worm, Trojan, time-bombs, keystroke loggers, spyware, adware or any other kind of malware or contamination of computing equipment.

Ownership

The information displayed on Floocrowd is owned by Loughborough University. On submitting information to Loughborough University, the provider accepts these terms and conditions and allows the information for the purposes of research and sharing with other researchers. Loughborough University is not responsible for the accuracy of information and cannot be held responsible for the misuse or misinterpretation of the information. The information is not suitable for any commercial, business, professional or other income generating purpose or activity. Loughborough University cannot guarantee that the website will be available at all times and shall not be liable for any system downtime or other associated issues. cannot be held responsible for any damage or costs associated with flooding or sharing of a flood observation.

Submitting information

Loughborough University reserves the right to publish or not publish information as it deems appropriate. Submitting information by Floodcrowd to Loughborough University through any channel is an acceptance of these terms and conditions. Information should be truthful accounts of observed flooding. If you share a photo as part of your observation, it is your responsibility to make sure you own the copyright for it. Loughborough University disclaims any and all liability for images shared on Floodcrowd without copyright. If there are any photos shared on Floocrowd in breach of copyright laws, please contact Avinoam Baruch at A.Baruch@lboro.ac.uk and he will remove them immediately.

Modification

Loughborough University has the right, at its sole discretion and at any time, to change or modify Floodcrowd, including the information that we gather to record the flood observations. Your continued use of the Floodcrowd after any changes shall constitute your acceptance of any revised terms and conditions.

Data Protection

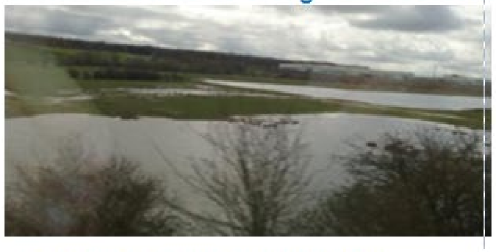
You agree not to use the Floocrowd information in any way that constitutes a breach of the Data Protection Act 1998. You are not obliged to provide your personal information to use Floodcorwd Under the Data Protection Act 1998 you are entitled to request access to information that Loughborough University holds about you and ask for any necessary changes to ensure that such information is accurate and up to date.

Appendix 3: Floodcrowd Leaflet

What people have shared

Observations of large floods in Cumbria…

...inundated fields along train routes…



...and small pools in Hertfordshire…

...have all helped support valuable **research** as they improve our understanding of flooding in the UK.

Floodcrowd was created by Avinoam Baruch was part of a PhD project at Loughborough University.

Visit floodcrowd.co.uk for more information.

Email: a.baruch@lboro.ac.uk

Address: Department of Geography, Loughborough University, Loughborough, Leicestershire , LE11 3TU, United Kingdom

Loughborough University

floodcrowd

Share your observations of floods to research their causes and what we can do about them.

What is floodcrowd?

Floodcrowd aims to improve our knowledge of **flooding** in the UK by asking those who have witnessed floods to **share their knowledge**.

These records will be used as part of a PhD citizen science research project at **Loughborough University**.

Citizen science is a term used to describe the public involvement in inquiry and discovery of new scientific knowledge.

How YOU can get involved

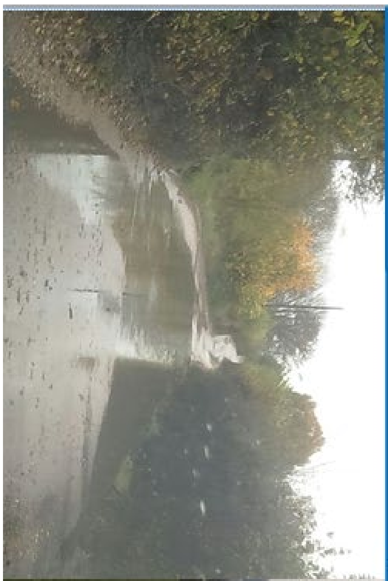
There is an urgent need for **up-to-date, local information** to build a more complete picture of flooding in the UK. The public can play a vital role in providing this information by sharing knowledge of:

- **Locations** and impact of **surface-water flooding** events
- **Flooding depths and extents**
- **Local knowledge** of causes of flooding
- **Flooding history.**

If you have witnessed a flood, no matter how big or small, old or recent, share it on **floodcrowd.co.uk.**

What will be done with my records?

All records will be analysed as part of a **citizen science** study into flooding in the UK. This will also form an important **database of flooding events** which are often unrecorded.



Appendix 4: List of outreach activities and events

Online outreach activity	Available at	Date

Twitter posts	https://twitter.com/Floodcrowd	January 2015 - present
Facebook posts	https://www.facebook.com/floodcrowd/	January 2015 - present
Loughborough University Research blog	http://blog.lboro.ac.uk/research/changing-environments-infrastructure/citizen-scientists-flooding-research/	January 2016
Scistarter page (Citizen science project website)	https://scistarter.com/project/1421-Share%20a%20flood%20observation	February 2016 to present
Saga magazine article	https://www.saga.co.uk/magazine/home-garden/craft-hobbies/hobbies/citizen-science-projects-get-involved	June, 2016
Personal blog	https://wordpress.com/stats/insights/avibaruch.wordpress.com	June, 2016
Flood meadows newsletter	http://www.floodplainmeadows.org.uk/sites/www.floodplainmeadows.org.uk/files/Newsletter%20summer%202016%20v12.pdf	September 2016
Discover magazine article	http://blogs.discovermagazine.com/citizen-science-salon/2016/03/03/citizen-science-mapping/#.V-KbifkrKUk	March, 2016
Citizen science news story	http://www.citizensciencecenter.com/assessing-flood-risks-crowdsourcing-floodcrowd/	March 2016
Hitchhikers guide listing	http://hitchhikersgui.de/List_of_citizen_science_projects	December 2015
Wikipedia online listing	https://en.wikipedia.org/wiki/List_of_citizen_science_projects	December 2015

