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Using serious games to evaluate the potential of social media information in early warning disaster management

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Abstract

In recent years, the sharp increase in the use of social media by the public during major natural disasters has attracted the attention of various public agencies and safety organizations. Social media present a potential alternative communication system not only for disseminating information to the public, but also for receiving information from the individuals at risk. However, there is limited research on how emergency managers would use such information and whether it would make warning decision-making more effective or not. To address this gap, we used an existing serious game to accommodate informational and communication complexities in early warning disaster management. We played 4 game sessions with practitioners and PhD students involved in disaster risk management to simulate and test how public information from social media is used in emergency operation centres to make (protective and communicative) decisions. This includes how information is perceived in terms of levels of trust, usefulness and completeness depending on its type, source, quality/content and channel. Overall, we observe that information from the crowd disseminated on social media leads to better decisions and increases associated confidence levels. More precisely, we find that information from weather spotters, i.e. people trained in meteorology, is more trusted than information from the general public independent of the information quality. Ultimately, we demonstrate the usefulness of public social media information in warning decision-making, as well as the potential of serious games to evaluate warning communication, for instance by increasing warning communication literacy and enhancing collaborative capacity.

1) Introduction

Despite considerable advances in the science of forecasting and improved technological approaches to disaster risk management, extreme natural hazards still affect the livelihoods of millions of people. For example, in 2018, the Mediterranean region was affected by extreme weather events. Especially, France, Italy and Mallorca were hit by severe storms and heavy rainfall that induced (flash) floods and land movements [1]. Many people died and economic losses were very high. In the future, more extreme weather and climate events are expected due to climate change impacts [2], rapidly expanding urbanization and accelerating environmental degradation, increasing exposure and vulnerability of many regions, across the world and in Europe [3]. Disaster risk management (DRM) and early warning systems (EWS) can reduce these risks and vulnerability at all levels [4]. Effective EWS require the contribution and coordination of different institutions and individuals with different competencies and responsibilities. For example emergency operation centres (EOC) include representatives from different agencies that have complementary competencies to make decisions to guarantee the public's safety, warn the population in case of an event and minimize losses. In the case of weather related events, the warning decision-making process starts with the observation of the atmospheric dynamics/weather, moves on with the production of different products and services (such as forecasts and warnings) and ends with the decision-making of the end-users, such as

emergency managers, but also the general public. Thereby, the different stakeholders work and/or act under constantly changing socio-technical, environmental and political conditions and they make a number of decisions under different degrees of uncertainty. For instance, people can use different technologies or channels to access information. Environmental conditions, such as sights and sounds that indicate hazard onset can influence their decision-making processes [5]. Moreover, individual factors, such as knowledge or experience can transfer the effective passing of information [6]. Ultimately, it's important to acknowledge that the warning process is neither solely linear nor one-way, but rather circular and two-way.

In the past decade, new technologies have certainly fostered the two-way character of the early warning communication process. For example citizens have been providing relevant warning-related information on social media, such as blogs or social networking sites. The type of information include audio, photographic and video files related to an imminent threat [7,8]. Such crowdsourced information, which is defined as a "the process of obtaining information from many contributors amongst the general public, regardless of their background and skill level" [9] presents a potential alternative data source and opportunity for both gathering data and bringing the public to the centre of the warning system (i.e. people-centred early warning systems). This is also in line with recent approaches in DRM that call for more participatory and community-based strategies, in which the end users of information are treated as partners [10–12].

However, limited research exists on how emergency managers in EOC would use information from social media in their decision-making process. Therefore, the first goal of the study is to demonstrate the usefulness of public social media information in warning decision-making. In specific, we analyse how information is perceived in terms of levels of trust, usefulness and completeness depending on its type, source, quality/content and channel. The application of these evaluation criteria for social media information is quite novel in the early warning disaster management sector. We derive the following research question: Does public information from social media improve decision-making in emergency operation centres?

To assess warning decision-making that is rather complex and dynamic by nature, we use serious games that have been applied to assist DRM, especially in the realm of awareness raising, undertaking preventive actions, empathy triggering and perspective-taking [13]. Serious games are "interactive computer application, with or without significant hardware component, that has a challenging goal, is fun to play and engaging, incorporates some scoring mechanism, and supplies the user with skills, knowledge or attitudes useful in reality" [14]. Thus, one key characteristic is that games refer to real life applications and put the player in an active role that stimulates him/her to think critically [15]. Serious games have several characteristics which we further describe in the section 2.2, but most importantly they refer to real life applications (that is, games that are played seriously and not for amusement). Thus, the second goal of this paper is to test the interest of using serious games for testing research hypothesis related to warning communication and decision-making processes, for instance to increase warning communication literacy and enhance collaborative capacity. We derive the following research question: Can serious games help to evaluate warning communication processes?

In this study, we explore emergency managers' use of social media information for decision making purposes. We play serious games with decision-makers involved in DRM to evaluate this alternative communication system. Limited research exists on how emergency managers in EOC would use information from social media in their decision-making process. To reach this aim, we simulate and test how weather-related observations from the public on social media influences decision-making in EOC; whether it increases confidence in decisions, affects decision-makers' risk and information perceptions and improves protective action decision-making and warning communication. Thus, we

provide first insights about the effectiveness of weather-related social media information in warning decision-making, as well as about the potential of serious games as tools to evaluate warning communication. The next section provides a literature review with two subsections on social media and serious games (section 2). In the following section we provide a description of the game (section 3), followed by the research design (section 4). Later sections describe and discuss the results (section 5 and 6). We end with a conclusion that includes some reflections about the limitations of the study (section 6).

2) Literature review

In this section we describe how social media is currently being used in weather and emergency operations. Then we describe the potential benefits as well as the limitations of social media in emergency management. We then describe some characteristics of serious games, including how these games can contribute to improve early warning disaster management. We further describe how serious games could be used to help evaluate the warning communication and decision-making process.

2.1. Social media

In recent years, the sharp increase in the use of social media by the public during major natural disasters has attracted the attention of various public agencies and safety organizations. So far, public agencies have been largely underutilizing social media [16,17]. For example, [18] highlighted that only very few emergency managers (less than one sixth) considered social media communication and that the majority of them manually reviewed social media content. In contrast, the majority of the public in the US felt that the regular monitoring of social media would be beneficial to national emergency response [19]. Worldwide, public expectations continue to grow in terms of how governments should monitor social media, identify reliable sources of information and include it in their decision-making [20]. Currently, National Meteorological and Hydrological Services (NMHS) and other public service organizations are trying to close the gap between information monitoring and use. For example, a recent survey among European NMHS has shown that many forecasters search for additional, non-conventional information about weather events and their impacts, but processes are still informal very often [21]. Likewise, practitioners that used an emergency application in a test phase (<http://www.i-react.eu/>), indicated that crowdsourced information would be especially useful in the early warning phase and that real-time reporting with pictures (with preference from other professionals) would be their most urgent need [22].

Social media provides several opportunities for public agencies that act in the early warning phase: a better understanding of public debates about weather related issues, monitoring dangerous situations and interacting with users, promoting crowdsourcing and other collaborations, as well as extending the reach of organizational information and improving their transparency, visibility and reputation [7,23]. Compared to traditional media, social media has several advantages as a risk and warning communication tool. First, information is rapidly and continuously updated throughout an event [24,25]. Second, information propagates rapidly and reaches a lot of people within a very short time [26]. Third, public safety organizations can also receive information that directly comes from the individuals affected by the hazard and allow these organizations to exploit and review informal communication networks. For instance, in 2014, the mountain municipality Schangnau, Switzerland, was hit by a severe flood. The warning and alerting systems worked well, also because affected farmers reported damages to the regional disaster management body [27]. Thus, it is critical that social networks can be used to communicate in two ways, where information is both disseminated to the public and received from it. However, the integration of social media into warning and crises decision-making has not happened yet [7]. For example, a lot of NMHS use social media to disseminate information, but very few actually monitor their accounts or engage in two-way communication [28].

Several challenges exist that currently hinder the incorporation of (event-related) social media into pre-existing emergency management systems. For example, agencies are afraid that social media will produce harmful and inaccurate information [29] and that it can be difficult to evaluate the credibility and validity of user-generated content [30]. Moreover, emergency management operates in command-and-control models, which do not easily adapt to the collaborative activities by the public [7]. Another challenge is the enormous amount of information generated that can be overwhelming. [31] compared finding useful content during major events on social media to “panning for gold in a raging river”. Finally, potential ethical dilemmas may further discourage agencies to fully explore the potential of social media. These issues include the potential for breaches of privacy, even from anonymized data sets, the lack of consent involved and the possibility of misuse by commercial entities interested in surveillance/tracking [7,32]. Other problems are related to unequal access to social media. For example, in 2016-17 nearly 1.3 million households had no internet connection in Australia and lower digital inclusion was observed in already vulnerable groups, including the unemployed, migrants and the elderly [33]. As a result, gaps between privileged and marginalized people may grow wider.

