Supporting participative pre-flood risk reduction in a UNESCO biosphere

O'Grady, Michael J.; Evans, Barry; Eigbogba, Sylvester; Muldoon, Connor; Campbell, Abraham; Brewer, Paul; O'Hare, Gregory M. P.

Published in:
Journal of Flood Risk Management

DOI:
10.1111/jfr3.12520

Publication date:
2019

Supporting Participative Pre-flood Risk Reduction in a UNESCO Biosphere

Michael O'Grady[1], Barry Evans[2], Sylvester Eigbogba[1], Conor Muldoon[1], Abraham Campbell[1], Paul Brewer[3], Gregory M.P. O'Hare[1]

[1]University College Dublin, Ireland.

[2]University of Exeter, UK.

[3]University of Aberystwyth, Wales.

Abstract
Disaster Risk Reduction (DRR) has become the predominant strategy for pre-emptively countering the havoc threatened by natural hazards, complementing traditional disaster management and recovery activities. An important component of DRR activities is community involvement, imbuing the community with a sense of ownership of the risk reduction process, and thus increasing resilience to deal with natural hazards. Though the desirability for community engagement is acknowledged, the differing hazards, environments and community contexts, all pose many obstacles to enabling meaningful participation. This paper describes a participative, community-oriented initiative for DRR in a context of the most common hazard faced by communities worldwide, that of flooding. A novel platform is presented which embraces participatory science principles in facilitating active community engagement in all stages of the flooding lifecycle. It is demonstrated how observations contributed by a community can contribute both to the practical mitigation of the effects of flooding and the calibration of inundation models. The novelty of the platform lies in its emphasis on mitigation activities during the pre-flood stage, as well as its innovative use of image capture for enabling the safe assessment of water levels by the community.

Keywords: Disaster Risk Reduction, flood risk management, crowd-sourcing**,** participatory science, resilience.

Introduction

Enabling communities and local stakeholders to proactively engage with, and contribute to, the disaster management process is increasingly perceived as a social good. Various advantages accrue from such an approach, non-least access to a community on the ground whose local knowledge and provision of near real-time updates on events even as they unfold can prove invaluable to local decision makers. Indeed, such information could be valued as equivalent to that of experts (Haworth, 2016). Historically, such a paradigm shift would have proved impossible. However, developments in Information and Communication Technologies (ICT) have combined to deliver robust platforms through which communities can engage in all stages of disaster management.

Opportunities have long existed for community engagement in crisis management and hazard mitigation (see e.g. Pearce, 2003); nonetheless, significant barriers must be overcome to ensure meaningful participation going forward. Existing institutional arrangements must be questioned, and in some cases, responsibility must be assigned to citizens (Scolobig et al., 2015). Conversely, the public must be prepared to share responsibility and information with authorities; paradoxically, the public may not always see their own involvement as a positive development (Preuner et al., 2017). Moreover, conflicts between public and private interests may emerge compromising accountability and decision-making. The adaptability and scalability of legacy management systems to handle additional categories of data, including Volunteered Geographic Information (VGI) provided by an external community, is also questionable (Haworth, 2018). Concerns about quality, privacy, liability and security are omnipresent.

To date, research in disaster management has focused on what might be loosely termed the systems perspective; however, the importance of human and social elements are increasingly recognised. Cognition and affect should be considered when communicating risk; furthermore, social networks should be utilised more effectively to facilitate the preparedness of citizens and communities (Kerstholt et al., 2017). Arrighi et al. (2017) have developed a novel model that explores the stability of the human body whilst partially immersed in flood waters; such a model could be used for augmenting existing hazard maps to highlight areas of heightened risk. Salvati et al. (2018) found that gender and age are important predictors of mortality both for landslide and flood events, suggesting that such factors should be considered in risk assessment.

This paper considers the issue of public participation in flood-related risk reduction actions; the specific context is that of a United Nations (UN) designated biosphere, namely the Dyfi Biosphere in Wales. Inherent to the biosphere designation is the proactive engagement of local communities in the sustainable management of the biosphere.

Disaster Risk Reduction

Disaster Risk Reduction (DRR) is a multi-dimensional concept and the subject of a global agreement, namely the Sendai Framework (UN, 2015). At a global level, the Sendai Framework represents a uniform approach to disaster risk management policy; this agreement unambiguously frames DDR within the context of sustainable development and poverty reduction, encourages an action-orientated approach whilst shifting the emphasis from disaster management to disaster risk management and the minimisation of disaster risk. Significantly, the framework emphasises the importance of the local level but not to the detriment for the national, regional, and global levels. DDR activities further align with another prominent global initiative, that of the Sustainable Development Goals (SDGs), especially SDG 11 – Sustainable Cities and Communities. DRR seeks to develop and implement an ethos of risk reduction though systematic analyses of potential contributory factors to disasters and the enabling of proactive approaches to their mitigation. Examples of DRR activities include environment management and planning, development of early warning systems and training of personnel. Effective implementation of DRR demands the involvement and contribution of all sectors of society including that of communities; in the case of flooding, this is also a specific requirement of the European Flood Directive (EC, 2007). A key challenge, however, is how to effectively enable such participation. Perceptions of different governance authorities towards citizen participation in flood risk management vary significantly; it is one crucial factor that must be addressed so as to deliver a consistent view of participation (Wehn et al. 2015). A further key impediment surrounds the chronic lack of tools and methodologies for enabling effective citizen participation.

The Cost of Flooding

Between 1996 and 2015, over 1.35 million lives were lost due to natural hazards; more than half died due to earthquakes while the remainder perished as a result of climate and weather-related hazards (CRED, 2015). Since 2002, natural disasters have caused over 80,000 deaths and €100 billion in economic losses in the EU alone (JRC, 2015).

A recent study suggests that river flooding in Europe will affect more than half a million people a year by 2050, as distinct from 200,000 at present; likewise, the cost of damage is estimated to increase from €5.3 billion up to €40 billion in 2050 (Alfieri et al., 2015). To mitigate flooding effects, ongoing initiatives seek to improve preparedness and responsiveness. The European Flood Awareness System (EFAS) (Demeritt et al., 2013) seeks to produce flood models that would enable predictions up to 10 days in advance. The Global Flood Awareness System (GloFAS) (see e.g. Alfieri et al., 2013) seeks to produce real-time global flood forecasts of up to 30 days in advance. The Global Flood Detection System (GFDS) (Revilla-Romero et al., 2014) seeks to provide real-time information on the extent of floods, including cross border scenarios, using satellite observations. In the case of EFAS, it has been estimated that the monetary benefits that accrue from such an early warning system are of the order of €400 for every euro invested (Pappenberger, 2015).