Outreach and feedback event	Activity	Date
Brown bag presentation at Loughborough University	Oral presentation	November 2015
Leicestershire resilience forum	Oral presentation	April, 2016
Leicestershire flood warden event	Oral presentation and stand	April, 2016
European Citizen Science Conference	Leaflets + Discussion	May 2016
Loughborough postgraduate geography seminar	Oral presentation	June 2016
Loughborough graduate school summer showcase	Poster presentation	June 2016
Vespucci summer institute	Oral presentation	July 2016
EMUA conference	Oral presentation	September 2016
BSG conference	Poster presentation	September 2016
West Yorkshire Resilience forum	Oral presentation	September 2016
BRIM academic event	Stand presentation	September 2016
Yorkshire flood warden event	Stand presentation	September 2016
Loughborough research conference	Oral presentation	October 2016
Leicestershire stakeholder resilience event	Oral presentation	October 2016
RMS conference call	Oral presentation	January 2017
Loughborough STEM day	Oral and stand	March 2017
Loughborough Water Res day	Stand	May 2017
Citizen Science Association	presentation	May 2017
Graduate school summer showcase	Oral presentation and stand	June 2017
Loughborough University cafe academique	Oral presentation and stand	July 2017
DARE Research Conference	Oral presentation	November 2017
Hydro-cluster research meeting	Oral presentation	November 2017

Appendix 5: A review of projects which generate flood event information through crowdsourcing

Executive summary

Crowdsourcing is being increasingly used as a tool to support community resilience to flooding through local workshops and mapping projects (Bracken et al. 2016; Lane et al. 2011; Wehn et al. 2015). On a larger scale, data on flood events are being generated by crowdsourcing through social media, micro-tasking projects and specialised observation sharing platforms. This report summarises seventeen of these projects and provides some insights into their usability and future directions.

Microtasking is the process of splitting a large job into small tasks that can be distributed, over the Internet, to many people. One example is Tomnod– an online mapping project that uses crowdsourcing to identify objects and places in satellite images. A number of different mapping campaigns are launched through the website (10 flood mapping tasks to date) and a number of other campaigns involving flood assessments e.g. Hurricane damage mapping. The project typically generates between 7,000 and 14,000 'tags' of flood impacts such as flooded buildings and blocked roads. These tags add significant value to the satellite imagery, but have a number of data quality issues which are discussed in Baruch et al. (in prep.). Another micro-tasking platform that is discussed is The Chronology of British Hydrological Events. This is a public repository for hydrological events and contains ~8,000 entries, although these do not contain precise locations and most refer to floods before the 21st century.

The efficacy of crowdsourced data to support institutional flood risk management is being explored through the use of social media (Smith et al. 2015; Fohringer et al. 2015; Kryvasheyeu et al. 2016). Geotagged tweets relating to flooding can be accessed in their millions. However, users of this data have noted significant data quality issues including false reports, inappropriate tweets and recycled observations. To combat this noise, campaigns such as #Petajakarta have aimed to gather higher quality tweet data by encouraging members of the public using these hashtags to provide specific information about events.

A number of specialised flood information sharing campaigns have been identified (listed in table 1) and are reviewed. These have generated data of a higher quality than most social media and microtasking campaigns as web and mobile apps enable organisers to request specific information types in each field. However, campaigns with larger numbers of fields have mostly experienced lower levels of participation.

The report also examines potential future sources of crowdsourced ‘big data’ including opportunities for Google and Facebook crowdsourcing to directly request information from their users (as they currently do for business reviews). Datasets such as public reports to water companies and city councils are also discussed.

Campaigns	Location(s)	Data	Data format	Availability
FEMA Disaster reporters	USA	~900 disaster impacts (many of which are floods)	P;T;D	Viewable
Floodcrowd	UK	>120 floods	P;T;D;F	Viewable and available on request
The City of Boulder 'Community Flood Assessment'	Boulder city, Colorado, USA	255 floods (some records note absence of flooding)	P;T;D	Viewable and available on request
Met Office's Weather Observations Website (WOW)	Global, with a UK focus.	~1,500 weather impacts (some of which are floods)	T;D	Viewable and may be available in 2017
SEPA report a flood tool	Scotland	>450	T;D;F	Last 24 hours, viewable. Dataset available on request
WeSenseIt	3 EU cities	Unknown	T;D;P;F	Currently unavailable
Environment agency's SWIM tool	Dorset; Cumbria	>450	T;D;P;F	Currently unavailable
Google 'MyMaps' independent mapping projects	Several global projects e.g. Chennai Rains	~100 per map	D;P;V	Viewable and available
Floodstones	UK	11 historical events (validated)	D;F;	Viewable

