Information Sharing and Coordination in Collaborative Flood Warning and Response Systems

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Abstract

The introduction of new information and communication technologies enables communities to share information and self-organize in the response to disasters. Crowd-sourcing approaches enable professional authorities to capture information from the ground in real-time. However, there is a gap between the professional and community-driven response: locally emergent initiatives may lack the overview needed for efficient coordination, while decisions taken by professionals may not consider the actual situation on the ground.

We study this information sharing and coordination gap through the lens of urban flood early warning and response systems. Based on a literature review combining academic articles as well as guidelines and reports from practice, we derive design principles for these systems. Considering the case study of Accra, specific requirements are individuated. The design principles are then used to address the requirements, resulting in a set of functionalities for a collaborative flood warning and response system. These functionalities provide the basis for further development and evaluation.

Keywords: Community Response, Community Resilience, Impact-Based Forecasting and Warning Systems.

1 Introduction

Information is crucial in the response to disasters, and increasingly information is understood as aid in itself [26]. New technologies are opening up opportunities to involve affected populations. Examples range from crisis mapping and crowdsourcing of information [52] to participatory approaches of community engagement to build resilience [7] [53].

Communities play an important role in disasters. The International Federation of Red Cross estimates that 90% of disaster response is carried out by communities alone [27]. Community-led efforts such as the Cajun Navy in Hurricane Harvey [50] or the Mud Army in Brisbane [37] suggest that communities can contribute to disaster response. This is facilitated by ICT technologies.

Nevertheless, community response also entails several risks.[62] [61] One of them is lack of coordination in information sharing between community and mandated responders, causing redundancies, gaps, and inconsistencies. [2] [9] These information gaps, in turn, hamper coordination of response and relief [11][54][61][62]. Some solutions to support information sharing were proposed in literature and practice such as the EV-CREW model [37] or the

COBACORE platform [41]. However, these approaches tend to focus on the relief and recovery phases of a disaster, not on Early Warning and Response.

Besides, the field of Early Warning Systems (EWS) has been moving towards a more participatory and end-user oriented perspective [23] [46] [63] [5]. The available design guidelines for such systems mention that the warning information should provide ground for action [63][8] and that such information should be tailored to specific user groups. [16][13][30][45]

However, the information provided to the users consists mainly of warnings at the urban scale. Previous research in rural communities has shown that providing complementary information to the warnings (such as suggestions for actions) can improve the response. [51] Moreover, information is shared only one way in the direction of citizens. This leaves undressed the lack of coordination across communities and with professional responders. [23] [46] [63]

Such an issue is also reflected in the case study area of Accra. During a major flood event in 2015, a gas station exploded causing several casualties among those who were seeking shelter in the location. [14] A warning, together with some indications on shelter locations to be reached, could have helped in reducing the impact of the explosion.

In order to address these information sharing and coordination gaps in theory and practice, this study aims to identify a set of design principles for collaborative early warning and response systems. The design principles are then applied to the case study of Accra.

The remainder of the paper is structured as follows. First, the methodology adopted is explained. Secondly, a review is provided on the risks and opportunities of community involvement in disaster response. Thirdly, the current practice of information sharing, coordination, and Early Warning systems design is reviewed to find design criteria for collaborative early warning and response systems. Thirdly, the requirements for the city of Accra are derived. Next, three functionalities of a Collaborative Early Warning and Response System for the city of Accra are proposed based on the requirements and the design criteria developed in the previous stages. Finally, conclusions and some future outlook are provided.

2 Methodology

We follow the design-science methodology for Information Systems as described by Hevner et al. [24] [25]. Therefore, to ensure connection to state-of-the-art theory, we perform the review of academic and grey literature, guidelines and reports across theory and practice in information sharing, coordination, and early warning systems. This results in a set of design principles for collaborative early warning systems (rigor cycle).

Next, we analyze in detail the current practice of flood early warning and response in the city of Accra. This way we individuate a set of information sharing and coordination requirements to be addressed among specific stakeholders (relevance cycle).

The design principles from the review are then applied to the case study in order to address the requirements. The result is a set of functionalities of a Collaborative Flood Warning and Response System in Accra (design artifact).

To complete and improve the design, the conceptual design and its functionalities will be implemented in IT applications and evaluated at a later stage (design cycle). The following sections further explain how the literature review and the requirements analysis are carried out.

2.1 Methodology for literature review

The objective of the literature review is to find a set of principles for the design of Collaborative Early Warning and Response Systems, based on state of the art theory and practice. This objective is then further divided into three sub-objectives: Identification of opportunities and challenges in community response to disasters; individuation of approaches in information sharing and coordination that address these challenges while fostering the opportunities; and integration of such principles in the context of early warning systems design.

For each of these sub-objectives, a literature review is carried out. The literature search relies on the following databases: Google Scholar, Google, ScienceDirect, and SpringerLink.

Table 1 summarizes for each review the keywords used for the literature search and the criteria adopted to select the most relevant articles. The academic and grey literature obtained this in this way is then snowballed backward to find further material. Zotero is used for saving the references.

The challenges and opportunities in community response are addressed first. Then, the remaining two reviews proceed in parallel: the approaches in information sharing and coordination with communities provide a term of comparison with the current principles in early warning systems design. This way, a set of gaps and corresponding design principles for collaborative early warning systems is found.