Related Research

A variety of platforms have been documented in the literature that seek to aid the DDR process, both in general and in the case of specific hazards. To elucidate briefly: in the Philippines, a Web-GIS tool, using mashups, has been developed to communicate potential geo-hazards warnings within a 6-hour lead-time to vulnerable communities (Lagmay et al., 2017). In Dijon France, an operational flood forecasting system has been implemented as a SaaS (Software as a Service); a stationary Kalman filter is used to assimilate real-time flow data to update the hydraulic states (Mure-Ravaud et al., 2016). Forecsts are provided at various locations on the watershed. The Iowa Flood Information System (IFIS) is a web-based platform that provides flood inundation maps, real-time flood conditions, and flood forecasts to communities in Iowa (Demir and Krajewski, 2013). Henriksen et al. (2018) proposed a web-based framework for flood risk that allows participation in all stages of the DRR cycle, providing a platform for stakeholder interaction and collaborative decision-making. Cloud computing has been harnessed to deliver a framework for data acquisition, assimilation and hydrological modelling for use in water resources management (Kurtz et al., 2017). The Flood

Disaster Management System (FDMS) seeks to provide disaster reduction capabilities that cover the entire flood management chain; modular design and the use of ontologies are notable technical features of this platform (Qiu et al., 2017). FLIRE is a web-based Decision Support System (DSS) that combines both fire and flood risk management (Kochilakis et al., 2016). In the specific case of the flooding domain, Teng et al (2017) review the state-of-the-art in flood inundation modelling; Jain et al (2018) present a review of flood forecasting techniques.

Studies that investigate the assimilation of crowd-sourced VGI data into hydrological and hydraulic models are rare, even though validation of flood models in often limited by data unavailability. While measurements from VGI increase spatial and temporal resolution, other issues including the viability of model assimilation are important for accurate flood predictions (Mazzoleni et al., 2018). Indeed, a reduction in model performance and flood forecasts will invariably occur unless participation remains above a certain threshold. Rollason et al. (2018) have demonstrated the use of quantitative and qualitative VGI data for validating flood inundation models, specifically the LiSFLOOD-FP model, enabling a realistic reconstruction of flood event dynamics, both spatially and temporally. Restrepo-Estrada et al. (2018) demonstrated that utilising authoritative rainfall data, with VGI (geosocial media) data as a hydrometeorological proxy variable, for input into the Probability Distributed Model (PDM), improved streamflow predictions, indicating its potential as a proxy for improving flood early-warning systems. Current monitoring systems cannot provide sufficiently high-quality data for accurate storm water modelling; this problem is particularly acute in developing countries. Yang and Ng (2017) demonstrated that utilising crowd-sourced data would lead to a more accurate modelling of storm water flow than if just using gauge data; though the VGI data was simulated in this instance, the results suggest a potential for use in urban scenarios. Rosser et al. (2017) showed how a combination of social media, remote sensing and terrain models could be harnessed to derive a Bayesian model for estimating flood inundation. An overview of the use of citizen observations for flood modelling applications has been compiled by Assumpção et al. (2018).

A wide variety of technologies has been explored in the scientific literature as a means of enabling practical citizen-initiated flood monitoring initiatives (McCallum et al 2016). Participatory sensing through VGI has been harnessed by Brovelli et al. (2014) for water management; here the authors adopt Web 2.0 technologies, enabling the contribution of georeferenced multimedia information concerning issues of interest. Creek Watch (Kim et al., 2011) consists of an iPhone App and supporting WWW site framework for waterway management; this project adopted a citizen science approach and was developed in collaboration with local state agencies. FloodPatrol (Victorino and Estuar, 2014) is an Android App that supports the crowdsourced reporting of flood levels. As flood level in this instance is subjective, issues concerning validation models are explored. Lanfranchi et al. (2014) describe a citizen observatory approach for engaging the public in decision-making processes relating to flood and water management; this differs from other efforts in that while it utilises an App, the platform is further augmented with an in-situ sensor network. Social.Water (Fienen and Lowry, 2012) may be regarded as a crowd hydrology project; it illustrates how simple text messages sent to a dedicated number may be categorized and visualized. As the technology is at once mature, ubiquitous and simple, it offers a practical solution for rural areas and developing countries. Little et al. (2016) describe how a community-based monitoring approach based on citizen science precepts has been harnessed to monitor an extensive network of private water-supply wells; collaboration with local municipals is a key contributor to the success of this project. Smith et al. (2015) developed a real-time modelling framework to identify probable flood areas using only social media data. Breuer et al. (2015) demonstrated the potential of crowd-sourcing for assessing the spatial distribution of solutes in streams. The Association of State Floodplain Managers (ASFPM) have developed the Flood Photo Viewer (ASFPM, 2014); this serves as an image archive that seeks to maintain flood history and an institutional memory for communities. However, it adopts a web-centric rather than App-centric approach to image collection. Hirata et al. (2015) describe a conceptual scheme for the dynamic and collaborative mapping of flooding points in the city of São Paulo. In the case of flood inundation modelling, StormSense (Loftis et al. 2017) is a particularly noteworthy initiative; here, the end-user walks along the boundary of the inundation, recording GPS positions as thewalk. Though effective, applicability is limited to scenarios where it is safe to encounter the flood waters.

This paper describes a platform entitled NOAH (citizeN flOod wAtcH) which seeks to promote the engagement of local communities in flood-related DDR. It complements and extends existing research in this domain. Specifically, two issues highlighted by the research community as necessitating additional attention are explicitly addressed:

1. The need for further research in the pre-event phases of disaster management where the active engagement of a community and the use of VGI would support disaster preparation and strengthen community resilience (Haworth and Bruce, 2015).
2. The development of novel and improved methods for estimating water levels from pictures (Assumpção et al., 2018).

Participatory Disaster Management

Through participatory disaster management, communities can engage at all stages of the disaster management life cycle on their own initiative, but ideally in collaboration with local government. Indeed, it is essential that their efforts complement, extend and align with those of all other stakeholders. Examples of such stakeholders include local civic groups, humanitarian and responder groups, as well as regional and national organisations concerned with policy definition. While several participatory models of community engagement in disaster management exist, those of the UN DRR and the disaster management cycle (Warfield, 2004) are particularly intuitive. It must be acknowledged that in the UN definition, incidences of flooding are regarded as emergencies rather than disasters; disasters demand external interventions. For the purposes of this discussion, participatory flood management is considered within the overall context of the Global Development Research Center (GDRC) disaster management cycle, and within the domain context of a flood management framework (Price and Vojinović, 2011). Figure 1 illustrates the principal activities in each stage.

Stage 1: Mitigation

DRR activities are classified as mitigation activities; these align with the ***Pre-flood*** mode of the flood management framework. Though an area may be prone to flooding, there are often issues which, if identified and remedied at a suitable time, reduce the impact of subsequent flooding events. For example, drains which are blocked as a result of autumn leaf fall, could generate a small-scale flooding event, and even prolong it.