However, recent research indicates that some of these barriers will be overcome in the near future. Research suggests that inaccurate rumours are not especially enhanced by the use of social networks and that agencies can further reduce misinformation and encourage public confidence if they have a social media presence before the disaster [26,34]. At a workshop organized by the WMO in 2018, NMHS also acknowledged that they have been worried too much about misinformation while ignoring the benefits of social media for a long time [35]. Concerning data management, it is nowadays possible to monitor social media (e.g., search through keywords or locations), to detect events based on social media streams and to provide informative classification of social media content [36]. Several studies in this respect have been conducted by the I-React project¹: mobile devices sending geolocated real-time in-field observations [37], using gamified crowdsourcing to meet data quality standards and ensure source trustworthiness [38], applying machine learning to automatically extract relevant information in real time from social media on generic hazard-related data streams [39], as well as in emergency situations [40,41]. Thus, the integration of social media into warning and crisis decision-making is a promising field [7] and coupling early warning services and crowdsourcing activities could help emergency management and better assist decision making [42].

So far, limited research focused on evaluating communication effectiveness on decision-making by using social media. In risk communication studies that focus on more traditional sources, channels and media, various quality dimensions have been used to evaluate the effectiveness of communication [43–45]. Credibility of message content or source trustworthiness is critical to transfer information [46]. For instance in warning communication, research showed that the more credible the message content (and also the source), the more likely are people to respond to the message [47]. More in general, credibility of online information is also influenced by trust in its source, which again depends upon trust in the medium [48]. Relevance, salience or usefulness of information are also important prerequisites for effective communication and influence decision-making [46,49]. The more useful the warning message, the more likely people are to respond to the message [50]. Other quality dimensions such as completeness, accuracy or interpretability have also been used across different sectors to evaluate credit [51] or hazard risk management [52]. For instance, literature on credibility of online information suggested that accuracy can also influence credibility judgements even though this depends on the individual degree of expertise in the domain [53]. Finally, factors such as confidence, reliability or trust in information play significant roles in prompting behavioural response [47,54]. We grounded on this literature to identify some of these quality dimensions to evaluate the effectiveness of social media communication on decision-making. To conduct the research, we use serious games.

¹ <http://project.i-react.eu/>

These games can account for the complex dynamic environment with different stakeholders under constantly changing environmental conditions, and thus they can best simulate the conditions of an extreme weather event. In the following paragraph we further describe the characteristics of serious games and explain why it is an appropriate tool for this research.

2.2 Serious games

Serious games represent an acknowledged potential for training and learning, because they are able to strongly motivate learners [55]. They challenge and support players to “approach, explore and overcome problems” [15]. Serious games provide a safe environment in which players can explore various situations and try out alternative pathways while experiencing the respective consequences [15,56]. This immersive environment further allows to test knowledge and practice skills in order to develop new knowledge, practices and solutions [55]. Serious games are low in external risks and give the players a sense of safety, which are necessary elements for experimentation and creativity [57]. This is of particular interest in emergency situations where mistakes could lead to loss of lives [58].

DRM, and warning decision-making, are not smooth and rational, but rather dynamic and complex processes. EOCs group actors from different agencies and departments, who have their own interests and agendas. These stakeholders may have different responsibilities and opinions on managing the crisis even though their common overarching goal is to ensure people’s safety. High levels of stress, uncertainty, time pressure, as well as coordination and communication problems between stakeholders are further elements that make decision-making in warning systems even more complex [4,13,59].

Compared to surveys, interviews or focus groups, serious games have unique characteristics in addressing the technical-physical complexity (i.e. as a result of the interactions among the system and the circumstances) and the social-political complexity (as a result of the interactions among the various stakeholders) and in letting stakeholders play with these complexities [57]. Thus, multiplayer serious games in DRM allow “to parallelly negotiate, persuade, ally, brainstorm or exchange information in order to take a collective decision, adapt a coherent strategy or cooperate for the common good” [13]. For example, NMHS currently need and want to evaluate the value of their warning products in a quick and effective way by using new approaches that focus on the centrality of the decision makers, their needs and the capability to act on the basis of the information provided by NMHS [60].

Very few games in DRM include elements of risk or warning communication into their design [13]. However, a few examples exist. The Red Cross Red Crescent Climate Centre has participated in the development of two games that include the concepts of EWS and forecast based early action. In the game *Paying for Predictions* players become humanitarian workers, who are facing changing risks [61,62]. They have to make individual and collective decisions with consequences. The primary objective of the game is to understand the value of forecasts. In the *Forecast-Based Early Action Game*, developed with the UK Met Office, players act different roles in a community affected by floods and have to make priorities for action once they received a severe weather forecast [63]. Both games were developed for the humanitarian sector and emphasize the importance of resources via penalty schemes. Another game was recently introduced at the conference Tech4development in Lausanne. Participants in the session *Adapted Technologies for Early Warning Systems: Playing with Uncertainty* were part of a role-playing game on EWS, with different scenarios of economic development, stakeholders’ participation, technology and uncertainty [64]. The game aims to illustrate the complexity of decision making on EWS and the need of integrating all its components, while assuring the constant participation of all the stakeholders. Moreover, some other disaster role-playing games exist, but which do not explicitly focus on warning communication, but on risk reduction and management [65], climate change adaptation education and engagement [66], natural risk

management [67] and post-earthquake recovery [68]. For instance, the *RAMSETE* games were developed by the ESPRESSO project to engage different stakeholders to openly discuss and objectively challenge ideas, policies, and processes related to transboundary disasters risk management, synergies between climate adaptation and disaster risk reduction and the science/policy interface in disaster management [65].

Several review papers underline the general scarcity of quantitative and qualitative research into the games' effectiveness in the field of disaster management [13,69,70] Even though literature exists that highlights the effectiveness of serious games in other fields, such as medicine [71], we focus on the few studies that exist in the field of disaster management to analyse the effectiveness. [72] used a pre- and post-survey to collect data on changes in participants' perceptions to evaluate the game *Sustainable Delta*. [73] applied learning outcome indicators from the game-based learning evaluation model (GEM) to evaluate *Ready*. Moreover, research highlights the importance of debriefing: "the real learning begins when the game stops" [74] or "collective learning can be fostered by discussions" [56]. The debriefing offers space for airing emotions and clarifying conflicts or misunderstandings. It also allows participants to process the game experience [13] and provide immediate feedback, that is efficient for procedural learning [58].

After having revised and considered a wide array of serious games, the role-playing game *ANYCaRE* came closest to fulfilling our research requirements. It investigates warning decision-making in weather-related hazards. It explores the value of impact-based vulnerability information on the decision-making process to manage an emergency response and communicate and trigger protective actions at different levels of the warning system across Europe [75]. We use the *ANYCaRE* design and structure as a backbone for our research and modified it in order to be able to explore the value of public social media information. We describe the game in more detail in the following Section.

3) Game design

3.1 *ANYCaRE* goes social

This game builds on *ANYCaRE* that was developed in the European project "EnhANCing emergency management and response to extreme WeatHER and climate Events" (ANYWHERE). It focusses on the preparedness and response phase and captures the dynamics of the warning and response processes which involves three major components; a) the type of actors and their role in decision-making, b) the timeline of the warning phases, c) the type of decisions to take [75]. The actors are stakeholders involved in the decision-making to ensure people's safety during an emergency. The timeline is adapted to the pace of the hazard under concern. Rounds are played successively to simulate the progression of the hazard from detection to landfall. Moreover, the characters of stakeholders and the potential decisions to be chosen by the players are "pre-defined based on qualitative evidence gathered during European workshops" [75]. *Social ANYCaRE* (*S-ANYCaRE* refers to the new game version) distinguishes between decisions related to protective action (i.e., stay aware, take precautionary actions or order evacuations) and communication (i.e., no communication, warn about fake news, provide general advice or inform the public about the emergency plan). However, instead of assessing the value of impact-based vulnerability information, *S-ANYCaRE* provides different material to the players and differentiates between standard weather information and additional information extracted from social media. Compared to the initial game, it also includes more options for communicating decisions to the public, such as choosing a channel (sirens, traditional media, social networking sites). Moreover, it assesses the value of social media information through a rigorous application of quality measures (usefulness, trustworthiness and completeness of information) and evaluates the effectiveness of the serious game itself by using a combination of quantitative and qualitative methods (see Section 4.1).