Table 1. Keywords used for the literature search and criteria for the selection of articles for each of the reviews.

<table>
<tr><th colspan="2">Review</th><th>Keywords</th><th>Selection Criteria</th></tr>
<tr><td colspan="2">Community Response: challenges and opportunities.</td><td>“Community Response” AND “Disaster”, “Informal” OR “Spontaneous” OR “Emergent” OR “Digitally Enabled” AND “Volunteering”, “Digital Humanitarians”.</td><td>Contains challenges and opportunities.</td></tr>
<tr><td rowspan="2">Information Sharing and Coordination in EWS.</td><td>Information Sharing and Coordination Approaches.</td><td>“Information Sharing”, “Coordination” AND “Disaster Response”, “Community Response”.</td><td>Provides approaches for info sharing and coordination.</td></tr>
<tr><td>Principles of EWS Design.</td><td>“Impact-Based” OR “Community-Based” AND “Flood Warning” OR “Early Warning” AND “System”.</td><td>Provides current criteria EWS Design.</td></tr>
</table>

2.2 Methodology for requirements analysis.

The objective of this review is to find design requirements for a collaborative Early Warning and Response System in the city of Accra. This is achieved by reviewing the current practice of early warning and response in the city and individuating unaddressed issues related to information sharing and coordination.

As a first step, the involved stakeholders and their activities are mapped. Then, possible information sharing and coordination gaps between these actors are investigated based on the available material. This is then converted into requirements for the case study.

The literature search is carried out on Google, Google Scholar, Relief Web, and FloodList. The considered keywords are “Accra Floods”, “Accra Flood 2015”, and “Community Response Accra”. Relief Web is used to find reports mainly related to the activities of professional responders. The activities of responding and affected communities are mainly found in academic research, news, FloodList and Social Media. As far as this is concerned, some information is retrieved on Twitter through the popular hashtag “#AccraFloods”.

3 Community Response & Coordination – Challenges and Opportunities

3.1 Community Response

Whittaker et al. [62] define such informal volunteerism as *“the activities of people who work outside of formal emergency and disaster management arrangements to help others who are at risk or are affected by emergencies and disasters”*. Other authors consider the broader concept of responding community [41] which encompasses all community-driven efforts including organized volunteers with established institutions such as the Red Cross.

The aspiration of affected populations to help themselves and each other is certainly not a new phenomenon, but in the hyperconnected society the capacity of communities to seek, share information and self-organize is amplified [61][44].

The increasing importance of digitally organized volunteers presents both opportunities and challenges to crisis response. The use of ICT to seek and share information, pool resources, request help, and create situational awareness are among the most frequently cited benefits of Community Response. [44] Moreover, communities have local knowledge and it is being increasingly recognized that this type of understanding can potentially help in improving disaster risk reduction [28] and response [21][43]. Additionally, community involvement in disasters can increase resilience in the long term as communities can gain skills, interests and build social capital that can be useful for coping with future disasters [40] [47] [1].

However, the emergence of community-led response efforts also entails several risks. The lack of information sharing and coordination of actions across communities can lead to duplication of efforts and other inefficiencies [3]. Moreover, a lack of coordination and information sharing between communities and professional actors can impair the professional response [17] [39][32]. A lack of training, skills and equipment can also cause safety and security issues [22][3][17]. Malevolent actors can take advantage of vulnerable individuals [3]. Other concerns are risks for minorities and vulnerable communities [43][10], lack of accountability and responsibility, and privacy and security infringements. [62] [44]

Irrespective of whether the opportunities or the risks dominate, communities *will* make use of ICT to self-organize [61]. Whittaker et al. [62] suggest that addressing these challenges while fostering the opportunities, requires a flexible and open approach, and the willingness to engage with emerging community responses as they occur.

Such a flexible and open approach could address, among other challenges, the lack of coordination between communities and across communities and professional response. Lessons learned from previous research on information sharing and coordination in disasters (e.g. the Haiti Earthquake or the Ebola response), imply that information systems need to be designed to facilitate the distribution of information such that they enable coordinated local decision-making and empowerment. [11][55][59][31]

The next section discusses how the lessons learned in the research and practice of information sharing and coordination with community response can be applied in the context of Early Warning Systems design.

4 Information Sharing and Coordination in Early Warning Systems

Early Warning Systems aim at providing information about future hazardous events to enable the population to take preventive actions and reduce risk [5]. According to the UNISDR [56], an EWS should ensure the following components: risk knowledge, *monitoring and warning service*, *dissemination and communication*, and *response capability*. We here focused on aspects of the following Early Warning Systems dimensions [5]:

- Information sharing: dissemination and communication, and monitoring and warning;
- Coordination: response capability.

The following sections focus on the current state of information sharing and coordination with communities in the three components of Early Warning Systems design listed above. Risk knowledge is not considered in this case as it does not fall into the context of the immediate response, which is the focus of the paper.

4.1 Information sharing in Dissemination and Communication

Building on the results of the Sendai conference [57], the World Meteorological Organization (WMO) stressed the necessity for impact-based forecasting and warnings. This constitutes a paradigm shift towards the users of an EWS system, who need to be provided with targeted information on the expected consequences of hazards [63].