During this stage of the GDRC cycle, community members assess their environment at periodic intervals and record their observations of any issue that could potentially give rise to, or exacerbate, a flooding event. Such issues are subsequently monitored both by the community and local government, allowing the identification of appropriate courses of action. For example, a responder (environmental official), who wanted to see if any culverts or flow pathways have recently been reported as being obstructed with debris, could search community-generated observations by keyword and date. Additional statistical information such as the number of times a culvert has been reported blocked could also be obtained; this would highlight potential issues in the area that merit further investigation.

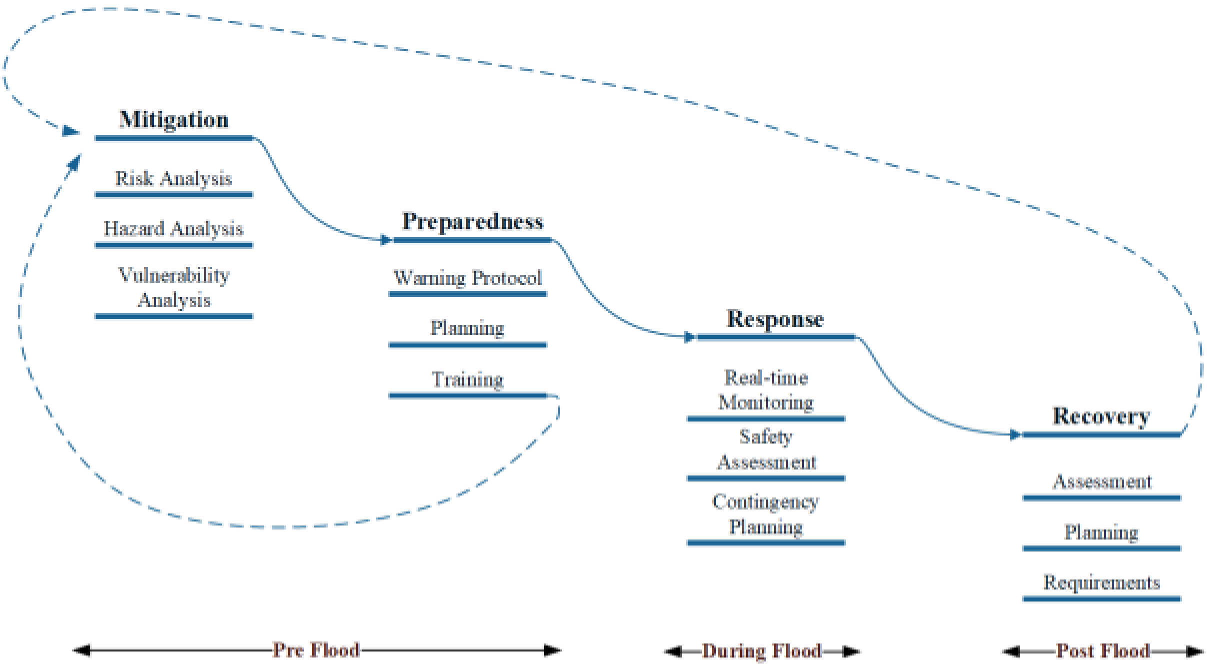

Figure 1: Flood life cycle in the context of disaster management.

Stage 2: Preparedness

This activity is concerned with planning for a response to a hazard; in the case of flooding, this occurs in ***Pre-flood*** mode. This may for example involve defining a protocol for generating alerts amongst the community. Appropriate training and exercise activities come under this part of the cycle.

Stage 3: Response

This phase of the cycle is concerned with managing the situation on the ground in ***During Flood*** mode. From an overall management perspective, real-time information concerning what is happening on the ground is invaluable to a number of stakeholders including disaster response teams; however, there is a risk to civilians who seek to monitor the flood, and who may compromise their own safety in their efforts to record ongoing events.

The response stage offers a singular opportunity to gather information of what is actually happening on the ground. Flood and inundation models predict incursions and flooding extents; validating such models demands information of what has really happened during the flood. Maintaining models is problematic due to evolving landscapes and the complexity of interactions within the environment during a flood event. Ultimately, the efficacy of any adopted model demands its evaluation. Water depth and flooding extent are variables that can be measured by the community; capturing other variables demanded by some models, for example, water velocity, may be beyond the capability of the community or perhaps cannot be captured safely. Ultimately, a suitably equipped and trained community can provide a metric that highlights where such differences between model and reality occur. Though satellites can and do provide useful data, timeliness cannot be guaranteed.

Stage 4: Recovery

After a flooding event, or in ***Post flood*** mode, it is necessary to assess damage and begin a recovery operation. By recording their observations of what has happened on the ground, for example, of damaged, waterlogged land, blocked bridges and so forth, a community can influence the prioritization of remedial works, thus enabling at least a partial mitigation of the severity of flooding. Insightsnto any changes in the paths of rivers are also gleaned; though river paths naturally change over time, extreme weather events influence and accelerate this process.

Case Study: Participative Community-driven Flood Monitoring

Biosphere reserves are apt locations to promote community participation. Such reserves comprise terrestrial, marine or coastal ecosystems of designated importance and thus recognised by UNESCO designation. At present, there are 669 biosphere reserves in over 120 countries. Fundamental to the biosphere designation is, amongst others, that local communities engage in the sustainable management of the biosphere; this demands an interdisciplinary approach. Biospheres are not immune to natural hazards; ramifications can be significant as sensitive ecosystems may be irreparably damaged.

For the purposes of this discussion, the Dyfi biosphere[1] in Wales is considered. This biosphere has been severely affected by flooding events in recent years. In an effort to enable the local community make an effective contribution to the management of their biosphere, a DRR initiative based on the Citizen Observatory concept (Grainger, 2017) was conceived and implemented.

Citizen Observatories represent a recent initiative to harness both crowdsourcing and citizen science as a means of enabling communities to take a greater role in the stewardship of their environments. The Citizen Observatory is not designed to compete with established and ongoing participatory and citizen science initiatives; rather it complements them but with an emphasis on methodology such that the quality and provenance of data can be established, whilst always seeking to uphold Open Science (Nosek et al., 2015) principles. It must be stressed that scientific objectives, as envisaged by particular citizen science initiatives are not the raison d'être for the citizen observatory. The emphasis is rather on enabling communities gather data that can have a meaningful impact on policy; nonetheless, such data must adhere to general scientific principles in terms of methodology and provenance. From an e-infrastructure perspective, observatories seek to provide a range of common services, for example, access and data management amongst others. Apps and other sensor devices for data collection and services for data processing are both domain dependent and are generally external to the core observatory platform.