3.2 Generalities

The serious game is a Pen-and-Paper role-playing game (PnP), played on a table top using information, images, instructions and set of roles. It is a narrative-based game with an interactive storytelling inviting participants to play specific characters of the decision-making chain. It allows face-to-face multiplayer experience with lively interactions between players. The target audience are decision-makers involved in the warning chain. They may play other roles than what they do in real life in order to push them to walk in someone else's shoes and to make them explore the perspectives they would otherwise not consider. This also avoids bias (e.g., negative attitude towards certain aspects) that may hinder reflection of certain aspects. Players have limited time to make collective decisions to create a realistic environment of stress, uncertainty and time pressure. The game focusses on decisions made by stakeholders in the warning chain and not the general public. A moderator guides the participants through the game, gives instructions to avoid misunderstandings or puts pressure on players to take imminent decisions.

3.3 Storytelling

ANYCaRE simulates an Emergency Operations Centre (EOC) where players act as representatives of four crisis management services (forecaster, road service, first responder, municipality) gathered under the leadership of one public official (the EOC leader) to take collective decisions in order to ensure citizens' safety and prevent disturbances in social life (e.g., delay in school pick-up time) while managing a budget. Each player has a specific role; the forecaster interprets the hazard model outputs and communicates warnings if needed; the first responder deals with possible evacuation of residences, schools, campsites and public events; the municipality makes decisions related to the everyday life (e.g., cancelation of school-related transportation) or recreational events in the city (i.e., festival); and the road service manages road closures and the maintenance of the main bridge road in case of flood emergency (see worksheet in Appendix A). The most important challenge is to decide if the festival should be cancelled or if the event could be maintained and probably set up flood protection measures in the bridge area [75].

The territory that the EOC has to manage is an agglomeration with three different areas which have different characteristics (Figure 1). Area A is characterized by relatively steep tree-covered slopes drained by a small basin (e.g. few hundreds km²) known for its fast response to precipitation. A village of about 1000 residents and one school is settled on the slopes and one campsite (100 camping pitches) is located in the forest close to the riverbed (within the 10-year return period flood prone zone). Area B is composed of both highlands and lowlands drained by a river basin of about 3000 km². The densely populated (e.g., 100000 citizens) urban area is located in the lower part of the basin. It includes the majority of schools, hospitals and other public services. 35 % of the residential areas and public services are located in the 20-year return period flood prone zone. Area C is typical lowland with a large floodplain located in the lower part of a larger river basin (up to 4000 km²). There are no permanent settlements in C but the area surrounds the main bridge of the agglomeration, calibrated to resist a 100-year flood. The area is characterized by seasonal agricultural activity and a natural recreation area where the annual festival is taking place on Saturday with 10000 expected participants coming from all over the country. Additional information can be found in [75].

We decided to have a very detailed storytelling in order to limit two major bias in our approach. First, simulations are no real events and the higher the amount of detail, the more realistic it will be. The second bias is linked to the experience of the participants. Even though they were familiar with the topic (see next chapter), they might have difficulties to play the role of different crisis management services.

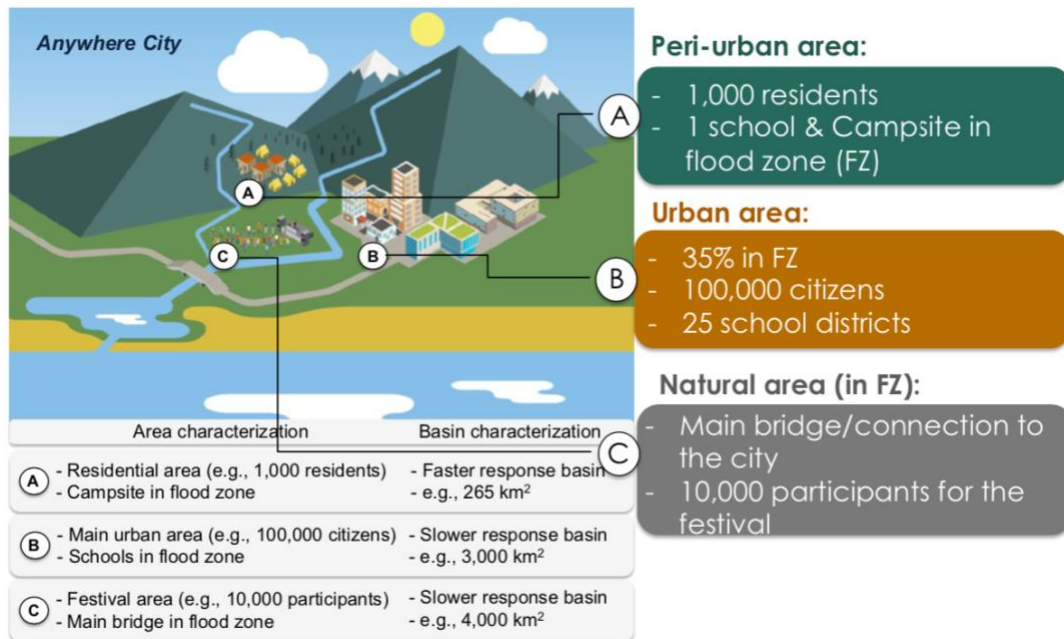


Figure 1: The territory that players have to manage including the area and basin characterizations of the three distinct areas A, B and C (adapted from [75]).

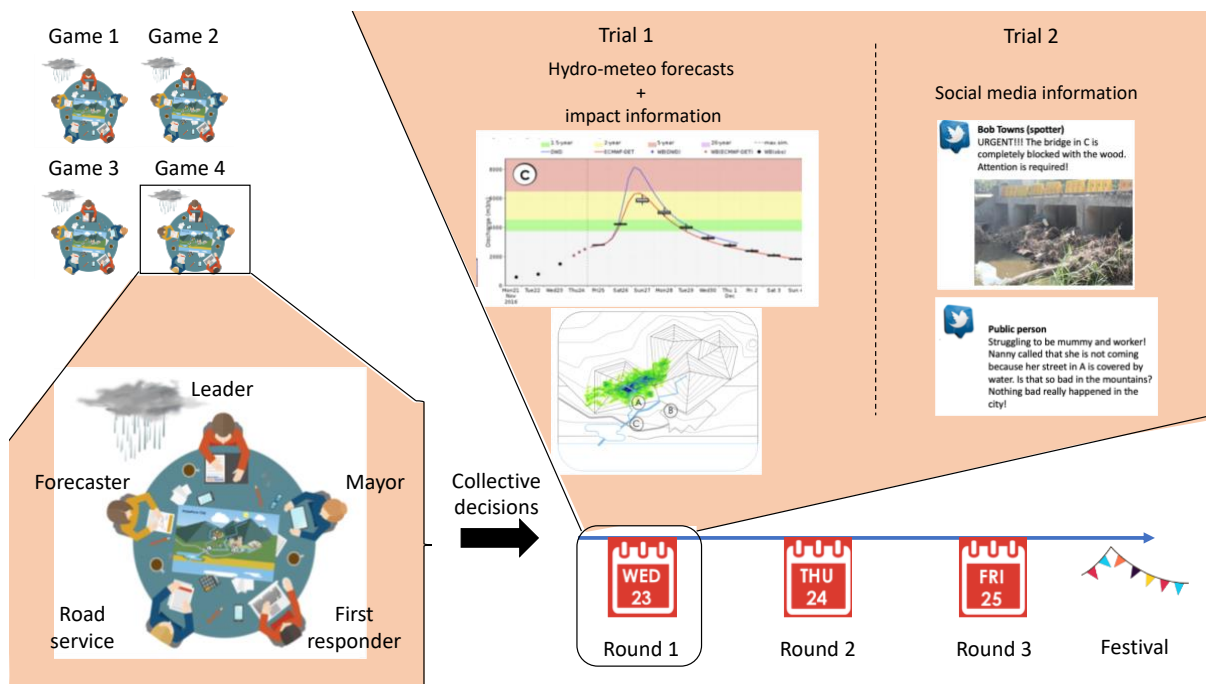


Figure 2: Illustration of the setting and the simulation timeline: Four S-ANYCaRE game sessions were played with five people representing different stakeholders that took collective decisions after each trial. Each round (1 to 3) represented a day from Wednesday to Friday (with the festival happening on Saturday). For each round, two trials were played for which different information was provided.