Moreover, Sai et al. [46] suggest a set of indicators for each of the components of an EWS provided by the UNISDR [56], aimed at guiding the design of an Impact-Based Forecasting and Warning System. The focus is mostly placed on effectively communicating targeted information to the relevant user groups on the expected consequences of hazards. This is expected to trigger actions, even though limited recommendations are given on complementary information that is required for communities and stakeholders to take action.

Shah et al. [51] found that also providing advice on the types of actions to be taken has a positive impact on the response of individuals. Similarly, Fakhruddin et al. [16] developed a set of possible response actions to be taken by farmers in different seasons, according to the hydrological cycles and the cropping patterns. This suggests that relevant information, together with a warning can improve the response of those who receive it.

Nevertheless, these studies focus on rural communities rather than on urban neighborhoods, where *information sharing is limited to warnings*. This could be addressed by providing relevant information in addition to warnings. This could empower communities to take actions after a warning has been issued.

4.2 Information Sharing in Monitoring and Warning

Relevant information can be crowdsourced by communities. Such information includes hydrological data provided by citizens, which was found able to improve the accuracy of the flood forecast. [36]

The monitoring could also be extended to situational information. [44] This information can support decision making (e.g. allocation of resources), and it is especially necessary in the context of disasters as the situation is dynamic and changes frequently. Nevertheless, the volume and velocity with which this information is produced can be overwhelming, and it can be challenging to find the information needed. Moreover, the veracity of this information is difficult to establish as most of the sources are unknow. [38] This generates a *lack of situational awareness* which can impair decision making and coordination of efforts. Additionally, Comes et al. conclude that such shared situational awareness should not be looked at for each individual actor, but rather it should be *shared* among all actor as a first step in triggering coordinated efforts. [9]

In this context, communities of online volunteers such as the StandBy Task Force are specialized in processing this information manually, searching for reliable information of particular types. Moreover, a considerable body of research focuses on processing automatically crowdsourced information in order to classify, verify and prioritize it. [29][6] Nevertheless, to date the practice of Early Warning Systems Design does not consider crowdsourcing and processing (manual or automated) of situational information as a key monitoring component.

4.3 Coordination in Response Capability

Malone and Crowston define coordination as “managing dependencies between activities”. [33] As such, coordination requires the definition of the actors involved, their activities and their dependencies. During disasters, the activities cannot be predetermined as emergency plans rarely predict all the possibilities of a disaster [20]. The same applies to the actors involved as community-led efforts tend to emerge during the event itself [62].

ICT technologies empower communities to exchange information and self-organize to address unmet needs. This generates grassroot efforts that tend not to coordinate with mandated responders. Moreover, these efforts also tend to be unaware of each other. All of which can create inconsistencies and redundancies and thus impair the overall response. [17] [39] [22][3]

In this picture, information sharing between all actors involved becomes highly relevant for all the actors to understand the latest developments, make informed decisions and share resources. Therefore, coordination in the field of disaster management is understood as information sharing, joint use of resources, division of tasks and shared responsibilities [12][48].

With regards to response capability, the literature on Early Warning Systems seems to be mainly focused on how response can be improved before the disaster occurs (in the preparedness phase) and includes elements of risk awareness, participation, education and contingency plans. [23][46][63]

However, *dissemination of warnings* (and the complementary information) *could be considered as a first step for triggering coordinated community actions*. [51] For instance, these actions could be aimed at avoiding or reducing losses and damages (e.g. placing sandbags in the right locations). Nevertheless, no design suggestion is found on how EWS could help in such actions should be coordinated across communities and with mandated responders. [23] [46] [63] Therefore there is an unaddressed *lack of coordination across communities and with professional responders.*

Some approaches and ICT platforms that address this coordination gap already exist both in research and practice. For instance, the EV-CREW model demonstrated that centralized *coordination through a "broker" agency* can increase the engagement of certain volunteer types and enhance the coordination of communities with the official response organizations. [37] Additionally, the COBACORE project proposed a multi-actor platform that provided users with different forms of coordination: both *across communities* (e.g. the Marketplace) and *between communities and institutions* (e.g. the Community Liaison Team). [42]

While both the COBACORE and the EV-CREW solutions focus or were applied mainly in the recovery and relief phases, lessons learned from these projects could be used to address the lack of coordination in early warning and response. More specifically, tools can be provided for communities to coordinate among themselves, even though this already happens with social media. But also, a "broker agency" or moderator between the professional responders and the responding communities can facilitate the coordination between the two. The result is a hybrid centralized/decentralized approach in which not all information is shared among everybody and a moderator between actors can decide in some cases which information is shared.

4.4 Design Principles for Collaborative Early Warning and Response Systems

Based on the review above, three gaps were individuated for the development of a collaborative early warning and response system at the urban scale. For each of these gaps, several possible solutions (design principles) were found in the literature. Table 2 summarizes these gaps and principles, including references to the papers and their original scope. For 'scope', it is intended the targeted users and disaster phase considered in the source paper.

Table 2. Design gaps, principles to address the gaps, and related sources in literature together with their original scope.