Design & Implementation

Requirements were established in close collaboration with a local community group in the Dyfi biosphere - the Talybont (Tal-y-bont) floodees[2]. This group take a proactive approach to the mitigation of flooding risk in their local environment – one that is susceptible to flooding and that has historically been severely affected by flooding. Table 1 outlines the required observations that emerged from this co-design process involving the community group and the authors; these are categorised as management observations that would help alleviate problems at any stage of the flood life-cycle and those (model-driven) that can produce data for subsequent integration into flood inundation models. These categories are not necessarily mutually exclusive, depending on the complexity of the model adopted. At their simplest, observations may consist of a photograph augmented with some metadata, for example, the position where the photograph was taken, and a corresponding textual comment by the user; additional data may be requested depending on the nature of the observation required.

Management-driven Observations	Model-driven Observations
Debris in river	High River level
Blocked drain	Water logged land
Blocked bridge	Flood water
Pollution	Trash/tide line
Flood damage	
Debris	
Land erosion	

Table 1: Two categories of observations are supported. Issues that may aggravate risk at any stage of the flood life cycle and that would be of immediate interest to management in the local municipality, and those that would serve as useful parameters for inundation models.

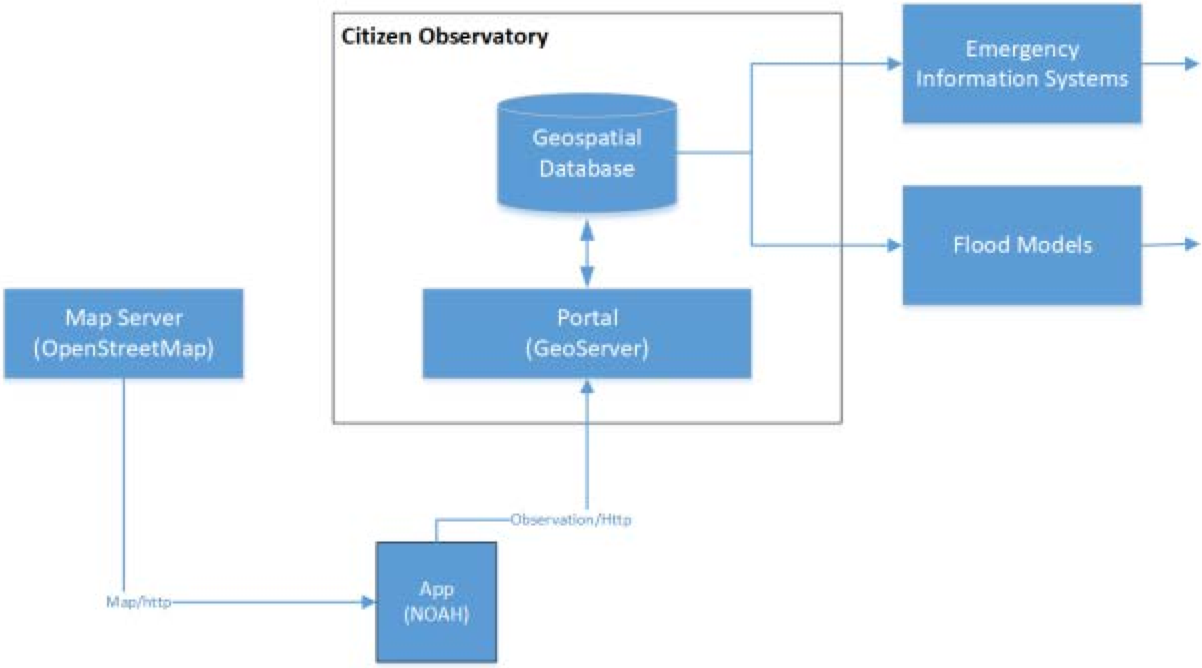

Figure 2: High-level schematic of a Citizen Observatory for flood risk reduction.

Harnessing a pre-existing citizen observatory framework, based on the generic Citizen Observatory Web (COBWEB) platform (Higgins et al., 2018), NOAH was developed for the community such that they could record and share their observations; the COBWEB platform was configured and augmented to ensure interoperability with the NOAH app. In brief: a standard App/Server model is adopted; figure 2 illustrates the succinct components of its architecture. Several standard services including access control and data management are harnessed. Much of this functionality is provided by the underlying GeoServer platform[3]; this is a well-established open-source GIS platform that supports the publication of geospatial data via a suite ofpen standards. A SAML (Security Assertion

Markup Language) protected endpoint is provided such that the platform can be integrated into pre-existed secure systems. GeoJSON, an extension of JSON (JavaScript Object Notation)[4], an open format for representing geographic information is used for data encoding; an efficient format from a data transmission perspective, GeoJSON is supported by the Internet Engineering Task Force (IETF)[5]. OpenStreetMap[6] an exemplar crowd-sourcing project, is central to all map-based functionality; a similar initiative delivered by the Humanitarian OpenStreetmap Team[7] supports community-based mapping projects for a variety of purposes including disaster preparedness.

Two categories of end-user are supported. *Anonymous mode* allows anybody to upload an observation. *Registered mode* on the other hand necessitates pre-registration on the portal prior to uploading of observations; in many circumstances, the credibility of an observation is synonymous with that of the reputation of the person who makes it. As damage to critical infrastructure is always a risk during an extreme weather event, observations are pre-cached on the mobile devices until such time as network connectivity is available.

Data quality is an omnipresent problem in volunteered information (Senaratne et al., 2017); maximising the quality of the data must begin during the construction of an observation. An observation cannot be uploaded to the portal unless it is accompanied by a valid GPS position; furthermore, additional GPS parameters are recorded for subsequent analysis. Photographs can only be taken when the phone is tilted at an appropriate angle; this is necessary to ensure that a Line of Sight (LoS) algorithm can be applied correctly. Measurements from the inbuild accelerometer on the smartphone ensure that the admissible angle is calculated almost instantaneously, enabling immediate feedback whilst positioning the camera on the mobile device. Validation of uploaded data usually occurs post event. No formal validation metric is practical in real-time, unless an in-situ monitoring network is in place. The proxy for such a metric, is however, the number of observations recorded by different people and the degree towards which these are consistent.

Modus Operandi

When somebody wishes to make an observation, a standard sequence of steps is followed:

I. A general classification is made with regard to the type of observation (Pre-flood, During Flood, Post-flood).
II. A category from a predefined list that characterizes the observation in a more descriptive way is then selected (Figure 3(a)).
III. Guided by a series of prompts, a photograph is taken.
IV. If the observation is of a category suitable as an inundation model parameter, the photo will be augmented with additional data such as polygons, polylines, and markers as needed. For example, Figure 3(b) prompts for the user to record the water line on the image; likewise, Figure 3(c) illustrates how a polygon can be defined on a map to indicate a waterlogged area.
V. A number of additional photos may be taken from different angles and positions if required and included in the one observation.
VI. Observations are uploaded either immediately, or when wireless connectivity has been re-established. In the former case, observations should be uploaded in less than a minute; however, if wireless connectivity in not available, observations can only be used for post-flood analyses.