Table 1: P= Photo, Video; F= flood type, T= Timing, D=details

Micro-tasking

Tomnod

- **Primary aim:** an online mapping project that uses crowdsourcing to identify objects and places in satellite images.
- **Project outline:** Launched in 2010. A number of different mapping campaigns are launched through the website (10 flood mapping tasks to date e.g. Fig. 1) and a number of other campaigns involving flood assessments e.g. Hurricane damage mapping.
- **Geographic scope:** Global, yet each campaigns focuses on a city or region.
- **Current flood dataset:** ~10 citywide flood damage maps with between ~ 7,000 and ~15,000 flood damage point data showing flood damage type (e.g. blocked road) with associated agreement rating (see fig. 2 for example of datasets).
- **Data use:** Data is marketed at emergency services but can be applied for other purposes such as academia.
- **Outreach:** Forums; blogs; news media; social media.
- **Quality assurance:** A specialised algorithm assesses data quality based on user experience and agreement between participants.
- **Data accessibility:** Data can typically be made available on request.
- **Participation:** Varies between campaigns: Typically, 1,000-5,000 but has reached as high as 8,000,000.
- Notes:
    - There is often a delay in data availability due to time taken for satellite imagery acquisition, campaign launch and sufficient number of tags for reliable data generation.
    - No further details in data.
    - No ground data.
    - Satellite imagery is not always good quality e.g. Fig. 1 – affecting results.
- **Useful links:** http://www.tomnod.com/ http://www.sciencedirect.com/science/article/pii/S0747563216305295 https://www.theguardian.com/world/2014/mar/14/tomnod-online-search- malaysian-airlines-flight-mh370
- **Similar projects:** Geotag-x and Carberus also produce emergency crisis maps.

Fig. 1: User interface on Tomnod Carlisle, 2015 flood mapping campaign.

Figure 2: Worldview 2 imagery of Tsukuba, Japan on 12th November, 2015 with Tomnod tags of damaged buildings and blocked roads.

The Chronology of British Hydrological Events

- **Primary aim:** To bring into searchable view as much material as possible on the spatial extent of hydrological events, and their relative severity.
- **Project outline:** Launched in 1998, A public repository for hydrological events.
- **Geographic scope:** UK focus.
- **Current flood dataset:** ~8,000 flood entries with estimated location or region. Majority of observations are pre-21st Century.
- **Data use:** Flood occurrence research.
- **Outreach:** Website; Scientific publication; British Hydrological Society events.
- **Quality assurance:** Contributors are asked to add to the database by drawing on reliable sources, such as: Contemporary newspaper reports, Published diaries, Published accounts of major events, Field observations.
- **Data accessibility:** Viewable on the platform.
- **Notes:** Location is only to the nearest town. Some reports are very brief (see Fig. 3).
- **Useful links:** http://cbhe.hydrology.org.uk/
  http://www.tandfonline.com/doi/abs/10.1623/hysj.49.2.237.34835

ID	Date	Quotation	Area	Contributor
13489	1991	". ..Situated at the meeting of the rivers Skell, Laver and Ure, there is a long history of flooding in Ripon. Recent flood events in 1982, 1991, 1995 and 2005 were caused by the River Ure. In 2000 it was the River Skell which caused flooding. In all cases significant numbers of properties were flooded.....	027 - Ouse (Yorkshire)	Frank Law
13793	1991	Drought year on River Wylye	043 - Avon and Stour	Frank Law
12338	1992	"...There were minor floods in 1990, 1992 and 1994/5 with larger floods occurring in 1999 and 2000...."	043 - Avon and Stour	Frank Law

Fig. 3: User interface on The Chronology of British Hydrological Events database

Observation reporting

FEMA Disaster Reporters

- **Primary aim:** To crowdsource and share disaster related information for events occurring within the United States.
- **Project outline:** Enable citizens, first responders, emergency managers, community response and recovery teams, and others to view and contribute information on a publicly accessible map using an app.
- **Geographic scope:** USA focus.
- **Current flood dataset:** ~900 disaster observations points with photos, many of which are flooding.
- **Data use:** Data viewable for all stakeholders.
- **Outreach:** Website; print media; social media.
- **Quality assurance:** Photos are required.
- **Data accessibility:** Viewable on a map and a table (see Fig. 4).
- Notes:
  - No quality control.
  - Potential bias in participation.
- **Useful links:** https://www.fema.gov/disaster-reporter https://www.fema.gov/blog/2013-08-02/crowdsourcing-disasters-and-social- engagement-multiplied

 View Full Size Report this Image	Hurricane Matthew, flooding 10/8-10/2016	Hope Mills	NC	Hurricanes	Sun, 10/09/2016 - 12:50	Sun, 10/30/2016 - 13:37

Fig. 4: Sample data point shared on FEMA's disaster reporter app.

Floodcrowd

- **Primary aim:** To improve our knowledge of flooding in the UK by asking those who have witnessed floods to share their knowledge of both current and historical events.
- **Project outline:** Launched in 2015, a web-based crowdsourcing platform which enables anyone to share their experiences of floods online. These observations can be shared anonymously or as registered users. The platform is also mobile friendly.
- **Geographic scope:** UK focus.
- **Current flood dataset:** >120 flood locations.
- **Data use:** Flood occurrence research; flood model validation; stakeholder reference material.
- **Outreach:** Website; social media; conference presentations; workshops; direct engagement with flood wardens and stakeholders.
- **Quality assurance:** Provision of photos and news stories is encouraged; All observations are evaluated for their quality and poor quality data are removed.
- **Data accessibility:** Viewable on the platform. Data available on request.
- Notes:
    - No app.
    - Significant sampling bias.
- **Useful links:** http://floodcrowd.co.uk/
  http://blog.lboro.ac.uk/research/changing- environments-infrastructure/citizen-scientists-flooding-research/
  http://www.citizensciencecenter.com/assessing-flood-risks-crowdsourcing- floodcrowd/