Design Gap	Design Principle	Source	Original Scope
Information sharing limited to warnings	User empowerment through relevant information.	Shah et al, 2012 Fakhruddin et al., 2015	Early Warning Phase for Rural Communities
Lack of shared situational awareness	Crowdsourcing and Processing of situational information.	Palen et al. 2010	Response phase for Community and Professionals
Lack of coordination across communities and with professional responders	Hybrid centralized / decentralized approach to information sharing.	McMillian et al, 2015 Neef and Rijken, 2016	Relief and Recovery Phases for Community and Professionals

5 Requirements analysis in Accra

The case study chosen is Accra, the capital City of Ghana, placed in western Africa and facing the Gulf of Guinea. The city suffers from severe and frequent flooding and it received international funding to address the problem of flood resilience. For this reason, an Early

Warning System was introduced to deliver warnings on smartphones through a specifically designed app. [49] The main objective was to provide easily understandable warnings in order to improve community resilience in the most vulnerable and exposed areas of the city [60].

5.1 Information Sharing Limited to warnings

The need for information complementary to warnings was also made clear in an unfortunate accident during a major flood in 2015 in Accra. A number of citizens lost their lives because of seeking shelter in a petrol station that exploded due to the flood. [14] Providing additional information on safer locations to seek shelters could have reduced the impact of the explosion.

5.2 Situational Awareness

Informal settlements are defined as "*unplanned settlements and areas where housing is not in compliance with current planning and building regulations (unauthorized housing)"*[58]. Not being officially recognized by the government, these areas tend to lack basic facilities and services including street addresses. This leads to inefficiencies during calls to the emergency lines because of the difficulties in concisely explaining the current location to the operator. Such a problem occurs in many African cities including Accra. [35].

A smartphone app was introduced in to create alphanumeric addresses that can be easily mapped by the National Ambulance Service (NAS)[1]. Though, the code is bound to a specific location and requires the user to be outdoor to be generated. This is not best suited to the dynamic nature of disasters, during which users might be stuck indoors and away from their homes. Then, sharing a GPS location alongside some additional information (e.g. the problem at hand) could be a solution. This would be a less accurate but still possible in (not too) closed locations.

Such information could also be useful for the Ghana Red Cross Society (GRCS). They already carry out a series of assessments on the ground as the situation evolves. This is meant to understand where and how to intervene, but also the number of materials to be supplied. All these activities require timely situational information which is gathered by a small number of volunteers, but that could also be complemented by crowdsourced information. [19]

5.3 Coordination with Community Response

Community-led initiatives are found in Accra. Amoako stresses how in the informal settlements of Agbogbloshie, Glefe and Old Fadama, communities tend to self-organize for coping with the lack of services and infrastructure. For instance, it is found that the inhabitants of Glefe autonomously clear the drains when it is expected to rain. [4] Similarly, both Marinetti et al. [34] and Douglas et al. [15] found that in Alajo (a town close to Accra) the population tends to rely on self-help and rescue other members of the community during floods.

Marinetti also found that the operations of the National Disaster Management Organization (NADMO) tend to start after the flood water flows away, which can contribute to the emergence of community-led response initiatives generated by unmet needs (e.g. need for search and rescue). [34] This can cause a lack of coordination between different community-led initiatives and with professional response activities. Therefore, the early warning and response system for Accra should make possible to coordination of NADMO with these community initiatives. While not being active, the agency could still direct and provide advice.

6 Functionalities for the Case Study Area

Based on the requirements analysis and the design principles derived for the review. A set of functionalities with their targeted users is designed. These functionalities are part of a

[1] http://snoocode.com/snoocode-red-the-story/

conceptual design of a collaborative flood warning and response system for the city of Accra. Table 3 summarizes these findings.

The actors considered in this study are the Crowdtasking Manager, Professional Responders and Communities. NADMO, GRCS and NAS are grouped together as Professional Responders for simplicity. Within the communities, we distinguish three sub-actors: Shelter Seekers (those who received a warning and look for shelter), Victims (those who are stuck somewhere due to the flood and need help to be rescued) and Responding communities (those who choose to help victims). The Crowdtasking manager is in Charge of providing communities with volunteering tasks they can join (but also propose).

Additionally, two tools are proposed: a smartphone application for communities (and the related sub-actors), and a web application for professional responders and the Crowdtasking Manager. Each functionality has components for both applications as shown in the following sections.

Table 3. Design components, requirements from the case study, functionalities to address them and the targeted users.

Design Principle	Requirement	Functionality	Targeted Users
User empowerment through relevant information in addition to warnings.	Need for information on shelter location alongside warnings.	Sharing up to date Shelter Locations alongside warnings	Professional Responders; Shelter Seekers
Crowdsourcing and Processing of situational information.	Provide NADMO, GRCS and NAS with information on victims' locations.	Crowdsourcing GPS location of affected population.	Professional Responders; Victims
Hybrid centralized/ decentralized approach to information sharing.	Support the coordination of NADMO with communities.	Task-Based coordination of communities and professionals.	Professional Responders; Crowdtasking manager; Responding Communities

6.1 Crowdsourcing victims' GPS location in Informal Settlements

In order to address the delays related to emergency calls in informal settlements, the smartphone application should give victims the possibility to share their GPS location. The report should also include a title and some descriptive text or images of the problem at hand. Moreover, in order to address GPS inaccuracy, the users should have the possibility to adjust their position manually on a map, based on their judgment. This feature should be an advanced option only for those users who feel comfortable with maps.