Figure 3: Options available when making an observation. (a) an item of interest is selected from a predefined list; (b) drawing a trash line on a river bank; (c) marking a zone of waterlogged land.

Model-driven Risk Reduction

Figure 4: A major flooding event took place in the small town of Tal-y-bont in the Dyfi biosphere in 2012. This photograph appeared in the national press. ©Henry Lamb. (Used with permission.)

In order to facilitate active citizen engagement with flood inundation modelling, a protocol that ensures citizens' safety whilst collecting data is a necessity. To ensure this, the app warns the user about the dangers of flooding on each initialisation of the app; moreover it is purposefully designed such that key data may be collected at a safe distance. This was primarily achieved through the capturing of GPS position, baring and tilt values of the device when the photo was being taken. These data values are then used as a means of geo-tagging at a distance utilising Line of Sight (LoS) methods as outlined by Meek et al. (2013). Using this data, with additional information about the camera on the device and two additional inputs by the user, approximate local flood levels may be estimated. The method designed is relatively simple yet robust; it can even be used with historical photographs where the user revisits sites of where flooding has occurred previously and captures data. Figure 4 illustrates a flooding event in of Tal-y-bont, a small town in the biosphere, that took place some years ago. Though a professional photo - one that was used in the national press at the time, it is archetypical of what could be captured in a flooding event.

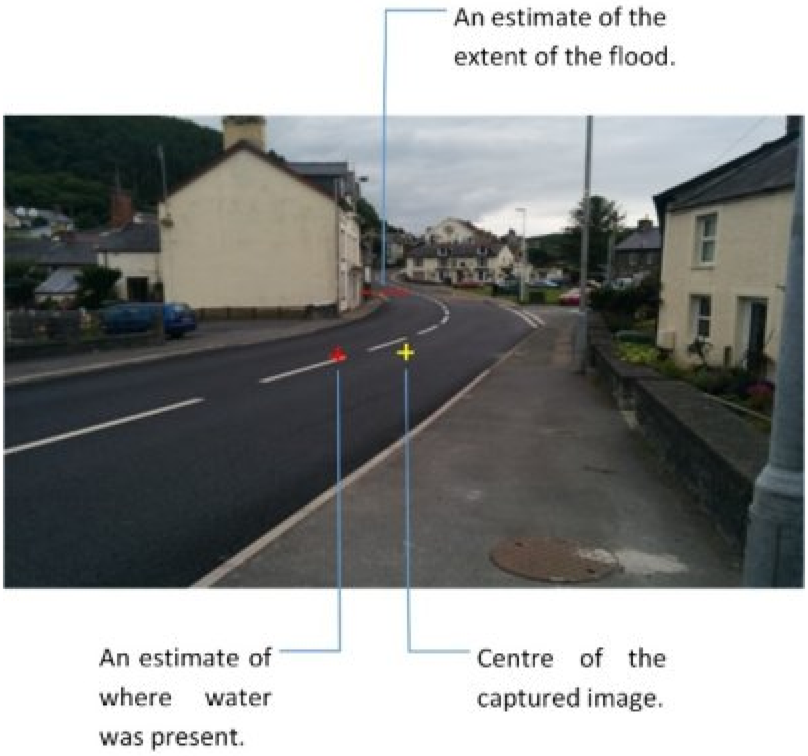

Figure 5: Using the photograph shown in Figure 4 as a reference, the extent of the (historical) flood is subsequently estimated and geotagged.

Using Figure 4 as a reference photo, a subsequent geotagged image can be captured at approximately the same location (Figure 5). Upon capturing the photo, a marker is placed on where flood water was present (red cross) and a line (red line) drawn to define the boundary of the flood extent, using (in this case) the historical photo as reference. The cross (yellow) in the middle of the photo is the key reference point used in the LoS calculation to estimate the distance from observer to observation. All this information captured is then used as parameters for later use in flood models.

Figure 6 shows the derived calculated likelihood of flooding extents based on the inputs captured from the smartphone device as depicted in Figure 5 used in combination with a Digital Terrain Model (DTM) and a simple bespoke (for testing purposes) rolling-ball flood model (see e.g. Lea, 1992). The manner in which this is derived is beyond the scope of this paper. In summary: the marker captured by the citizen on their devices is translated to real coordinates, and then to a location where to add water to surface of the DTM in the model. A rolling ball method is then applied to allow water to move along the surface until it reaches the line (also translated from photo to real coordinates on the DTM). Once a predefined percentage of the derived geo-referenced line is covered by water the model stops. The model irun multiple times with different derived geo-referenced positions of the flood marker and extent lines, based on the uncertainties inherent in GPS, bearing and tilt. Combining all the model outputs whereby cells in the DTM are classed as either wet or dry based on water level being above a threshold value, a “fuzzy-based” risk of flooding extent can be derived (Figure 6). This “fuzzy-based” approach was selected as it allows for the combination of results from multiple users thereby potentially allowing for a more comprehensive depiction of the flood extent from a given event.

Figure 6: Figure 6: Using a DTM in conjunction with data captured by NOAH and the rolling ball technique, the likelihood of flooding is predicted and compared with the authoritative flood warning area as identified by the Environmental Agency (EA).

Although the modelling approach in the above example used a simple bespoke rolling-ball model for deriving flood extents, it is envisioned that the derived geo-referenced data captured by NOAH could be utilised either directly in established flood models, or indirectly as a means of calibration using citizen’s captured data for reference.

The User Experience

To assess the usability of NOAH, two instruments were administered. The System Usability Scale (SUS) was firstly adopted. SUS is a well-known, cost-effective instrument that has been applied in a wide variety of domains and a diverse suite of technologies; it has also been harnessed for the evaluation of crowd-sourcing Apps (see e.g. Fröhlich et al. 2016). As the questionnaire consists of 10 items rated in a 5-point Likert scale, it can be quickly completed and analysed. As SUS is not diagnostic, a second instrument, namely a customised questionnaire, was constructed to garner some deeper insights into the user experience and afford an opportunity to present free feedback.

Volunteers were requested to record five distinct archetypical observations for river level, status of a drain culvert, any debris that could aggravate a situation, and the presence of water anywhere outside of the local river. After being briefed on the objectives and installing the NOAH App, volunteers were encouraged to explore their locality whilst completing the observations in their own time. Volunteers then completed and returned the questionnaires some days later. As SUS gives statistically valid results with a relatively small number of subjects, eleven volunteers (n=11) were recruited in a small urban area in the sparsely-populated biosphere; this group consisted of 6 females and 5 males. The operational assumption was that of pre-flood mode; it was considered unsafe and unethical to ask volunteers to assess an unproven tool in a real flooding situation.