3.4 Information input and simulation

The game has three rounds that simulate the progression of the hazard from Wednesday to Friday (Figure 2). Each round is composed of two trials: in the first trial we provide only hydro-meteorological forecasts and impact information, in the second trial we provide additional information from social media. Collective decisions are taken after each trial, which lasts 10 minutes. More information about the rules and the forecasts can be found in [75]. As we played the game several times, we changed information source and quality through the rounds, so that we could analyse the effects of information

source and quality independently. Table 1 shows the information that was provided in each round and trial. In the first trial of each round, players received the same products (i.e., standard phenomenon-based forecasts and simple risk matrixes), which slightly evolved with the progression of the hazard. In addition, in round 2, we included an online newspaper article. In the second trial of round 1 and 3, players received additional weather-related observations extracted from social media. The tweets were from different sources (weather spotters or the general public) and the information content was either consistent or inconsistent (and thus quality good or bad). In the second trial of round 2 we included a tweet related to the online newspaper. Some of the tweets could be geolocated through the inclusion of a picture or other information, while other tweets just incorporated text (e.g. talking about severe weather). However, the multiple rounds and game sessions ensured that these different levels of accuracy did not impact the evaluation of message quality (i.e. consistency).

Table 1: Information provided in each round and trial. The grey colour indicates the information for which the source was changed in different games. Note that this is only one of some possible set-ups that were used.

Information type per trial	Round 1	Round 2	Round 3
1 st Trial: Traditional information	Forecasts, risk mapping	Forecasts, risk mapping	Forecasts, risk mapping
		Online article from journalist	Online article from journalist
2 nd Trial: Social media information	Consistent tweet from public	Tweet from journalist	Inconsistent tweet from public
	Inconsistent tweet from spotter		Consistent tweet from spotter

4) Methods

4.1 Data

End of May 2019, we played four game sessions with in total 20 participants that were involved in an advanced training course at the University of Geneva, the CERG-C (<https://www.unige.ch/sciences/terre/CERG-C/>). CERG-C is a specialization and postgraduate certificate for the assessment and management of geological and climate related risk. Among others, participants are trained on how to assess risk and incorporate it into their working practices in order to reduce losses and communicate effectively with different stakeholders in the natural hazard warning chain during and after natural hazard events. The CERG-C participants were practitioners or young scientists that work in disaster risk management in various countries worldwide. Their experience in weather related risk management was rather low. However, their education and training in the field of natural hazard and emergency management qualified the participants to participate in the game. We pre-tested *S-ANYCaRE* (including the survey) in the Climate Policy seminar at ETH Zurich in March 2019. Before that, the validity of the scenario and the functionality of the game was also tested several times during the ANYWHERE project [75].

We evaluated the benefits of social media information by using several indicators. First, we evaluated whether players took more relevant decisions with or without additional information. Concerning the emergency activities, they could choose between 3 types of decisions: i) stay aware and monitor the situation; ii) act in the context of the warning phase and take precautionary actions, iii) activate the emergency plan. In addition, they indicated their levels of confidence in the decisions (scale from 1=not confident to 5= very confident), as well as their interactions with the other participants (from 1=very weak to 5= very strong) after each trial. Concerning the communication activities, players could choose between different communication content (i.e., no communication, warn about fake news, provide general advice or inform the public about the emergency plan). They also indicated what communication channel (sirens, traditional media and/or social networking sites) they use to inform

the public about their decisions and their respective level(s) of trust in the channel (from 1=very weak to 5= very strong). The worksheet with the different actions is provided in Appendix A.

Second, we grounded on various concepts in risk communication and decision-making theory to select variables that are commonly known to impact human assessment when making decisions [5,45,76]. These are information type, source, quality/content and channel. As Table 2 shows, we distinguished between information from traditional forecasts and social media information (i.e. Twitter) (type), between public, journalists and spotters (source), between consistent and inconsistent information (quality) and between Twitter and online newspaper (channel). Thus, we focus on weather-related observations that is provided by lay people on social media. We studied the influence of information quality on decision-making along the dimensions of relevance, trust and completeness. After each round, players indicated the usefulness, trustworthiness and completeness of each social media information they receive (on a scale from 1=very bad to 5= very good), as well as report whether the information influenced their decisions or not.

Table 2: Information provided in the serious games and differentiated by type, source, quality and channel

Type	Source	Quality	Channel
<ul style="list-style-type: none"> • Traditional forecasts, • Social media information 	<ul style="list-style-type: none"> • Public, • Journalists, • Spotters 	<ul style="list-style-type: none"> • Consistent (good), • Inconsistent (bad) 	<ul style="list-style-type: none"> • Twitter, • Online newspaper

We used a combination of quantitative and qualitative methods to evaluate the effectiveness of the serious game and to demonstrate whether serious games increase warning communication literacy and enhance collaborative capacity. Before the simulation, players answered a short survey with three open questions that were derived from [75]: What keywords does the term warning decision-making evoke in you? What types of information are necessary to take decisions with respect to an imminent threat? What challenges warning decision-makers have to face when flooding occurs? They also replied to a battery of questions (5-point Likert scale) on how they perceived the use of social media in decision-making (e.g., how useful or trustworthy they find social media). After the simulation, players answered the same questions again (but framed slightly differently) to identify potential changes in participants' perceptions related to warning decision-making and the use of social media. Furthermore, participants responded to an additional set of questions to evaluate learning outcomes. Following game-based learning evaluation model (GEM), we asked specific post-game questions on a 5-point Likert scale (that were mostly derived from [73] to collect data on emotional-motivational cognitive learning indicators, and assess the appreciation of game design and learning outcome. We finally asked more general questions, such as whether they use social media information in their daily work or collaborate with citizens. Last but not least, we asked participants in the debriefing session whether their expectations were fulfilled or not and what could be improved. They wrote down short textual annotations on post-its which were then further discussed with the participants. Similar to [75,77], we conducted a basic qualitative analysis of the debriefing sessions by grouping the comments into themes and describing them. Due to the small sample size, statistical analysis (and thus also reliability and validity measures) were not performed. However, this should not disprove the explorative character of this research. The pre- and post-survey is provided in Appendix B.

4.2 Hypotheses

H1: Social media information improves warning decision-making.

We expect that participants perform better in trial 2 with additional meteorological-related observations from Twitter compared to trial 1 with traditional forecast and impact information (first and third round). We also expect that players take more often the relevant decision and report higher

levels of confidence on decisions in trial 2. In addition, providing them with information from online newspapers on local damage (trial 1) performs less good than providing very similar information on Twitter (trial 2) from a journalist due to the real-time character of social media information.

H2: For social media information, source is more important than information quality.

Participants prefer information from trusted sources (i.e. weather spotters that received some training in meteorology) which is also perceived more useful and complete compared to identical information from less trusted sources (i.e. general public that did not receive such training). Overall, we expect that weather-related social media information will influence players in their decision-making, which is especially true when the information is from spotters.

H3: Communication activities (i.e. decisions on content and channel) will differ depending on whether social media information is provided (trial 2) or not (trial 1).

All decisions will obviously depend on the timeline of the warning event and on the choice of protective actions by the participants (e.g. inform the public about the emergency plan when deciding to activate the plan). For the communication activities, we expect higher confidence levels in decisions in trial 2 compared to trial 1. We also assume that players will indicate higher levels of trust in efficiently communicating their message on social networking sites in trial 2 (when being confronted with the potential benefits of social networking sites) compared to trial 1.

H4: Research-based game exercises increase warning communication literacy and enhance collaborative capacity.

We expect that serious games will increase warning communication literacy (e.g., increased understanding about the warning system communication chain; increased understanding of the role and potential of social media in warning communication), and enhance collaborative capacity (e.g., increased perceived importance of engaging diverse participants, including the public, in warning decision-making; increased understanding of and empathy for diverse perspectives). Thus, we will also demonstrate the use of serious games as a communication tool to evaluate warning communication.

5) Results

5.1 Comparison of S-ANYCaRE game results: social media and warning decision-making

First, our results confirm the hypothesis that weather-related observations from the general public on social media improves warning decision-making. In rounds 1 and 3, participants performed better in trial 2 with additional information from Twitter compared to trial 1 with traditional forecast and impact information. For instance, in the first trial of round 1 in two of the four game sessions, players would not evacuate area A. However, in the second trial, in all four game sessions players decided to evacuate this area (which is the appropriate decision). These emergency decisions had some implications on the communication too: they only decided in the second trial to inform the public about the emergency plan and to communicate the decisions taken. We observed a similar influence on the emergency decisions in the third round. In the first trial, only in one of the four game sessions, players decided to close the bridge, whereas in the second trial, participants in all four sessions took the appropriate decision to close the bridge.