The information obtained from the reports actively produced by communities could also be summarized as a crisis map in the Web Application for Professional Responders. The map could use clustering of victim reports for a quick overview of the most affected area and should be updated in real time. This could improve situational awareness for Professional Responders.

More specifically Professional Responders could use the map for better directing limited resources. In particular, in the case of NADMO this would translate in the allocation of response forces. But it could also help the GRCS to judge which types of humanitarian interventions are best suited, where they should be carried out, and the number of supplies needed [18].

The crisis map should also contain the expected flood extent produced by the Flood Forecasting System. This would help to get a better understanding of the situation on the ground (e.g. which roads are expected to be flooded, at which time or which areas will be / are most likely to be flooded and so on). For this reason, the platform should also allow adding external vector and raster layers, and GIS analytics tools.

Figure 1 summarizes the information flow from the Smartphone app user (victim of the flood) to the server (where the crowdsourced information is stored) and from the Server to the creation of a crisis map that can be used to by Professional Responders.

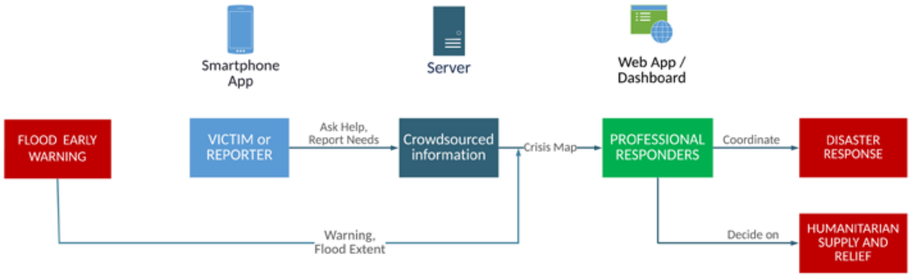

Fig. 1. I Need Help Feature: crowdsourcing of victims' locations and decision support for professional responders through a crisis map including victims' locations and flood extent.

6.2 Information Sharing of Shelter locations alongside Warnings

While Early Warning systems usually provide information on when to start preparing for a flood, they usually do not provide advice on which locations should be reached once a warning is issued. The need for this type of information was made evident from the 2015 flood event in the city of Accra, Ghana. [14] This is an example of how information complementary to warnings can be beneficial for the end users.

A possible way of bridging this gap could be to make sure that information on when to leave and where to go are provided together to citizens. More specifically, such information on "where to go" could be an up to date list or map of shelters available and their locations. This could be provided through the Smartphone App.

The App should also show, along with the shelters, the expected flood extent (provided by the Early Warning System). This would provide those looking for Shelter with a more complete picture of the current situation. Such a feature would be useful as a follow up after a flood warning, but also during all phases of the disaster, whenever citizens need a shelter.

Besides, the Web Application should give Professional Responders the possibility to map the location of the shelters and change it over time dynamically as new ones are added or removed for any reason. Figure 2 shows a graphical summary of this component.

Fig. 2. Where should I go feature: both from the perspective of the smartphone app user (Shelter Seeker) and from the perspective of the dashboard users (Professional Responders);

6.3 Task-Based Coordination of Community and Professional Response

A new role is introduced among the Professional Responders: the Crowdtasking Manager. This actor understands the needs of the Responding Professionals and publishes tasks through the Dashboard that any member of the Responding Community can join. Besides, the Responding community consists of citizens who take action to help those affected by the disaster and engage with the responding professionals by joining volunteering tasks through the smartphone app.

Therefore, the Smartphone App should show Responding Community members a map with volunteering tasks that they can join. Also, the responding community should be able to propose tasks that other community members can join. The users should also be able to share a link to the app via social media, thus potentially spreading its use. The map could also show the expected flood extent for a more complete picture.

Then, the Web Application should provide the Crowdtasking manager the possibility to add volunteering tasks to the server, share them via Social media, and conduct oversight and moderation of volunteering tasks suggested from community members. Moreover, to avoid overcrowding, tasks should come with a limited number of contributors. The number should be choice of the Crowdtasking manager or of the task creator.

The system should keep track of how many responding community members decided to join and remove a task from the map once the required number has been reached. The task should also include what type of skills and equipment are required so that community members can better choose appropriate tasks. Figure 3 summarizes graphically what written above.

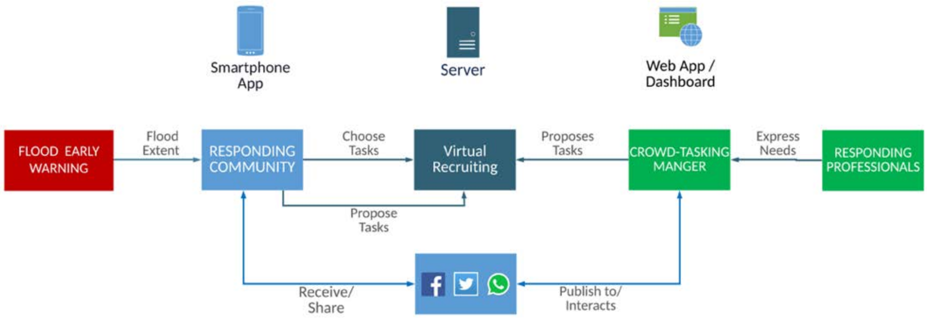

Fig. 3. Virtual Recruiting of volunteers. The Crowdtasking manager and the Responding Community propose tasks that the Responding Community can join. Both Crowdtasking Manager and the Responding Community can share tasks through social media.