An analysis of the SUS questionnaire, following the guidelines of Sauro (2011), yielded a score of 75. As this is above the threshold of 68, it is concluded that the software usability is above average. An analysis of the custom questionnaire gives insights into where potential users encountered difficulties. Table 2 outlines six dimensions of the user experience; each dimension consists of a number of 5-point likert-type items that define the (sub) scale for each dimension. As can be seen, the results indicate broad agreement with SUS. To elucidate briefly: D2 relates to the attention given to the introductory screens. As these incorporate an important safety message, as distinct from the usual terms and conditions, an alternative approach for emphasising safety is needed. D5 concerns the uploading of observations to the observatory server. In areas where network coverage is intermittent, of which biospheres are archetypical, data is pre-cached on the device for uploading on subsequent network re-connectivity. Though a well understood methodology in the ICT community, difficulty was encountered by the group in the understanding and implementation of this process. Where the open feedback section of the questionaire was completed, the technical nature of the language used was identified as a deficiency. The issue of pre-caching resurfaced and was used by some within the group as an illustration of the kind of concept with which they were unfamiliar. Overall, functionality was broadly understood; however, minor changes regarding the Look & Feel (L&F) were proposed.

D.#	Dimension	Items	Mean	SD
D1	Overall Satisfaction	8	3.97	1.10
D2	Understanding of Introductory Screens	4	3.15	1.52
D3	Completion of an Observation	7	4.64	0.88
D4	Mark-up of Photograph	4	3.88	1.54
D5	Uploading of Observations to Portal	4	3.45	1.43
D6	Completion of pre-assigned Tasks	5	4.72	0.73

Table 2: Usability was assessed through 6 discrete dimensions.

Discussion

NOAH and similar initiatives illustrate the viability of harnessing local communities in proactively monitoring their own environments and actively participating in DDR activities. Though the tool of choice is that of the smartphone, other technologies such as sensors and UAVs offer additional possibilities going forward. The increased interest in participative paradigms such as crowd sourcing suggest that local community groups could be quickly assembled. In areas susceptible to flooding, motivation should not be an issue; nonetheless, it is important to stress the need for maintaining community involvement. This is always an issue with participative science projects. In areas where flooding events are rare yet impact upon the population, the assumption that a motivated group is available is open to question. Gamification is one strategy often proposed to counter fatigue and lack-of-interest (see e.g. Frisiello et al., 2017).

Participative DDR in flooding scenarios is viable and has significant potential; nonetheless, three key issues need resolution for the effective fulfilment of this promise – 1) commonality of protocol for all stages of the flooding lifecycle; 2), standardisation of data in terms of formats and availability, and 3) the issue of safety on the ground.

NOAH, in line with similar initiatives, adopts an ad-hoc solution for data management; such approaches are unsustainable. There is a need for a standardised approach to the collection and management of data pertaining to all events in the flooding lifecycle. Documented guidelines exist; for example, those of the US Federal Emergency Management Agency (FEMA)[8]. In Ireland, the Office of Public Works (OPW), the national organisation responsible for flood risk management provides data collection guidelines for its own staff[9]. Interestingly, it does not encourage members of the public to engage in such activities; in this, the OPW is probably archetypical. WaterML, an initiative of the Open Geospatial Consortium (OGC), focuses solely on water observation data. Other OGC initiatives, SensorML and Observations and Measurements (O&M), are more generic. A more holistic approach that standardises data collection for risk and damage assessment is required; the need for such an approach has also been advocated elsewhere (see e.g. Molinari et al., 2016). The RISPOSTA procedure (Ballio et al., 2015), though focusing exclusively on damage data in the aftermath of floods, suggest a model that might be harnessed and augmented to include the full flooding cycle.

Standardisation is fundamental for data harmonisation, reuse and integration. Data collected as part of participative processes must be made available in standardised formats either via open datasets or through appropriate services; in all cases, the necessary metadata to ensure its effective utilisation should be provided. This is a prerequisite for the integration of data gathered by communities into information systems utilised by local authorities as well as flood models developed by the research community. Novel citizen observatory frameworks offer an intriguing vision for participative community flood monitoring; however, interoperability in terms of data, protocol and services remains a key challenge.

In developed countries, the majority of flood-related fatalities occurs due to inexperienced people entering floodwater either in boats, vehicles or on foot (Arrighi et al., 2017). In a case study undertaken in Italy, Salvati et al. (2018) identified three specific hazardous behaviours that contribute to fatality in floods – 1) crossing a river with a vehicle, 2) standing on the bank of a river and 3) standing on a bridge. Such risky behaviours suggest low risk perception in the case of those involved. Indeed, the latter two behaviours may be considered archetypical of what would happen in participative DDR. Thus before any activity is undertaken, there is a primary need to raise awareness of safety concerns in the community through appropriate training.

Conclusion

This paper has considered the most common natural hazard, that of flooding, and outlined a methodology and toolkit for empowering a community in the collection of data that could be meaningfully used at all stages of the flooding life-cycle. The critical issue of capturing observations that would serve as useful parameters for flood inundation, hazard mapping, and flood model refinement, was addressed. A novel proof-of-concept platform has been implemented and validated. Future work will focus on addressing how to expose and serve community-generated observations; it is envisaged that the OGC initiative on Sensor Web Enablement (SWE) for Citizen Science (SWE4CS) will be utilised. The potential of UAVs and other innovative sensor platforms for use by communities will also be considered. In the longer term, the needs of other stakeholders such as flood managers should be considered.

Acknowledgements

The practical support of the staff at EcoDyfi – Lucy Morus-Baird, Andy Rowland, Caroline Freeman in facilitating access to the Dyfi biosphere was fundamental to the completion of this work; the authors are most grateful for their efforts and encouragement. The practical advice of the Talybont (Tal-y-bont) Floodees is gratefully appreciated.

This project has received funding from the European Union's Seventh Programme for research, technological development and demonstration under grant agreement No 308513. The support of the COBWEB consortium is acknowledged.

Conflict of Interests

The authors declare no conflict of interests.

References

Assumpção, T.H., Popescu, I., Jonoski, A. and Solomatine, D.P., 2018. Citizen observations contributing to flood modelling: opportunities and challenges. *Hydrology and Earth System Sciences*, *22*(2), p.1473.

Alfieri, L., Feyen, L., Dottori, F. and Bianchi, A., 2015. Ensemble flood risk assessment in Europe under high end climate scenarios. *Global Environmental Change*, *35*,199-212.

Alfieri, L., Burek, P., Dutra, E., Krzeminski, B., Muraro, D., Thielen, J. and Pappenberger, F., 2013. GloFAS-global ensemble streamflow forecasting and flood early warning. *Hydrology and Earth System Sciences*, *17*(3), 1161-1175.

ASFPM - Association of State Floodplain Managers, 2014. The Flood Photo Viewer [Online]. http://floodatlas.org/floodview/ [accessed 25 October 2018]

Arrighi, C., Oumeraci, H. and Castelli, F., 2017. Hydrodynamics of pedestrians' instability in floodwaters. *Hydrology and Earth System Sciences*, *21*(1), p.515.