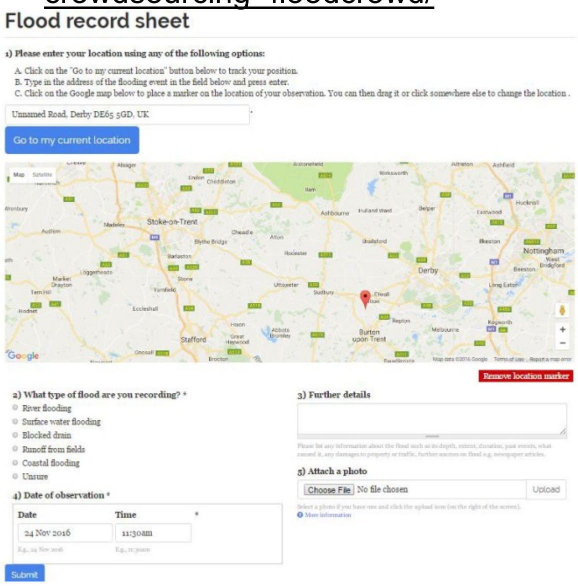


Fig. 5: User interface on floodcrowd website for sharing flooding observations Fig. User interface on floodcrowd website for map of records

The City of Boulder ‘Community Flood Assessment’

- **Primary aim:** to generate data on place-and-time flooding which will assist in the flood assessment and inform future planning efforts.
- **Project outline:** Launched in 2013 to provide a venue for residents and businesses to share their data and stories about the 2013 Boulder, Colorado floods
- **Geographic scope:** Boulder, Colorado, USA.
- **Current flood dataset:** 255 flood locations with further details and photos (see Figs. 6 and 7).
- **Data use:** Assist in flood assessment and informing future planning efforts.
- **Outreach:** Website; media
- **Quality assurance:** Photo submissions are encouraged; Observations can be validated and assessed for their credibility.
- **Data accessibility:** Viewable on the platform and available on request.
- Notes:
  - Observation bias.
  - Few observations are verified.
  - Campaign has not received any new observations for two years.
  - Some reports are of fixed problems or the absence of flooding so the details of each report need to be examined when analysing the data as a whole.
- **Useful links:**
  https://boulderflood2013b.crowdmap.com/page/index/1
  http://boulderfloodinfo.net/

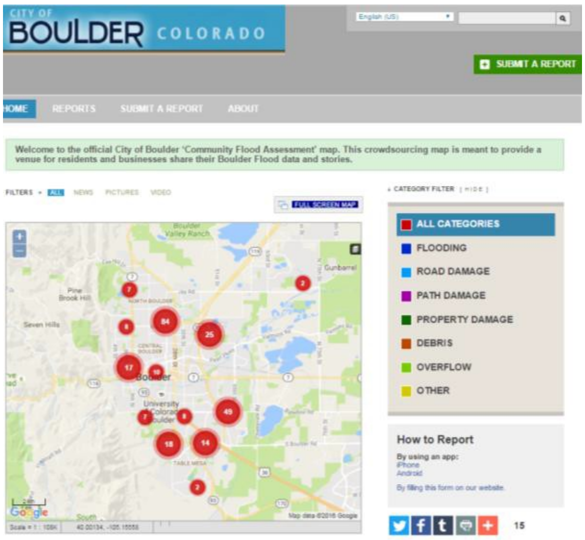


Fig. 6: User interface on The City of Boulder ‘Community Flood Assessment’

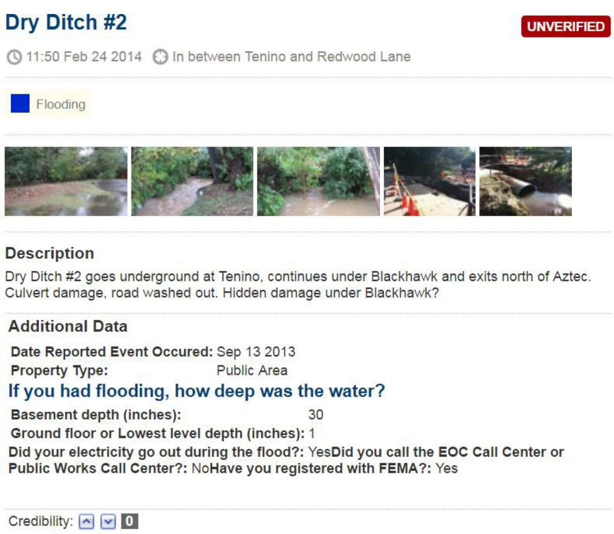


Fig. 7: Sample record on The City of Boulder ‘Community Flood Assessment’

Met Office’s Weather Observations Website (WOW)

- **Primary aim:** To collect of citizen weather observations for the Met Office’s use.
- **Project outline:** Launched in 2011, enables submissions of weather and weather impacts (including flooding) online for an operational service. Does not currently include an app but this may be developed in future.
- **Geographic scope:** Global, with a UK focus.
- **Current flood dataset:** ~1,500 location points of weather impacts in whole archive ~150 of which are floods (Fig. 8).
- **Data use:** Validation of weather warnings; near real-time identification of localised severe weather events; public information.
- **Outreach:** Website; direct engagement with schools and weather enthusiasts.
- **Quality assurance:** Registered users can flag data that they suspect as erroneous.
- **Data accessibility:** Viewable on the platform. Bulk download option may be available in 2017.
- **Participation:** In the first 12 months there were over 165,000 different visitors to the site from 152 different countries. There is no information on how many of these submitted flood observations.
- Notes:
    - The extent to which observations are used by Met Office is unclear.
    - Sampling bias.