Examples of tasks suggested could be: “500 volunteers needed to place sandbags in this area”, “Help us tracking people in need, use the I Can Help Tool” or “10 people with relative boats needed in this area for rescuing people in need”.

7 Discussion and Conclusions

This research focused on finding a conceptual design for a Collaborative Flood Early Warning and Response Platform, based on the consideration that the provision of warnings can be a first step in triggering coordinated community actions. The design artifact was developed through a design-science research methodology. The considered case study was the city of Accra, in Ghana.

Based on a literature review from research and practice three design principles were individuated for the design Collaborative and Early Warning and Response Systems: user empowerment through the provision of relevant information in addition to warnings, crowdsourcing and processing of situational information in order to improve situational awareness, and hybrid centralized/decentralized approach to information sharing.

Based on information available on the case study area, the following requirements were found: Need for information on shelter location alongside warnings; provision to the National Disaster Management Organization, Ghana Red Cross Society and National Ambulance Service with information on victims’ locations and other situational information; and Support the coordination of the National Disaster Management Organization with communities.

The requirements were then addressed with some of the design principles in order to design functionalities. These functionalities represent the first conceptual design of a collaborative early warning and response system in the city of Accra: Sharing up to date Shelter Locations alongside warnings, Crowdsourcing GPS location of affected population, and Task-Based coordination of communities and professionals.

While this design was developed especially for the city of Accra, many cities face similar challenges related to informal settlements, especially in developing countries. For such contexts, this study could provide some indications for the design of urban early warning and response system, not just in terms of general design principles but also in terms of specific functionalities.

Nevertheless, further research is required to improve the conceptual design by involving the end users. The conceptual design should be first discussed with the stakeholders for an initial round of development. Then, the result should be implemented as prototypes in a smartphone app and a web application. These should be evaluated iteratively with simulation exercises involving local actors and communities.

Further research is also needed on the coordination of shelter evacuation processes. In fact, while it could be beneficial for a single or a group of individuals to know which shelters to reach, this feature could have a detrimental impact of the overall evacuation process (e.g. by causing traffic jams).

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References

1. Aldrich, D.P., Meyer, M.A.: Social Capital and Community Resilience. American Behavioral Scientist. 59 (2), 254–269 (2015)
2. Altay, N., Labonte, M.: Challenges in humanitarian information management and exchange: evidence from Haiti. Disasters. 38 (s1), S50–S72 (2014)
3. Ambinder, E., Jennings, D.M., Blachman-Biatch, I., Edgemon, K., Hull, P., Taylor, A.: The resilient social network:@ OccupySandy# SuperstormSandy. Falls Church, VA: Homeland Security Studies and Analysis Institute. (2013)
4. Amoako, C.: Brutal presence or convenient absence: The role of the state in the politics of flooding in informal Accra, Ghana. Geoforum. 77 5–16 (2016)
5. Basher, R.: Global early warning systems for natural hazards: systematic and people-centred. Philosophical Transactions of the Royal Society of London A: Mathematical, Physical and Engineering Sciences. 364 (1845), 2167–2182 (2006)
6. Burel, G., Saif, H., Alani, H., Burel, G., Saif, H.: Semantic Wide and Deep Learning for Detecting Crisis-Information Categories on Social Media. In: The Semantic Web – ISWC 2017. pp. 138–155. Springer, Cham (2017)
7. Comes, T.: Designing for Networked Community Resilience. Procedia Engineering. 159 (Supplement C), 6–11 (2016)
8. Comes, T., Mayag, B., Negre, E.: Decision Support for Disaster Risk Management: Integrating Vulnerabilities into Early-Warning Systems. In: Information Systems for Crisis Response and Management in Mediterranean Countries. pp. 178–191. Springer, Cham (2014)
9. Comes, T., Meesters, K., Torjesen, S.: Making sense of crises: the implications of information asymmetries for resilience and social justice in disaster-ridden communities. Sustainable and Resilient Infrastructure. 0 (0), 1–13 (2017)
10. Comes, T., Sandvik, K.B., Walle, B.V. de: Cold chains, interrupted: The use of technology and information for decisions that keep humanitarian vaccines cool. Jrnl Hum Log and Sup Chn Mnage. 8 (1), 49–69 (2018)
11. Comes, T., Vybornova, O., Van de Walle, B.: Bringing Structure to the Disaster Data Typhoon: An Analysis of Decision-Makers' Information Needs in the Response to Haiyan. In: 2015 AAAI Spring Symposium Series. (2015)
12. Comfort, L.K.: Crisis Management in Hindsight: Cognition, Communication, Coordination, and Control. Public Administration Review. 67 189–197 (2007)
13. Cumiskey, L., Werner, M., Meijer, K., Fakhruddin, S.H.M., Hassan, A.: Improving the social performance of flash flood early warnings using mobile services. International Journal of Disaster Resilience in the Built Environment. 6 (1), 57–72 (2015)