Ballio, F., Molinari, D., Minucci, G., Mazuran, M., Arias Munoz, C., Menoni, S., Atun, F., Ardagna, D., Berni, N. and Pandolfo, C., 2015. The RISPOSTA procedure for the collection, storage and analysis of high quality, consistent and reliable damage data in the aftermath of floods. *Journal of Flood Risk Management*. doi:10.1111/jfr3.12216.

Breuer, L., Hiery, N., Kraft, P., Bach, M., Aubert, A.H. and Frede, H.G., 2015. HydroCrowd: a citizen science snapshot to assess the spatial control of nitrogen solutes in surface waters. *Scientific reports*, *5*.

Brovelli, M.A., Dotti, L., Minghini, M., Pancaldi, M. and Zamboni, G., 2014. Volunteered Geographic Information for water management: a prototype architecture, 11th International Conference on Hydroinformatics (HIC 2014), New York City, USA, [online]. http://academicworks.cuny.edu/cc_conf_hic/293/ [accessed 25 October 2018]

CRED - Centre for Research on the Epidemiology of Disasters 2015. The human cost of natural disasters 2015: a global perspective [Online]. http://www.cred.be/node/1355 [accessed 30 May 2018]

Demeritt, D., Nobert, S., Cloke, H.L. and Pappenberger, F., 2013. The European Flood Alert System and the communication, perception, and use of ensemble predictions for operational flood risk management. *Hydrological Processes*, *27*(1), 147-157.

Demir, I. and Krajewski, W.F., 2013. Towards an integrated flood information system: centralized data access, analysis, and visualization. *Environmental Modelling & Software*, *50*, pp.77-84.

EC - European Commission 2007. The EU floods directive. [Online]. http://ec.europa.eu/environment/water/flood_risk [accessed 25 October 2018]

Fienen, M.N. and Lowry, C.S., 2012. Social. Water—A crowdsourcing tool for environmental data acquisition. *Computers & Geosciences*, *49*, pp.164-169.

Frisiello, A., Nguyen, Q.N. and Rossi, C., 2017, December. Gamified crowdsourcing for disaster risk management. In *Big Data (Big Data), 2017 IEEE International Conference on* (pp. 3727-3733). IEEE.

Fröhlich, S., Springer, T., Dinter, S., Pape, S., Schill, A. and Krimmling, J., 2016. BikeNow: a pervasive application for crowdsourcing bicycle traffic data. In *Proceedings of the 2016 ACM International Joint Conference on Pervasive and Ubiquitous Computing: Adjunct* (pp. 1408-1417). ACM.

Grainger, A., 2017. Citizen Observatories and the New Earth Observation Science. *Remote Sensing*, *9*(2), p.153.

Haworth, B.T., 2018. Implications of volunteered geographic information for disaster management and GIScience: A more complex world of volunteered geography. *Annals of the American Association of Geographers*, *108*(1), pp.226-240.

Haworth, B., 2016. Emergency management perspectives on volunteered geographic information: Opportunities, challenges and change. *Computers, Environment and Urban Systems*, *57*, pp.189-198.

Haworth, B. and Bruce, E., 2015. A review of volunteered geographic information for disaster management. *Geography Compass*, *9*(5), pp.237-250.

Higgins, C.I., Williams, J., Leibovici, D.G., Simonis, I., Davis, M.J., Muldoon, C., and O'Grady, M.J., 2018. Citizen OBservatory WEB (COBWEB): A generic infrastructure platform to facilitate the collection of citizen science data for environmental monitoring. *International Journal of Spatial Data Infrastructures Research, 13*, pp. 78-87.

Hirata, E., Giannotti, M.A., Larocca, A.P.C. and Quintanilha, J.A. 2015. Flooding and inundation collaborative mapping – use of the Crowdmap/Ushahidi platform in the city of Sao Paulo, Brazil. *J. Flood Risk Manage*. doi:10.1111/jfr3.12181

Jain, S.K., Mani, P., Jain, S.K., Prakash, P., Singh, V.P., Tullos, D., Kumar, S., Agarwal, S.P. and Dimri, A.P., 2018. A Brief review of flood forecasting techniques and their applications. *International Journal of River Basin Management*, pp.1-16.

JRC - EU Joint Research Centre 2015. New knowledge centre to help the EU minimise risk of disasters [Online https://ec.europa.eu/jrc/en/news/new-knowledge-centre-help-eu-minimise-risk-disasters [accessed 25 October 2018]

Kerstholt, J., Duijnhoven, H. and Paton, D., 2017. Flooding in The Netherlands: How people's interpretation of personal, social and institutional resources influence flooding preparedness. *International journal of disaster risk reduction*, *24*, pp.52-57.

Kim, S., Robson, C., Zimmerman, T., Pierce, J. and Haber, E.M., 2011. Creek watch: pairing usefulness and usability for successful citizen science. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 2125-2134).

Kochilakis, G., Poursanidis, D., Chrysoulakis, N., Varella, V., Kotroni, V., Eftychidis, G., Lagouvardos, K., Papathanasiou, C., Karavokyros, G., Aivazoglou, M. and Makropoulos, C., 2016. A web based DSS for the management of floods and wildfires (FLIRE) in urban and periurban areas. *Environmental Modelling & Software*, *86*, pp.111-115.

Kurtz, W., Lapin, A., Schilling, O.S., Tang, Q., Schiller, E., Braun, T., Hunkeler, D., Vereecken, H., Sudicky, E., Kropf, P. and Franssen, H.J.H., 2017. Integrating hydrological modelling, data assimilation and cloud computing for real-time management of water resources. *Environmental modelling & software*, *93*, pp.418-435.

Lagmay, A.M.F.A., Racoma, B.A., Aracan, K.A., Alconis-Ayco, J. and Saddi, I.L., 2017. Disseminating near-real-time hazards information and flood maps in the Philippines through Web-GIS. *Journal of Environmental Sciences*, *59*, pp.13-23.

Lanfranchi, V., Wrigley, S.N., Ireson, N., Wehn, U. and Ciravegna, F., 2014. Citizens' observatories for situation awareness in flooding. *Proc. of the 11th Int. Conf. on Information Systems for Crisis Response and Management (ISCRAM 2014)*, 2014, pp. 145–154.

Lea, N.L., 1992. An aspect driven kinematic routing algorithm. *Overland flow: hydraulics and erosion mechanics*, *147*, p.175.

Little, K.E., Hayashi, M. and Liang, S., 2016. Community-Based Groundwater Monitoring Network Using a Citizen-Science Approach. *Groundwater*, *54*(3), pp.317-324.

Loftis, J.D., Wang, H., Forrest, D., Rhee, S. and Nguyen, C., 2017. Emerging flood model validation frameworks for street-level inundation modeling with StormSense. In *Proceedings of the 2nd International Workshop on Science of Smart City Operations and Platforms Engineering* (pp. 13-18). ACM.