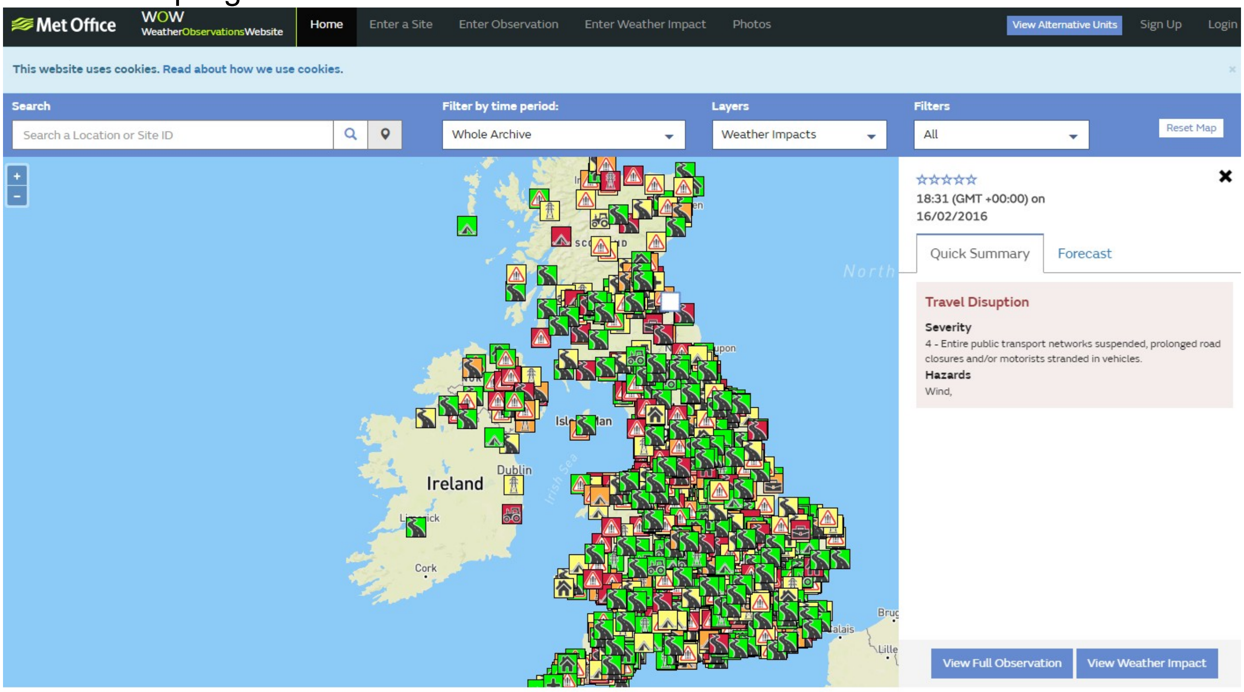


Figure 8: User interface of platform showing all weather impacts in archive.

- **Useful links:** http://wow.metoffice.gov.uk/, https://www.ceh.ac.uk/sites/default/files/citizensciencereview.pdf

SEPA report a flood tool

- **Primary aim:** To empower communities to be flood-prepared, to increase awareness of local flood impacts and help keep communities moving.
- **Project outline:** Launched in November, 2015: a tool enabling reporting and publishing of flood observations online by providing a forum for members of the public to share information on local flood impacts as they happen (Fig. 9).
- **Geographic scope:** Scottish focus.
- **Current flood dataset:** ~450 weather impacts in whole archive (Fig. 10).
- **Data use:** Public information; data available to local authorities.
- **Outreach:** Website; press release.
- **Quality assurance:** 10% of observations have been verified by local authorities.
- **Data accessibility:** Data from last 24 hours can be seen online. Whole dataset available via data request.
- **Participation:** >23 different users.
- Notes:
    - No photos.
    - Majority of observations unverified.
    - Observation bias.
- **Useful links:** http://www.floodlinescotland.org.uk/report-a-flood/ http://media.sepa.org.uk/media-releases/2015/sepa-launches-new-interactive- flood-reporting-tool-1/