In the second round, we provided participants with information from online newspapers on local damage (trial 1), as well as similar information from a journalist on Twitter (trial 2). We did not observe any influence on the decision-making or perception of information in the four game sessions, which indicates that the source (i.e. the journalist), which people found very trustworthy, is more important than the channel. This suggests that social media can be used as a channel to disseminate information as it has the same effect than more traditional information channels on decision-making, but with certain advantages (e.g., rapid dissemination, up-to-date information).

5.2 Social media information and warning decision-making across *S-ANYCaRE* games

Across the four game sessions, participants reported on average slightly higher levels of confidence in emergency decisions when receiving event-related social media information ($M=4.3$ compared to $M=4.0^2$). Confidence levels in communicating actions did not change through the trials and were overall high. Also, the use of communication channel (i.e. sirens, traditional media or social networking sites), as well as trust in these did not really differ between the trials.

Moreover, the results very much confirm our hypothesis that social media information source is more important than quality. Independent whether the information that players received from social media was relevant or consistent with the weather forecast, they believed the information from the spotters ($M=3.9$) significantly more than the same information from the general public ($M=2.8$) as shown in Figure 3. As the levels of perceived usefulness, trust and completeness did barely change with information quality (i.e., consistent or inconsistent information), we conclude that information source clearly outweighs information quality. Moreover, we did not observe any major differences between the mean values for consistent and inconsistent information which we explain by the fact that players always preferred the information that included pictures and were specifically geo-locatable (that was sometimes inconsistent and sometimes consistent). For example, they perceived an inconsistent tweet that included a picture more useful than a consistent tweet with no visual reference. We further expand on this in the next sections. Also, participants indicated that the information from spotters almost always influenced their decision-making in round 1 and 3 (7 yes and 1 no) (even though it was inaccurate in half of the cases). This was not true for the information from the general public (4 yes and 4 no), which people found only useful when it was actually relevant. We also note that through all cases, the usefulness of social media information was rated higher than the trustworthiness and the completeness. This is also confirmed by the survey (see following section).

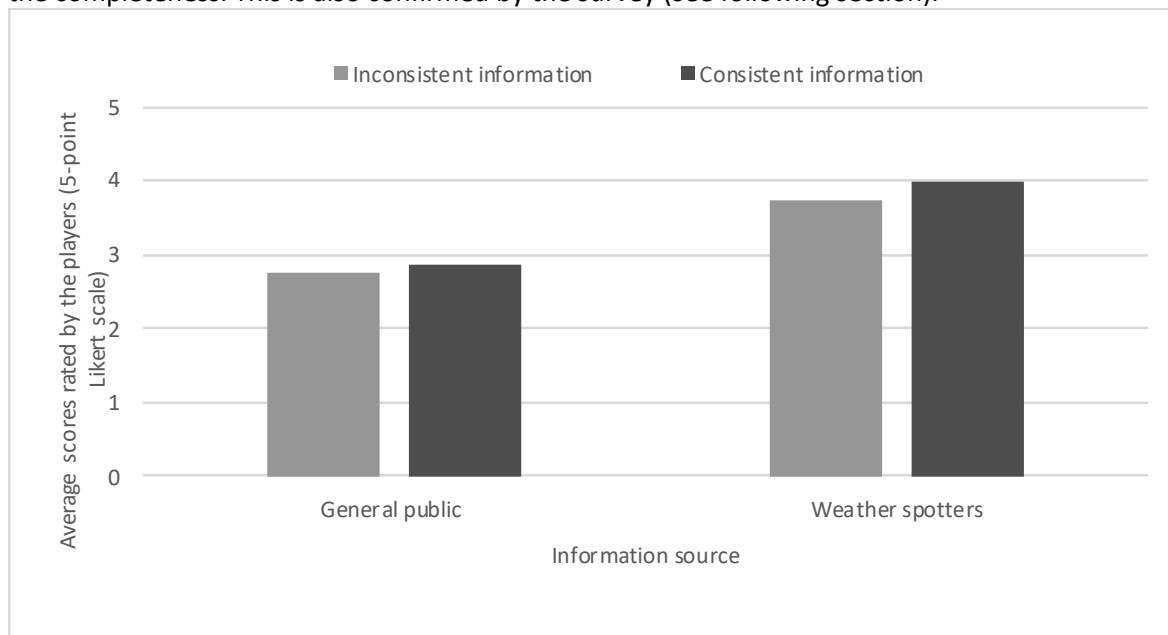


Figure 3: Average of perceived usefulness, trustworthiness and completeness of social media information from different sources and with different quality. These scores are calculated based on 8 decisions: 4 (number of games) x 2 (number of rounds in which social media information was provided). For each decision, the group had to agree on the perceived the usefulness, trustworthiness and completeness of the different social media information.

5.3 Game evaluation

² These scores are the mean values of confidence calculated based on 8 decisions: 4 (number of games) x 2 (number of rounds in which social media information was provided).

Third, our findings indicate that research-based game exercises increase warning communication literacy and enhance collaborative capacity. People answered three open questions related to weather-related crisis management before and after the simulation. Before the game, people associated most often 'safety' and 'evacuation' with warning decision-making and only two people indicated for instance communication aspects. After having played the game, people reported most often the following keywords related to warning decision-making of which they did not think of in the first place: 'communication', 'information source' and associated 'uncertainty' and 'timing' (i.e. to make decisions). This indicates that the key message of the game passed through. This trend was also confirmed when participants had to indicate the types of information necessary to take decisions. Prior to playing the game information on hazard characteristics, but also data on vulnerability and exposure was considered by almost all participants to be especially important to make decisions. After the game, players mentioned very often social media information, as well as, related to this, information source, real-time data, communication and citizens information. In the third question, asking about challenges that decision-makers face, uncertainties related to the physical characteristics were most often cited before the exercise, compared to communication aspects after the exercise. Interestingly, players did not only mention the communication of advice or decisions to the general public, but also the communication to reach an agreement among the different experts that have different agendas or interests. Again, uncertainty related to the social media data (e.g. "fake news") and also the hazard, as well as time pressure and stress were mentioned. These answers indicate that the game effectively simulated a real warning situation and that players increased their warning communication literacy and collaborative capacity.

With respect to the closed questions (5-point Likert scale) related to the usage of social media, on the one hand people indicated that they found social media information more useful (+0.25³) and were more likely to use it to help in warning decision-making (+0.10³) after having played the game. On the other hand, they also found the information from social media in general less trustworthy (-0.15³), less accurate (-0.25³) and less reliable (-0.20³) than before playing the game. This reflects the game design, which was centred around social media information from different sources which were more or less consistent.

To better evaluate the learning outcomes of the game, we asked additional questions on emotional-motivational cognitive learning indicators, and assessed the appreciation of game design and learning outcome, shown in Figure 4. The emotional-motivational items self-efficacy, motivation and engagement were evaluated high (M=3.9), as well as the three cognitive indicators learning activity, self-directedness and mental effort (M=4.1). Concerning the game design, people found the rules clear, the game and the information easy to understand and the pace pleasant (M=4). In general, they also liked to play the game (M=4). In line with findings from the debriefing, lowest scores were reported for the question whether the game was realistic (M=3.3). Participants also indicated a positive learning outcome, for example in applying what they learnt, the usefulness of the game or gaining new knowledge (M=3.7). The specific questions to assess the variables are provided in the Appendix B.

³ This score is the simple difference between the mean value of the Likert scale before and after the game.