14. Davies, R.: Flood and Fire Disasters in Accra, Ghana, *FloodList*, http://floodlist.com/africa/flood-accra-ghana-fire-explosion, Accessed: September 20, 2016, (2015)
15. Douglas, I., Alam, K., Maghenda, M., Mcdonnell, Y., Mclean, L., Campbell, J.: Unjust waters: climate change, flooding and the urban poor in Africa. Environment and Urbanization. 20 (1), 187–205 (2008)
16. Fakhruddin, S.H.M., Kawasaki, A., Babel, M.S.: Community responses to flood early warning system: Case study in Kaijuri Union, Bangladesh. International Journal of Disaster Risk Reduction. 14 323–331 (2015)
17. Fernandez, L.S., Barbera, J.A., Van Dorp, J.R.: Spontaneous volunteer response to disasters: the benefits and consequences of good intentions. Journal of emergency management. (2006)
18. GRCS: Emergency Plan of Action (EPoA). Ghana Red Cross Society. (2015)
19. GRCS: Emergency Plan of Action Final Report (EPoA) Ghana Red Cross Society. (2016)
20. Hardy, K., Comfort, L.K.: Dynamic decision processes in complex, high-risk operations: The Yarnell Hill Fire, June 30, 2013. Safety Science. 71 39–47 (2015)
21. Haynes, K., Bird, D.K., Carson, D.B.: Indigenous experiences and responses to Cyclone Tracy. In: Palutikof, J.P., Boulter, S.L., Barnett, J., and Rissik, D. (eds.) Applied Studies in Climate Adaptation. pp. 297–306. John Wiley & Sons, Ltd (2014)
22. Helsloot, I., Ruitenberg, A.: Citizen Response to Disasters: a Survey of Literature and Some Practical Implications. Journal of Contingencies and Crisis Management. 12 (3), 98–111 (2004)
23. Henriksen, H.J., Roberts, M.J., van der Keur, P., Harjanne, A., Egilson, D., Alfonso, L.: Participatory early warning and monitoring systems: A Nordic framework for web-based flood risk management. International Journal of Disaster Risk Reduction. (2018)
24. Hevner, A.R.: A Three Cycle View of Design Science Research. 19 7 (2007)
25. Hevner, A.R., March, S.T., Park, J., Ram, S.: Design Science in Information Systems Research. MIS Quarterly. 28 (1), 75–105 (2004)
26. IFRC: Data or dialogue? The role of information in disasters. In: World Disaster Report 2005. (2005)
27. IFRC: World Disaster Report 2013. (2013)
28. Kelman, I., Mercer, J., Gaillard, J.: Indigenous knowledge and disaster risk reduction. Geography. 97 (1), 12–21 (2012)
29. Khare, P., Burel, G., Alani, H.: Classifying Crises-Information Relevancy with Semantics. In: The Semantic Web. pp. 367–383. Springer, Cham (2018)
30. Koks, E.E., Jongman, B., Husby, T.G., Botzen, W.J.W.: Combining hazard, exposure and social vulnerability to provide lessons for flood risk management. Environmental Science & Policy. 47 42–52 (2015)
31. Landgren, J.: Insights from an ethnographic study of a foreign response team during the EBOLA Outbreak in Liberia. Decision Support Systems. 7 (2015)
32. Liath, S.: Averting a disaster within a disaster: the management of spontaneous volunteers following the 11 September 2001 attacks on the World Trade Center in New York. (2004)
33. Malone, T.W., Crowston, K.: The Interdisciplinary Study of Coordination. ACM Comput. Surv. 26 (1), 87–119 (1994)
34. Marinetti, C., Martens, E., Modderman, N., Arntz, L.R.: Methodology Urban Flood Risk Assessment. Final report Project Flood Risk Accra. September 22 2016. TU Delft, The Netherlands (2016)
35. Matthews, C.: Finding your way in a country without street addresses, http://www.bbc.com/news/world-africa-35385636, (2016)
36. Mazzoleni, M., Cortes Arevalo, V.J., Wehn, U., Alfonso, L., Norbiato, D., Monego, M., Ferri, M., Solomatine, D.P.: 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). Hydrol. Earth Syst. Sci. 22 (1), 391–416 (2018)