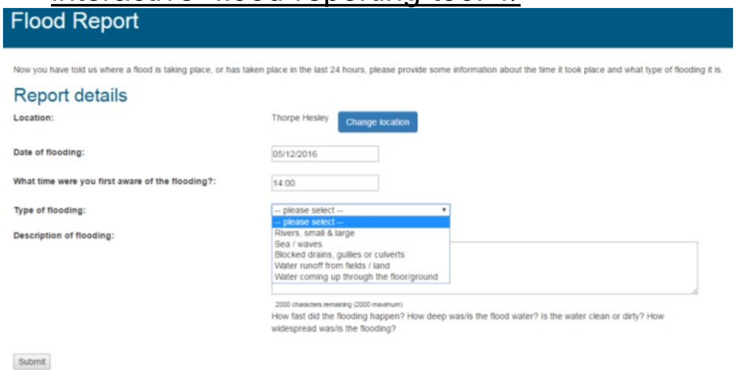


Fig. 9: User interface of SEPA’s report a flood tool

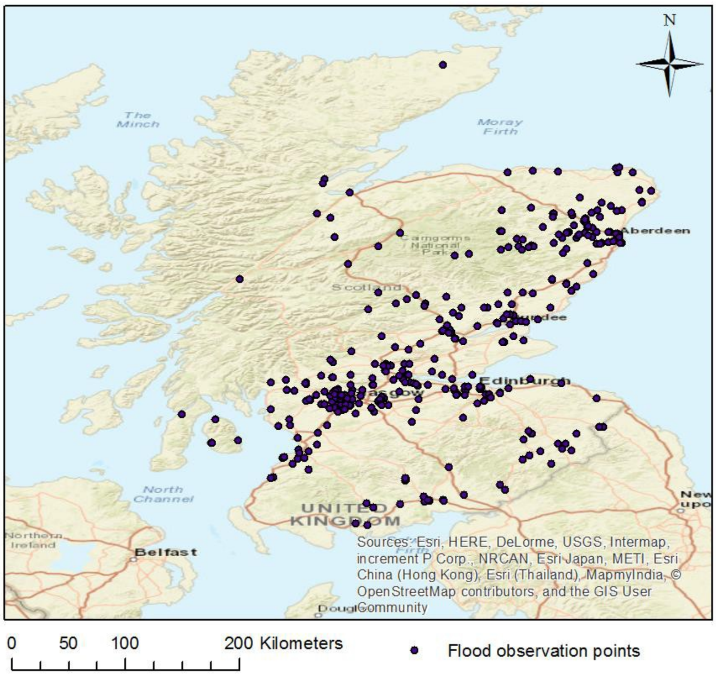


Fig. 10: Map of SEPA's 'report a flood' observations during 2015/2016 winter floods

Flood Network

- **Primary aim:** Build a network of waterbody monitoring systems to improve knowledge of river systems and flood risks.
- **Project outline:** Low-cost (£270) flood sensors are sold to public to collect data on water levels in nearby streams. They are powered by battery and can connect wirelessly to a gateway which channels the data back to our system using the Internet.
- **Geographic scope:** Oxfordshire.
- **Current flood dataset:** 7 monitoring stations in Oxfordshire providing continuous data
- **Data use:** Update users about waterways, culverts, rivers, ditches and even groundwater. Users can choose to publish open data for use by flood modellers and forecasters to improve resilience and response.
- **Outreach:** Academic conferences; social media; community events.
- Notes:
  - Differences between low-cost and environment agency sensors may affect results.
  - Small number of monitoring stations resulted in limited scale of project.
- **Useful links:** https://flood.network/news/2015/9/2/our-sensors https://www.eventbrite.co.uk/e/floodhack16-tickets-21304303746#

Floodstones

- **Primary aim:** To compile a database of so called “coastal floodstones.”
- **Project outline:** Launched in 2016, A public repository for floodstone observations showing historical flood depths.
- **Geographic scope:** UK focus.
- **Current flood dataset:** 11 locations containing floodstones.
- **Data use:** Historical food occurrence research.
- **Outreach:** Website; Social media; Newspaper article.
- **Quality assurance:** Provision of a photo is recommended. Submissions investigated by researcher.
- **Data accessibility:** Viewable on the platform.
- **Notes:** Lack of data despite a news story in the Telegraph.
- **Useful links:** http://floodstones.co.uk/

Fig. 11: Worcester Floodstones: Anonymous (Floodstones, 2016)

- **Useful links:** http://floodstones.co.uk/
  http://www.telegraph.co.uk/science/2016/04/03/ancient-floodstones-sought-to- help-predict-climate-change/
  https://www.youtube.com/watch?v=9iFByiRkw8k

WeSenseIt

- **Primary aim:** To harness environmental data and knowledge to effectively and efficiently manage water resources.
- **Project outline:** An EU FP7 project (funded from 2012 to 2016) developing citizen observatories of water and flooding using a specialised app.
- **Geographic scope:** Trialled in three EU cities: Doncaster, UK; Delft, Netherlands and Alto Adriatico, Italy.
- **Current flood dataset:** Point data; photos; videos of events in real-time; Sensors placed on rivers.
- **Data use:** Situation awareness; response and recovery; prevention, protection and preparedness for future emergency situations; understanding citizens' needs
- **Outreach:** Website; Community events; Academic conferences.
- **Quality assurance:** Sensors are calibrated; Sampling instructions are provided.
- **Data accessibility:** Available to local authorities.
- Notes:
  - Labour intensive.
  - Authorities complained of data overload during peak flooding events.
- **Useful links:** http://wesenseit.eu/
  http://ww.w.iscram.org/legacy/ISCRAM2014/papers/p40.pdf
  http://meetingorganizer.copernicus.org/EGU2016/EGU2016-16678.pdf

Fig. 12: Water level gauge measurer at Marano Vicentino on River Timonchio[7]

Environment agency's SWIM tool

- **Primary aim:** To aid multiple agencies in their combined response to flooding both during an event and after.
- **Project outline:** Launch in 2015 to enable the public to update local authorities about flooding in their homes. It is developed and maintained by GeoWessex in partnership with the Environment Agency.
- **Geographic scope:** Focus in Dorset but has been launched in response to flooding in other UK regions including Cumbria.
- **Current flood dataset:** >450 form submissions.
- **Data use:** Inform Flood Risk Management Strategy.
- **Outreach:** Website; News stories; Flood warden communications.
- **Quality assurance:** Many fields in form which aims to assess quality. Contact details are requested for potential follow up on data submissions.
- **Data accessibility:** Available to local authorities.
- **Participation:** Members of the Public, Flood Wardens and Flood Risk Management Authorities are encouraged to participate.
- Notes:
    - Participation is lower than number of properties affected i.e. 450 reports in 2015 while official data reports that 16,000 properties were affected.
- **Useful links:** https://swim.geowessex.com/dorset/Report http://www.blackmorevale.co.uk/dorset-designed-app-swim-helps-flood-hit- north/story-28481145-detail/story.html http://www.ukauthority.com/smart- places/entry/5883/dorsets-flood-data-app-helps-to-bail-out-cumbria-victims