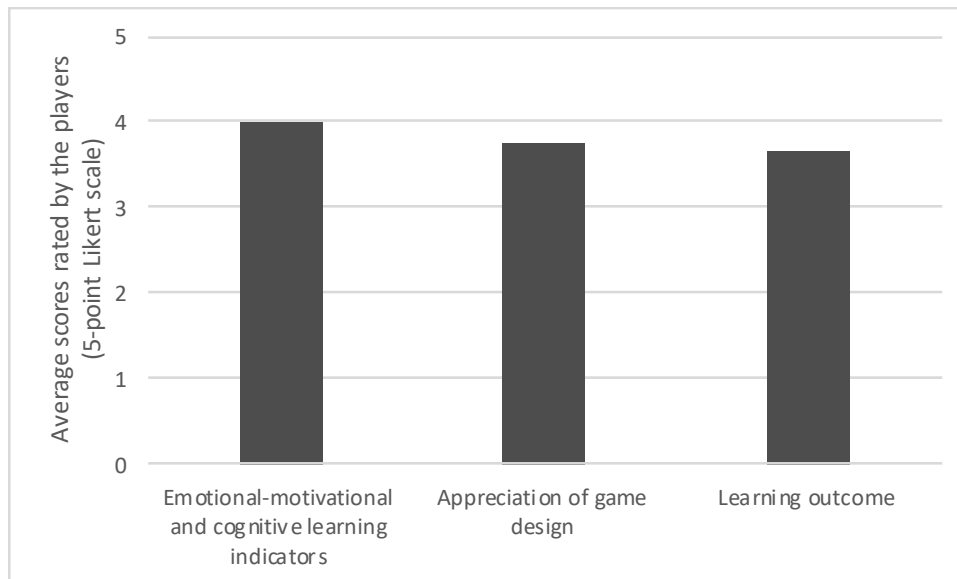


Figure 4: Scores of players assessing the emotional-motivational and cognitive learning indicators, the appreciation of game design and the learning outcome on a 5-point Likert scale from very low to very much. Estimations based on total of four game sessions (i.e. 20 players).

5.4 Debriefing

Finally, the debriefing discussion helps to put these results into some context and disentangle what worked and what could be improved. Most participants indicated that their expectations were fulfilled by the game and very much appreciated the experience. On the one hand, several positive aspects were mentioned. Half of participants reported that the game provided valuable insights into the “processes and challenges of decision-making” and helped them to better “understand how crisis management works” (10 instances). Some people also highlighted that they learned how social media information from different sources can influence decision-making (4 instances). Moreover, players pointed out that they understood the “need to act quickly” and the “amount of pressure” involved in taking timely decisions (4 instances). However, even though players appreciated the pace of the game in general, they were actually given more time than the anticipated 10 minutes in the first trial of each round. Some players also indicated that they appreciated the small group size (5 instances), compared to an earlier exercise that they did (3 instances).

On the other hand, suggestions to improve the game were also mentioned in the discussions. First, some of the players had difficulties to fully play their role as they lacked experience. For instance, the first responders pointed out that they did not receive vulnerability data or did not know whether mitigation actions were already in place or not. Half of the people indicated that they would have preferred additional information (e.g. a hazard map) (10 instances). Two of these also mentioned that they missed economic input data, e.g. on cost of protection measures. Indeed, this is a limitation of the game, but it was our deliberate decision. We decided to not use tokens or other material to symbolize a given budget (financial or human resources for each action) in order to reduce the complexity of the game and to focus on the social media information. Some players also mentioned that they would prefer a real setting instead of an imaginary scenario or city (4 instances).

6) Discussion

We start with discussing the practical implications of the study and afterwards we focus on the theoretical contribution. Our findings show that information source outweighs quality. People perceived the information from weather spotters (i.e. people with some training in meteorology) to be more useful, trustworthy and complete than from the general public, independent whether the quality of information was consistent or inconsistent with the weather forecasts. This finding on

credibility of social media online information is novel and the distinction between source and message is highly relevant. The research complements other research on credibility of online information that highlights the influence of source and medium cues in credibility evaluation [48]. Practitioners that use the App i-React also indicate that they prefer the information that comes from other professionals [22]. Thus, practitioners should be aware that trusted sources can provide inconsistent information too and acknowledge that the general public can contribute information to produce new knowledge. This disconfirms theories like the “deficit-model” of the public understanding of science [78] which sees the general public as scientifically ignorant and passive consumers of information and which, for instance, was observed in the weather forecasting practice [79]. Indeed nowadays, the sharp increase in the use of smartphones and social media gives the general public the opportunity to become a trusted and legitimate source of information as they can for instance geo-reference their location. The citizens actually may have additional information on the weather or any other dangerous situation by which he or she is affected, which the practitioners working for weather or safety agencies may not have, simply because they are not in the same location. Thus, experts should consider the information provided by the general public for the benefits of more effective DRM.

Moreover, our results show that the usefulness of social media information was rated higher than the trustworthiness and the completeness. This indicates that practitioners see the (possible) added value of social media information in warning decision-making, but, at the same time, have some questions with respect to trust and completeness. This shows that they are aware of the associated uncertainty and challenges. This also reflects the still existing fear of public agencies to use social media, for instance with respect to harmful and inaccurate information [29]. Even though rumours or fake news do not seem to play a major role during disaster management as pointed out by a recent study [26], other social media information could influence decision-making as well, which could justify the fear of using social media by authorities in crisis management. Our findings further highlight that perceived relevance, trust and completeness significantly increases when the information includes a picture and/or is precisely geo-locatable (e.g., at the bridge in area C). This is in agreement with recent studies which highlight that practitioners find crowdsourced information to be especially useful when it includes pictures or videos [22].

Concerning the methodology, we conduct the serious game *S-ANYCaRE* to test the use of social media information for decision-making support and evaluate its effectiveness through a combination of quantitative and qualitative methods [56,72,73,75]. Serious games have been recognized to serve as participatory, learning and training tools, and thus have been applied to assist DRM [13,55]. Our findings highlight an enhanced warning communication literacy (e.g., increased understanding about the warning system communication chain; increased understanding of the role and potential of social media in warning communication) among the participants. The game also increased their collaborative capacity. Participants realized the importance of engaging diverse stakeholders, including the public, in warning decision-making and increased their understanding of and empathy for diverse perspectives. Thus, we demonstrate the use of serious games not only as learning and training tools, but also a communication tool to evaluate warning decision-making. Therefore, we assume that serious games could also be a valuable tool for related fields where communication is critical, but more research needs to be conducted.

7) Conclusion

Our study highlights that meteorological-related observations provided by citizens on social media can improve warning decision-making. In this research, decision-makers took better decisions when provided with social media information compared to without this input. For instance, they evacuated people from an exposed area only after receiving social media information from citizens which is the appropriate decision according to the scenario. Recent research shows that it is possible to monitor social media (e.g., search through keywords or locations), to detect events based on social media

streams and to do informative classification of social media content [36]. Thus, social media present a potential alternative communication system for receiving information from the individuals at risk in real time. In its own turn, this could help practitioners in taking more effective decisions.

Moreover, serious games can be used as a research tool in disaster risk reduction: warning communication literacy was increased and collaborative capacity enhanced. However, the debriefing session at the end pointed out some limitations of *S-ANYCaRE*, as well as what could be further improved. Even though the small group sizes forced also the less active people in acting their role and contributing their expertise to the decisions, we observed that some players were more passive than others, which was also noted in the earlier versions of the game [75] and in many other game studies [80]. In a following application, the setting could be slightly changed and based on an existing city (participants suggested Les Diablerets in the Swiss Alps). This could make the experience more realistic as one could also rely on already existing hazard maps or vulnerability data and empirical knowledge from past events. Indeed, it is important to acknowledge that serious games are in the end also simulations of real situations. Emotions such as fear experienced in a real-life situation -compared to a simulation- could also impact decision-making and lead to different results. Moreover, a next step in the game development must be the inclusion of metrics such as financial resources, human safety or wellness, that could be a further indication on how well or poorly the participants scored. Even though it is a challenge to evaluate the cost and benefit of each action, such a point-system with penalties would also avoid that people always go to the side of safety and thus would make the simulation even more realistic. Last but not least, several case and hazard-specific characteristics may hinder result generalization. For instance, hazards can be slower-onset, spatially diffuse (such as droughts) or rapid-onset, spatially localised (such as flash floods). This clearly has relevant implications for the impact of social media information on decision-making. Furthermore, decision-making is not only impacted by the hazard characteristics and the information available on social media, but also by social, cultural, institutional and political aspects that can strongly differ from one region/case to another.