37. McLennan, B., Molloy, J., Handmer, J.: Centralised coordination of spontaneous emergency volunteers: The EV CREW model. Australian Journal of Emergency Management, The. 31 (1), 24 (2016)
38. Meier, P.: Human Computation for Disaster Response. In: Michelucci, P. (ed.) Handbook of Human Computation. pp. 95–104. Springer New York (2013)
39. Miller, A., Jensen, S., Moore, A.: Managing Spontaneous Volunteers in Times of Disaster. In: EIIP Virtual Forum Presentation. (2005)
40. Murphy, B.L.: Locating social capital in resilient community-level emergency management. Nat Hazards. 41 (2), 297–315 (2007)
41. Neef, M.: The COBACORE Project - A Community-Based Approach to Disaster Recovery. (2014)
42. Neef, R.M., Rijken, M.: COBACORE Community Based Comprehensive Recovery : D3.3: Report on procedures and use scenarios in which the COBACORE tool is used, http://resolver.tudelft.nl/uuid:04faa307-0828-4a40-b48e-4e62a4d9d821, (2016)
43. Norris, F.H., Stevens, S.P., Pfefferbaum, B., Wyche, K.F., Pfefferbaum, R.L.: Community Resilience as a Metaphor, Theory, Set of Capacities, and Strategy for Disaster Readiness. American Journal of Community Psychology. 41 (1–2), 127–150 (2008)
44. Palen, L., Anderson, K.M., Mark, G., Martin, J., Sicker, D., Palmer, M., Grunwald, D.: A Vision for Technology-mediated Support for Public Participation & Assistance in Mass Emergencies & Disasters. In: Proceedings of the 2010 ACM-BCS Visions of Computer Science Conference. pp. 8:1–8:12. British Computer Society, Swinton, UK, UK (2010)
45. Rahman M.M., Goel N.K., Arya D.S.: Study of early flood warning dissemination system in Bangladesh. Journal of Flood Risk Management. 6 (4), 290–301 (2012)
46. Sai, F., Cumiskey, L., Weerts, A., Bhattacharya, B., Haque Khan, R.: Towards impact-based flood forecasting and warning in Bangladesh: a case study at the local level in Sirajganj district. Nat. Hazards Earth Syst. Sci. Discuss. 2018 1–20 (2018)
47. Schellong, A.: Increasing Social Capital for Disaster Response through Social Networking Services (SNS) in Japanese Local Governments. 23
48. Schryen, G., Rauchecker, G., Comes, T.: Resource Planning in Disaster Response. Bus Inf Syst Eng. 57 (4), 243–259 (2015)
49. Schuurmans, H.: Fingertip Flash Flood Forecasting, https://www.royalhaskoningdhv.com/en-gb/news-room/news/fingertip-flash-flood-forecasting/6671, Accessed: September 21, 2016, (2016)
50. Sebastian, A.G., Lendering, K., Kothuis, B.L.M., Brand, A.D., Jonkman, S.N., Gelder, P.H.A.J.M., Kolen, B., Comes, M., Lhermitte, S.L.M., Meesters, K.J.M.G., van de Walle, B.A., Ebrahimi Fard, A., Cunningham, S., Khakzad, N., Nespeca, V.: Hurricane Harvey Report: A fact-finding effort in the direct aftermath of Hurricane Harvey in the Greater Houston Region. (2017)
51. Shah, M.A.R., Douven, W.J.A.M., Werner, M., Leentvaar, J.: Flood warning responses of farmer households: A case study in Uria Union in the Brahmaputra flood plain, Bangladesh. Journal of Flood Risk Management. 5 (3), 258–269 (2012)
52. Shanley, L., Burns, R., Bastian, Z., Robson, E.: Tweeting Up a Storm: The Promise and Perils of Crisis Mapping. Social Science Research Network, Rochester, NY (2013)
53. Soden, R., Palen, L.: From Crowdsourced Mapping to Community Mapping: The Post-earthquake Work of OpenStreetMap Haiti. In: COOP 2014 - Proceedings of the 11th International Conference on the Design of Cooperative Systems, 27-30 May 2014, Nice (France). pp. 311–326. Springer, Cham (2014)
54. Starbird, K., Palen, L.: "Voluntweeters": Self-organizing by Digital Volunteers in Times of Crisis. In: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. pp. 1071–1080. ACM, New York, NY, USA (2011)
55. Turoff, M., Chumer, M., Walle, B.V. de, Yao, X.: DERMIS: The Design of a Dynamic Emergency Response Management Information System. JITTA : Journal of Information Technology Theory and Application; Hong Kong. 5 (4), 1–35 (2004)
56. UNISDR: Developing early warning systems: a checklist, United Nations International Strategy for Disaster Reduction. (2006)

57. UNISDR: Sendai Framework for Disaster Risk Reduction 2015 - 2030. 37 (2015)
58. United, N.: Glossary of environment statistics, studies in methods. United Nations New York, NY Google Scholar. (1997)
59. Van de Walle, B., Comes, T.: On the Nature of Information Management in Complex and Natural Disasters. Procedia Engineering. 107 403–411 (2015)
60. VIAWater: Flash Flood Forecasting App, https://www.viawater.nl/projects/flash-flood-forecasting-app, Accessed: September 29, 2016, (2015)
61. Waldman, S., Kaminska, K.: Connecting emergency management organizations with digitally enabled emergent volunteering Literature review and best practices. Defence Research and Development Canada (2015)
62. Whittaker, J., McLennan, B., Handmer, J.: A review of informal volunteerism in emergencies and disasters: Definition, opportunities and challenges. International Journal of Disaster Risk Reduction. 13 358–368 (2015)
63. WMO: WMO Guidelines on Multi-hazard Impact-based Forecast and Warning Services, *floodcba2.eu*, http://www.floodcba2.eu/site/knowledge-toolkit-2/frm-measures-and-plans/categories-of-flood-prevention-measures/flood-forecasting-and-warning/flood-forecasting-and-warning-wmo-guidelines-on-multi-hazard-impact-based-forecast-and-warning-services/, Accessed: March 05, 2018, (2015)