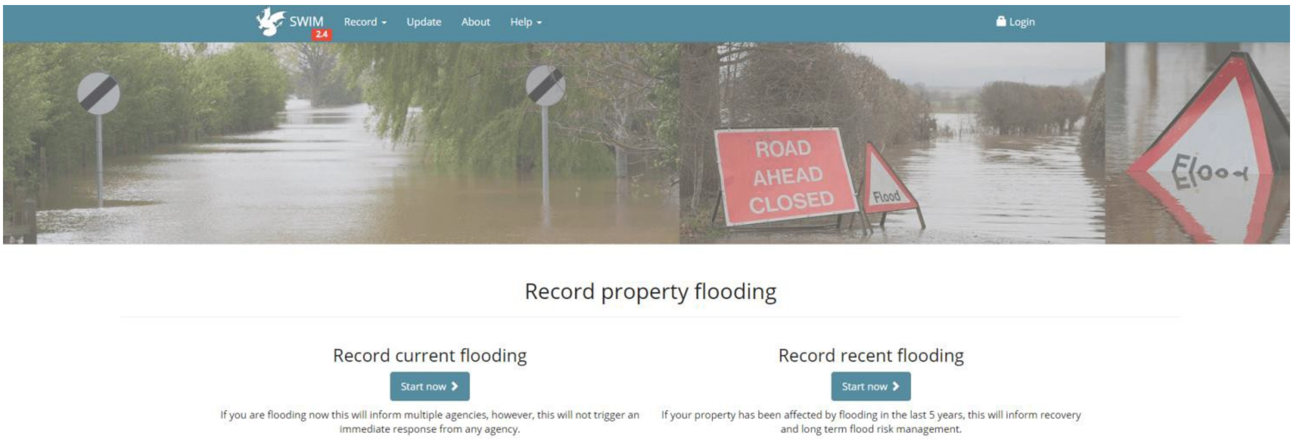


Fig. 13: Website interface of SWIM platform

Google 'MyMaps' independent mapping projects

- **Primary aim:** Aims vary from community flood group information sharing projects to citywide mapping campaigns to raise awareness.
- **Project outline:** A way of enabling points, drawings and photos of events to be shared and made public. Maps can be embedded on website or downloaded.
- **Geographic scope:** Typically city or town scale e.g. Chennai, India; Patterdale, England.
- **Current flood dataset:** Several independent maps, typically <100 points.
- **Data use:** Public awareness; assisting response.
- **Data accessibility:** Data is freely downloadable.
- Notes:
  - Difficult to find specific flood campaigns.
  - Key data such as date is often missing as there are no fields.
  - Metadata is often limited.

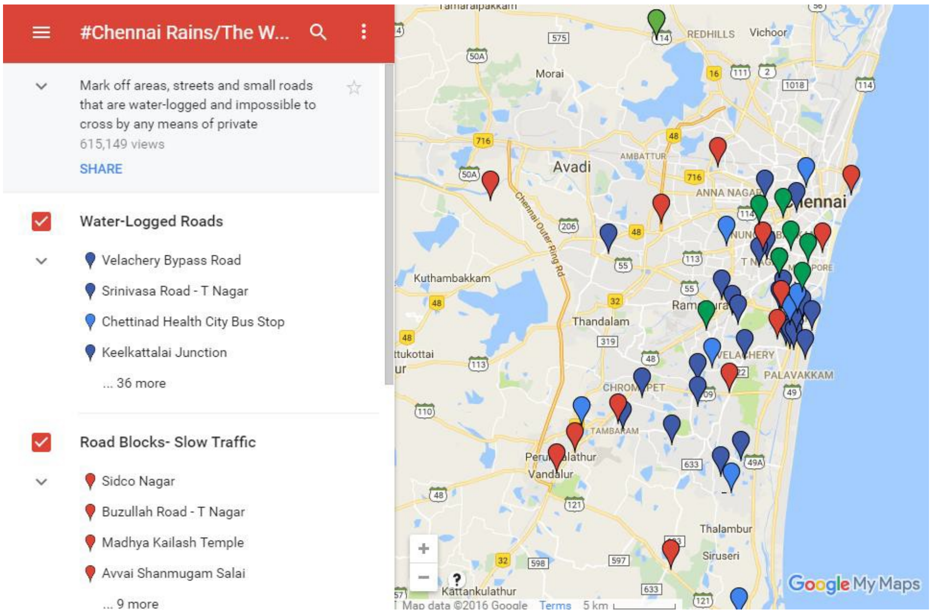


Fig. 14: User interface of Google MyMaps for #Chennairains mapping campaigns

- Useful links:

https://www.google.com/maps/d/viewer?mid=1F54bkFfiULpzExvfAsiGyW67tlg&ll=14.104705509660802%2C78.89870424635637&z=9
http://www.parishfloodgroup.org/patterdale.html
https://www.google.com/maps/d/viewer?mid=1hDk3OY8yH91ViMzcX1S9BO- GFEU&hl=en&ll=51.477640783667646%2C-1.014851500000077&z=10

Social media campaigns

Extracting usable social media data for assessing flood events is highly challenging given the level of noise in posts from the public[3]. Yet, the sheer volume of up-to-date data makes it potentially valuable for a number of applications. Twitter participation could be used to validate scenarios and quickly identify particular areas of need.
However, at present, only a small portion (approximately 1.5% but increasing) of Tweets are precisely geotagged[4]. Even when Tweets are geotagged, these data can rarely be considered reliable for inferring flooded locations[5].