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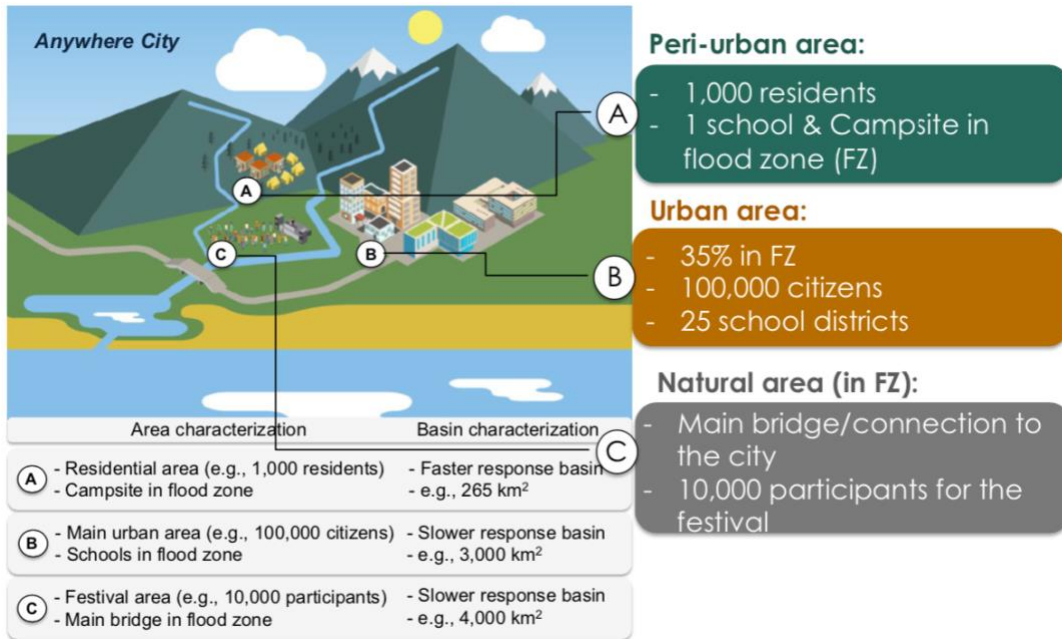


Figure 1: The territory that players have to manage including the area and basin characterizations of the three distinct areas A, B and C (adapted from [75]).

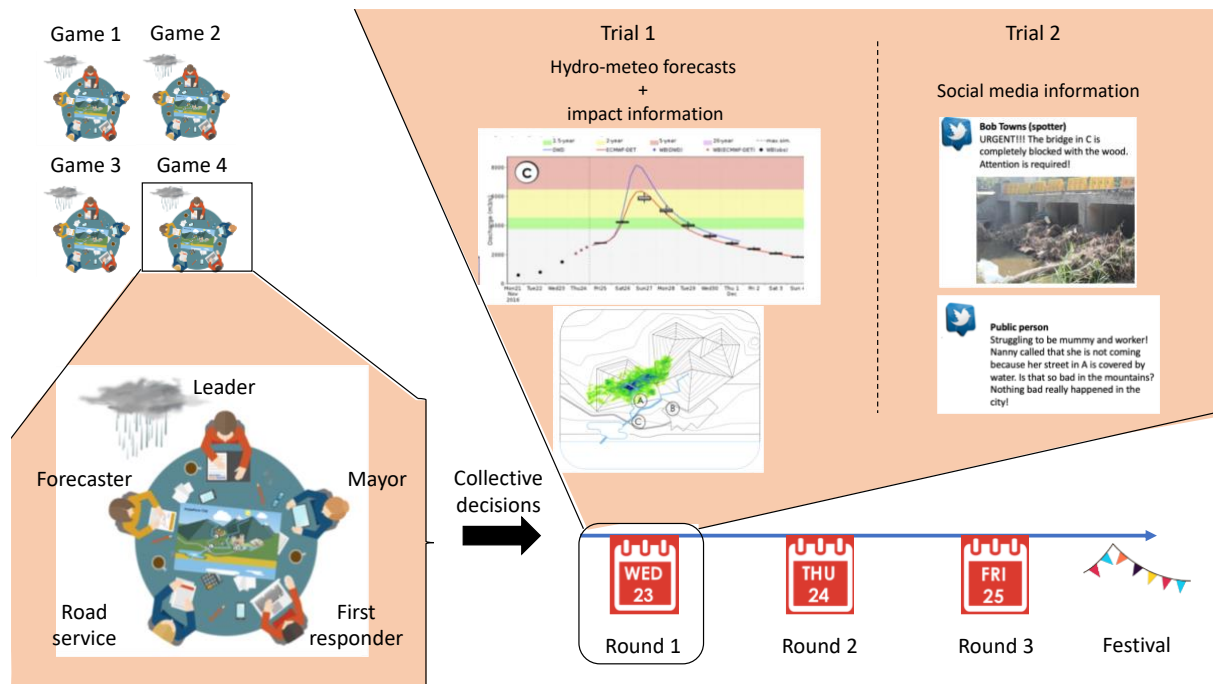


Figure 2: Illustration of the setting and the simulation timeline: Four *S-ANYCaRE* game sessions were played à five people representing different stakeholders that took collective decisions after each trial. Each round (1 to 3) represented a day from Wednesday to Friday (with the festival happening on Saturday). For each round, two trials were played for which different information was provided.

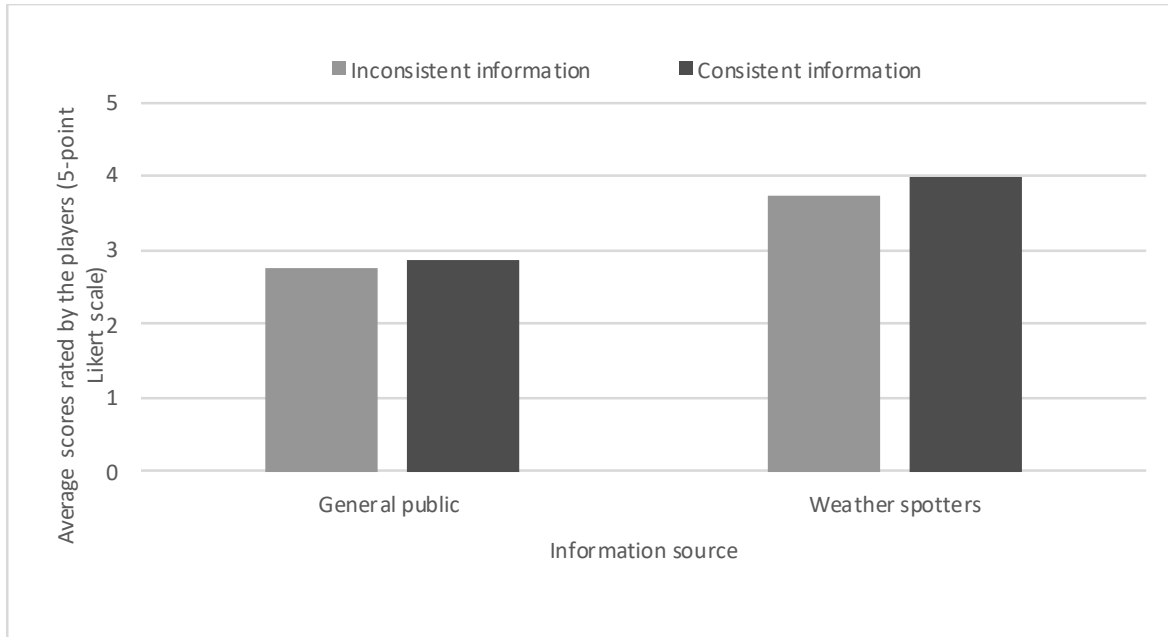


Figure 3: Average of perceived usefulness, trustworthiness and completeness of social media information from different sources and with different quality. These scores are calculated based on 8 decisions: 4 (number of games) x 2 (number of rounds in which social media information was provided). For each decision, the group had to agree on the perceived the usefulness, trustworthiness and completeness of the different social media information.

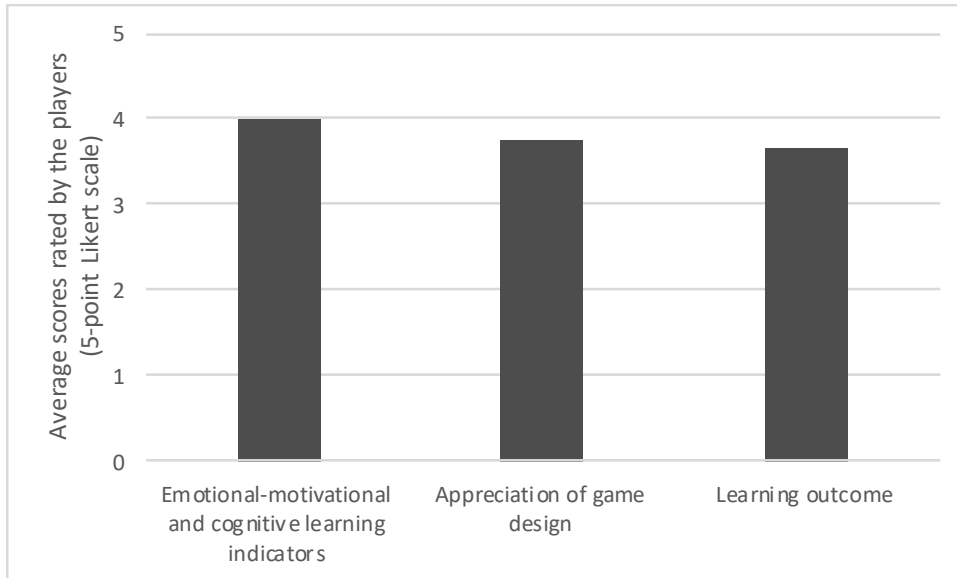


Figure 4: Scores of players assessing the emotional-motivational and cognitive learning indicators, the appreciation of game design and the learning outcome on a 5-point Likert scale from very low to very much. Estimations based on total of four game sessions (i.e. 20 players).