Mazzoleni, M., Arevalo, V.J.C., Wehn, U., Alfonso, L., Norbiato, D., Monego, M., Ferri, M. and Solomatine, D.P., 2018. Exploring the influence of citizen involvement on the assimilation of crowdsourced observations: a modelling study based on the 2013 flood event in the Bacchiglione catchment (Italy). *Hydrology and Earth System Sciences*, *22*(1), p.391.

McCallum, I., Liu, W., See, L., Mechler, R., Keating, A., Hochrainer-Stigler, S., Mochizuki, J., Fritz, S., Dugar, S., Arestegui, M. and Szoenyi, M., 2016. Technologies to Support Community Flood Disaster Risk Reduction. *International Journal of Disaster Risk Science*, *7*(2), pp.198-204.

Meek, S., Priestnall, G., Sharples, M. and Goulding, J., 2013. Mobile capture of remote points of interest using line of sight modelling. *Computers & geosciences*, *52*, 334-344.

Molinari, D., Prades, R., Garcia-Fernandez, M., Dolan, M., Menoni, S. and Marcellini, D., 2016. Flood damage data analysis: towards an improvement of data quality and usability. In *E3S Web of Conferences* (Vol. 7, p. 05009).

Mure-Ravaud, M., Binet, G., Bracq, M., Perarnaud, J.J., Fradin, A. and Litrico, X., 2016. A web based tool for operational real-time flood forecasting using data assimilation to update hydraulic states. *Environmental Modelling & Software*, *84*, pp.35-49.

Nosek, B.A., Alter, G., Banks, G.C., Borsboom, D., Bowman, S.D., Breckler, S.J., Buck, S., Chambers, C.D., Chin, G., Christensen, G. and Contestabile, M., 2015. Promoting an open research culture. *Science*, *348*(6242), pp.1422-1425.

Pappenberger, F., Cloke, H.L., Parker, D.J., Wetterhall, F., Richardson, D.S. and Thielen, J., 2015. The monetary benefit of early flood warnings in Europe. *Environmental Science & Policy*, *51*, pp.278-291.

Price, R.K. and Vojinović, Z. 2011. *Urban hydroinformatics: data, models, and decision support for integrated urban water management*. IWA publishing.

Preuner, P., Scolobig, A., Linnerooth Bayer, J., Ottowitz, D., Hoyer, S. and Jochum, B., 2017. A Participatory Process to Develop a Landslide Warning System: Paradoxes of Responsibility Sharing in a Case Study in Upper Austria. *Resources*, *6*(4), p.54.

Qiu, L., Du, Z., Zhu, Q. and Fan, Y., 2017. An integrated flood management system based on linking environmental models and disaster-related data. *Environmental Modelling & Software*, *91*, pp.111-126.

Revilla-Romero, B., Thielen, J., Salamon, P., De Groeve, T. and Brakenridge, G.R., 2014. Evaluation of the satellite-based Global Flood Detection System for measuring river discharge: influence of local factors. *Hydrology and Earth System Sciences*, *18*(11), pp.4467-4484.

Restrepo-Estrada, C., de Andrade, S.C., Abe, N., Fava, M.C., Mendiondo, E.M. and de Albuquerque, J.P., 2018. Geo-social media as a proxy for hydrometeorological data for streamflow estimation and to improve flood monitoring. *Computers & Geosciences*, *111*, pp.148-158.

Rollason, E., Bracken, L.J., Hardy, R.J. and Large, A.R.G., 2018. The importance of volunteered geographic information for the validation of flood inundation models. *Journal of Hydrology 562*, pp. 267-280.

Rosser, J.F., Leibovici, D.G. and Jackson, M.J., 2017. Rapid flood inundation mapping using social media, remote sensing and topographic data. *Natural Hazards*, *87*(1), pp.103-120.

Salvati, P., Petrucci, O., Rossi, M., Bianchi, C., Pasqua, A.A. and Guzzetti, F., 2018. Gender, age and circumstances analysis of flood and landslide fatalities in Italy. *Science of the Total Environment*, *610*, pp.867-879.

Sauro, J. 2011. Measuring usability with the System Usability Scale [Online]. http://www.measuringusability.com/sus.php [accessed 25 October 2018]

Scolobig, A., Prior, T., Schröter, D., Jörin, J. and Patt, A., 2015. Towards people-centred approaches for effective disaster risk management: Balancing rhetoric with reality. *International journal of disaster risk reduction*, *12*, pp.202-212.

Senaratne, H., Mobasheri, A., Ali, A.L., Capineri, C. and Haklay, M., 2017. A review of volunteered geographic information quality assessment methods. *International Journal of Geographical Information Science*, *31*(1), pp.139-167.

Smith, L., Liang, Q., James, P. and Lin, W., 2015. Assessing the utility of social media as a data source for flood risk management using a real-time modelling framework. *Journal of Flood Risk Management*, 10, 370–380.

Teng, J., Jakeman, A.J., Vaze, J., Croke, B.F., Dutta, D. and Kim, S., 2017. Flood inundation modelling: A review of methods, recent advances and uncertainty analysis. *Environmental Modelling & Software*, *90*, pp.201-216.

UN - United Nations, 2015. Sendai Framework for Disaster Risk Reduction 2015-2030. [Online]. Available: http://www.unisdr.org/we/inform/publications/43291. [accessed 25 October 2018]

Victorino, J.N.C. and Estuar, M.R.J.E., 2014. Profiling flood risk through crowdsourced flood level reports. *2014 International Conference on IT Convergence and Security (ICITCS),* Beijing, China, 1-4.

Warfield, C. 2004. The Disaster Management Cycle [Online]. http://www.gdrc.org/uem/disasters/1-dm_cycle.html [accessed 25 October 2018]

Wehn, U., Rusca, M., Evers, J. and Lanfranchi, V., 2015. Participation in flood risk management and the potential of citizen observatories: A governance analysis. *Environmental Science & Policy*, *48*, pp.225-236.

Yang, P. and Ng, T.L., 2017. Gauging Through the Crowd: A Crowd-Sourcing Approach to Urban Rainfall Measurement and Storm Water Modeling Implications. *Water Resources Research*, *53*(11), pp.9462-9478.

Word Count

5994 excluding references.

[1] http://www.dyfibiosphere.wales
[2] https://m.facebook.com/Talybont-Floodees-1394482304150667/
[3] (http://geoserver.org/);
[4] http://geojson.org
[5] https://tools.ietf.org/html/rfc7946
[6] https://www.openstreetmap.org/
[7] https://www.hotosm.org/
[8] https://www.fema.gov/guidelines-and-standards-flood-risk-analysis-and-mapping
[9] https://www.opw.ie/en/media/Guide%20to%20Flood%20Data%20Collection.pdf