#PetaJakarta

- **Primary aim:** enable Jakarta's citizens to report the locations of flood events using the hashtag: #Petajakarta on Twitter.
- **Project outline:** A research project led by the University of Wollongong from December 2014 to March 2015, producing a publicly accessible real-time map of flood conditions.
- **Geographic scope:** Jakarta, Indonesia focus.
- **Current flood dataset:** 150,000 tweets from 100,000 different users (5,000 of which were geolocated)
- **Outreach:** Newspaper articles; Social media
- **Data use:** Data were used to cross-validate formal reports of flooding from traditional data sources, supporting the creation of information for flood assessment, response, and management in real-time.
- Notes:
  - Jakarta has the highest rates of social media participation in the world. The campaign relies on high concentrations of social media users.
  - Observation bias against those without twitter.
  - Useful links:

https://petajakarta.org/banjir/en/research/
http://www.citymetric.com/horizons/making-smart-cities-work-people-no-1- crowdsourcing-flood-maps-jakarta-1228

#Toonflood

- **Primary aim:** A research project to derive flood information for validating surface water flood models.
- **Project outline:** Two storms in Newcastle, UK in 2012 resulted in hashtags '#toonflood' and '#newcastleendofdays' trended nationally.
- **Geographic scope:** UK focus.
- **Current flood dataset:** >8,000 tweets were posted, most contributed no usable information for understanding the hazard. Nevertheless, by looking for key words such as 'ankle' 'knee' 'height' and 'depth', a

number of general patterns of flooding across the city could be determined (Smith et al., 2015).

- **Data use:** Flood model validation.
- Notes:
  - Geotagged tweets identified during both events were not found to be of practical use. In some instances the geotag identified a location different to where flooding was occurring, often in the case of retweets. To produce geographical data that is usable, a separate website for geo-located flood data was set up and 194 submissions were received, almost all including a photo, and the approximate time and location.
  - The lack of geotags on twitter makes any spatial analysis difficult to perform.
  - Initial activity on social media tends to focus on the intensity of the weather, whilst useful activity detailing areas explicitly affected can sometimes come much later.

Useful links:
https://www.theguardian.com/news/datablog/2012/nov/28/data-shadows-twitter-uk-floods-mapped
http://onlinelibrary.wiley.com/doi/10.1111/jfr3.12154/abstract
http://eprint.ncl.ac.uk/file_store/production/211053/3A060588-AE72-4FA5-A2D3- 6D71C5D91592.pdf

Potential future sources of data

Many of the projects outlined in this review suffer from significant sampling bias. The following potential future sources of crowdsourced data largely avoid such biases by actively targeting members of the public in locations of interest.

Google crowdsourcing

A new Google application called Crowdsource asks users to perform brief tasks. The app, surprisingly, doesn't offer any sort of rewards or micropayments in exchange for users' work. It simply writes:

"Every time you use it, you know that you've made the internet a better place for your community."

A future use of google crowdsourcing could notify anyone in a flood disaster area with a smart phone about the risk and ask for photos for flood emergency response.

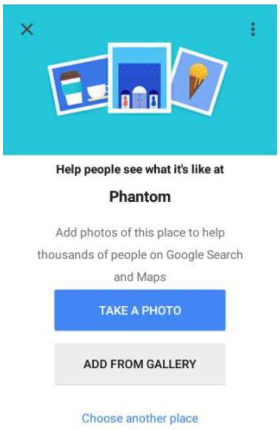


Fig. 15: Screen grab of google crowdsourcing notification appearing on a number of users' phones.

Useful links: https://techcrunch.com/2016/08/29/googles-new-app-crowdsource- asks-users-to-help-with-translation-transcription-more/ http://www.androidpolice.com/2016/08/29/new-google-crowdsource-app-asks-help- translation-text-transcription-seconds-time/ https://www.cnet.com/news/new- crowdsource-app-lets-you-work-for-google-for-free/

The Gig economy

A number of organisations with an interest in flood risk management are exploring the opportunities presented by the gig economy. Potential future projects could involve specialised apps that provide payment for members of the public in flood hit regions to report on the extent of flooding and provide real-time mapping products.

Aggregation of public reports to governmental and commercial bodies

Public reports of flooding are regularly made to highways agency, local government and water companies. These could be compiled in a nationwide or international database.

Appendix 6: Interview questions

1) What type of data on flooding are you lacking/ do you want from crowdsourcing?
2) Do you have any quality or quantity requirements? – photos, outlines depths
3) [Brief summary of currently available datasets].
    a. Would any of them be useful to you?
    b. How would you make use of them/ How would it be managed?
    c. What would make them more usable?
    d. How do lags between event and data availability affect their usability? e.g. delay in Boulder data or historical data
    e. More datasets are emerging, what sort of data would get your interest?
        i. Low vs high resolution
4) Public perceptions are mixed about institutional use of their voluntary contributions and crowdsourcing could provoke a negative response.
    a. How do you think institutions can build a positive relationship and trust with members of the public?
    b. Are there any assurances you can give to members of the public?
    c. Are there any incentives e.g. gig economy?
    d. How many/what type of observations would need to support your work? e.g. town or property level?
5) What sort of resources would you invest in processing the data e.g. for quality?