Table 1: Information provided in each round and trial. The grey colour indicates the information for which the source was changed in different games. Note that this is only one of some possible set-ups that were used.

Information type per trial	Round 1	Round 2	Round 3
1 st Trial: Traditional information	Forecasts, risk mapping	Forecasts, risk mapping	Forecasts, risk mapping
		Online article from journalist	Online article from journalist
2 nd Trial: Social media information	Consistent tweet from public	Tweet from journalist	Inconsistent tweet from public
	Inconsistent tweet from spotter		Consistent tweet from spotter












Table 2: Information provided in the serious games and differentiated by type, source, quality and channel





Type	Source	Quality	Channel
<ul style="list-style-type: none"> • Traditional forecasts, • Social media information 	<ul style="list-style-type: none"> • Public, • Journalists, • Spotters 	<ul style="list-style-type: none"> • Consistent (good), • Inconsistent (bad) 	<ul style="list-style-type: none"> • Twitter, • Online newspaper

11) Appendix

APPENDIX A: Worksheet with list of emergency and communication activities, as well as some questions delivered to participants for each round.

Round 1

Worksheet for emergency activities to be considered for the following day	Trial 1	Trial 2
<ul style="list-style-type: none"> No action is performed. You just follow the weather updates and keep monitoring the situation. 		
<ul style="list-style-type: none"> Activate the Emergency Operation Center to coordinate the rescue services and operational forces. You may choose to take one or more of the following precautionary measures (please circle the areas of your choice): <ul style="list-style-type: none">  Set up flood protection measures in: area A area B area C  Anticipate or delay school pick-up time in: area A area B  Cancel the school and the school-related transportation in: area A  Close the main roads in: area A area B area C  Cancel the festival planned for the weekend in area C. <p>Other?</p>		
<ul style="list-style-type: none"> Activate the emergency plan to trigger evacuation of exposed areas and vulnerable populations. You may choose to take one or more of the following emergency measures (please circle the areas of your choice): <ul style="list-style-type: none">  Evacuate campsite in area A.  Evacuate schools or shelter pupils in schools in area B.  Evacuate the festival in area C (if it's the day of the party).  Evacuate and shelter the population in: area A area B area C  Clean/maintain the bridge in area C.  Close the bridge road in area C. <p>Other?</p>		
<ul style="list-style-type: none"> Deactivate the emergency measures for: area A area B area C 		
<p>Please rank your confidence on your decisions from 1 (not confident) to 5 (very confident)</p>		
<p>Please rank your level of communication with other stakeholders from 1 (very weak) to 5 (very strong)</p>		

Worksheet for communication activities to be considered for the following day	Trial 1	Trial 2
<ul style="list-style-type: none">  No information to communicate. 		
<ul style="list-style-type: none">  Notify and forewarn about fake news and rumors shared on social networking sites. 		
<ul style="list-style-type: none">  Provide general advice for safety. As examples: “Ask for information before travelling” / “Do not drive into flooded areas. If floodwaters rise around your car, abandon the car and move to higher ground if you can do so safely.” (please circle the areas of your choice): <div style="display: flex; justify-content: space-around; width: 100%;"> area A area B area C </div> 		
<ul style="list-style-type: none">  Inform the public for the emergency plan and communicate the decisions taken in “Emergency activities” card. For example, order schools directions or the residents in general to evacuate. “Evacuate immediately. Be sure to lock your home as you leave. If you have time, disconnect utilities and appliances. Return home only when authorities indicate it is safe.” (please circle the areas of your choice): <div style="display: flex; justify-content: space-around; width: 100%;"> area A area B area C </div> 		
Please rank your confidence on your decisions from 1 (not confident) to 5 (very confident)		
Please rank your level of communication with other stakeholders from 1 (very weak) to 5 (very strong)		
What communication channel would you use to inform the public about your decisions (please circle the areas of your choice).	T 1	T2
Sirens area A area B area C		
Traditional media (e.g. TV, radio) area A area B area C		
Social networking sites (e.g. Twitter, Fb) area A area B area C		
Please rank your level of trust in the communication channel in efficiently delivering your message from 1 (very weak) to 5 (very strong) for <ul style="list-style-type: none"> Sirens Traditional media Social networking sites

Answer only after Trial 2

Please tell us how you perceived the **tweets from the general public** in terms of

	Very bad	Bad	Neither	Good	Very good
Usefulness for decision-making					
Trustworthiness					
Completeness					

Did the tweets from the general public influence your decision-making?

Yes	No

Please tell us how you perceived the **tweets from the spotters** in terms of

	Very bad	Bad	Neither	Good	Very good
Usefulness for decision-making					
Trustworthiness					
Completeness					

Did the tweets from the spotters influence your decision-making?

Yes	No

APPENDIX B: Survey (pre- and post-game) and debriefing discussion.

Survey
Part A, to be answered before the game!

1. Perception related to weather-related crisis management

- What keywords does the term “warning decision-making” evoke in you?

- What types of information are necessary to take decisions with respect to an imminent threat?

- What challenges warning decision-makers have to face when flooding occurs?

2. Perception related to the usage of social media

	Very little	Little	Just enough	A lot	Very much
How useful is social media/crowdsourced information in warning decision-making?					
How trustworthy do you find information from social media?					
How accurate do you find information from social media?					
How reliable do you find information from social media?					
How likely is it that you would use information from social media to help in warning decision-making?					

Part B, to be answered after the game!

3. Perception related to weather-related crisis management

- After having played the game, are there any keywords with respect to “warning decision-making” you did not think of in the first place?

- After having played the game, are there additional information types which are necessary to take decisions in a warning situation you did not think of earlier today?

--

- After having played the game, what additional challenges do you think warning decision-makers face you did not think of in the first place?

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4. Perception related to the usage of social media

After having played the game, could you please rate again the following statements.

	Very little	Little	Just enough	A lot	Very much
How useful is social media/crowdsourced information in warning decision-making?					
How trustworthy do you find information from social media?					
How accurate do you find information from social media?					
How reliable do you find information from social media?					
How likely is it that you would use information from social media to help in warning decision-making?					

5. Emotional-motivational and cognitive learning indicators

	Very little	Little	Just enough	A lot	Very much
How well did you perform?					
How interesting did you find the game?					
How much absorbed were you into the game?					
How much did you reflect on the learning process?					
How much did you interact with the other players?					
How busy were you with the game?					

6. Appreciation of game design

	Very little	Little	Just enough	A lot	Very much
How much were you challenged in the game?					
Has the game met your expectations?					
Was the game realistic?					
Were the rules of the game clear and easy to understand?					
Was the information provided clear and easy to understand?					
Was the pace of the game pleasant?					
Did you like the game in general?					

7. Learning outcome

	Very little	Little	Just enough	A lot	Very much
Can you apply what you learnt today in your work?					
Will you act differently in real life after playing the game?					
Did you gain new insights after playing this game?					
Did you become more aware of the risks involved?					
Was playing this game a useful experience?					

8. General information

- Do you or your organization use volunteered information by the public, spotters or spotter groups?

Yes	No	Does not apply

- If YES, via which channel?
- If YES, do you use the information spontaneously or is it assessed in a systematic and/or continuous way?
- If NO, would you like to use volunteered information by the public or spotters in the future?

- Do you collaborate with specific citizens or spotters?

- Do you give advice, offer education or training for individual citizens or spotters?

- Do you perform a quality control of incoming information from social media or from spotters?

Debriefing session

Were your expectations fulfilled by the game itself and especially with respect to the information provided as input data to support decision-making in the simulation?

Very little	Little	Just enough	A lot	Very much

The following two questions will be discussed together. Therefore, please write down short textual annotations on post-its.

Which expectation were fulfilled?

What could be improved in order to fulfill your expectations?

Please write down short textual annotations on post-its.